Department of Sustainability and Environment

Ecological impacts of firewood collection — a literature review to inform firewood management on public land in Victoria

Geoff Brown, Arn Tolsma, Simon Murphy, Anne Miehs, Ed McNabb and Alan York

2009

Arthur Rylah Institute for Environmental Research

and

Department of Forest and Ecosystem Science, The University of Melbourne

Ecological impacts of firewood collection — a literature review to inform firewood management on public land in Victoria

Geoff Brown, Arn Tolsma and Ed McNabb

Arthur Rylah Institute for Environmental Research
Department of Sustainability and Environment

In partnership with:

Simon Murphy, Anne Miehs and Alan York

Department of Forest and Ecosystem Science,
The University of Melbourne

April, 2009

Published by the Victorian Government Department of Sustainability and Environment

Melbourne, July 2010

Authorised by the Victorian Government, 8 Nicholson Street, East Melbourne

ISBN 978-1-74242-699-0 (online)

For more information contact the DSE Customer Service Centre 136 186

Accessibility
If you would like to receive this publication in an accessible format, such as large print or audio, please telephone 136 186, 1800 122 969 (TTY), or email customer.service@dse.vic.gov.au
This document is also available in PDF format on the Internet at www.dse.vic.gov.au

Contents

List of tables and figures

List of tables

List of figures

Acknowledgements

This project was funded by the Division of Natural Resources, Department of Sustainability and Environment, Victoria. We thank the following individuals and agencies for their important contributions:

DSE: Natural Resources: Joanne Wallace, Shaun Suitor, Lisa Saxton

DSE: Arthur Rylah Institute for Environmental Research: Kasey Stamation, Richard Loyn, David Cheal

DSE Land and Fire Management: Mary Camilleri, Jim Allen, Les Vearing (all Bendigo), Paul Bates (Maryborough)

DSE: Statewide Services, Biodiversity Services: Peter Johnson, Peter Morison (both Bendigo), Jerry Alexander (Wodonga), Steven Deed (Ovens), Ryan Incoll (Traralgon)

DSE: Biodiversity and Ecosystems Services: James Todd

DSE: members of the Ecological Impacts and Opportunities Working Group

DSE: Information and Business Technology: Sally Dwyer (East Melbourne)

DPI: staff of the Knowledge Resource Centre (Werribee)

CSIRO Sustainable Ecosystems (Canberra): Jacqui Stol

Monash University: Greg Horrocks, Jody Taylor

NSW DPI Science and Research Division: Brad Law

Summary

In this commissioned review we report on the ecological impacts of firewood supply, from: (1) ***collection*** of ground woody debris – 'dry' firewood, and (2) ***harvesting*** of living trees for firewood – 'green' firewood. The review is to inform the development of a Victorian statewide strategy that ensures that firewood supply from public land has a sustainable future, and that the associated environmental impacts continue to be managed to a high standard. This report reviews existing scientific information and also provides information that has emerged since recent Australian reviews on firewood (or coarse woody debris (CWD)) availability and distribution, its biodiversity, and firewood demand and usage.

For the purposes of this review we have adopted a broad definition of firewood: the detrital biomass encompassing a wide variety of material, including standing dead trees (also called snags or stags), stumps, dead branches, whole fallen trees, coarse roots and wood pieces that have resulted from the fragmentation of larger dead trees and logs. Firewood also includes residual wood generated from harvesting operations.

We have taken as our primary focus those forests and woodlands of north-central Victoria that supply the bulk of the firewood market, although reference is also made to wetter ash-type forests of southern and eastern Victoria, even though they are not considered to be traditional sources of domestic or commercial firewood, because they provide much of the available ecological knowledge.

To our knowledge there have been no empirical studies on the impacts of firewood supply on flora, fauna and ecosystem processes. However, the amount of inferential and correlative evidence is sizeable, particularly for fauna in relation to its use of CWD (including dead standing timber) and hollow-bearing trees and, to a lesser extent, timber harvesting residue.

Vegetation

Nine vegetation communities that are likely to be affected by firewood harvesting are listed under Victoria's Flora and Fauna Guarantee Act (FFG), while three ecological communities are listed under the Commonwealth Environmental Protection and Biodiversity Conservation Act (EPBC). About 60 vascular plant species that occur in forests or woodlands of concern are listed under the EPBC Act, FFG Act or both. However, the extent to which these species and communities will be affected by firewood harvesting or collection is unknown, as are the minimum levels of CWD that should be retained to allow ecosystem functions to operate. There may be some negative effects from soil disturbance associated with collection activities.

Overstorey trees might benefit from the thinning of the canopy associated with firewood harvesting, with an increase in growth rates and eventually more profuse flowering. However, selective cutting of preferred species might lead to long-term changes in overstorey composition, and affect the availability of floral and nectar resources upon which many fauna species rely.

Understorey species may also benefit from canopy thinning, with increased light and other resources leading to increased vigour and flowering. However, some species, such as winter-flowering orchids, might be disadvantaged by an increased light regime, while weeds may be encouraged by soil disturbance, particularly near tracks and roads.

Vertebrates

CWD is important for a multitude of Australian vertebrate species; logs are acknowledged by many authors as a critical resource for small Australian ground mammals. Logs provide nesting,

sheltering and foraging sites, food sources, particularly for insectivorous or mycophagous (fungus-feeding) mammals, facilitate movement, and can be important in the social behaviour of some forest-dependent taxa. Key mammal studies include the CWD manipulation research in northern Victoria and the study of Yellow-footed Antechinus *Antechinus flavipes* in a fragmented woodland landscape of the South West Slopes region of New South Wales.

Fallen trees and branches as well as the residual wood from timber harvesting provide vital habitat for a range of birds. Twenty-one species of native birds are considered to be threatened by firewood collection in Australia; nineteen of these species occur in Victoria. One example, the hollow-nesting Brown Treecreeper *Climacteris picumnus*, forages predominantly amongst standing dead trees and logs, gleaning invertebrate prey from fissures and hollows. Studies have shown that densities of the Brown Treecreeper increased substantially in River Red Gum forests where fallen timber loads exceeded 40 t ha^{-1}. In Victorian box-ironbark forests in the Goldfields bioregion, bird numbers were found to be nine times greater, and bird species diversity three times greater, in areas containing piles of CWD.

Many terrestrial reptile species are dependent on suitable structural heterogeneity in the ground strata, typically around CWD, and this has been documented for a number of Australian species in a variety of wet and dry forest types — reptiles use logs for a variety of purposes, including basking, nesting, shelter, hibernation and foraging. Large logs, which are able to retain moisture, may also provide refuge during drought or fire.

The role of CWD in amphibian occurrence is poorly understood and therefore primarily inferential. The value of CWD for amphibians probably lies in its moisture holding qualities and its ability to provide refuge from environmental extremes (e.g. fire, temperature). Other qualities of CWD include the provision of calling sites for males, oviposition sites, refuge from predation, and probably even a contributing determinant of the composition of frog assemblages.

The mammals of south-eastern Australia include many arboreal and aerial taxa that depend on hollow-bearing trees, as well as some facultative hollow users. The presence, abundance and taxonomic diversity of mammals have been correlated with the number of hollow-bearing trees, and tree size (dbhob) is significantly correlated with occupancy of tree-hollows, in both dead and live trees, by mammals.

Large trees are known to be important for other woodland mammals. Woodland patches in southern New South Wales are more likely to support populations of Yellow-footed Antechinus if they contain, *inter alia*, larger trees of select species(Korodaj 2007). In the box-ironbark woodlands of central Victoria, gullies, which occupy a very limited area in the ecosystem, are known to support significantly greater numbers of some arboreal mammals compared with non-gully sites.

In Victoria, tree hollows are considered essential for 47 bird species, 14 of which are listed as threatened, which use them primarily for nesting or roosting. Many additional species nest on ledges or open hollows (e.g. woodswallows), or use hollows opportunistically. Some bird species require highly specific nest hollow characteristics; therefore, a diversity of hollow types is more likely to support a diversity of bird species.

About 10% of the Australian reptile assemblage use hollows in Australia, as either den or nest sites, and by some reptiles as sources of prey. Two such threatened taxa in the 'firewood' regions of Victoria are the Tree Goanna and the Carpet Python, both of which utilise hollows in both large logs and large trees. To our knowledge there have not been any empirical studies on the use of hollow-bearing trees by frogs, although the number of arboreal frog species in south-eastern

Australia, principally from the *Litoria* genus, suggests that hollows are used, if only opportunistically.

Site impacts

Harvesting of standing forest as part of 'green' firewood-related operations is carried out in accordance with the Victorian Code of Practice for Timber Production and the specific guidelines and prescriptions that are applicable in that location. These, in general, are designed to allow the harvesting of firewood (a minor forest product) from GMZ and SMZ providing it is: (1) compatible with Forest Management Plan objectives, and; (2) it is for silvicultural, ecological, safety, or specific construction and maintenance requirements. Domestic Firewood Permits allow the conditional collection of 'dry' firewood from the forest floor.

The long-term ecological condition of a site is influenced by the functional impacts of firewood collection and harvesting; by the way in which a site retains (or leaks) its soil, nutrient, carbon and water resources. Additionally, the relationship of fire, wind, extended drought and pests and disease with firewood management needs to be considered in the context of long-term ecological condition.

Functional impacts will be affected by the spatial and temporal scales of harvesting and collection activities, and their intensity. These vary substantially, and consequently collection or harvesting may result in effects that are high-impact but localised, to low-impact but broadscale. The characteristics of specific sites will also vary considerably and influence the level of impact. These impacts have been considered under the following headings:

Soil fertility

With appropriate management, the impact of firewood-related harvesting disturbance on soil fertility and associated forest productive capacity is likely to be only a minor element of the production and supply of sustainable firewood. While soil fertility can be affected by the loss of nutrients and carbon as 'dry' and 'green' firewood is removed, or through associated soil disturbance, a key issue is whether this may affect long-term forest health, productivity or other ecosystem processes.

Most nutrient studies have focussed on the wetter forests, and typically include: Leaves;Stembark; Stemwood; Subordinate vegetation (understorey, shrubs and ground-layer), and; Litter layer. The nutrient content of CWD has been poorly reported, however, generally smaller pieces (i.e. <3 cm diam.) tend to be higher in nutrients than larger ones (i.e. >7 cm diam.). In drier forests it is expected that similar trends would be observed.

Because the concentration of nutrients in wood is small relative to those in other parts of trees, collecting or harvesting part of the wood removes a relatively small nutrient store. However, if bark and smaller diameter branch and bole material is also removed then the amount of specific nutrients removed will increase significantly and could lead to longer-term impacts on some sites. Losses of nutrients such as N can be replaced by biological N_2-fixation, and P from reserves and through the weathering of parent rock, however, Ca may be more problematic. Fire intensity and frequency can also be important considerations in nutrient budgets where these are influenced by firewood activities.

Disturbance associated with dry and green firewood removal will likely lead to some small decreases in soil organic carbon (SOC) due to oxidation of carbon in residues from the disturbance and in soil organic matter. However, this is unlikely to be significant given the limited soil mixing and compaction associated with firewood harvesting. The response of biomass carbon to harvesting disturbance is most likely to be influenced by the inherent nature of the forest. Partial harvesting for firewood will stimulate some growth response, which is usually more rapid and vigorous in the more productive wetter forests and slower in drier forests. Collection of dry firewood from the forest floor is unlikely to cause any growth response and the net result will be a loss of carbon. However, the gradual decay of CWD or consumption by fire will also result in loss of carbon over time, with some level of carbon residue. In some management areas the collection of naturally fallen wood is not permitted.

Carbon

The impact on carbon budgets and Greenhouse gas (GHG) emissions of firewood-related disturbance is likely to be a minor element of the production and supply of sustainable firewood. Its potential to reduce fossil fuel use and attendant CO_2 emissions, is dependent on a number of factors, including: forest growth rate, management, harvesting and transport systems, and; the efficiency with which firewood is burnt. This must be balanced against carbon losses from any reductions in CWD and soil organic carbon.

Forests sequester carbon in biomass and as below ground carbon. CWD has been recognised as a quantitatively important component of the forest's carbon stocks, equivalent to approx 10-20% of the above ground carbon biomass. However, generally little work has been conducted on the amount of carbon held in CWD in Australian systems.

Carbon is 'lost' in wood taken off-site as part of the collection and harvesting of dry and green firewood. There are different management regimes under which this firewood removal can occur, each with a different impact on carbon balances. To affect an understanding of these different regimes simulation modelling is required which incorporates the following: forest growth; natural mortality; disturbance related mortality; fire impacts; forest product removals; decay rates; SOC losses; etc., to keep track of all the key carbon pools. It is important that appropriate time horizons for the analysis are used when modelling to explore the influence of carbon balances on net CO_2 emissions, otherwise misleading conclusions may be reached. The task of exploring the carbon impact of different firewood options is significant.

Modelling has indicated that in regard to CO_2 emissions firewood may be generally more favourable for domestic heating than other sources of domestic heating such as gas and electricity. Fuelwood modelling has found that for CO_2 equivalent emissions, greenhouse balances are dominated by the potential savings due to the offset of fossil fuel emissions. Consequently, the type of energy generation that will be replaced by the use of the harvesting residues was critical to any evaluation.

In normal forestry operations there is generally only a slight change, if any, to total soil carbon, however, the inclusion of soil cultivation can led to some reduced soil carbon storage, particularly in the labile carbon and microbial carbon fractions which make up 13-18% of SOC. Recalcitrant carbon, or the 'stable' carbon fraction, can make up 69-81% of SOC, with char (charcoal, black carbon) comprising about 13-27%. These fractions are considered to be generally inert components of the soil.

Access

With appropriate access management, the impact of firewood-related harvesting disturbance on water quality and forest health is likely to be a minor element of the sustainable production and supply of sustainable firewood. The physical disturbance associated with accessing 'dry' or 'green' firewood, or with its production can impact on soil condition and water quality, and on forest health, with both the nature and timing of access significant influences. The factors that are most relevant to minimising soil disturbance and compaction are soil moisture content at the time of collection or harvest, machinery type, extraction track design and factors specific to soil type. Current codes of practice and management procedures ensure that the risk of connectivity between sources of sediment and drainage lines is minimised to acceptable levels, and the impact of harvesting operations is mainly found to be minimal. Generally, off-coupe road networks have been found to be the dominant source of sediment, with the landscape position of roading identified as a critical linkage factor together with the nature of road surfacing.

The principal forest diseases that could impact on firewood operations are Armillaria root rot and Phytophthora, being known dieback diseases of mixed-eucalypt forest types. The local risk of tree mortality from these diseases will need to be evaluated, bearing in mind local conditions and the suitability of remedial techniques to help minimise risk.

Fire

The management for both planned and unplanned fire is important to the management of CWD. Fire is often the dominant disturbance in forests, and either directly or indirectly responsible for much of the creation of CWD from trees, contributing to tree injury, death and collapse, and also to the consumption of CWD. Fire management should be an integral part of the planning and implementation of any native forest silviculture, and consequently it is necessary to a consideration of the amount and nature of firewood which may be collected; as firewood removal impacts on the size and amount of woody debris fuels remaining on site. While information on CWD-related fauna species is scarce, the limited information indicates that some species are well adapted to fire, whilst others are more at risk, depending on fire frequency, timing and intensity. Large pieces of CWD have been described as "effective small-scale fire breaks" because of their greater ability to survive fire and the protection their larger size provides.

Harvesting for firewood produces additional fuel loads and changed fuel drying conditions, which will likely increase fire risks. Planned fire can be an important consideration in managing these higher risks, and used to reduce fuel loads; removing much of the fine elevated fuel and some of the litter. However, burning of larger-diameter woody residue could cause substantial tree damage. Due to this type of damage, post-thinning burning is not generally recommended where wood degrade is likely to be unacceptable (eg. in ash and some mixed species regrowth). Where planned burning may be appropriate there are guidelines that assist in its implementation and the reduction of ecological impacts. Given adequate management of fuel hazard, any additional fire risk associated with harvesting is likely to be small.

Firewood collection has been proposed as a way of reducing fuel loads and subsequent fire risk. The effectiveness of this approach will be influenced in particular by the standard of firewood utilisation. Removal of coarse woody material down to a small end diameter (under bark) of around 10cm will have little impact on the rate of fire spread - finer fuels (generally < 6mm) are more important to the flame height, fireline intensity and rate of spread of a fire. Coarse fuels do impact on the total heat output of the fire, which can affect soil heating, plant/tree injury and mortality.

Burning for fuel reduction appears to be generally a more useful approach at the broader landscape scale than firewood collection for managing overall fuel hazard. At the smaller scale, CWD fuel manipulation by removal (firewood collection) or relocation may be a useful method of managing coarser fuel loads around high-value assets.

During fire suppression of wildfire, particularly in the “first-attack”, “mop-up” and “blacking-out” stages, the proximity of CWD and its impact on bulldozer activities and vehicle access can be an important consideration, especially on strategic firebreaks.

Knowledge Gaps

Most research has concentrated on the moist forests of eastern and south-eastern Australia where CWD production is higher, though the impacts on biodiversity and ecosystem processes are arguably less than those in woodlands — more research is required in these drier, less productive forests. There has been a tendency to utilise anecdotal observations and inferential evidence in the absence of empirical data and to conclude that particular taxa are likely to decline if this habitat resource was removed. We suggest a variety of key research areas based on a lack of information, particularly in dry forests and woodlands. We particularly note the lack of information on the non-vertebrate biota, particularly invertebrates, vascular flora and cryptogams, as well as the potential effects on ecosystem processes, such as nutrient, carbon and energy cycling, pollination, water cycling and filtration, decomposition, soil production and climate regulation.

1 Introduction

Since European settlement there has been extensive clearing of private land. Dry forests in particular, such as box-ironbark, have been cut over multiple times since the 1840s (Calder *et al.* 1994; Environment Conservation Council 2001a; Newman 1961), as the hardness and durability of the timber made it suitable for fuel, structural applications, fence posts and sleepers.

Ecological consequences of the removal of trees and logs include a shortage of suitable habitat logs, a substantial reduction in the number of standing mature or dead trees, and a significant increase in the density of small trees (Edgar 1958; Environment Conservation Council 2001a).

Firewood removal remains a long-standing use of public land and is an important source of heating and energy for many people in regional Victoria. However, in recent years there have been increases in the number and area of National Parks and other conservation reserves, reducing the areas available from which to obtain firewood. This will place additional pressures on those forests that remain available, on top of a range of other pressures such as climate change, fragmentation and weed invasion.

The Victorian Government is currently developing a statewide strategy to ensure that firewood collection from public land has a sustainable future, and that the environmental impacts from firewood collection continue to be managed to a high standard.

In drafting this review we have taken into account two different methods of obtaining firewood:

1. ***collection*** of ground woody debris – 'dry' firewood, and
2. ***harvesting*** of living trees for firewood – 'green' firewood

These two methods are elements of the domestic and commercial firewood supply chain as outlined below in Figure 1.1. The paths highlighted in yellow describe the two methods, with the path *forest stand/material on the ground/processed into firewood* describing "**collection** of dry firewood", and *forest stand/trees harvested/residual roundwood not suited to paper making/processed into firewood* describing "**harvesting** for green firewood". Where trees are harvested in Victoria's State forests, DSE is responsible for ensuring compliance with the Code of Practice for timber production on public land (DSE 2007) and for the implementation of Management Procedures covering timber harvesting operations and associated activities (DSE 2007). The main environmental focus of DSE is on those requirements associated with timber harvesting which either minimise or lead to an acceptable level of environmental impact. Firewood collection usually occurs in conjunction with forest management or production activities (such as timber harvesting or silvicultural operations, or other operation such as road works).

All coupes in which tree falling is planned to occur for the production of firewood must be included in the Wood Utilisation Plan (WUP) or an approved Timber Release Plan (TRP). Coupes designated for the collection of firewood that was fallen during a previous harvesting activity do not require inclusion in the WUP. Domestic firewood permit or licence holders are not permitted to fall trees for domestic firewood. Tree felling is undertaken by appropriate DSE officers or by contractors engaged by DSE in accordance with the Management Procedures (DSE 2007)

Domestic firewood collection requires a Domestic Firewood Permit or Forest Produce Licence, which amongst other things has conditions requiring compliance with either, (1) Standard Operation Procedure: Domestic Firewood collection in non-Timber Release Plan coupes (DSE 2006), or (2) Standard Operation Procedure: Domestic Firewood collection in approved Timber Release Plan coupes (DSE 2006), depending on who has been responsible for the coupe. Persons harvesting/collecting firewood for commercial purposes from coupes managed by DSE must hold a Forest Produce Licence.

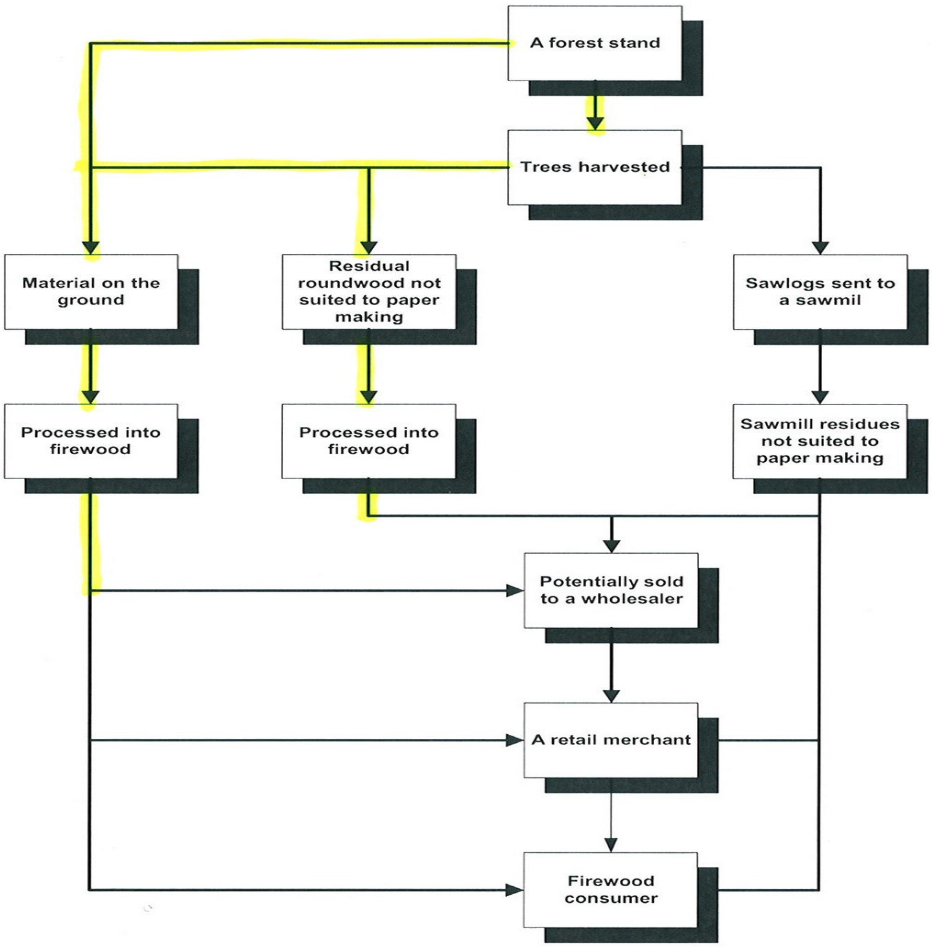


Figure 1.1 Domestic and commercial firewood supply chain, from forest stand (includes woodland) to end user (*adapted from Sylva Systems (2007)*).

In this commissioned review we report on the ecological impacts of firewood collection and harvesting in Victoria. This report reviews existing scientific information and also provides information that has emerged since recent Australian reviews on firewood (or coarse woody debris (CWD)) availability and distribution, its biodiversity, and firewood demand and usage (Department of Natural Resources and Environment 2002; Department of Sustainability and Environment 2003e; Driscoll *et al.* 2000; Grove and Meggs 2003; Sylva Systems Pty Ltd 2007; Woldendorp and Keenan 2005; Woldendorp *et al.* 2002).

The licensed collection and harvesting of firewood on public land in Victoria accounts for approximately 20% of all firewood in the state (Department of Natural Resources and Environment 2002). This review considers the impact of these operations on the flora, fauna and key ecological processes. Our primary focus is on the value for biodiversity, particularly threatened taxa, that is held by CWD on the forest floor as well as live and standing dead timber, and those Victorian bioregions or broad vegetation communities that provide the bulk of firewood, through legal collection. We also examine the effects that thinning of the canopy might have on subordinate vegetation strata.

To our knowledge there have been no empirical studies on the impacts on flora, fauna and ecosystem processes of the collection or harvesting of firewood. However, the amount of inferential and correlative evidence is sizeable, particularly for fauna in relation to its use of CWD (including dead standing timber) and hollow-bearing trees and, to a lesser extent, timber harvesting residue — it is primarily this information that we draw upon for this report. We also note the lack of information on the non-vertebrate biota, particularly invertebrates, vascular flora and cryptogams, as well as the potential effects on ecosystem processes, such as nutrient, carbon and energy cycling, pollination, water cycling and filtration, decomposition, soil production and climate regulation.

In this report nomenclature for the vertebrate fauna follows Van Dyck and Strahan (2008) for mammals and bats, Christidis and Boles (2008) for birds, and Wilson and Swan (2008) and Cogger (2000) for the herpetofauna.

1.1 What is firewood CWD?

Coarse Woody Debris (CWD) occurs naturally as a result of branch or tree death, or as a by-product of harvesting. CWD encompasses a broad range of material, including standing dead trees (aka ‘stags’ or ‘snags’), stumps, dead branches, whole fallen trees, coarse roots and wood pieces derived from the disintegration of larger stags and logs (Woldendorp and Keenan 2005).

CWD loads are dependent the rate and timing of tree death, limb fall and trunk decline in forests and woodlands which are influenced by several factors, including the size and density of trees, wood durability, and disturbance regimes. Fire is one of these disturbances as are extended drought, pests and disease, wind damage, and various land use. For example, if silvicultural operations are undertaken, the amount of harvesting residue left in situ.

It varies substantially between sites according to forest type and site history, and is considered to be as important as the living overstorey, leaf litter and soil components in maintaining biodiversity and conserving biodiversity (Australian and New Zealand Environment and Conservation Council 2001b). However, it also represents an easy source of firewood.

For the purposes of this review we have adopted a broad definition of firewood CWD, following Woldendorp and Keenan (2005) who describe CWD as detrital biomass encompassing a “wide variety of material, including standing dead trees (also called snags or stags), stumps, dead branches, whole fallen trees, coarse roots and wood pieces that have resulted from the fragmentation of larger snags and logs”. The definitions and size thresholds utilised to define CWD vary widely among researchers, making results between different studies and ecosystems difficult to interpret (Meggs 1996; Woldendorp and Keenan 2005); the largest discrepancy in the definition of the form of CWD appears to be whether standing dead trees and stumps are included in overall assessments.

There is considerable variation in the minimum CWD diameter thresholds adopted by land managers and researchers. While these range from 1–25 cm (reviewed in Harmon *et al.* 1986), the minimum diameter threshold of 10 cm appears to be the most commonly utilised in forestry or wildlife work. Fire research generally categorises minimum diameter CWD in the range 2.5–7.5 cm. A maximum CWD diameter threshold is also apparent in some fire-fuel studies where CWD is characterised by its burning time (Table 1.1) (Woldendorp and Keenan 2005).

Table 1.1 Fuel classes used by management specialists.

Fuel class is related to time-lag, the time it takes for a fuel to lose 63 percent of the moisture content under a particular set of conditions (Maser *et al.* 1979).

Fuel size	Fuel time-lag class	Range of time-lags	Definition
< 0.6 cm	1 - hour	0 - 2 hours	Dead herbaceous and woody fuels less than 0.6 cm in diameter and the uppermost 0.6 cm of needles and leaves on the forest floor.
0.6 – 2.5 cm	10 - hour	2 - 20 hours	Dead fuels from 0.6 to 2.5 cm in diameter and litter from 0.6 to 2.5 cm below the surface of the forest floor.
2.5 – 7.6 cm	100 - hour	20 - 200 hours	Dead fuels from 2.5 to 7.6 cm in diameter and litter from 2.5 to 10.2 cm below surface of the forest floor.
7.6 – 20.3 cm	1000 - hour	200 - 2000 hours	Dead fuels from 7.6 to 20.3 cm in diameter and litter 10.2 cm below surface of the forest floor.
> 20.3 cm	> 10000 - hour	> 2000 hours	All dead fuels larger than 20.3 cm in diameter or more than 30.5 cm below surface of the forest floor.

1.2 How does CWD differ between forest types?

Few data exist on the amount of CWD expected to occur under 'natural' conditions in the various woodlands and forests from which firewood is sourced. Woldendorp and Keenan (2005) have summarised the findings of a literature review (to 2002) of CWD and fine litter quantities, and provide a breakdown, albeit in broad terms, of CWD loads by state and broad forest type. The latter category includes 'woodland' and 'open forest', the two forest types that account for the bulk of firewood collected in Victoria. The constituent vegetation communities of these two categories are very diverse; however, they serve to underscore the relative differences in CWD loads across the landscape. Mean mass of CWD for woodland was 18.9 t ha^{-1}, and for open forest 50.4 t ha^{-1} (Woldendorp and Keenan 2005).

Two recent Victorian studies serve to underscore the influence of forest type on CWD loads. Mac Nally *et al.* (2002a; 2000a; 2002c) have provided recent evidence for the post-European settlement depletion of CWD in floodplain forests of northern Victoria. Historical levels of CWD in this ecosystem were probably in the order of 125 t ha^{-1}; current mean loads are approximately 19 t ha^{-1}.

Volumes of fallen logs across four age-classes of Mountain Ash *Eucalyptus regnans* forests of the Central Highlands of Victoria were reported by Lindenmayer *et al.* (1999) to be approximately 350 m^3 ha^{-1}. This converts to 210 t ha^{-1} using the volume-mass conversion approach adopted by Mac Nally *et al.* (2002c), more than the 134.1 t ha^{-1} reported for Australia-wide 'tall open forest' by Woldendorp and Keenan (2005). To illustrate further, the lowest biomass estimation (0.2 t ha^{-1}) was recorded in 5-year-old Mountain Ash forest that had been clear-felled and burnt, while the highest (1089 t ha^{-1}) was from 63-year-old Messmate Stringybark *Eucalyptus obliqua* forest that had regenerated after fire (Woldendorp and Keenan 2005). In general, older forests contain a higher biomass of CWD than younger forest (Woldendorp and Keenan 2005).

The Victorian Department of Sustainability and Environment (2008c) makes available EVC benchmarks — "An EVC benchmark is a standard vegetation-quality reference point relevant to the vegetation type that is applied in assessments. It represents the average characteristics of mature and apparently long-undisturbed stands of the same vegetation type. EVC benchmarks have been developed to assess the vegetation quality of the EVCs at the site scale in comparison to the 'benchmark' condition. Each EVC benchmark contains a range of information necessary for conducting a vegetation quality assessment" (2008c). One element of these benchmarks is the average amount of logs ha^{-1} — this amount is an estimate, using total log length (not volume), by experienced DSE ecologists. This measure is a conservative underestimate (to accommodate variability), yet it is the only state-wide measure available for CWD in most Victorian forest or woodland EVCs. Despite its obvious limitations, it nonetheless serves to provide a useful comparison of CWD loads in those forests and woodlands from which most of Victoria's firewood is obtained (Table 1.2).

Substantial differences exist in the amount of CWD expected to occur in particular EVCs, with log benchmarks ranging from 50 to 300 linear metres of logs per hectare (Table 1.2). In previous research, total log lengths in 41 Grassy Dry Forest sites ranged from 61 to 696 m ha^{-1} (average 334 m ha^{-1}), while that in 85 Box-Ironbark Forest sites ranged from 13 to 530 m ha^{-1} (average 116 m ha^{-1}), reflecting the substantial degree of disturbance in the latter (Arthur Rylah Institute for Environmental Research, unpublished data).

1.3 Which areas are most affected?

In Victoria, the proportions of retail firewood types vary dramatically. River Red Gum and box species dominate the northern floodplain forests and central Victorian woodlands (Goldfields bioregion), account for approximately 92% of all sales in the state (Driscoll *et al.* 2000).

The Bendigo Forest Management Area, which incorporates much of Victoria's box-ironbark forest and woodlands, accounts for approximately 21,000 tonnes of firewood per annum, more than twice the amount of firewood than the next most significant FMA (Midlands) (Department of Natural Resources and Environment 2002). The Mid Murray FMA, which roughly corresponds to the Murray Fans bioregion, is dominated by floodplain forests and box-ironbark woodlands. This FMA provides the third-most significant volume of firewood per annum in Victoria (4,000 tonnes, North East Catchment Management Authority 2004).

Then primary foci of this report then are the forests and woodlands of north-central Victoria, from which the largest proportion of Victoria's firewood is obtained. Ash-type wet forests of southern and eastern Victoria are not considered to be traditional sources of domestic or commercial firewood, as their burning properties are poorer than most other eucalypt species. Also, the non-sawlog component of ash-type forests is normally used for domestic pulping and by the export woodchip markets, although small quantities of Mountain Ash *Eucalyptus regnans* have recently been sold by VicForests for firewood (Sylva Systems Pty Ltd 2007). In relation to ecological impact, green-firewood collection on ash-type coupes would follow the harvest of sawlogs and pulpwood and be taken from that component which is largely consumed by slash-burning as part of coupe regeneration. These high intensity fires remove residual debris and expose mineral earth seedbeds suitable for the sowing and growth of ash species (Flint and Fagg 2007). Consequently, removal of some of this residue as firewood, prior to burning, will have marginal ecological impact in the overall context of the harvest and regeneration operations. For these reasons ash-type wet forests will not be considered specifically in this literature review of Victoria's main firewood species. However, there will be considerable reference to this forest type through the reviewed literature, as it provides much of the available knowledge.

Table 1.2 EVCs most likely to be affected by firewood harvesting, and log benchmarks. Log benchmarks, derived from Department of Sustainability and Environment (2008c), provide a standard reference point relevant to the vegetation type that is applied in assessments; it represents the average characteristics of a mature and apparently long-undisturbed stand of the same vegetation type.

EVC No.	EVC Name	Logs (m ha^{-1})
16	Lowland Forest	200
20	Heathy Dry Forest	200
21	Shrubby Dry Forest	200
22	Grassy Dry Forest	200
23	Herb-rich Foothill Forest	200
24	Foothill Box Ironbark Forest	200
45	Shrubby Foothill Forest	200
47	Valley Grassy Forest	200
55	Plains Grassy Woodland	100
56	Floodplain Riparian Woodland	300
61	Box Ironbark Forest	200
66	Low Rises Woodland	200
68	Creekline Grassy Woodland	300
69	Metamorphic Slopes Shrubby Woodland	150
70	Hillcrest Herb-rich Woodland	150
71	Hills Herb-rich Woodland	150
80	Spring Soak Woodland	50
103	Riverine Chenopod Woodland	50
106	Grassy Riverine Forest	300
127	Valley Heathy Forest	200
128	Grassy Forest	200
151	Plains Grassy Forest	200
168	Drainage-line Aggregate	200
169	Dry Valley Forest	200
175	Grassy Woodland	150
177	Valley Slopes Dry Forest	200
198	Sedgy Riparian Woodland	200
282	Shrubby Woodland	150
295	Riverine Grassy Woodland	200
641	Riparian Woodland	200
652	Lunette Woodland	100
659	Plains Riparian Shrubby Woodland	200
663	Black Box Lignum Woodland	150
679	Drainage-line Woodland	300
704	Lateritic Woodland	150
793	Damp Heathy Woodland	100
803	Plains Woodland	100
813	Intermittent Swampy Woodland	200
814	Riverine Swamp Forest	200
815	Riverine Swampy Woodland	100
816	Sedgy Riverine Forest	200
818	Shrubby Riverine Woodland	100
823	Lignum Swampy Woodland	100

2 Ecosystem processes relating to CWD collection

Dead and dying trees and logs are key habitat components for a broad variety of plants, animals and microorganisms. These components of nearly all terrestrial ecosystems also play a crucial role in ecosystem processes and contribute to species richness. The myriad ecological functions of dead wood have been neatly summarised recently by several authors (e.g. Grove and Meggs 2003; Grove *et al.* 2002; Harmon *et al.* 1986; Lindenmayer *et al.* 2002; McComb and Lindenmayer 1999) and include, *inter alia*, nutrient cycling and energy flow, carbon storage, soil conditioning, substrate for saproxylic (pertaining to dead or decaying wood) and epixylic (living on the surface of wood) organisms, refuge from environmental extremes, moisture reservoir, as well as habitat for fauna (e.g. provision of nesting, denning, shelter and feeding sites).

CWD adds complexity to the forest floor, in so doing affecting the function of terrestrial systems. This has an important temporal dimension across forest stands; the stage of dying and decaying logs influences the occurrence of and use by fauna; animal taxa that use a particular stage of log (or tree) decay in one seral stage may differ from those that can use the same type of log (or tree) in another seral stage (McComb and Lindenmayer 1999). The availability of logs varies with stand age in Victorian box-ironbark forests; older growth forests have been found to contain more than three times the density of logs and nine times the volume of logs than stands of young regrowth (Venosta 2001).

The long-term ecological condition of a site is also influenced by the functional impacts of firewood harvesting (Freudenberger *et al.* 2004). In other words, changes to the way in which a site retains (or leaks) its soil, nutrient, litter and water resources after disturbances such as harvesting, will affect the function of a site. Sustainable firewood harvesting will depend on a site's capacity for tree regeneration; the capacity for tree regeneration is essential for sustainable firewood harvesting, thus the satisfactory regeneration of canopy trees relies on the ecosystem functioning properly.

The value of CWD (including dead and standing material) for biodiversity and ecological processes is recognised in the official listing in Victoria of (1) the loss of coarse woody debris from Victorian native forests and woodlands as a key threatening process (Department of Sustainability and Environment 2008b) and (2) the loss of hollow-bearing trees from Victorian native forests as a key threatening process (Department of Sustainability and Environment 2008b). The removal of dead wood and dead trees is also officially listed as a key threatening process in NSW (Department of Environment and Climate Change 2008).

In the following sections we elaborate on the ecological functions associated with CWD, and possible alterations to ecosystem processes associated with CWD collection. However, the spatial and temporal scales of harvesting and collection activities, and their intensity, vary substantially. Consequently, collection or harvesting may result in effects that are high-impact but localised, to low-impact but broadscale. It is not our intent to differentiate between these two extremes, but the reader must nonetheless be mindful of the implications of scale.

2.1 Soil and nutrient processes

2.1.1 Nutrient cycling (see also 4.1.1.)

CWD is a structurally and chemically heterogeneous substrate (Brown *et al.* 1996a). It consists of a number of layers including the outer and inner bark, the sapwood and heartwood (Mackensen *et al.* 2003). The inner bark usually decomposes most quickly. It contains the cambium and phloem and is rich in sugars (Brown *et al.* 1996a). The sapwood usually decays faster than the heartwood. Heartwood is the largest component of CWD and decomposes more slowly than the other wood components, in part because it has lower carbon:nutrient ratios (Mackensen *et al.* 2003). Many nutrients occur in freshly fallen CWD in low concentrations, but as decomposition proceeds and carbon is lost via respiration, the concentration of nutrients may increase (Brown *et al.* 1996a). In many cases the carbon (C):nitrogen (N) ratio decreases as decay proceeds (Mackensen *et al.* 2003). There are approximately seventeen elements essential to higher plants, but C, hydrogen (H) and O (oxygen) make up most of undecayed CWD. The elements phosphorus (P), magnesium (Mg), iron (Fe) and sodium (Na) are more concentrated in sapwood while manganese (Mn) is more concentrated in the heartwood. Nitrogen content is higher in the sapwood than it is in the heartwood (Brown *et al.* 1996a). Unfortunately, CWD has largely been ignored by soil scientists, even though it is a significant source of soil organic matter (McKenzie *et al.* 2000).

Decomposing CWD enables a large proportion of the nutrients accumulated by living trees to be returned to the soil for reabsorption by flora and other organisms (Franklin *et al.* 1987; Grove *et al.* 2002). The amount of nutrients returned is dependent on the input of CWD into the system. Decomposition is brought about by fungi and micro-organisms, often assisted by invertebrates. As decomposition progresses CWD enriches the soil (Bull *et al.* 1997; Sollins *et al.* 1987). For example, mulga *Acacia aneura* log mounds have been described as fertile patches within the semi-arid woodlands of eastern Australia. Their soils differ from surrounding soils in having significantly greater amounts of mineralizable nitrogen as well as more organic carbon and total nitrogen. They appear to be more suitable for the growth of perennial herbs (Tongway and Ludwig 1989). A study in a mixed Tasmanian forest showed that CWD had significantly higher concentrations of Nitrogen than soil in half of the study sites (McKenny and Kirkpatrick 1999).

While leaf litter decomposition has been widely studied, the break down of CWD has received little attention (Brown *et al.* 1996b). As most woods are high in polymeric material and low in soluble substrates (Harmon *et al.* 1986), there is an expectation of slow rates of mass loss and mineralisation of nutrients from woody material compared with leaf litter components (Brown *et al.* 1996b). Nutrient concentrations tend to be higher in bark than in wood pieces and smaller pieces of CWD (i.e. 3-5 cm diameter) tend to be higher in nutrients than larger ones (i.e. 10-15 cm in diameter). A decay study of CWD in Western Australian forests found Nitrogen was the only nutrient to be immobilised over the 5-year study period (Brown *et al.* 1996b) and research conducted in a pine plantation in the ACT found that only 12% of the original Nitrogen was released in eight years of decay exhibiting the length of time it takes for nutrients to be returned to the soil. Research examining the nutrient content of CWD in an open eucalypt forest in north-eastern Victoria found CWD had the ability to contribute to soil nutrients (Stewart and Flinn 1985). Some nutrient concentrations in woody debris from this study are outlined in Table 2.1.

With improved water and nutrient conservation, CWD should help provide better conditions for seedling germination and plant growth. However, drier forests such as Box-Ironbark are often low in nutrients with low water-holding capacity (Muir *et al.* 1995), and localised increases in moisture and nutrients might favour weed species. In Box-Ironbark and Heathy Dry forests, the author (AT) has observed piles of branches acting as 'run-on' zones for the accumulation of water and nutrients, encouraging high localised cover of the short-lived weeds Large Quaking-grass *Briza maxima* and Hair-grass *Aira* spp.

CWD adds complexity to ecosystems (Harmon *et al.* 1986; Lindenmayer *et al.* 2006), but its removal for firewood will simplify those ecosystems by reducing CWD-associated taxa and ecosystem pathways and functions. Long-term site productivity, particularly in lower-nutrient sites, may be reduced (Davidson *et al.* 2007; Harmon *et al.* 1986), with implications for forest sustainability. The degree to which nutrient cycling would be affected depends heavily on the intensity of firewood harvesting and collection. Nonetheless, codes of forest practice should recognise the importance of CWD as part of ecosystem function (Lindenmayer and McCarthy 2002). Some DSE Forest Management Plans place conditions on licenced firewood cutters that do not permit the collection of naturally fallen wood or the harvest of dead standing trees (DSE 2001)

2.1.2 Carbon cycling (see also 4.1.2.)

Forests sequester carbon in biomass and through plant residues in the soil, with the accumulation of above ground carbon generally reflecting forest growth and productive capacity. Below ground, carbon accumulation is affected by root growth and soil-carbon balances. Soils are expected to increase in carbon, dependent on soil type, and then reach stability. Disturbances to CWD such as firewood collection lead to direct losses of carbon from the system followed by a process of re-accumulation during forest recovery.

Table 2.1 Mean concentrations of nutrients in debris before burning component of experiment (Nutrient concentrations g/kg) (Stewart and Flinn 1985).

Debris size	Nitrogen	Phosphorus	Potassium	Calcium	Manganese
≤6 mm	6.10	0.37	4.77	4.79	1.27
6-30	2.05	0.10	1.12	1.94	0.45
30-70	1.66	0.10	0.94	1.23	0.45
≥70	1.26	0.06	0.45	1.26	0.32

In addition to its role in nutrient cycling, CWD represents a large and long term store of carbon, which is gradually released through its decomposition (Brown *et al.* 1996b; Grove *et al.* 2002). Guo *et al.* (Guo *et al.* 2006) estimated that only 42% of carbon was released during eight years of the decay of *Pinus radiata* logs. During the decomposition process, microbes turn organically bound carbon (which accounts for approximately 50% of the organic material) into carbon dioxide (Mackensen and Bauhus 1999). The decay rate is slower in dry forests and is predicted to exceed 25-30 years in most cases (Mackensen and Bauhus 1999). However, Barrett (2002) found the carbon turnover times in three Australian biomes to be reduced and more rapid in drier areas (i.e. 23 years in tall forests, 4 years in arid shrubland, 3 years in open woodland). The amount of CWD in some areas is equivalent to approx 10-20% of the above ground carbon biomass, indicating that dead wood can represent a significant amount of carbon in forests (Delaney *et al.* 1998). Roxburgh *et al.* (2006) found in a temperate eucalypt forest in NSW that the mean carbon stock of CWD was 52.2 ± 15.6 tC/ha (tonnes of carbon equivalent per hectare). This made up approximately 19% of the total above-ground biomass. Guo *et al*. (2006) found CWD partly offset soil carbon losses after alterations in land use and removing CWD from sites may well reduce soil carbon. Unfortunately, little work has been conducted on the amount of carbon held in CWD in Australian systems.

Modelling can be used to explore these losses on net CO_2 emissions. The AGO's FullCAM model (Paul *et al.* 2003) was developed to track carbon flows in a range of ecosystems. Paul *et al.* (2003) report that for remnant woodlands with a maximum aboveground biomass of about 77 t DM ha^{-1} (tonnes of dry matter per hectare) three case studies were simulated over a 100 year period: (1) *No firewood collection* – dead wood resulting from tree death and litterfall was left on the ground to decompose; (2) *Firewood collection* – 80% of fallen dead wood was manually collected every five years, the rest remaining on-site to decompose; (3) *Intense firewood collection* – both dead trees and fallen wood were collected each year. The modelling found that the woodland systems were degrading because old dying trees were not being replaced, and there was a release of between about 30 and 60 t CO_2 ha^{-1}. When firewood was collected every five years from the ground, net emission of greenhouse gas increased by 20.0 t CO_2 ha^{-1}, and when firewood was collected each year from both the ground and dead trees, an extra 26.6 t CO_2 ha^{-1} was emitted. The impact of harvesting in managed native forests on the net amount of CO_2 emitted is explored in Section 4.1.2.

2.1.3 Soil and water quality (see also 4.1.3.)

The removal of CWD from the forest floor can expose the soil to wind and water, potentially leading to an increase in soil erosion and sedimentation (New South Wales Department of Environment and Climate Change 2003). CWD may help control the downslope movement of water, soil and litter on hillsides, reducing erosion and helping to capture sediment and organic matter (Harmon *et al.* 1986). On steeper slopes CWD is an important component of 'surface roughness', slowing down overland flow and aiding infiltration. Groves (run-on zones with CWD and plants) in Mulga *Acacia aneura* woodlands had a mean water infiltration rate that was 154% higher than in inter-zones (Berg and Dunkerley 2004).

Additionally, the combination of CWD, saproxylic invertebrates such as termites, and decay fungi have been shown to increase soil and water quality by creating degraded-wood barriers and infiltration zones. For example, Mulga log mounds (where mounds develop around dead or fallen mulga trees due to termite activity and earth movement) have a higher water filtration rates and higher nutrient contents than soils away from the mounds (Tongway and Ludwig 1989).

Bioturbation of soil can be observed around decayed pieces of CWD where fauna such as echidnas and fungi-eating macropods forage for food. This is often important to the breakdown of litter and soil-mixing processes and the development of macropores and good soil structure, which are important to water infiltration.

However, soil and water quality are more likely to be affected by vehicle and machinery access to firewood areas than by removal of CWD. Surfaced roads are not normally constructed to these areas due to resource limitations and vehicles can damage tracks, compact soil and significantly impact on water quality. In some areas firewood collection is not permitted in winter to reduce damage to wet tracks (Department of Sustainability and Environment 2004a). These issues are reviewed in more detail in Section 4.1.3, dealing with harvesting impacts.

2.2 Habitat

Several reviews of the relationships between Australian fauna and key habitat and structural components of woodland and forest ecosystems, generally including dead and dying trees and logs, have been prepared in the last decade (Department of Natural Resources and Environment 2002; Driscoll *et al.* 2000; Freudenberger *et al.* 2004; McElhinny *et al.* 2006). Each of these reviews has generally summarised the documented associations between the major vertebrate groups and vegetational structural attributes or complexity, though most studies reviewed have concerned birds and mammals (both ground and arboreal). By comparison, relatively few studies have investigated the habitat requirements of bats, reptiles, frogs or invertebrates, let alone microorganisms.

There are few Australian (or Victorian) empirical studies that have as their focus the value of CWD for fauna, though the most notable recent exception has been the experimental study of vertebrate biodiversity in relation to CWD loads on the River Red Gum floodplains of northern Victoria (Mac Nally 2006; Mac Nally *et al.* 2002a; Mac Nally and Horrocks 2002; Mac Nally and Horrocks 2008; Mac Nally *et al.* 2002b; Mac Nally and Horrocks 2007; Mac Nally *et al.* 2001; Mac Nally *et al.* 2000a; Mac Nally *et al.* 2002c). In that study, the amount of manipulated CWD was found to influence the densities of select vertebrates (Yellow-footed Antechinus *Antechinus flavipes*, Brown Treecreeper *Climacteris picumnus*); both species responded strongly, through elevated densities, to increased loads of CWD.

In another recent manipulation study, this time to determine whether faunal habitat was enhanced by coarse woody debris in semi-arid grasslands and woodlands of Terrick Terrick National Park, north-central Victoria, strategically placed fence-posts were used to mimic natural accumulations of fallen timber (Michael 2001; Michael *et al.* 2004). In that study there was evidence of seasonal and spatial usage of these refuges by several vertebrate species, including the threatened Fat-tailed Dunnart *Sminthopsis crassicaudata* and Curl Snake *Suta suta*.

The key bioregions of this review support an array of threatened Victorian and Australian vertebrate fauna (Department of Sustainability and Environment 2007; Department of the Environment Water Heritage and the Arts 2008), many of which are dependent on or utilise logs or tree hollows (Table 2.2; Appendix 1). The categories for national and state conservation status for threatened vertebrate fauna follow those of the International Union for Conservation of Nature and Natural Resources (IUCN 2008). Taxa listed under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG, Department of Sustainability and Environment 2008b) statutory lists of threatened taxa are also acknowledged.

2.2.1 Mammals

The relationship between CWD and the occurrence of many mammal species has been documented for a variety of ecosystems, though, for the purposes of this review, we have generally restricted our focus to Australia and, where information is available, Victoria.

Driscoll *et al.* (2000) reported nearly a decade ago that international investigations of the relationship between CWD and mammals comprised a handful of correlational studies, no definitive experimental work and contrasting results, though there was evidence to show that some species are influenced by the existing range of woody debris. In the USA, voles (Bowman *et al.* 2000) and shrews (Butts and McComb 2000) are known to be positively influenced by the cover and type of CWD.

Since the review by Driscoll *et al.* (2000) several studies in different ecosystems of south-eastern Australia have demonstrated the importance of CWD for some Australian terrestrial mammals. These studies include the CWD manipulation research in northern Victoria mentioned above (Mac Nally *et al.* 2002a; Mac Nally and Horrocks 2008; Mac Nally *et al.* 2001; Michael 2001; Michael *et al.* 2004) and the study of Yellow-footed Antechinus *Antechinus flavipes* in a fragmented woodland landscape of the South West Slopes region of New South Wales (Korodaj 2007). Korodaj found that at the trap-site scale, greater structural complexity best explained occurrence patterns of *A. flavipes*, and that there was a strong association with hollow-bearing logs.

Logs are acknowledged by many authors as a critical resource for small Australian ground mammals. Lindenmayer *et al.* (2002) and McElhinny *et al.* (2006) summarised the importance of logs as nesting, sheltering and foraging sites for many mammals, including many species that occur in south-eastern Australian forests and woodlands (e.g. Bush Rat *Rattus fuscipes*, Agile Antechinus *Antechinus agilis*, Dusky antechinus *A. swainsonii*, Eastern Quoll *Dasyurus viverrinus*, Mountain Brushtail Possum *Trichosurus cunninghami*, Short-beaked Echidna *Tachyglossus aculeatus*). Logs provide a large proportion of available shelter sites for many mammal species; for instance, in south-eastern Queensland, the Short-beaked Echidna typically preferred log-hollows and depressions under the roots of fallen trees as shelter sites, disproportional to their availability (Menkhorst 1995; Wilkinson *et al.* 1998), and partially decayed logs in Tasmanian wet sclerophyll forest are important nest-sites for Pygmy-possums *Cercartetus* spp. (Duncan and Taylor 2001).

Lindenmayer *et al.* (2002) also note the value of logs as important food sources, particularly for insectivorous or mycophagous (fungus-feeding) mammals. Logs are sites where hypogeous (underground fruiting) mycorrhizal fungi develop and become an important source of food for several forest-dwelling mammal taxa, like the Bush Rat, Southern Brown Bandicoot *Isoodon obesulus*, and Mountain Brushtail Possum *Trichosurus cunninghami* (as *T. caninus*) (Claridge 1988; Claridge and Barry 2000; Claridge *et al.* 2000; Claridge and Lindenmayer 1998). A similar relationship has been found in the USA between small terrestrial mammals, fungi and decaying logs (e.g. Bowman *et al.* 2000; Bull 2002).

Logs also facilitate movement for many terrestrial mammals, providing travel routes along or beside logs through undergrowth, and can be important in the social behaviour of some forest-dependent taxa, such as the Common Wombat *Vombatus ursinus* and the Mountain Brushtail Possum, two species that deposit scats on logs to designate territory boundaries (Halstead-Smith 1999; Lindenmayer *et al.* 2002; McElhinny *et al.* 2006).

2.2.2 Birds

Fallen trees and branches as well as the residual wood from timber harvesting provide vital habitat for a range of birds.

Twenty-one species of native birds were considered by Garnett and Crowley (2000) to be threatened by firewood collection in Australia; nineteen of these species occur in Victoria. One example, the hollow-nesting Brown Treecreeper *Climacteris picumnus*, forages predominantly amongst standing dead trees and logs, gleaning invertebrate prey from fissures and hollows as well as from fallen branches on the ground below. Studies by Mac Nally *et al.* (2001) and Mac Nally *et al.* (2002b) have shown that densities of the Brown Treecreeper increased substantially in River Red Gum forests where fallen timber loads exceeded 40 t ha^{-1}. Other examples include the nocturnal Australian Owlet-nightjar *Aegotheles cristatus*, which roosts and nests in hollows in standing and fallen timber (EM pers. obs.), and the Bush Stone-curlew *Burhinus grallarius*, which roosts and forages amongst fallen logs. The Bush Stone-curlew nests beside a fallen log to avoid detection, relying on camouflage to avoid predation (Department of the Environment Water Heritage and the Arts 2005). Its current range is now largely confined to grassy woodlands (as in the Goldfields and Riverina bioregions in Victoria) (Department of the Environment Water Heritage and the Arts 2005).

CWD provides shelter for species that forage in the lower strata. In Victorian box-ironbark forests in the Goldfields bioregion, bird numbers were found to be nine times greater, and bird species diversity three times greater, in areas containing piles of CWD (Laven and Mac Nally 1998) than in areas lacking such features. A range of bird taxa, strongly associated with logs for foraging or shelter in box-ironbark and River Red Gum forests from which large volumes of firewood are extracted were identified by Laven and Mac Nally (1998). These include: robins *Petroica* spp., Eastern Yellow Robin *Eopsaltria australis*, thornbills *Acanthiza* spp. and White-throated Treecreeper *Cormobates leucophaeus*.

Table 2.2 Threatened vertebrate taxa for the key Victorian bioregions of this review, compiled from the Atlas of Victorian Wildlife (DSE database), January 2009.

Victorian (Vict Cons and FFG code) and national (EPBC) threatened status* are shown. Genera are arranged alphabetically within Family and Families are arranged taxonomically within Order. Only extant non-vagrant Victorian native taxa are included. Appendix 1 provides a full list of extant vertebrate fauna per bioregion and the use of CWD and hollow-bearing trees by this fauna.

	Common name	Scientific name	EPBC	Cons. Vict.	FFG
MAMMALS					
Dasyuridae	Swamp Antechinus	*Antechinus minimus*		NT	L
	Brush-tailed Phascogale	*Phascogale tapoatafa*		VU	L
	Spot-tailed Quoll	*Dasyurus maculatus*	EN	EN	L
	Fat-tailed Dunnart	*Sminthopsis crassicaudata*		NT	
	White-footed Dunnart	*Sminthopsis leucopus*		NT	L
	Common Dunnart	*Sminthopsis murina*		VU	
Peramelidae	Southern Brown Bandicoot	*Isoodon obesulus obesulus*	EN	NT	
	Eastern Barred Bandicoot	*Perameles gunnii*	EN	CR	L
Petauridae	Squirrel Glider	*Petaurus norfolcensis*		EN	L
Macropodidae	Eastern Wallaroo	*Macropus robustus robustus*		EN	L
	Brush-tailed Rock-wallaby	*Petrogale penicillata*	VU	CR	L
Pteropodidae	Grey-headed Flying-fox	*Pteropus poliocephalus*	VU	VU	L
Rhinolophidae	Eastern Horseshoe Bat	*Rhinolophus megaphyllus*		VU	L
Vespertilionidae	Common Bent-wing Bat	*Miniopterus schreibersii (group)*			L
	Southern Myotis	*Myotis macropus*		NT	
	Greater Long-eared Bat	*Nyctophilus timoriensis*	VU	VU	L
Muridae	Broad-toothed Rat	*Mastacomys fuscus*		DD	
	Smoky Mouse	*Pseudomys fumeus*	EN	CR	L
Canidae	Dingo	*Canis lupus dingo*		NT	
BIRDS					
Megapodiidae	Malleefowl	*Leipoa ocellata*	VU	EN	L
Phasianidae	Brown Quail	*Coturnix ypsilophora*		NT	
	King Quail	*Excalfactoria chinensis*		EN	L
Anseranatidae	Magpie Goose	*Anseranas semipalmata*		NT	L
Anatidae	Australasian Shoveler	*Anas rhynchotis*		VU	
	Hardhead	*Aythya australis*		VU	
	Musk Duck	*Biziura lobata*		VU	
	Cape Barren Goose	*Cereopsis novaehollandiae*		NT	
	Blue-billed Duck	*Oxyura australis*		EN	L
	Freckled Duck	*Stictonetta naevosa*		EN	L
Columbidae	Diamond Dove	*Geopelia cuneata*		NT	L
Phalacrocoracidae	Pied Cormorant	*Phalacrocorax varius*		NT	
Ardeidae	Intermediate Egret	*Ardea intermedia*		CR	L
	Eastern Great Egret	*Ardea modesta*		VU	L
	Australasian Bittern	*Botaurus poiciloptilus*		EN	L
	Little Egret	*Egretta garzetta*		EN	L
	Australian Little Bittern	*Ixobrychus dubius*		EN	L
	Nankeen Night Heron	*Nycticorax caledonicus*		NT	

Threskiornithidae	Royal Spoonbill	*Platalea regia*		VU	
	Glossy Ibis	*Plegadis falcinellus*		NT	
Accipitridae	Grey Goshawk	*Accipiter novaehollandiae*		VU	L
	Spotted Harrier	*Circus assimilis*		NT	
	White-bellied Sea-Eagle	*Haliaeetus leucogaster*		VU	L
	Square-tailed Kite	*Lophoictinia isura*		VU	L
Falconidae	Grey Falcon	*Falco hypoleucos*		EN	L
	Black Falcon	*Falco subniger*		VU	
Gruidae	Brolga	*Grus rubicunda*		VU	L
Rallidae	Lewin's Rail	*Lewinia pectoralis*		VU	L
	Baillon's Crake	*Porzana pusilla*		VU	L
Otididae	Australian Bustard	*Ardeotis australis*		CR	L
Burhinidae	Bush Stone-curlew	*Burhinus grallarius*		EN	L
Charadriidae	Inland Dotterel	*Charadrius australis*		VU	
	Greater Sand Plover	*Charadrius leschenaultii*		VU	
	Pacific Golden Plover	*Pluvialis fulva*		NT	
Pedionomidae	Plains-wanderer	*Pedionomus torquatus*	VU	CR	L
Rostratulidae	Australian Painted Snipe	*Rostratula australis*	VU	CR	L
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*		VU	
	Red Knot	*Calidris canutus*		NT	
	Pectoral Sandpiper	*Calidris melanotos*		NT	
	Long-toed Stint	*Calidris subminuta*		NT	
	Great Knot	*Calidris tenuirostris*		EN	L
	Latham's Snipe	*Gallinago hardwickii*		NT	
	Black-tailed Godwit	*Limosa limosa*		VU	
	Eastern Curlew	*Numenius madagascariensis*		NT	
	Wood Sandpiper	*Tringa glareola*		VU	
Turnicidae	Red-chested Button-quail	*Turnix pyrrhothorax*		VU	L
	Little Button-quail	*Turnix velox*		NT	
Glareolidae	Australian Pratincole	*Stiltia isabella*		NT	
Laridae	Whiskered Tern	*Chlidonias hybridus*		NT	
	White-winged Black Tern	*Chlidonias leucopterus*		NT	
	Gull-billed Tern	*Gelochelidon nilotica*		EN	L
	Caspian Tern	*Hydroprogne caspia*		NT	L
Cacatuidae	Glossy Black-Cockatoo	*Calyptorhynchus lathami*		VU	L
	Major Mitchell's Cockatoo	*Lophocroa leadbeateri*		VU	L
Psittacidae	Swift Parrot	*Lathamus discolor*	EN	EN	L
	Elegant Parrot	*Neophema elegans*		VU	
	Turquoise Parrot	*Neophema pulchella*		NT	L
	Regent Parrot	*Polytelis anthopeplus*	VU	VU	L
	Superb Parrot	*Polytelis swainsonii*	VU	EN	L
Cuculidae	Black-eared Cuckoo	*Chalcites osculans*		NT	
Strigidae	Barking Owl	*Ninox connivens*		EN	L
	Powerful Owl	*Ninox strenua*		VU	L
Tytonidae	Masked Owl	*Tyto novaehollandiae*		EN	L
	Sooty Owl	*Tyto tenebricosa*		VU	L
Alcedinidae	Azure Kingfisher	*Ceyx azureus*		NT	
Halcyonidae	Red-backed Kingfisher	*Todiramphus pyrrhopygia*		NT	
Climacteridae	Brown Treecreeper (south-eastern ssp.)	*Climacteris picumnus victoriae*		NT	
Acanthizidae	Rufous Fieldwren	*Calamanthus campestris*		NT	
	Chestnut-rumped Heathwren	*Calamanthus pyrrhopygia*		VU	L
	Speckled Warbler	*Chthonicola sagittata*		VU	L
Meliphagidae	Regent Honeyeater	*Anthochaera phrygia*	EN	CR	L

	Painted Honeyeater	*Grantiella picta*		VU	L
	Purple-gaped Honeyeater	*Lichenostomus cratitius*		VU	
	Black-chinned Honeyeater	*Melithreptus gularis*		NT	
Pomatostomidae	Grey-crowned Babbler	*Pomatostomus temporalis*		EN	L
Eupetidae	Spotted Quail-thrush	*Cinclosoma punctatum*		NT	
Campephagidae	Ground Cuckoo-shrike	*Coracina maxima*		VU	L
Pachycephalidae	Crested Bellbird	*Oreoica gutturalis*		NT	L
	Apostlebird	*Struthidea cinerea*			L
Petroicidae	Hooded Robin	*Melanodryas cucullata*		NT	L
Estrildidae	Diamond Firetail	*Stagonopleura guttata*		VU	L
REPTILES					
Cheluidae	Murray River Turtle	*Emydura macquarii*		DD	L
	Broad-shelled Turtle	*Macrochelodina expansa*		EN	L
Agamidae	Bearded Dragon	*Pogona barbata*		DD	
Pygopodidae	Pink-tailed Worm-lizard	*Aprasia parapulchella*	VU	EN	L
	Striped Legless Lizard	*Delma impar*	VU	EN	L
	Hooded Scaly-foot	*Pygopus schraderi*		CR	L
Scincidae	Swamp Skink	*Egernia coventryi*		VU	L
	Alpine Water Skink	*Eulamprus kosciuskoi*		CR	L
	Samphire Skink	*Morethia adelaidensis*		EN	L
	Glossy Grass Skink	*Pseudechis rawlinsoni*		NT	
Varanidae	Lace Goanna	*Varanus varius*		VU	
Boidae	Carpet Python	*Morelia spilota metcalfei*		EN	L
Typhlopidae	Woodland Blind Snake	*Ramphotyphlops proximus*		NT	
Elapidae	Bandy Bandy	*Vermicella annulata*		NT	L
FROGS					
Hylidae	Booroolong Tree Frog	*Litoria booroolongensis*		CR	L
	Large Brown Tree Frog	*Litoria littlejohni*	VU	NT	L
	Growling Grass Frog	*Litoria raniformis*	VU	EN	L
	Spotted Tree Frog	*Litoria spenceri*	EN	CR	L
	Alpine Tree Frog	*Litoria verreauxii alpina*	VU	CR	L
Myobatrachidae	Giant Burrowing Frog	*Heleioporus australiacus*	VU	VU	L
	Giant Bullfrog	*Limnodynastes interioris*		CR	L
	Baw Baw Frog	*Philoria frosti*	EN	CR	L
	Brown Toadlet	*Pseudophryne bibronii*		EN	L
	Dendy's Toadlet	*Pseudophryne dendyi*		DD	
	Smooth Toadlet	*Uperoleia laevigata*		DD	
	Rugose Toadlet	*Uperoleia rugosa*		VU	L

* Status under the Victorian DSE Advisory List (Vic. Cons., Department of Sustainability and Environment 2007): CR – Critically Endangered, EN – Endangered, VU – Vulnerable, NT – Near Threatened; Status under the Victorian Flora and Fauna Guarantee Act 1988 (FFG) (Department of Sustainability and Environment 2007): L – Listed; Status under the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999 (Department of the Environment Water Heritage and the Arts 2008): EN – Endangered, VU – Vulnerable. ^Type of hollow: H – enclosed hollow, L – may be ledge, crevice or below bark; symbols bracketed if other types of nest-site or roost-site are commonly used. + nests in hollows only in Tasmania.

2.2.3 Reptiles

Many terrestrial reptile species are dependent on suitable structural heterogeneity in the ground strata, typically around CWD, and this has been documented for a number of Australian species in a variety of wet and dry forest types — reptiles use logs for a variety of purposes, including basking, nesting, shelter, hibernation and foraging (e.g. Brown 2001; Brown and Nelson 1993b; Driscoll *et al.* 2000; Fischer *et al.* 2003; Henle 1989; Kanowski *et al.* 2006; Lindenmayer *et al.* 2002; McElhinny *et al.* 2006; Melville and Swain 1997; Sumner *et al.* 1999). Large logs, which are able to retain moisture, may also provide refuge during drought or fire (McElhinny *et al.* 2006).

Many species of oviparous reptiles are known to lay their eggs in or under logs; indeed, some skink species demonstrate communal egg-laying, in which large aggregations of eggs are often deposited inside or under a log (Couper 1995; Porter 1993; Radder and Shine 2007; Wells 1981). At other times of the year, aggregations of some species can be found overwintering deep within rotting logs (Lindenmayer *et al.* 2002).

Logs are important basking sites for heliothermic taxa — often, logs are used as elevated perches for basking, especially in wetter forests where a dense ground cover of vegetation may restrict basking opportunities (GB pers. obs.) — and can also play a vital role in the social behaviour of some species, exemplified by the territoriality displayed by some log-utilising skinks (e.g. *Eulamprus* spp.). Several reptile taxa (Southern Water Skink *E. tympanum*, Coventry's Skink *Niveoscincus coventryi*, Spencer's Skink *Pseudemoia spenceri*) in mesic Mountain Ash forest of the Victorian Central Highlands are arboreal or extensive users of logs, though empirical studies failed to find a significant positive association between skink abundances and total number or volume of logs, probably because logs are not a limiting factor in these environments (Brown and Nelson 1993a; b). However, counts of the arboreal Spencer's Skink were significantly correlated with both the number of large trees and the number of highly decomposed logs (Brown and Nelson 1993a; b). This raises the notion that CWD may be a more important habitat component in dry forests and woodlands than more mesic environments.

In the River Red Gum forests of northern Victoria, reptile numbers are relatively low — this may be a reflection of historical impoverishment, perhaps as a consequence of broad-scale depletion of fallen timber (Mac Nally *et al.* 2001), or else naturally low occurrence in flood-prone environments. Nevertheless, these forests support several reptile taxa, including the threatened Inland Carpet Python *Morelia spilota metcalfei*. This large nocturnal predator is dependent on large hollow-bearing logs and trees in some systems, including the floodplain forests of northern Victoria (Department of Sustainability and Environment 2003c; Heard *et al.* 2004), where, Driscoll (2000) reports, the predominant choice of rest-sites of radio-tracked pythons were tree hollows and logs on the ground.

A recent investigation of the reptile fauna of the Victorian Riverina found that this assemblage is in serious decline, and argued that this is primarily a result of changing land use across different spatial scales, including disturbance to structural complexity of vegetation and ground strata; specifically, it found the occurrence of total number of blind snakes to have significant positive relationship with the amount of coarse litter (Brown *et al.* 2008). The Riverina bioregion in Victoria currently supports a diverse, though diminished, reptile fauna, many species of which depend on CWD or hollow-bearing logs and trees (Brown and Bennett 1995; Brown 2002; Brown *et al.* 2008; Brown and Nicholls 1993). These species include, amongst others, the threatened Tree Goanna *Varanus varius* and Carpet Python, Tree Skink *Egernia striolata*, and several gecko species (Brown 2002).

In the Midlands bioregion (primarily box-ironbark woodlands) of Victoria, historically the source of approximately half of the firewood in the state (Driscoll *et al.* 2000), reptiles are known to rely on structural components of the ground-layer and are disadvantaged by its disturbance or removal (Brown 2001). Brown (2001) found that reptiles were generally 2.4 times more abundant on 'undisturbed' than 'disturbed' sites — where 'disturbed' sites had less structural and floristic diversity and less CWD — and that this disparity was also reflected in the number of species per site. The greater species richness and abundance of reptiles recorded for 'undisturbed' sites were attributed to the greater structural complexity of the ground strata on these sites.

In their review of the ecological roles of logs in Australian forests, Lindenmayer *et al.* (2002) provided an extensive, though incomplete, list, sourced from general texts, of south-eastern Australian reptiles that utilise logs. This list, comprising nine families and fifty-seven species, serves to highlight the diversity of reptile taxa that depend on or utilise logs, as well as the dearth of dedicated research on this association.

The Four-fingered Skink *Carlia tetradactyla*, a common resident of box and stringybark woodlands in north-eastern Victoria and southern New South Wales, is regularly observed in association with logs (GB pers. obs.). Recent modelling of the occurrence of this lizard at different spatial scales failed to identify a relationship between it and the abundance of fallen timber, though this was attributed to the preponderance of fallen timber across the study sites such that it wasn't a limiting resource (Fischer *et al.* 2003).

2.2.4 Amphibians

The role of CWD in amphibian occurrence is poorly understood and therefore primarily inferential — we could find no Australian studies that have documented this relationship, although one study currently underway in fire-prone stringybark woodlands of south-western Victoria is investigating the association between select vertebrate taxa, including frogs, and CWD (Miehs *et al.* unpubl. data), and only a handful of international (American) studies have included amphibians (including salamanders) (Bull 2002; Butts and McComb 2000; McCay *et al.* 2002; Owens *et al.* 2008).

It is easy to surmise that the value of CWD for amphibians lies in its moisture holding qualities and its ability to provide refuge from environmental extremes (e.g. fire, temperature) (Grove *et al.* 2002). Other qualities of CWD, as reviewed by McElhinny *et al.* (2006) include the provision of calling sites for males, refuge from predation, and probably even a contributing determinant of the composition of frog assemblages. CWD also provides sites for oviposition — this is reported for several south-eastern Australian toadlet species (e.g. Pseudophryne spp., Anstis 2002; Chambers *et al.* 2006; Woodruff 1976a; b).

In a study of the relationship between terrestrial vertebrate diversity and CWD in riverine floodplains of northern Victoria, Mac Nally *et al.* (2001) used pitfall traps to record frogs (as well as other vertebrates). While there was no significant difference in total frog records or species richness between River Red Gum sites with different CWD loads, about twice as many species were recorded on average at sites with CWD loads > 14 t/ha than sites with very low CWD loads (Mac Nally *et al.* 2001).

While international studies are not the focus of this review, some hold particular relevance because they underscore the associations between herpetofauna and CWD, especially where local data are lacking. Two recent studies in the USA revealed the importance of this habitat component; in loblolly pine forests of south-eastern USA, where CWD loads were experimentally manipulated, increased capture rates of amphibians were related to increased loads of CWD (Owens *et al.*

2008), and in Douglas-fir stands of north-western USA, the abundance of two salamander species increased with CWD volume (Butts and McComb 2000).

2.2.5 Invertebrates

Saproxylic invertebrates are a diverse and dominant functional group that are dependent on dead or dying wood during some part of their lifecycle, or upon wood-inhabiting fungi or the presence of other saproxylic species (Speight 1989 in Grove 2002a). Examples demonstrating the broad array of CWD habitat features required to maintain saproxylic species diversity are provided in Table 2.3.

We could not source any Australian studies that have examined the impacts of firewood harvesting or collection on saproxylic invertebrate abundance, richness or distribution. Much of the work on the impacts of forestry has focussed on saproxylic beetles in the wet forests of Tasmania; more research is required in drier, less productive ecosystems and on other invertebrate groups.

The dependence of saproxylic invertebrates on CWD and the impacts of forestry on their abundance and distribution has been extensively reviewed (Grove 2002b; Grove *et al.* 2002). Most invertebrate taxa have members from this guild (especially Coleoptera (beetles) and Diptera (flies)). Saproxylic insects make up a large proportion of the fauna in any forest (Grove 2002b; Grove *et al.* 2002). For example, one hundred and forty eight saproxylic beetle species were first identified during the first year of the Warra log-decay project in Tasmania (Grove and Bashford 2003; Grove and Meggs 2003) and Yee (2005) found more than 350 beetle species associated with logs in an intermediate decay stage. Saproxylic species play an important role in the decomposition of CWD and are a key food source for other forest-dwelling organisms. Termites in particular are reported to have a great influence on the decomposition of CWD (Mackensen and Bauhus 1999). They are an important food source for an array of Australian vertebrates including frogs, skinks and small mammals (e.g. Craig *et al.* 2007; Pengilley 1971).

Coarse woody debris is also a key habitat for generalist ground-dwelling invertebrate predators, such as spiders which utilise this habitat and leaf litter directly adjacent to the dead wood yet are not strictly dependent on this resource (Buddle 2001; Varady-Szabo and Buddle 2006). CWD can also influence the movement of fine litter through the forest and therefore contribute to the heterogeneity of the litter layer and patterns of ground cover (Lindenmayer *et al.* 2002), providing habitat for litter-dwelling fauna (Andrew *et al.* 2000). Other species such as the endangered stage beetle from south-eastern Tasmania are soil-dwelling but exhibit a preference for inhabiting the upper layer of soil underneath CWD (Meggs and Munks 2003).

Table 2.3 Examples demonstrating the array of CWD habitat features required to maintain saproxylic species diversity.

CWD feature	Details	Forest type	Authors
Abundance	Stag beetle *Lissotes latidens* prefers forests with > 10 % ground cover of CWD	Dry – wet eucalypt forests in south-eastern Tasmania	Meggs and Munks (2003)
Abundance	Species richness and abundance of Coleoptera greater in plots where slash piles were retained rather than removed	Mature, managed boreonemoral forests of Sweden.	Gunnarsson *et al.* (2004)
Charring	The abundance of saproxylic beetles was higher on charred CWD and there was a higher species richness of pyrophilic beetles. Eleven red-listed species were found on charred CWD.	Boreal zone in northern Sweden and spruce dominated forest in Norway.	Hjältén *et al.* (2007)
Charring	Charred CWD had a lower abundance of beetles than non charred CWD. Interestingly pyrophilous insects were almost exclusively confined to burned forest but occurred in both charred and uncharred CWD.	Boreal forest in central Sweden	Wikars (2002)
Decay stage	Less decayed CWD had greater species diversity, however web-building species were more diverse in more decayed logs.	Maple forest in Canada	Varady-Szabo and Buddle (2006)
Decay stage	Two species of tenebrionid species exhibited a preference for undecayed CWD reflecting field observations that they feed on hard wood.	Eucalypt and pine forests in Tumut, New South Wales	Schmuki *et al.* (2006)
Decay stage	Adult and larvae of the eucalyptus longhorned borer exhibited a preference for undecayed CWD	Eucalypt forest in Brisbane.	Paine *et al.* (2001)
Elevation (ground-level vs vertical)	There was a lower abundance and species richness of spiders on elevated CWD. Less than half of the spider species collected on elevated wood were shared with those collected from ground-level CWD.	Deciduous forest in Canada	Buddle (2001)
Fungi	One lucanid beetle species was associated with soft rot and another two species associated with brown rot (out of eight lucanid beetle species)	Broad-leaved forest in Central Japan	Araya (1993)
Shading of CWD	The assemblage of saproxylic beetles found in the shade treatments were significantly different than the control CWD. Four red-listed species were found on naturally shaded logs.	Boreal zone in northern Sweden and spruce dominated forest in Norway.	Hjältén *et al.* (2007)
Size	Stag beetle *Lissotes latidens* prefers small (<10 cm) and medium (10-50 cm) diameter logs	Dry – wet eucalypt forests in south-eastern Tasmania	Meggs and Munks (2003)

Size	One lucanid beetle species was found in significantly smaller diameter (i.e. 8 cm) CWD than the other seven species. However this may be related to rot type.	Broad-leaved forest in central Japan	Araya (1993)
Substrate type (logs, snags and tree tops)	Abundance and species richness was higher in logs, however species composition varied between the three substrate types	Boreal zone in northern Sweden and spruce dominated forest in Norway.	Hjältén *et al.* (2007)

Research has highlighted the sensitivity of saproxylic invertebrates to forest management, with secondary forests generally supporting lower species abundance and richness than old-growth or primary forests. In Europe for example, many saproxylic species have gone extinct (Grove 2002a; Grove *et al.* 2002; Odor *et al.* 2006) and 542 saproxylic invertebrates have been red-listed in Sweden (Jonsell *et al.* 1998). This diminution of the invertebrate fauna is not only linked to an overall reduction in the amount of CWD left on the forest floor and the low dispersal abilities of some saproxylic invertebrates, but altered features of individual pieces of CWD (Table 3.3, Schmuki *et al.* 2006). Many saproxylic species exhibit preferences for larger diameter CWD. Research in Tasmania's wet sclerophyll forest suggests that smaller diameter CWD (30 - 60 cm in diameter) do not exhibit all the rot types that large (> 100 cm) ones do. Therefore beetles that are dependent on particular rot types may not be present in the smaller pieces of CWD. Over the long-term this has management implications for the use of CWD as industrial firewood (Yee *et al.* 2006; Yee *et al.* 2001). Araya (1993) found that three out of eight lucanid beetle species captured in a Japanese forest preferred a particular type of wood rot.

Declines in one group caused by firewood removal could have indirect impacts on an array of other species and ecosystem processes, due to the co-adapted systems of these invertebrates with fungi and other fauna species. For example, the endangered large ant-blue butterfly *Acrodipsas brisbanensis* and its association with the threatened coconut ant *Papyrius nitidus* are jeopardized by the removal of CWD in Broadford for fire wood collection (Department of Sustainability and Environment 2003a).

Many invertebrates also play a pivotal role in ecosystem processes by facilitating the entry of decay organisms into the heartwood of living trees. It remains unclear which saproxylic species also depend on living trees for part of their lifecycle (Hopkins *et al.* 2005). Local declines in these species could have a marked impact on the creation of hollows in trees, stags and CWD in forests. Trees >150 years old in *Eucalyptus obliqua* forests in Tasmania were found to contain higher amounts of decay and higher species richness of beetles and fungi (Hopkins *et al.* 2005; Yee *et al.* 2006).

Some invertebrates whose larval forms inhabit CWD are reported to be important pollinators in Australian forests. Unfortunately, no studies were sourced that examined this relationship in Australia. In other areas only limited information is available on invertebrate use, such as the use of tree-hollows in Australia (Gibbons and Lindenmayer 2002).

Not only can firewood collection reduce habitat for particular species at a site, but the collection and transport of CWD can potentially alter the natural distributions of invertebrates by introducing species into new areas (Driscoll *et al.* 2000; Todd and Horwitz 1990).

2.3 Flora

Nationally, three quarters of people who collect firewood for personal use claim to target fallen timber (Driscoll *et al.* 2000). However, while CWD has been well documented as being important habitat for various fauna groups, its contribution to vegetation structure and ecological functioning is less well known. Existing research focuses almost exclusively on CWD in wet forests, not in the drier forests from which most firewood is collected (Driscoll *et al.* 2000). Therefore, this review can only provide a general overview rather than an in-depth summary.

Moss cover is significantly higher on logs in older stands of Mountain Ash forest (Lindenmayer *et al.* 1999), where it can form thick mats. Other autotrophic (synthesising their own organic substances from inorganic material using light or chemical energy) taxa that commonly occur on CWD include lichens, liverworts, ferns, gymnosperms (conifers, cycads) and angiosperms (flowering plants) (Harmon *et al.* 1986). However, while CWD can be a substrate for seedling germination in some ecosystems (Harmon *et al.* 1986; Heinemann and Kitzberger 2006), it appears to be a feature restricted to wetter forests. For example, tree seedlings were more abundant on fallen logs than on adjacent ground in moist forests in Tasmania, but have not been observed on fallen wood in drier forests (McKenny and Kirkpatrick 1999). Where seedling growth occurs on CWD, it is generally slower than growth in mineral or organic soils, due to the lower concentrations of nutrients in CWD (Harmon *et al.* 1986).

In some instances, the mass of small branches and foliage from a fallen branch or tree might act as a protective cage against grazing animals (Harmon *et al.* 1986; Kirkpatrick 1997), improving the rate of seedling survival. CWD may also moderate environmental extremes and provide shaded microsites for seedlings, particularly in disturbed areas (Harmon *et al.* 1986). However, increased leaf litter (as may be expected immediately following harvesting operations) may also have an adverse effect on seedling survival, at least initially, as noted in Jarrah *Eucalyptus marginata* forest (Stoneman *et al.* 1994). In forests or woodlands subject to firewood harvesting, the amount of litter would depend on the severity of the thinning operations, degree of post-harvest burning and the canopy size of felled trees.

2.4 Fungi and microbial organisms

Fungi and bacteria are highly specialised and perform an important role in ecosystem health and function. There are fungi (moulds and staining fungi) that live on the cell contents of dying and recently dead wood and those fungi (soft rots, white rots and brown rots) and bacteria that degrade already dead wood and break down cellulose and lignin (Harmon *et al.* 1986). No Australian studies were found that examined the relationship between CWD and bacteria.

CWD hosts a wide range of fungi species that help to break down the wood and thereby eventually cycle nutrients back into the soil (Driscoll *et al.* 2000; Harmon *et al.* 1986; Lindenmayer *et al.* 2002; O'Connell 1997). Nitrogen fixing can also occur in CWD, making it an important source of this element (Harmon *et al.* 1986). CWD may host mycorrhizal fungal species that have symbiotic associations with various vascular plant species (Driscoll *et al.* 2000), and those vascular species might be at risk if CWD is continually removed. Partial cutting of European oak-rich forests led to a significant decline in the richness of fungi species, particularly basidiomycetes (Norden *et al.* 2008), although the authors warned against extrapolating these results to drier forests.

Fungi are the principal agents of wood decay in terrestrial ecosystems and they provide habitat for many organisms and enable the regeneration of forests (Lonsdale *et al.* 2008). CWD is an important substrate for certain fungi (Andersson and Hytteborn 1991). For example, fruiting bodies of hypogeous mycorrhizal fungi are often produced in association with tree roots in CWD. These sporocarps provide nutrients to invertebrates and mammals (Scotts 1991). Mycorrhizal symbiosis is essential for tree growth and establishment. The species richness of CWD dependent fungi has been shown to increase with the abundance of substrate in international research (Odor *et al.* 2006). Amaranthus *et al.* (1994) found truffles were eight times more abundant in mature Douglas fir forests than in the surrounding plantations. Of the twenty one truffle species recorded, eight species only occurred in or under CWD.

Different fungal species occupy and utilise CWD of differing host species, decay stages, various diameters and lengths (Kuffer and Senn-Irlet 2005; Sylva Systems Pty Ltd. 2002) highlighting the importance of maintaining a diversity of CWD. Küffer and Senn-Irlet (2005) found that even fine and very fine woody debris served as important refuges for many species in an array of Swiss forest types. However, the importance of CWD in fungi conservation may differ according to the individual species and the forests in which they inhabit. Claridge *et al.* (2000) developed a model for examining the habitat explainors of seven hypogeous fungal taxa sampled in 136 forested study sites in East Gippsland and NSW. Only one of the taxa exhibited a relationship with CWD and this was a negative one. Stag abundance also did not feature. Leaf litter depth and diversity of potential host eucalypt species were important explanatory variables. In thinning operations it would therefore be wise to keep a diversity of tree species and not just to concentrate on large tree species that can potentially develop large hollows.

No information was found during this review relating to the amounts of CWD that are required to ensure the maintenance of adequate nutrient recycling and related ecosystem processes, or the possible effects of CWD removal in drier forests in Australia. There is also little available research on the decomposition of CWD in Australian forests (Mackensen *et al.* 2003). The small amount of research uncovered predominantly focused on the wet forests of Tasmania (i.e. Hopkins *et al.* 2005; Yee *et al.* 2006; Yee *et al.* 2001) and south-eastern Australia (East Gippsland) and adjacent New South Wales (Claridge and Barry 2000; Claridge *et al.* 2000).

2.5 Fire considerations

Planned burning to meet multiple objectives, including ecological and fuel hazard, and unplanned fire, such as wildfire, will impact on forest ecosystem processes at different scales and different intensities than disturbances such as harvesting. Fire management must be an integral part of the planning and implementation of any native forest silviculture (McCaw et al. 2001), and consequently it is critical to any consideration of the amount and nature of firewood which may be collected; as firewood removal impacts on the size and amount of woody debris fuels remaining on site. Fire is often the dominant disturbance in forests, and either directly or indirectly responsible for much of the creation of CWD from trees. Fires can cause or contribute to tree injury, death and collapse, and also to the consumption of CWD.

Unplanned fire

Unplanned fires by their nature usually show considerable variation in fire intensity across the burnt area. Consequently, it is not surprising to find that ecological studies also show that unplanned fire impacts are highly variable depending on a range of factors including fire intensity and forest type in particular. Higher-intensity unplanned fires (3000-70000 kW/m) will, depending on specific intensities and canopy height, have a more direct effect on forest structure. They will remove a greater proportion of tree canopy, tree bole bark, and more of the woody debris from the forest floor, as well as inducing greater soil heating and plant death and causing higher fauna mortality (DSE 2003).

Stands of many eucalypts are seldom killed by fire, of any intensity, while others are killed by moderate fire intensities. For forest trees, bark thickness rather than type is the most important factor in protecting the cambium of eucalypts from lethal temperatures (McArthur 1968). During drier periods, severe fires are capable of completely killing individual trees, even where these species are fire resistant. Bark is drier and burns more readily and sap flow is usually much reduced and unable to carry heat away from the cambium (Gill and Ashton 1968, DSE 2003). Burning around and up a tree stem may lead to superficial damage and charring, death of part of the underlying cambium (forming a fire scar or 'dryside') or death of the stem. Young trees are most susceptible, as they have relatively thin bark and their crowns are close to the ground (Incol 1981). Old trees may also be more susceptible to unplanned fire than trees of intermediate to mature age, able only to produce less vigorous epicormics than younger stems. Additionally, tree collapse is more likely in older trees that have previously been damaged by fire. Butt damage is common in many forests and is often related to the presence of large fuel accumulations near the base of trees (Gill 1981). Fire-related tree deaths are important in stand and CWD dynamics. Fire can result in significant thinning of stands, provide conditions for regeneration, and also contribute to the generation of new CWD. The death and collapse of larger-diameter trees is particularly important in relation to CWD because this material can potentially provide habitat for many decades, depending on rates of decay and fire consumption.

In an unplanned fire, much of the pre-existing larger-diameter CWD may suffer little more than external charring, depending on moisture status. Some CWD-dependent species are fire-dependent and well adapted to disturbances of this nature. CWD may function as critical shelter during fires and provide remnant islands from which fauna and micro flora can colonise surrounding areas following burning (Lee *et al.* 1997; DSE 2003). Some skink species (e.g. *Nannoscincus maccoyi* and *Sphenomorphus tympanum*) have been observed under CWD after prescribed burns (Humphries 1992) and an investigation of invertebrates revealed they could shelter under CWD and survive fires, even though the leaf litter associated with it had been burnt. The area under CWD was found to reach lower temperatures than the surrounding litter and showed less moisture fluctuations (Campbell and Tanton 1981). CWD has also been identified as important habitat for maintaining ant species diversity in areas subject to frequent low intensity burns (Andrew *et al.* 2000) and lucanid beetle abundance in forestry clearfell burns (Michaels and Bonemissza, 1999). However, excessive soil heating is also reported to be concentrated beneath large pieces of CWD, particularly where they intersect (Brown *et al.* 2003). The security of these refuges may therefore be dependent on a number of factors including: CWD size and decay state as well as seasonal dryness and fire intensity (Humphries 1992). After a prolonged rain-free period, when soil moisture deficit is high (high Soil Dryness Index or Ketch Byram Drought Index), there is greater opportunity for larger-diameter CWD to dry, which increases the risk of it being consumed by fire. The risk of consumption is increased by CWD having more advanced decay, or large pieces of CWD being elevated or intersecting.

Fire impacts on tree growth, with the radial stem growth of mixed-eucalypt species usually reduced following fire. In Messmate (*Eucalyptus obliqua)* and possibly Silvertop (*E. sieberi)*, radial stem growth is likely to be reduced for two to four years following fire, depending on the severity of crown damage (Incoll 1981). The evidence also suggests that stand growth lost during this period is not regained (Kellas and Squire 1980). When fire intensity is insufficient to kill the cambium but sufficient to damage the phloem of a tree, gum veins form (Jacobs 1955). The shedding of epicormic shoots may also give rise to gum veins. However, when fire is severe enough to kill appreciable areas of cambium, the bark dies and the xylem is exposed to the entry of insect and decay organisms, contributing to tree hollow formation. Hollow formation can be further exacerbated by subsequent fires, as dry partially decayed wood is readily consumed.

Few studies on the long-term frequency of unplanned fires are available. Analysis of damp forest in east Gippsland (Silvertop Ash) indicates an average fire-free period of 22.6 years over the last 300 years (Woodgate et. al. 1994). Historically, it is suggested that most of the fires in this remote stand originated naturally. Closer to human habitation fire frequency and intensity is usually more variable.

During fire suppression of unplanned fire, particularly in the "first-attack", "mop-up" or blacking-out" stages, the proximity of CWD can impact on the effectiveness or speed of different activities. The smouldering of CWD for days/weeks can impact on fire control, being a potential point of fire escape across containment lines (Tolhurst *et. al* 1992). Also, bulldozer fire-line construction and vehicle access can be hindered by heavy fuels (McCarthy *et.al*. 2003).

Where harvesting/thinning produces additional fuel loads and there is an increased rate of drying associated with opening the forest canopy, this will likely have an impact on unplanned fire behaviour. Buckley and Corkish (1991) found that in east Gippsland regrowth forests dominated by Silvertop (*Eucalyptus sieberi*) and White Stringybark (*E. globoidea*), thinning significantly altered the type, quantity and distribution of fuels. Typically, they found that commercial thinning, where not more than 60% of the original basal area was removed, added about 10 t ha^{-1} a of leaf and twig material and about 14 t ha^{-1} of coarse fuels (2.6-10.0 cm diam.). They also found debris from previous harvesting and dead mature trees were critical factors, producing fire of higher intensity and duration which caused cambial butt damage on living trees. McCaw *et al.* (1997) reported a fuel loading of 76 t ha^{-1} of leaf litter and woody fuel <10cm diameter following commercial thinning in a 21 year-old stand of Karri (*Eucalyptus diversicolor*) that had been unburnt since the time of establishment. When compared to unthinned stands this was an increase in fuel of a bout 36 t ha^{-1}; being mostly due to woody fuel 2.5-10cm in diameter.

In relation to fuel loads and their management, firewood collection has been proposed as a way of reducing this fire risk. The effectiveness of this approach will be influenced by a number of factors including the standard of firewood utilisation. Also, there may be some additional risk of unplanned fire where firewood collection is being conducted, particularly in areas with increased levels of dry fine-fuels where equipment such as chainsaws are used. Generally the use of chainsaws is not permitted on days of Total Fire Bans, and during the period of fire restrictions a chemical fire extinguisher or water are required on site (DSE 2007). Firewood collection generally involves the utilisation of woody material down to a small end diameter (under bark) of around 10cm ([1]Paul Bates pers. comm.). Coarse fuels >10 cm have not been shown to affect the rate of fire spread (Brown *et al.* 2003), like the finer fuels. Dynamically, these finer fuels are burnt in the continuous flaming zone of a fire and are hence important to the flame height, fireline intensity and rate of spread of a fire (Burrows 1994). Coarse fuels usually require fine fuels to be present before they ignite, and if they do burn they contribute little to the flame front (Luke and McArthur 1978). While coarser fuels do not significantly affect the rate of spread of fires (Cheney 1990; Burrows 1994), their ignition does impact on the total heat output of the fire. Total heat output of the fire can affect things such as soil heating, plant death and convective updraughts (Burrows 1994).

Research conducted by Cheney *et al.* (1980) on heavy fuels in an undisturbed forest in Tumbarumba indicates how unplanned fires can impact on CWD. They found that pieces of CWD >22.5 cm were not wholly consumed by low or high intensity fires unless they were highly decayed. They reported that 56% of CWD in the 10-20 cm diameter class and 26% in the >20 cm diameter class was consumed during a moderate intensity wildfire in the long unburned sub-alpine

[1] DSE, Bendigo

eucalypt forest. The moisture content of larger woody fuels is much slower to respond to environmental conditions than fine fuels and therefore smaller diameter classes of CWD are most likely to be consumed by fires (Tolhurst *et al.* 2004). Large pieces of CWD have been described as “effective small-scale fire breaks” because of their greater ability to retain moisture and larger size (Andrew *et al*. 2000).

Planned burning

Planned burning to meet multiple objectives, including ecological and fuel hazard, can impact on CWD. Burning for fuel hazard reduction aims to reduce forest fuels so they are less available to unplanned fire and to subsequently influence its intensity and extent. Evidence is overwhelming for the effectiveness of this approach in reducing finer fuels, ‘flash fuels’ that contribute to the bulk of the flames, and which are typically dead woody material <6mm in diameter (Tolhurst and Cheney, 1999). Typically, burning for fuel hazard reduction and ecological objectives involves lower-intensity fires (<500 kW/m), which are variable in intensity and extent across the burnt area, so that some habitats remain unaffected for a given fire (Tolhurst and Cheney, 1999).

Long-term burning studies in the mixed eucalypt foothill forests of west-central Victoria provide some useful guidance on the impact of planned low-intensity fires to ecosystem processes in these forests (DSE 2003). In relation to habitat, CWD discontinuities such as those created by fallen logs are important firebreaks, assisting in creating unburnt patches (as small as 1 m^2) scattered across the burnt area. These patches can provide significant habitat and are more likely to be found in damp gullies than on the drier slopes and ridges. Burning when seasonal dryness is such that fallen logs are unlikely to actually burn away, is preferable to when there is a high likelihood of total consumption, e.g. after a prolonged rain-free period. Seasonally, these conditions are more likely to occur during spring, when fuels are on a drying cycle.. Over a long period of time, these studies have indicated that a fire frequency averaging less than every 10 years is likely to result in a gradual decline in soil fertility and hence site productivity. Whilst surface fine fuels can re-accumulate very quickly following low intensity fire, the overall fuel hazard levels are likely to continue to rise for 20 years or more due to accumulations in bark and elevated fuels (DSE 2003, Tolhurst and Cheney 1999).

Planned fire can be an important consideration in managing higher fire hazards where additional fuel loads are created by thinning for firewood. Buckley and Corkish (1991), Cheney *et al*. (1990) and McCaw *et al.* (1997) concluded that the hazard from thinning slash fuels and the potential damage from unplanned fire could be minimised by implementing planned fires to reduce fuel loads. They found that post-thinning burning could remove much of the fine elevated fuel and some of the litter, however, larger-diameter woody residue could cause substantial tree damage. It was also identified that fire damage to retained stems could be reduced by the use of appropriate management and harvesting prescriptions. Fuel reducing the stand prior to thinning by burning was considered as an option; however, this created potential charcoal contamination problems for the residual log (pulpwood) that was a product of the thinning operation. Additionally, debarking of residual log material was made more difficult by fuel reducing the stand prior to thinning. Operational implementation of other research guidelines was attempted but they were found not to be practical and in need of modification. Further consideration of the fuel dynamics of thinned areas indicated that whilst overall fuel loadings do indeed increase, there is generally a reduced aerated fine fuel component as a result of the flattening of the shrub layer during thinning operations (Sebire and Fagg 1997). As a consequence potential flame height was limited, reducing the likelihood of flames spreading into tree crowns. Forward rate of spread of fire was also generally reduced, but this could be influenced by wind speed which may be higher in thinned stands. Given the higher fuel loads and size of woody debris, fire residence time and consequent damage to regrowth (stems) increased (McCaw *et al.* 2001). Burrows (1987) reported that the proximity of debris (CWD) could cause significant fire damaged to Jarrah *(Eucalyptus marginata)* and Marri *(Eucalyptus calophylla)* if they were less than one metre away. Similar findings have been reported by Cheney *et al* (1990), Buckley and Corkish (19991) in Silvertop (*Eucalyptus sieberi*) regrowth forests, and McCaw et al. (2001) in Karri regrowth. Due to this type of damage, post-thinning burning is not generally recommended where wood degrade is likely to be unacceptable (eg. in ash and some mixed species regrowth) unless the area lies within a strategic burning corridor or area (Sebire and Fagg 1997).

Sebire and Fagg (1997) and McCaw *et al.* (2001) have identified some strategies which may avoid the need to burn in thinned regrowth. These include either consolidation or broad dispersal of harvest areas, fuel reduction burning around thinned areas rather than in them, and selection of thinning coupes to avoid high fire hazard areas. Additionally, where ash regrowth is thinned Fagg (2006) has indicated that these areas should be located at least 1 km from current clear-felling coupes that will have slash-burns. Where fuel reduction burning may be appropriate, Sebire and Fagg (1997) have identified a number of factors that should be considered for mixed species regrowth. Similarly, Fagg and Bates (2009) have outlined factors influencing burning in box-ironbark forests. Generally, these factors relate to:

- positioning of fuels in relation to retained trees
- timing of burning and lighting patterns
- acceptable flame height
- distance between tree crowns and fuel layer

Given adequate management of fuel hazard, any additional fire risk associated with harvesting is likely to be small and should diminish further as fine fuel resulting from thinning breaks down within about 2-3 years (Sebire and Fagg (1997), Fagg and Bates (2009)).

From the literature viewed, where burning for fuel reduction is used appropriately it appears to be generally a more useful approach at the broader landscape scale than firewood collection for managing overall fuel hazard. At the smaller scale, CWD fuel manipulation by removal (firewood collection) or relocation may be a useful method of managing coarse fuel loads around high-value assets (eg. very old or culturally significant trees). Where the risk of damage from fire is high, consideration should be given to the proximity of fuel and the potential impact to the tree in the case of fire, weighed against the impact of physically removing CWD fuel.

This review is drawn largely from literature reporting on wet forests or drier mixed-eucalypt forests, rather than the Box-ironbark and River Red Gum forests where much of the firewood collection has traditionally occurred. They need to be viewed in this light.

2.6 Assessing the habitat quality of logs

While the primary focus of this review is the value that CWD (down and standing) holds for biodiversity, and how this may inform the development of firewood management on public land, the value of logs as important habitat elements is recognised in the DSE vegetation ‘net gain’ policy, the main goal of which is to achieve a reversal, across the entire landscape of the long-term decline in the extent and quality of native vegetation; this is set out in Native Vegetation Management: A Framework for Action released in 2002 (Department of Sustainability and Environment 2006).

DSE manages native vegetation and forest products on public land to conserve biodiversity based on sustainability principles. This framework focuses on the need to restore the health of the environment while at the same time building a sustainable and competitive economy. The approach adopted seeks to improve the clarity and flexibility of native vegetation management and, in part, improve biodiversity outcomes through better strategic and regional planning, simpler regulations, flexible offset arrangements and incentive programs. Such incentive schemes assist landholders with their native vegetation management efforts, and result in both environmental and commercial gains.

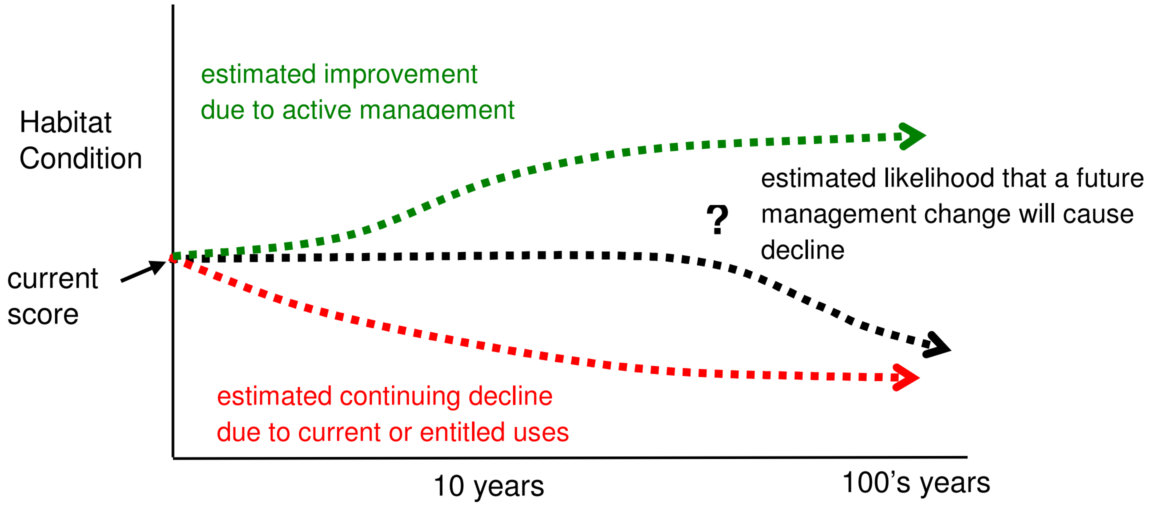
Programs such as BushTender and BushBroker pay landholders in return for delivering improved management of native vegetation under management agreements signed with DSE. EcoTender pays landholders for delivering broader environmental benefits through native vegetation-related activities. Under these schemes, retention of logs qualifies as a native vegetation gain. The amount of "log gain" is assessed by qualified DSE and agency staff, calculated using the DSE Gain Calculator and depends on the amount and type of logs currently on the site and the landholder commitments to forego any entitlement to remove these for the length of the agreement. Landholders establish the price required to deliver these management services either through a competitive auction (BushTender, EcoTender) or offset market (BushBroker) (http://www.dse.vic.gov.au).

The assessment of the habitat quality of logs and gains from management requires consideration of multiple factors both for quantity (area, quality and time) and value (types and locations). Area and quality uses the habitat hectares approach that assesses the quality of the vegetation in comparison to a benchmark that represents the average characteristics of a mature and apparently long-undisturbed state for the same vegetation type (Department of Sustainability and Environment 2004b; Parkes *et al.* 2003).

Generating gains depends on the activities (delivering either active improvement or avoidance of future impacts) and the 'starting quality' of the vegetation – see graph below. Gains are recognized for land manager commitments that forego a current use entitlement (e.g. grazing, firewood collection) that may otherwise contribute to the decline in vegetation quality over time (maintenance gains) and for land manager commitments beyond current obligations under legislation (e.g. weed control, supplementary planting) that improves the current vegetation quality (improvement gains). Security gains are also generated depending on the level of changed security of the site that averts a future risk of loss (e.g. state forest to nature conservation reserve, freehold land to on-title agreement).

Value is assessed using the conservation status of vegetation types (EVCs at the bioregional scale; listed floristic communities) and habitat types (including the relative habitat quality of locations), and other recognised criteria for significance.

Under habitat hectares, logs are assessed according to the observed amount and type (large / small) of logs per unit area in comparison to the relevant Bioregional EVC benchmark (see also Section 1.2 How does CWD differ between forest types?). This contributes 5% of the overall vegetation quality score (Department of Sustainability and Environment 2004b; Parkes *et al.* 2003). Maintenance gains for logs can be scored where a land manager is currently entitled to remove fallen timber and agrees to forego this entitlement (Department of Sustainability and Environment 2006).


estimated improvement
due to active management
Habitat
Condition
estimated likelihood that a future
management change will cause
decline
?
current
score
estimated continuing decline
due to current or entitled uses
10 years
100's years

3 Harvesting operations

Wood harvesting practices in general are known to have had a detrimental impact on CWD and its associated biodiversity in Australian and international forests. Harvesting practices tend to reduce veteran trees and simplify stand structure with a bias towards younger trees (Kirby *et al.* 1998; Mac Nally *et al.* 2002a; Mac Nally *et al.* 2002c). This results in an overall reduction in CWD abundance in the long-term and a greater proportion of smaller size classes in logged stands, compared to primary forests or old-growth stands (Andersson and Hytteborn 1991; Grove 2001; 2002a; b; Harmon *et al.* 1986; Kirby *et al.* 1998; Lindenmayer *et al.* 2002; Woldendorp and Keenan 2005; Yee *et al.* 2001). In production forestry, CWD is often referred to as "waste wood", implying it could be put to better use (Grove *et al.* 2002; Maser *et al.* 1988; Yee *et al.* 2001) than fulfilling an ecological role. It is often subjected to mechanical damage from harvesting machinery, further altering its nature (Grove *et al.* 2002; Lindenmayer *et al.* 2002; Maser *et al.* 1988).

Timber utilisation and the silvicultural regimes that support it are linked to the management objectives for State Forest in that region. These objectives are based on state government policies relating to natural resource management, the Regional Forest Agreements that coordinate state and federal policies, Forest Management Plans and timber resource data that assist in the location and scheduling of individual coupes.

Of particular importance are the Forest Management Plans that delineate areas available for harvesting. The Plans sub-divide State Forest into:

- *Special Protection Zone*. These generally have special conservation values that may be incompatible with timber harvesting and where the precautionary principle dictates that harvesting not occur.
- *Special Management Zone.* These also have conservation values; however, modified harvesting is permitted where it is compatible with the identified values.
- *General Management Zone.* This area is available for timber harvesting after consideration and management for any conservation, social and economic values that are identified for the area.

In all cases timber harvesting must be carried out in accordance with the Victorian Code of Practice for Timber Production (http://www.dse.vic.gov.au/dse/index.htm) and the specific guidelines and prescriptions that are applicable in that location. These, in general, require the reservation of filter and buffer strips to protect water quality and faunal values, reservation of habitat trees and the implementation of strategies that minimize or prevent soil movement within and from the harvested area.

A number of silvicultural systems can be used, dependent on specific management objectives or priority, stand conditions (e.g. slope, forest structure, age/size class distribution, seed sources and availability, etc), and commercial factors, such as market access, availability and skill of the harvesting crew and appropriate machinery configurations. The selection of a silvicultural system may often be a compromise between the desirable outcome from a silviculture view and the economic and social realities of the task. The 'triple bottom line' of social, economic and environmental factors should be maximized. Often guidelines do not exist to assist in the decision-making process and a successful result relies on the skill of the forester planning and supervising the operation. A general principle that is applicable across most silvicultural systems is that the simpler the system, the easier it will be to implement; however, the risks associated with a simple system may also increase the possibility of failure. Conversely, the more complex the system, the more difficult and costly it will be to implement; however, it will also probably have more inbuilt safeguards to help ensure its successful implementation.

Generally, the underlying aim of silviculture applied to Forest Management Areas where firewood is produced is to continually improve the existing forest structure by promoting health and growth of stands. This is achieved with thinning operations to promote a healthy multi-aged forest with more larger trees for conservation purposes and the remainder as a continued timber resource (DSE 2006, DSE 2008). Firewood is produced from the residue of harvesting operations, including thinning. Suppressed, poorly-formed or unhealthy stems are removed to maximise the growth and health of retained trees (thinning from below). These retained trees benefit from reduced competition for light, nutrients and water. Forest regeneration occurs primarily from new growth sprouting from the cut stumps, known as coppicing. Many of the traditional firewood forests are coppice regrowth forests that have been selectively cut-over several times (DSE 2006).

The planning of harvesting by DSE is carried out using a Wood Utilisation Plan (WUP). This plan outlines areas (known as coupes) proposed for harvesting over a rolling 3 year period. The draft WUP is prepared in consultation with business units in DSE, such as Fire and Biodiversity. Public comment is also encouraged (DSE 2006).

This review focuses on forests and harvesting operations where the generation of firewood is an intended product, rather than those operations where firewood is unintended. A brief review of the structure of these forests, their silviculture and the harvesting systems that are used will be conducted under forest type headings. More detailed descriptions of the harvesting and silvicultural systems are outlined in Section 3.2.

3.1 Forest types that provide firewood

The main firewood species and the forest management areas (FMAs) where they occur are outlined in Sylva Systems Pty Ltd (Sylva Systems Pty Ltd 2007) and identified as either common (non-durable) or durable species. These species are found in the following forest types:

- Mixed-species (non-durable) forests: *Eucalyptus baxteri, E. consideniana, E. dives, E. globoidea, E. macrorhyncha, E. muelleriana, E. obliqua, E. sieberi, E. viminalis*
- Box-ironbark (durable) forests: *E. melliodora, E. microcarpa, E. polyanthemos, E. sideroxylon, E. tricarpa*
- River Red Gum (durable) forests: *E. camaldulensis*

Flinn *et al.* (2001) provided comparative estimates of biomass and broad average growth rates for volume, as outlined in Table 3.1. They felt that the estimates for River Red Gum were conservatively low and the estimates for Mixed Species would not be realised without future attention to thinning, fire protection and disease management.

Table 3.1 Comparative estimates of biomass and broad average growth rates for three firewood forest types (Flinn *et al.* 2001).

Forest type	Mean annual increment (m^3/ha/yr)		Dry weight
	Sawlog volume	Gross bole volume	(t/ha)
Mixed-species	1.80	3.85	340
Box-ironbark	0.10	0.22	85
River Red Gum	0.25	0.55	135

3.1.1 Mixed-species non-durable forests

Significant statewide variation in soil types, elevations, aspect, climatic conditions, disturbance history and management are reflected in the nature of these 'common species' forests. Species variation, age, stand structure and health, understorey composition and many other forest characteristics are affected by these factors.

Most stands are uneven-aged (more than three age classes present), but the extent to which this is so depends on their disturbance history. Past timber harvesting and unplanned fire events in these forests have resulted in extensive areas of eucalypt regrowth, particularly in East Gippsland. These forests are considered to be fire-prone, and all species have fire adaptive traits rather than population lifecycle adaptations found in wetter forests where regeneration is more dependent on seed (Ashton 1981). Unplanned fires periodically impact on these forests, so that dense patches of fire regrowth of varying ages are characteristic. Dependent on fire intensity, duration and frequency, these unplanned fires can result in an overstorey of senescent, dead and degraded trees, often referred to as overwood.

Firewood Fallen (FWF)*	
Objective	To reduce fire hazard and supply firewood
Site characteristics	Areas where firewood is lying on the ground as a result of natural events or previous forest operations
Prescription	All fallen timber available for collection
Thinning from Below (THB)*	
Objectives	To release larger better formed trees and allow them to increase their growth and accelerate hollow development, by removing the smaller and poorly formed trees from the stand.
Site characteristics	Uneven-aged stands, or young regrowth stands with trees suitable for use as firewood (10-30cm Diameter Breast Height Over Bark (dbhob))

Prescription	Retention of at least 50% of the pre-harvest basal area, including trees with identified habitat values (e.g. hollows) and trees selected for multiple purposes.

These forests are used to produce a range of wood products, specifically sawlogs, posts and poles, chop logs, and firewood. The silvicultural systems that are used to provide a sustainable supply of commercial and domestic firewood can be outlined, as follows:

* Source: Department of Sustainability and Environment (2008e; 2009).

3.1.2 Box-Ironbark (durable) forests

Victoria's Box-Ironbark forests have been extensively disturbed since European settlement. The discovery of gold in the region, for example in Castlemaine in 1851, initiated dramatic long-term changes to the structure of these forests. Original stands of box-ironbark were clearfelled to provide timber and fuel for the mining industry and associated settlements. In the 1890s, the rapid expansion of the railway system across Victoria made additional demands for heavy construction and sleeper timbers from the box-ironbark forests. By the 1920s, when the newly created Forests Commission introduced forest utilisation controls, all box-ironbark forests, especially those near population centres, had been selectively cut-over several times (Department of Natural Resources and Environment 1998).

The heavy cutting during the latter half of the nineteenth century resulted in seedling and coppice regeneration over extensive areas of these forests, while the supervised harvesting and thinning, commencing early this century, produced forests containing essentially two size-classes, with various strata of regrowth beneath older and larger overwood stems. Typically, over-wood stems are uniformly distributed with a total basal area of about 11 metres/ha, whereas regrowth occurs in clumps within which basal area may be equivalent to about 10 metres/ha, with individual stems often under intense competition (Kellas *et al.* 1998). Diameter growth in fully or over-stocked stands is very low and recruitment into larger size classes relies on reducing competition through death or removal of individual trees. Natural self-thinning in box-ironbark forests is slow because the trees are tolerant of extreme conditions so they tend to persist through droughts and fires.

The current forest structure is indicated by data from the Bendigo Forest Management Area and Pyrenees Ranges, for predominantly merchantable stands of durable species, where there is an average of almost 500 stems per hectare, most being less than 25 cm diameter. However, there is considerable variation, as illustrated by the data in Tables 3.2 and 3.3. Table 3.3 provides summary stocking, basal area and basal area distribution by species for work centres in the Bendigo Forest Management Area.

Table 3.2 **Number of stems per hectare by diameter class in each working circle (Victorian Environmental Assessment Council 2001).**

Data from recommended parks and reserves has been excluded.

	Stocking (stems per hectare)				
Working Circle	**< 20 cm**	**20-40 cm**	**40-60 cm**	**> 60 cm**	**Total**
St Arnaud	117	86	18	3	224
Inglewood-Dunolly	207	85	13	0	305
Avoca Maryborough	582	82	13	1	678
Bendigo	451	65	9	0	525
Castlemaine	607	84	6	0	697
Rushworth-Heathcote	300	100	12	0	412

Table 3.3 **Stocking level, basal area and basal area distribution by species composition for DSE work-centres in the Bendigo Forest Management Area (Department of Natural Resources and Environment 1998).**

Workcentre	Stocking Level (stems/ha)	Basal Area (m^2/ha)	Species Percentages by Basal Area							
			Red Ironbark	Grey Box	Red Stringybark	Red Box	Yellow Gum	Long-leaved Box	Yellow Box	Other *
Avoca	595	19	3%	4%	40%	14%	1%	15%	6%	18%
Bendigo	574	11.7	37%	27%	15%	6%	9%	6%	1%	0%
Castlemaine	776	14.5	4%	25%	20%	21%	7%	11%	4%	8%
Dunolly	358	12	43%	32%	4%	6%	12%	1%	2%	0%
Heathcote	439	13.2	44%	28%	10%	10%	3%	2%	2%	1%
Inglewood	321	9.4	19%	49%	0%	3%	23%	1%	5%	1%
Maryborough	780	9	30%	26%	6%	11%	15%	9%	3%	0%
Rushworth	420	12.4	63%	25%	5%	5%	2%	0%	0%	0%
St Arnaud	229	12.5	16%	31%	17%	9%	12%	5%	8%	1%
Average	499	12.5	30%	24%	14%	10%	9%	6%	3%	4%

* Includes mallee and mixed species (non-durable) eucalypts.

Studies on thinning have indicated that removal of competing coppice and the wider spacing of trees will lead to improved growth on the remaining individual trees (Kellas *et al.* 1982). The results showed that individual Red Ironbark *E. tricarpa* trees retain a capacity to respond to reductions in competition in fully stocked stands. For regrowth (dbhob <20 cm), the response was rapid with the removal of competing overwood and could be further enhanced by also reducing the regrowth competition. For overwood (dbhob >20 cm), the response was slower. For both regrowth and overwood trees, total competition from all competitors appears more important than that from overwood or regrowth alone. The thinning response of early-1930's Red Ironbark, in the absence of overwood, has been studied near Heathcote. The trial provided an opportunity to better understand the thinning response in a small stand situation, particularly in the 25-40 cm (dbhob) size class, and also to better understand the effect of the coppice on retained tree growth (Murphy and Forrester 2009 in prep.). Murphy and Forester (2009 in prep.) reported that over a ten-year period the heaviest thinning, the 33% retention thinning (for largest 100 trees ha^{-1}), was the only treatment which significantly increased growth (basal area and volume). For this treatment, when coppice was retained there was a small and insignificant reduction in tree size compared to when coppice was removed.

These studies show that while the box-ironbark forests have low productive capacity (relative to forests in the higher rainfall zones), significant growth responses can be expected with appropriate thinning regimes but responses may be limited to less than 10 years, requiring periodic thinning for sustained responses. However, impacts on other values would possibly not make this appropriate.

While these forests have a history of low fire frequency, all species have fire adaptive traits. Natural disturbance appears generally to be infrequent. Early records indicate that wind damage, either through breakage or uprooting of trees (James Clow in Bride 1898; Brough Smyth 1878; Mitchell 1839, [2]Ron Hateley per. comm.) may have been a significant local disturbance. The areas affected by these tornadoes were reported as 500m or so wide and a few kilometres long, with the length apparently determined by topography. These are small areas of disturbance, but if 'tornadoes' were relatively frequent or 'nested' then historically the overall disturbance over several hundred years could have been significant.

These forests are used to produce a range of wood products, specifically sawlogs, posts and poles, and firewood. The silvicultural systems that are used to provide a sustainable supply of commercial and domestic firewood can be outlined, as follows:

Single Tree Selection (STS)*	
Specific objective	To produce sawn timber products and minimise impacts on species composition and forest structure.
Site characteristics	Previously thinned sites which contain trees up to 59cm dbhob
Prescription	Retention of at least 50% of the pre-thinning basal area, including all trees >60cm dbhob and trees with identified habitat values (e.g. hollows). Species composition to be maintained.

Thinning from Below (THB)*	
Specific objective	To release larger better formed trees and allow them to increase their growth and accelerate hollow development, by removing the smaller and poorly formed trees from the stand.

[2] Ron Hateley, DFES, University of Melbourne

Site characteristics	Regrowth dominated stands with trees suitable for use as firewood (<20 cm dbhob)
Prescription	Retention of at least 60% of the pre-harvest basal area, including trees with identified habitat values (e.g. hollows) and trees selected for multiple purposes. Species composition maintained.
Ecological Thinning+	
Specific objective	To test different methods of ecological thinning (and associated works) and examine the impacts of these methods on biodiversity, forest structure and habitat values.
Site characteristics	Box-Ironbark forests and woodlands
Prescription	Four different experimental treatments: Isolated (habitat trees selected and retained, remaining area thinned to 50% of unthinned stem density), Patchy 1 (unthinned patches retained in 10% of plot, remaining area thinned to 25% of unthinned stem density), Patchy 2 (unthinned patches retained in 25% of plot, remaining area thinned to 50% of unthinned stem density), Control (no thinning).

Source:
*(Department of Sustainability and Environment 2008a);
+ (Pigott *et al.* 2008); Where habitat values have been diminished by past practices, "ecological thinning" is a developing silvicultural option, which has the objective of encouraging the development of habitat trees (Victorian Environmental Assessment Council 2001). The thinning aims to advantage trees with either existing or potential habitat values rather than the best formed, vigorous trees. The capacity of these trees to respond to release is unknown, but is the focus of current studies.

3.1.3 River Red Gum (durable) forests

Throughout much of its range riverine Red Gum forests provide the only forested habitat over large expanses of less fertile lands. Tree hollows and coarse woody debris provide essential habitat for arboreal mammals, vertebrates and macro-invertebrates. Most of our knowledge of the silvics (the study of forests and their ecology) of these forests has been derived from a series of experiments conducted in the Barmah State Forest (Dexter 1968; Dexter 1970; 1978; Dexter *et al.* 1986). Further studies conducted in subsequent years have substantiated most of these findings. Documents detailing silvicultural practices in NSW and Victoria exist (e.g. Department of Natural Resources and Environment 2001; Forestry Commission of NSW 1984). These provide a useful summary of the most effective harvesting systems, ways to stimulate tree production through thinning and the importance of retaining tree species for habitat value.

These forests are used to produce a broad range of wood products, specifically sawlogs, sleepers, posts and poles, miscellaneous sawn product, garden mulch, and firewood. The silvicultural systems that are used to provide a sustainable supply of commercial and domestic firewood can be outlined, as follows:

Firewood Fallen (FWF)	
Objective	To reduce fire hazard and supply firewood
Site characteristics	Areas where firewood is lying on the ground as a result of natural events or previous forest operations
Prescription	All fallen timber available for collection
Single Tree Selection (STS)	

Objective	To produce sawn timber products and minimise impacts on species composition and forest structure.
Site characteristics	Uneven-aged sites with scattered mature trees
Prescription	Felling individual mature trees, reducing basal area by generally less than 10%, at intervals (generally 10-15 year cycle) over the rotation. Identified habitat values (e.g. hollows) are retained.
Thinning from Below (THB)	
Objectives	To release larger better formed trees and allow them to increase their growth, by removing the smaller and poorly formed trees from the stand.
Site characteristics	Stands dominated by young regrowth trees suitable for use as firewood
Prescription	Retention of at least 50% of the pre-harvest basal area, including trees with identified habitat values (e.g. hollows) and trees selected for multiple purposes. CHECK??

* Source: Department of Sustainability and Environment (2008d)

Traditionally, harvesting in Red Gum forests is primarily done through single tree selection; however, small-group selection is currently the most widely used silviculture, and aims at leaving gaps of generally less than a hectare (Di Stefano 2002). Single tree selection has been criticized as it promotes small canopy gaps favouring seedling regeneration in close proximity to established Red Gum species (DNRE, 2001). Also, the large zone of influence of River Red Gum can negatively impinge on seedling germination and survival (Dexter 1968). Single tree and small-group selection encourages mixed aged stands and is in marked contrast to the natural condition of River Red Gum forests (Di Stefano 2002), which tends to regenerate along the edge of receding flood waters resulting in a more even-aged stand development.

One of the most important findings of Dexter's research was the favourable response of River Red Gum ecosystems to seed tree silviculture, whereby intensive clear-felling in clumps was followed by seed application. The creation of these larger gaps helps maintain the natural stand age. Despite these findings, single tree and small-group selection remain the standard industry practice. Seed tree silviculture may be used in some selected areas where there is significant tree mortality and poor health, such as following unplanned fire or dieback (Murray Thorson[3] pers. comm.).

Incoll (1981) reported on thinning trials in 20-26 year old regrowth stands of low productivity River Red Gum. Commercial thinning trials that removed competing stems (for firewood and posts up to 20 cm dbhob) at a number of intensity levels increased the growth of retained stems. Recent measurements indicated that net basal area growth was greatest in moderately thinned stands, whereas the diameter growth of the largest 123 trees/ha was greatest in the most heavily thinned stands. Variation in branch retention and incidence of stem bends with initial density were not measured, although observations suggest that both were more prevalent at low initial densities. If the thinning objective is to achieve near maximum diameter growth for stands of about 20 years, then thinning to approximately 7-8 m^2/ha of retained basal area will produce an increase in diameter growth without noticeable increase in branch retention or in frequency of stem bends (Connell 2005).

[3] Murray Thorson – FIC, Cohuna, Department of Sustainability and Environment,

Although fire is a natural feature of the River Red Gum forests, the trees are more susceptible than many eucalypts to damage by fire. In Aboriginal times it seems that fire was used regularly in the forests, maintaining them in a fairly open condition, and undoubtedly contributing to the butt damage of many of the stems. Fire of only moderate intensity will kill the cambium near the base of the tree, leading to dry sides. Such wounds are often quite rapidly occluded, but enclose pockets of dead sapwood; the fires also promote the formation of gum veins. Intense fire round the base of a tree may kill the tree or, if more localised, lead ultimately to the hollow, burnt out butts that are encountered in many of the larger River Red Gums (Forestry Commission of NSW 1984).

The extent, frequency, seasonality and duration of flood events will influence the distribution, quality and growth of River Red Gum forests, as illustrated by forested areas on higher-ground which are frequently less productive and of poorer quality due to the high moisture stress (Davies 1953). Whilst flooding is normally vital to the existence of the River Red Gum forests, prolonged inundation will ultimately kill trees. This is one of the effects of river regulation which maintains higher than natural summer flow levels, leading to the prolonged, or even permanent, flooding of some of the lower lying, and usually highest site quality, stands.

3.2 Types of thinning operations

3.2.1 Firewood fallen

The collection of fallen firewood for domestic use occurs in areas where firewood is lying on the ground as a result of natural events or previous forest operations. The collection does not involve any additional felling of trees, but material will need to be crosscut (DNRE 2001). The fallen firewood can either be ‘dry’ or ‘green’ firewood. Green firewood is becoming more common as firewood collection is more closely integrated with recent harvesting or contract felling. Designated areas are usually set-up that allow car and trailer or light truck access to facilitate manual loading. Crosscutting is usually done by chainsaw. The ecosystem processes and impacts related to the collection of fallen CWD were covered in Section 2.

3.2.2 Commercial thinning

Commercial thinning usually involves the silvicultural treatment of overstocked, mainly even-aged regrowth stands to release potential sawlogs from competition. These stands of young trees have regenerated either naturally, such as following unplanned fire, or been assisted following a previous harvesting operation. Where the primary objective of the thinning treatment is wood production, suppressed trees or trees of poor form or quality are removed and dominant and co-dominant trees of good form and quality are retained, so that all the growth potential of the site is available to the retained stems. This “thinning from below” results in either a shorter rotation or larger trees at harvest. Also, wood that would be otherwise lost through death due to natural suppression in the stand is harvested, providing an interim return for the forest owner. Thinning is not intended to encourage regeneration, with the stand already considered to be fully stocked.

While increased wood production is usually the primary goal, thinning may also enhance conditions for biodiversity. The specific habitat retention prescriptions will reflect the overall management objectives, such as a desire to restore forest structure while providing a sustainable timber supply and maintaining forest habitat (e.g. Department of Sustainability and Environment 2008e).

Commercial thinning is restricted to stands that meet specific criteria, with the economic viability affected by:

1. Tree size and yield
2. Site factors
3. Coupe size and location
4. Harvesting system and operator experience, and
5. Thinning system

Some of these factors are covered in more detail in Sebire and Fagg (1997), Brown *et al.* (2001), and Kerruish and Rawlins (1991).

Generally, about one-half of the fully stocked live basal area may be removed providing minimum basal areas are retained, although a minimum retained basal area may be specified, which is often age and forest type related (Sebire and Fagg 1997). Commercial thinning in fully stocked young regrowth is normally conducted using an 'outrow and bay' method, where a 4.5m strip, or access track, is removed and 12m bays retained. This non-selectively removes about 25% of the stand and allows machinery access for the selective felling and removal of stems from the bays.

Commercial thinning methods used in the generation of green firewood, and which satisfy silvicultural requirements as well as returning a commercial return for the operator include the following elements:

1. Felling and crosscutting techniques – felling and crosscutting is done either manually using chainsaws, mechanically using specifically designed felling machinery (usually tracked rather than wheeled) or using a combination of both. Mechanical felling and crosscutting has definite advantages over the manual alternative. It is much safer, more productive, and offers better tree control both during felling and crosscutting. However, with mechanical operations there is considerably greater capital and running costs, and manual felling is more flexible across a range of terrain (Kerruish and Rawlins 1991).
2. Extraction – both shortwood (billet) and longwood (bole length) operations are used depending on the configuration of the harvesting system. Depending on the nature of the operation, the ease of access and piece-size of this operation can be conducted using a truck, tractor or specialised equipment such as skidders or forwarders. Loading onto trucks is usually done by crab-grab or grapple loaders (built-on or stand-alone).

Depending on the system used, woody debris can impact on stand access and machine movement, as well as butt damage to retained trees. This debris can be entirely natural or incorporate old logging material. Sebire and Fagg (1997) identify 50 t/ha and less than 0.5m diameter as being critical indicators for mixed species regrowth.

3.2.3 Selective harvest

Selective silviculture involves the selection-felling of marked trees, either individually or in small groups, with the objective of producing sawn timber products, whilst minimising impacts on species composition and forest structure. The harvest is focused on previously-thinned sites which contain trees up to 59cm dbhob, and involves the retention of at least 50% of the pre-thinning basal area, including all trees >60cm dbhob and trees with identified habitat values (e.g. hollows).

Species composition is maintained (Department of Sustainability and Environment 2008d). Sawlog and sleeper operations cut trees from 45 cm to 60 cm diameter. Post-cutters harvest trees up to 40 cm diameter, mostly for sawing into split posts and other fencing products, and cut smaller dimension wood, producing round posts. Firewood is produced as a by-product of the sawlog harvesting and post-cutting, from the heads of felled trees and thinning of small stems. The current specification is a minimum Small End Diameter Under Bark (SEDUB) of 10cm and 30cm dbhob.

In selective harvesting, felling and crosscutting are done manually using chainsaws, and extraction of both shortwood (billet) and longwood (bole length) is conducted using truck, tractor or specialised equipment such as skidders or forwarders to suit the product being extracted. Loading onto trucks is usually done by crab-grab or grapple loaders (built-on or stand-alone).

3.2.4 Ecological thinning

Thinning is a silvicultural technique used in forest management to modify tree growth by reducing the competition for resources. Where trees are managed commercially, stems that exhibit less favourable timber quality potential are removed to reduce competition. When left in a natural state trees will 'self-thin' but this process of natural selection can sometimes be unreliable and slow; for instance, the Box-Ironbark forests and woodlands of Victoria support a large proportion of trees that are multi-stemmed regrowth (or coppice), a consequence of timber-cutting over previous decades (Muir *et al.* 1995). Ecological thinning has the principal aim of forest thinning to increase growth of selected trees, favouring development of wildlife habitat (such as hollows) over increased timber yields.

Research programs under way in various parts of the world (e.g. USA, Australia) are aimed at providing an alternative approach to forest management where conservation objectives are a high priority. Recently (2003), Parks Victoria initiated the Ecological Thinning Trial in box-ironbark woodlands of central Victoria (Parks Victoria 2007; 2009), a direct response to ECC recommendations for the management of box-ironbark forests and woodlands (Environment Conservation Council 2001b). This is a long-term field-based experimental programme that aspires to evaluate different methods of ecological thinning and the effects they have on components of the box-ironbark forest ecosystem, including select vertebrate fauna and key habitat characteristics, with the broad aim of restoring a greater diversity of habitat types to the landscape, and therefore allowing the improved functioning and persistence of key communities and species populations.

According to Parks Victoria (2007; 2009), ecological thinning is one of the methods that will be used as part of an Ecological Management Strategy to improve the ecological integrity of the forests and woodlands and their flora and fauna species instead of just maintaining the status quo. In contrast to silvicultural thinning, ecological thinning retains trees of all forms and sizes in a patchy distribution (clumps of high tree density are retained within a general mosaic of wider spaced trees to support species that favour both or either habitat) and competition is reduced to address the low proportion of larger trees in these forests.

4 Ecosystem processes relating to harvesting

4.1 Soil and nutrient processes

4.1.1 Soil fertility (see also 2.1.1)

When forest produce is removed in the form of 'dry' and 'green' firewood, either from the forest floor or following harvesting of standing forest, nutrients and carbon are removed with this wood. Associated soil disturbance can also lead to nutrient losses, either as soil erosion, leaching, or through losses of soil organic matter through soil respiration (Attiwill *et. al.* 1996, O'Connell and Grove 1996).

Nutrient losses

Strong associations exist between forest types and site characteristics. Species with greater site demands are found on better soils and this is reflected in growth rates and the nutrient status. While in absolute terms the quantities of nutrients removed in dry and green firewood removals will differ between sites, generally they are proportionally similar across most sites. However, results obtained for one forest type cannot necessarily be applied to other site types.

The quantities of nutrients available in the soil for forest growth are affected by a number of factors. A key issue is whether firewood management activities can or will lead to a reduction in soil nutrient status and whether this may affect long-term health, productivity or other ecosystem processes. Typically, to investigate this issue the approach has been to estimate quantities of nutrients in the system together with nutrient fluxes and then use a simple input/output model over a number of rotations to determine possible impacts. Quantities of nutrients will include total and available nutrients contained in each component of biomass. Inputs usually include precipitation inputs and nitrogen fixation while losses include those in runoff water, forest product removal and fire. Most of these nutrient studies have focussed on the wetter forests, and typically for this forest, biomass nutrient content varies as follows (Attiwill *et. al.* 1996):

- Leaves account for 1-2% of the total biomass of the trees above-ground, but for 20% of the N and P contents;
- Stembark accounts for 10% of the total mass of the trees above-ground, but for 25-40% of the N, P and Mg and up to 60% of the K and Ca contents;
- Stemwood is nutrient-poor relative to other components of the tree, accounting for almost 80% of tree biomass but containing 10-20% of the K, Ca and Mg and 30-40% of the N and P content;
- Subordinate vegetation (understorey, shrubs and ground-layer) accounts for <5% of above-ground mass but contains 10% of the N and Ca and 14% of the P content;
- Litter layer accounts for 6% of above-ground mass but contains 14-16% of the P, Ca and Mg, and 24% of the N.

CWD nutrient content has been poorly reported, however, generally smaller pieces of CWD (i.e. <3 cm diam.) tend to be higher in nutrients than larger ones (i.e. >7 cm diam.) (Table 2.1, from Stewart and Flinn 1985). Sites with large amounts of slash often have lower soil temperatures during summer, with smaller diurnal variation, and higher mineralizable soil nitrogen concentration (O'Connell *et al.* 2004). In northern hemisphere conifer forests, the concentrations of calcium and magnesium were significantly lower when slash was removed from thinned stands (Rosenberg and Jacobson 2004). On low fertility sites where intensive harvesting is practiced inter-rotational management of the forest floor and harvesting residues is critical to maintain soil fertility (productive capacity) (Hopmans 2009) Long-term studies evaluating the sustainability of fast-growing second rotation plantations (*Pinus radiata*) on podsolised sands have indicated that productivity was maintained or improved. This was attributed to the conservation of organic matter and nutrients through retention of litter and harvesting residues after the first rotation and the exclusion of fire. Where only foliage was retained (log residues and branches removed) nutrient accession was not exceeded over 30 years except for N. In contrast, whole-tree harvesting including foliage increased nutrient exports above inports and fertilizers are likely to be required for this additional removal of nutrients to maintain site productivity in the next rotation.

In drier native forests forests used for firewood collection, it is expected that similar trends would be observed. Because the concentration of nutrients in wood is small relative to those in other parts of trees, collecting or harvesting part of the wood removes a relatively small nutrient store. On this basis, where only wood >10 cm diameter is removed for dry and green firewood it is not expected that the level of nutrient removals would have a detectable impact on forest productivity. However, if bark and smaller diameter material is also removed then the amounts of nutrients removed will increase significantly and there may be a greater impact. Losses of other nutrients such as N will generally be replaced by biological N_2-fixation, and P from reserves and through the weathering of parent rock (Attiwill *et. al.* 1996).

Where dry and green firewood removal is only associated with stem wood (i.e. larger diameter wood), the level of nutrient removals is not expected to have a detectable impact on productive capacity. Removal of biomass components other than the stem should be avoided, as this is likely to impact on site nutrient budgets and consequently on soil organic carbon. Foliage, smaller diameter branchwood (<7 cm diam.), and stembark should be retained and evenly distributed in forest partially-harvested for 'green' firewood. The most susceptible nutrient to change will be the base cation, such as calcium, this being even more so in some soils with low reserves of this element.

Nutrients are also lost through high-intensity fire, which oxidises much of the available litter fuels and some nutrients (particularly N) are lost from the system by volatilisation and the convection of particulate matter. In more intense fire SOM near the soil surface will also be oxidised (Bauhus *et. al.* 2003). However, low-intensity fires such as those generally found with fuel reduction burning (FRB), are more subtle, and frequent fires over a long period of time are required before irreversible changes to soil structure and fertility will most likely result (DSE 2003).

Soil organic matter

Organic matter in forest soils (SOM) is fundamentally important in maintaining soil fertility, with more than 95% of total nitrogen and more than 50% of total phosphorous in surface soils of forests is in organic combinations (Raison *et. al*. 2002). SOM accounts for a major part of cation exchange capacity in surface soils, and plays a key role in preserving soil structure. Soil organic carbon (SOC) occurs in a variety of forms such as fresh litter, microbial biomass, humic substances, char (charcoal, black carbon), etc., which have different turn-over times and are likely to differ in their sensitivity to disturbance. Soil carbon plays an important role in contributing to soil fertility both chemically and physically. Reductions in total SOC are usually not significant, but where they do occur they are often associated with soil cultivation. Any soil carbon increases tend to be associated with additional growth, such as that stimulated by the inclusion of nitrogen-fixing legumes (Attiwill *et. al.* 1996). Disturbance associated with dry and green firewood removal will likely lead to some small decreases in SOC due to oxidation of carbon in residues from the disturbance and in soil organic matter.

Where dry firewood is removed from the forest floor the ability to restore this lost carbon is limited, as there is unlikely to be any associated growth response from the forest. However, if this dry firewood is left as CWD then it will be exposed to gradual decay, diminishing to some level of residual carbon. Unfortunately, knowledge about the decay rates of CWD is limited, and can be summarised in two general relationships: (1) a decrease in decay rates with increasing log size, and; (2) a decreasing rate of decomposition with increasing wood density (Raison *et. al*. 2002). There are no clear rates for the conversion of CWD into SOC (Mackensen and Bauhus 1999). Additionally, fire will readily convert decaying wood into char and release bound nutrients. Carbon in char is inert and its contribution to soil fertility is difficult to interpret, although it appears to influence soil structure and water infiltration (Bauhus *et. al.* 2003).

Where firewood is been derived from harvesting of the forest, then it is likely that there will be some growth response. In wetter forests, where growth responses are usually more rapid and vigorous, any decrease in carbon is usually relatively short-lived, but in drier forests there will be a slower recovery as growth responses are more restrained. The sensitivity of site fertility to the effects of disturbance on SOC and other measures of fertility has been studied for disturbance factors, such as canopy removal, extraction track use, fire intensity, and soil disturbance in clearfell silviculture (Bauhus *et. al.* 2003). The major impact on these measures was on areas where extensive mechanical soil disturbance was used to prepare a seedbed for regeneration, compared to where harvesting slash was burnt, where only minor effects were observed. Where there is no requirement for the preparation of a receptive seedbed, soil fertility impacts can be reduced if soil disturbance is minimised and organic matter conserved by retained harvesting debris (Raison *et. al*. 2002).

4.1.2 Carbon cycling (see also 2.1.2)

The impact on carbon budgets and Greenhouse gas (GHG) emissions of firewood-related disturbance is a critical element of sustainable firewood production. Its potential to reduce fossil fuel use and attendant CO_2 emissions, is dependent on a number of factors, including: forest growth rate, management, harvesting and transport systems, and; the efficiency with which firewood is burnt (Raison *et. al*. 2002). Additionally, any possible reduction in the use of fossil-fuels must be balanced against carbon losses from the reduction in CWD and soil organic carbon.

Carbon storage

Forests sequester carbon in biomass and through plant residues in the soil, as soil organic carbon (SOC), with the accumulation of above ground carbon generally reflecting forest growth and productive capacity. The quantities of carbon vary according to a number of factors including soil, climate, forest type, stage of stand development and level and type of disturbance. Grierson *et al.* (1992) estimated the above-ground quantities of carbon in Victoria's forests using a series of age-dependent biomass functions. The forests types that contain firewood species are outlined in Table 4.1. These forests contribute about 71.8% of the above-ground carbon storage described by Grierson *et al.* (1992).

Table 4.1 Area, biomass and carbon density (above-ground) of Victoria's predominant firewood forest types (Grierson *et al.* 1992).

Forest type	Total area (ha)	Mean above-ground density (t DM/ha)		Carbon Storage (tonne x 10^6)
		Biomass	Carbon	
Foothill mixed species	2,639,735	477.3	238.6	629.840
Coastal mixed species	404,050	379.1	189.5	76.567
Box-ironbark	236,262	149.2	74.6	17.625
River Red Gum	112,851	417.0	208.5	26.529
Main firewood spp.	3,392,898			751.886
Alpine Ash	311,997	394.8	197.4	61.588
Mountain Ash	181,989	492.1	246.0	44.769
Shining Gum	13,057	469.8	234.9	3.067
Mountain mixed species	464,761	423.7	211.9	98.460
Alpine mixed species	203,224	450.0	225.0	45.725
Lesser firewood spp.	1,175,028			253.609
Other (native forests)	1,896,226			42.249

Below ground, carbon accumulation is affected by root growth and SOC balances. Soils are expected to increase in carbon, dependent on soil type, and then reach stability. Disturbances, such as fire lead to direct losses of carbon from the system followed by a process of re-accumulation during forest recovery (DSE 2003).

CWD has been recognised as a quantitatively important component of the forest's carbon stocks. The amount of CWD in some areas is equivalent to approx 10-20% of the above ground carbon biomass, indicating that dead wood can represent a significant amount of carbon in forests (Delaney *et. al.* 1998). However, generally little work has been conducted on the amount of carbon held in CWD in Australian systems. CWD inputs are often from dieing or dead standing trees, and often associated with fire, wind damage, or disease. CWD represents a large and long term store of carbon, which is gradually released through its decomposition (Brown *et al.* 1996b; Grove *et al.* 2002). Decay often starts in standing trees and usually increases once trees fall over and there is greater contact with the ground (Raison *et. al*. 2002). During decomposition, microbes turn organically bound carbon (which accounts for approximately 50% of the organic material) into carbon dioxide (Mackensen and Bauhus 1999).

Changes in soil carbon are potentially very important for carbon budgets because soil carbon tends to be more stable than other carbon pools so that any increases or decreases in soil carbon are potentially longer-lasting than changes in other carbon pools. Char (charcoal, black carbon) can comprise a significant proportion of SOC, particularly in those forests where wildfire or regeneration burning have been significant disturbances. This fraction has been reported to contribute 13-27% of SOC, and together with the 'stable' carbon fraction can make up 69-81% of SOC (Bauhus *et. al.* 2003, Hopmans *et. al*. 2005)). These fractions are considered to be inert components of the soil, along with, arguably fragmented rocks and mineral aggregates. Fire will readily convert CWD into char, particularly decaying wood, providing burning conditions are suitable. Other components, such as labile carbon and microbial carbon make up the oxidisable organic carbon (13-18%) (Bauhus *et. al.* 2003). In normal forestry operations there is generally only a slight change, if any, to total soil carbon, however, the inclusion of soil cultivation can led to some reduced soil carbon storage, particularly in the labile carbon and microbial carbon fractions.

Carbon is 'lost' in wood taken off-site as part of the collection and harvesting of dry and green firewood. There are different management regimes under which this firewood removal can occur, each with a different impact on carbon balances. To affect an understanding of these different regimes (e.g. Selective harvesting, no firewood collection; Selective harvesting with firewood collection; Selective harvesting with intense firewood collection) simulation modelling is required which incorporates the following: forest growth; natural mortality; disturbance related mortality; fire impacts; forest product removals; decay rates; SOC losses; etc., to keep track of all the key carbon pools. Such an undertaking, especially for different forest types, is beyond the scope of this review, but simulations of carbon emissions or GHG balances which have been reported are considered in the next Section.

Greenhouse gas (GHG) emissions

The task of exploring the impact of different firewood options on GHG balances is significant and is considered generally here with reference to published material. Modelling can be used to explore the influence of carbon balances on net CO_2 emissions, with particular care needed to select an appropriate time horizon for the analysis. The AGO's FullCAM model was developed to track carbon flows in a range of ecosystems, accounting for changes in carbon in all forest pools including vegetation (above ground and roots), litter, soils, and in carbon taken off-site in wood products. Additionally, it also tracks carbon use in the harvest and transport of forest products, and account for the decomposition of these products (Paul *et. al*. 2003). The model was used to explore two forest types: (1) unmanaged remnant woodlands (maximum aboveground biomass of about 77 t DM ha^{-1}), and; (2) managed native forest with selective harvesting (maximum aboveground biomass of about 140 t DM ha^{-1}). Scenarios involving a number of harvesting and firewood collection intensities were modelled over a 100 year period. The modelling found that the unmanaged woodland systems were degrading because old dying trees were not being replaced, and there was a release of CO_2. Firewood collection further increased the net emission of GHG. For the managed native forest the FullCAM model indicated that the forest was in a state of near equilibrium with respect to increments of tree growth, with a small sequestering of carbon. Firewood collection resulted in net emission of GHG. When the firewood was used for domestic heating, the net amount of GHG emitted per unit of heat energy produced ranged from 0.03-0.11 kg CO_2 per $kWhr^{-1}$ depending on the scenario. This indicated that firewood may be generally more favourable for domestic heating than other sources of domestic heating such as gas and electricity (which generally produce at least 0.31 kg CO_2 per $kWhr^{-1}$, excluding solar-, wind- or hydro-electricity)

Additionally, GHG balances (including non-CO_2 gases) have been evaluated for the proposed use of fuelwood for electricity generation, involving the use of harvesting residue from wet forest in Tasmania. This modelling found that for CO_2 equivalent emissions, greenhouse balances were dominated by the potential savings due to the offset of fossil fuel emissions (Raison *et. al*. 2002). Consequently, the type of energy generation that will be replaced by the use of the harvesting residues was critical to this evaluation. This highlights the importance of assumptions in this modelling, particularly in relation to fossil fuel offsets, but also more generally. Both this example and the previous example using the FullCAM model contain many assumptions and the results are only semi-quantitative. As a consequence, they are useful in comparing contrasting scenarios, but not as useful in fully quantifying a particular option.

In evaluating the GHG balances of different firewood options, it is worth noting that CO_2 emissions from burning wood are 1,687 kg CO_2 tDW^{-1}. Additionally, non-CO_2 GHGs are also an important consideration (Raison *et. al*. 2002). This principally involves the GHGs methane and nitrous oxide that are released during burning. In uncontrolled burning, such as a forest fire, it is estimated that for each tonne of wood (dry weight) 6.1 kg of methane and 0.006 kg of nitrous oxide are released, or 128.5 and 17 kg CO_2 tDW^{-1}(Raison *et. al*. 2002). More efficient burning (industrial boilers) significantly influences the emission of methane, but has little effect on nitrous oxide emissions. Domestic firewood use is likely to have limited effect on burning efficiency.

4.1.3 Soil and water quality (see also 2.1.3)

The physical soil disturbance associated with accessing 'dry' or 'green' firewood, or with its production can impact on water quality. The nature and timing of access can significantly influence this impact (Rab *et. al*. 2005). Harvesting and collection activities associated with firewood lead to differing levels of soil physical disturbance including soil movement and compaction (Rab 2004). Loss of soil through erosion may reduce productive capacity and impact on aquatic values.

Much of the literature on the impact of harvesting on soil and water quality is focussed on harvesting associated with clearfell rather than harvesting for firewood or selective harvesting. It is expected that firewood harvesting operations would result in a much lesser impact on water quality than the more intense operations associated with clearfell. Generally, firewood-related operations will result in reduced areas of extraction track and a lower unit wood volume extracted. Water quality impacts usually associated with native forest harvesting operations include:

1. Operations in the harvested coupe; (felling, snigging/forwarding, processing, loading and transporting) resulting in soil disturbance and compaction and associated surface runoff of sediment/nutrients

2. Outside the coupe activities; road and stream crossing construction, maintenance, usage and associated increases in sediment loads in surface runoff.

In-coupe, the factors that are most relevant to minimising soil disturbance and compaction are soil moisture content at the time of collection or harvest, machinery type, extraction track design and factors specific to soil type (Rab *et. al*. 2005). In particular, soil trafficability (or resistance to compaction) is affected by soil type; with the soil layer supporting traffic loads the critical factor. Gravel content along with a soil dryness index (SDI) are good indicators of soil trafficability during harvesting in the 'shoulder-periods' of Spring and Autumn. During these wetter periods it is often necessary to call a halt to forest operations for a winter break, generally using a trigger, such as a closure date or soil moisture conditions (e.g. soil saturation). SDI is one possible mechanism by which such a halt can be 'triggered' (Rab *et. al*. 2005). It is a soil water balance model, which is driven by rainfall and temperature, and is expressed as the nominal rainfall deficit from field capacity. It is easily used and can be useful in predicting threshold values where soil trafficability is important.

Sediment and nutrients (e.g. total phosphorus and total nitrogen) are common pollutants of streams and water impoundments. Comparatively, in-coupe, the literature indicates that the dominant source of sediment/nutrients (pollutants) to streams is often roads/extraction tracks, with the more heavily used extraction and access tracks responsible for most of the water runoff and movement of soil (Dignan 1999). Croke *et al.* (1999) conducted rainfall simulator erosion studies within a range of forest types in Victoria and NSW and concluded that tracks and snigging areas were responsible for most of the runoff and erosion. The general harvest area was found to act more as a sink for runoff water and sediment generated on the road/track surfaces, rather than a source of sediment. Current codes of practice and management procedures ensure that the risk of connectivity between sources of sediment and drainage lines is minimised to acceptable levels, and the impact of harvesting operations is mainly found to be minimal.

The most striking aspect of the literature relating to forest harvesting and water quality under modern management prescriptions is the almost universal finding that the road network is the dominant source of sediment. The impact of harvesting operations is generally found to be minimal (Cornish 2001; Grayson *et al.* 1993). Motha *et al.* (2003) used sediment tracing techniques and estimated that between 18%-39% of the sediment load from a Victorian forest was from unsealed roads while harvest areas contributed only 5-15%. Unsealed roads are identified as major contributors to sediment levels (Sheridan and Noske 2007). They found that annual sediment load was found to be twenty five times higher on an unsurfaced road on erodable subsoil (5373 mg/m² per millimetre of rain) than for a high-quality gravel surface road (216 mg/m² per millimetre of rain). The landscape position of roading has been identified as a critical factor in determining linkage between the road network and the stream network. Ridge-top roading has less direct linkage than roads lower in the landscape, with stream crossings and associated approaches being identified as the critical linkage points (e.g. Hairsine *et al.* 2002).

Several studies have investigated the relationship between traffic volume and sediment generation from unsealed roads. These studies have reported a range of increases in sediment generation due to traffic. Grayson *et al.* (1993) found a 2 fold increase, Croke *et al.* (1999) report a 4-5 fold increase with traffic, Foltz (1996) an 8-12 fold increase depending on gravel quality, Bilby *et al.* (1989) a 20 fold increase, and Reid and Dunne (1984) a greater than 100 fold increase. If traffic occurs during a rainfall event, sediment concentrations have been reported to increase immediately by 25% (Constantini *et al.* 1999), 600% (Reid and Dunne 1984) and 2500% (Bilby *et al.* 1989). However, Sheridan *et al.* (2005) found that for well-maintained gravelled roads of moderate slope and length, average suspended sediment generation rates are around 200-300 mg/L, increasing 3 to 10 fold to a maximum of 900-2000 mg/L with heavy traffic. Following the cessation of traffic, generation rates declined exponentially to pre-traffic levels after 50-70 mm of runoff. He found that these sediment generation values and traffic related increases are substantially less than generally reported previously. The results also showed that if roads are surfaced well and maintained correctly, their use in moderately wet conditions should not result in a more erodable surface than if used in dry weather. However, use of poorly surfaced roads or tracks should cease when the risk of damage to the road or sediment pollution of watercourses is high. During wetter periods it is often necessary to call a halt to forest operations, generally using a trigger, such as a closure date or soil moisture conditions (e.g. soil saturation).

4.1.4 Forest hygiene and health

Forest hygiene and health (and vitality) relates to the general condition of the forest, with reference to soundness and vigour; freedom from injury, damage, decay, defect and disease; robustness; invasive species and capacity for energetic active growth. The impact of firewood harvesting on eucalypt health and its ability to influence the general condition of the forest is the particular focus here.

Insects

Native eucalypt forests support a wide range of foliage-feeding and wood boring insects. To date, research on insects in native forests has generally focused on specific major pest species and their impact, distribution, abundance, autecology and control. Also, the impact of disturbance events, including wildfire, fuel reduction burning and timber harvesting have been studied, with studies focusing on insect recovery, as an indicator of forest resilience to disturbance (Neumann and Marks 1976; Neumann 1991, 1992; Collett 1997, Collett and Neumann 2003). Economically important outbreaks of insect defoliators usually occur in the simpler ecosystems, examples of which are natural single species forests and even-aged stands that regenerate following large destructive fires. Insects that degrade timber or cause wood destruction in standing trees seem more common in overstocked or fire-damaged stands (Neumann and Marks 1976). No studies to date have specifically examined the effects of harvesting for firewood in Victorian forests on insect pest species and insect biodiversity, although a few have studied the impact of thinning. One study examined the influence of non-commercial thinning upon defoliation by the Gumleaf Skeletoniser (*Uraba lugens*) in river red gum (*Eucalyptus camaldulensis*) forests (Harris 1974). He found that thinning regrowth stands to a density of less than 750 stems per hectare appeared to significantly reduce the severity of outbreaks which followed, provided the stumps of thinned trees were prevented from coppicing and thinning debris was removed. In older stands of river red gum, thinning using patch-cutting, has been used to manage areas of eucalypt die back (Murray Thorson[4] pers. comm.).

A lack of specific study in this area means that information tends to be anecdotal and general observation rather than based on scientific assessment. For example, it is a commonly held view that losses of wood production from insect attack may be lowered by the early removal of suppressed or dying trees or by the prevention of damaging ground fires or of injuries to remaining trees during felling and timber extraction. This view is based on observation rather than based on scientific assessment.

Within Victorian native forests there are a wide range of insect pest species that cause damage of varying degrees to a wide range of tree species. By far, the majority of these insect pests cause damage on an infrequent basis with the immediate effects generally short-term in duration and localised in their extent. Examples of these insect species are adults of leaf-chewing Christmas beetles (*Anoplognathus chloropyrus, A. hirsutus*), larvae of the leaf-mining Leafblister sawfly (*Phylacteophaga froggatti*), and larvae and adults of the leaf-feeding Eucalypt Weevil (*Gonipterus scutellatus*) (Collett 1997). While the causes of such outbreaks are not fully understood, factors such as availability of food resources, prevailing climatic conditions, foliage nutrient conditions, whether host trees are in single or mixed species stands, and population status of predator species all appear to play a role (Collett 2001).

Observations made over many years in Victoria have identified a group of insect species that have caused economically and aesthetically significant damage to occur on an ongoing basis. These insect species and the principal forest types they impact are, as follows:

- Spurlegged Phasmatid (*Didymuria violescens*), Ash and damper mixed-eucalypt forests
- Mottled Cup Moth (*Doratifera vulnerans*), mixed-eucalypt forests
- Mountain Ash Psyllid (*Cardiaspina bilobata*), Ash forests
- Southern Eucalyptus Leaf Beetle (*Chrysophtharta agricola*), Ash forests
- Wood boring moths (Family Cossidae), Ash forests
- Dampwood termite (*Porotermes adamsoni),* Ash forests

All these insect pest species are considered significant, causing widespread severe defoliation damage (e.g. *D.violescens* and *D.vulnerans*) or having the ability to cause significant wood degradation of wood in standing trees (eg. *Phorocantha spp* and *Cossidae*).

Hygiene

Within forested areas movement of machinery, vehicles and other equipment can potentially result in the transport of weeds and disease. These weeds and diseases can come from both within and

[4] Murray Thorson – FIC, Cohuna, Department of Sustainability and Environment,

also from outside the forest. Weeds are discussed in Section 4.4 Flora. In relation to diseases, native eucalypt forests support a broad range of fungal pathogens that cause tree diseases. To date, research has mainly focused on the distribution, life cycle and control of a few specific diseases that have, or are likely to have, significant economic impact in native forests. The extent of tree disease in a forest is the result of an interaction between a host, a pathogen and the environmental factors that affect host response and pathogen virulence. Of the several significant pathogens, both native and exotic, that have been recorded (Marks et al 1982, Keane et al 2000), few have been studied in sufficient detail to be enable an accurate prediction of the impact that harvesting for firewood may have on disease development. Of principal interest to this review are collar rot and root diseases, and wood decay.

The introduced soil-borne pathogen *Phytophthora cinnamomi* and native *Armillaria* spp. (notably *A. luteobubalina*), are recognised across Australia as the principal causal agents of collar rot and root disease associated with native forest dieback and isolated patch death of eucalypts (Shearer and Smith 2000, Shaw and Kile 1991, Kile 2000).

Phytophthora cinnamomi

Significant outbreaks of phytophthora-related dieback were recorded in the mid 1950's and 60's, and 1971 associated with heavy summer rainfall and autumn droughts (Tregonning and Fagg 1984), combined with the use of a selection felling silvicultural systems which resulted in reduced basal area on affected sites (Marks and Smith 1991). While the pathogen is now widely distributed in Victoria, the symptoms of disease are mainly confined to the coastal and foothill forests of East and South Gippsland, where significant dieback of eucalypts and losses of understorey species have occurred. These forests are significant sources of firewood.

Research indicates that phytophthora is an introduced primary plant pathogen of native plants. This root rot is favoured by the following conditions (Marks *et al*. 1982):

1. Saturation of soil for short periods of time, usually after heavy rain or as a result of run-off from hill slopes and drains.
2. Poor, internal soil drainage caused by either poorly developed crumb structure or by clay-rich layers close to the surface.
3. Soils of low fertility containing little organic matter
4. Soil temperature above 16^{o}C.

Combinations of these conditions greatly aggravate disease. For example, heavy summer rainstorms can produce severe disease conditions in infertile, sandy soils overlying a clay-pan close to the surface. The motile spores (zoospores) of the pathogen infect the roots of susceptible species when the soils are wet, and in highly susceptible species spread through the root system until it girdles the major roots and stems. As the roots die, the pathogen produces resting spores (chlamydospores), which can survive dry soil conditions and can be picked up in gravel taken from pits surrounded by infected vegetation. Soil adhering to vehicles, machinery, animals and footwear, and infected nursery plants provides a means for long-distance spread.

In south west Western Australia, management has placed seasonal restrictions on forest operations in areas affected by *P.cinnamomi*, where high soil moisture conditions increase the risk of its spread by vehicles and machinery (J. Bradshaw[5] pers. comm.).

Armillaria luteobubalina

---

[5] Jack Bradshaw –Silviculturalist (retired), CALM, WA

This fungus is a native primary pathogen of many species of both native and introduced trees (Shaw and Kile 1991, Kile 2000). The conditions that trigger an outbreak are not clear but appear related to the presence of a food base (e.g. stump), and/or soil moisture and physiological state of the host. Symptoms vary from the occurrence of scattered dead individual trees to distinct patches or infection centres up to 20 ha in extent (Edgar *et al.* 1976). In Victoria, it occurs naturally mainly in mixed species eucalypt forests and is an important disease in some Damp and Wet Forest types, principally in west-central Victoria. Historically, it has been mainly associated with selectively logged areas, with the disease impact being greatest in mature and overmature stands, causing crown dieback, reduction in basal area and volume and eventually death. *A.luteobubalina* has damaged approximately 2000 ha of mixed forest in Mt Cole and Wombat State Forests. As with *P. cinnamomi,* this species kills trees and shrubs of any age through the infection of the major roots and stem of the plant. It spreads between plants mainly through root to root contact. To reduce the chance of contact between healthy trees and the fungus, clearfelling (followed by regeneration burning) rather than selective harvesting techniques, may reduce the effects of Armillaria in areas prone to infestation. The creation of an ashbed should promote dense and healthy seedling regeneration that will allow for disease escape, genetic selection for resistance to infection, and drying of the site, thus making conditions less favourable for Armillaria (Smith and Smith 2003).

Wood decay fungi

There are two principal sources of wood decay formation. Those associated with defective branch ejection and wounding, and those linked to stem damage and decay in the major roots. White and Kile (1991) have demonstrated that stem wounds inflicted during harvesting operations can lead to the development of substantial columns of decay. Decay pathogens are most active in areas of high rainfall where their impact can be considerable on wood quality (Wardlaw and Neilsen 1999).

4.2 Tree hollow development

The loss of hollow-bearing trees in Victorian native forests (including native forests on private land) is listed as a potentially threatening process under the Flora and Fauna Guarantee Act 1988 (Department of Sustainability and Environment 2003d). Because hollow-bearing trees are likely to be affected by firewood harvesting (felling of standing trees), we will commence this chapter with a brief introduction to the formation of hollows.

There are no Australian vertebrates that actually excavate hollows in eucalypt trees in temperate forests, although several parrot and marsupial species may chew at hollow entrances to enlarge them or keep them open (Richard Loyn pers. obs.). Hollow development in eucalypts is generally considered to be a long-term (>100 year) process, though other schools of thought hold that hollows are formed in trees of any age through damage to the bark layer caused by fire, lightning or wind storm (Vearing 2000). Different species begin to develop hollows at different ages and rates (Mackowski 1984; Stoneman *et al.* 1994). Therefore, older forests have more hollow trees than younger forests (Lindenmayer 1996). An example of this was shown by Soderquist (1999) who reported that the frequency of hollows increased as tree size and age increased in box-ironbark forests.

A range of factors are known to contribute to hollow formation. These include mechanical damage during high winds, branch abscission and breakage, lightning strike and fire. Such damage can leave an open scar which is susceptible to fungi and insect (predominantly termite) attack, thus initiating the decomposition process (Department of Sustainability and Environment 2003d). Fire can also accelerate enlargement of tree hollows (particularly base hollows) and subsequent deterioration and collapse of older trees (EM pers. obs., Department of Sustainability and Environment 2003d). These contribute to the abundance of coarse woody debris on the forest/woodland floor (see below).

When fire is severe enough to kill tree cambium, the bark dies and the xylem is exposed to the entry of insect and decay organisms. Species such as Messmate *Eucalyptus obliqua*, Silvertop *E. sieberi*, Red Ironbark *E. tricarpa* are quite fire resistant, with Messmate having a thick fibrous bark persistent to the smallest branches, and Silvertop thick bark that persists to the larger branches of the crown. McArthur (1968) and others have reported that bark thickness rather than type was the important factor in protecting the cambium of eucalypts from lethal temperatures. Other species, such as River Red Gum are thinner barked and quite fire-sensitive, and fire-related mortality or damage is more likely when fires occur. In older trees, structural stem failure is more likely, as fire-damaged butts are more likely in older trees that have previously been damaged by fire. Butt damage is common in many forests and is often related to the presence of large fuel accumulations near the base of trees.

Tree damage by fire and consequent hollow development is influenced by the location of CWD. Burrows (1987) found that 92% of Jarrah *Eucalyptus marginata* and Marri *E. calophylla* trees were damaged by low and medium intensity fires if they were less than one metre away from CWD. This was due to the long duration of heating produced by the burning log. Buckley and Corkish (1991) found that in East Gippsland Lowland and Damp regrowth forests, debris from previous harvesting was a critical factor affecting butt damage. Retained trees suffered severe butt damage up to 3.2 m from the old logs that caught alight during post-thinning burning. Standing dead trees were also often ignited during post-thinning burning and damaged retained trees. Fire was also found to expand the area of damage on trees that suffered mechanical damage during thinning.

4.3 Habitat

The ecological importance of stand structural complexity has been articulated by Lindenmayer *et al.* (2002), amongst others, and their review of this important habitat component is summarised here. The two key reasons that stand structural complexity is important are (1) structurally complex forests allow the potential for greater inter-specific segregation of resources and microhabitats thereby enabling more species to occur locally, and (2) many types of structural attributes can be essential nesting, sheltering and foraging sites for a wide variety of taxa. The loss of key elements of stand structural complexity, like large diameter trees, thickets of understorey plants and logs, can: (1) eliminate organisms from logged areas that would otherwise occur there, (2) prolong the period that logged and regenerated stands are unsuitable habitat for species that have been displaced, (3) impair the dispersal and movement of some animals through logged areas, and, (4) eliminate within-stand variation in habitat conditions required by some taxa. Forests where stand structural complexity has been simplified through intensive management have impaired value for biodiversity.

Hollows are considered essential for a range of fauna, and each species has its own requirements for type of hollow (Australian Rainforest Conservation Society 1999; Gibbons and Lindenmayer 2002; Gibbons *et al.* 2002); in Victoria, the abundance of arboreal mammals has been correlated with densities of hollow-bearing trees in montane ash, River Red Gum and box-ironbark forests (Department of Sustainability and Environment 2003d).

Stand thinning is the most common harvesting method for obtaining firewood from live trees. Typically, select trees are removed from a dense regrowth stand in order to achieve a particular management objective or different structure of the forest stand — when less desirable trees are removed, resources may become available to the remaining trees and their growth and vigour increased (see earlier). There are potential ecological benefits associated with the removal of smaller trees — larger trees are expected to grow faster and provide for more rapid hollow development as well as the development of other habitat components (e.g. increased CWD loads, understorey growth). Carefully-controlled ‘ecological thinning’ aimed at increasing average tree size has been advocated, particularly within areas dominated by regrowth forest, as a means to enhance habitat for hollow-dependent fauna, including the Squirrel Glider (Department of Sustainability and Environment 2003b). This means that, for biodiversity, particular habitat characteristics are removed or modified. The removal of trees by thinning means that, in the short-medium term, there are fewer resources (e.g. roosting, nesting, basking, shelter and foraging structures, food, nest material) available to wildlife.

4.3.1 Mammals

The mammals of south-eastern Australia include many arboreal and aerial taxa that depend on hollow-bearing trees, as well as some facultative hollow users (Menkhorst 1995; Van Dyck and Strahan 2008). The distribution and abundance of such mammals in the landscape is typically patchy, reflecting an association with variety in habitat quality and floristic diversity. Arboreal mammals depend on the following critical habitat attributes: foliage, flowers, bark and hollows (McElhinny *et al.* 2006), and the removal of trees for firewood (and other reasons) will obviously diminish the availability of these crucial resources for fauna. The importance of these resources, particularly hollows, has been documented for a variety of south-eastern Australian arboreal and aerial mammals (Duncan and Taylor 2001; Friend and Wayne 2003; Gibbons and Lindenmayer 1997; Gibbons and Lindenmayer 2002; Gibbons *et al.* 2002; Harper 2005; Kavanagh *et al.* 1995; Kavanagh and Stanton 2005; Lindenmayer 1997; Lindenmayer *et al.* 1991; Lindenmayer *et al.* 2008; Lindenmayer *et al.* 1998; Lumsden *et al.* 2002a; b; McElhinny *et al.* 2006; Menkhorst 1995; Soderquist and Mac Nally 2000; Traill 1991; Tzaros 2005; Van Dyck and Strahan 2008). Indeed, the presence, abundance and taxonomic diversity have been correlated with the number of hollow-bearing trees, and that tree size (dbhob) is significantly correlated with occupancy of tree-hollows by mammals (McElhinny *et al.* 2006). Most of these arboreal and aerial species are known to utilise hollows in both dead and live trees.

Several scientific studies have demonstrated the direct association of mammal taxa with tree hollows in the forests of Australia, and a couple of examples are provided here. Dickman and Steeves (2004) documented the significance of, variously, tree hollows and logs for the Agile Antechinus, Brown Antechinus *Antechinus stuartii* and Bush Rat *Rattus fuscipes* in forests of eastern Australia.

Tree hollows are also a key habitat component for the Common Ringtail Possum *Pseudocheirus peregrinus*, especially where the ability to construct nests (dreys) in understorey vegetation is limited (Lindenmayer *et al.* 2008). The frequent use by the Common Ringtail Possum of smaller diameter trees with fewer cavities in the Victorian Central Highlands is at odds with other findings for this species (e.g. Gibbons and Lindenmayer 2002) and may mean that animal size and competition for hollows with other (larger) species may be determinants of hollow utilisation. The partitioning of hollow-bearing trees by arboreal marsupials in the Central Highlands has been documented by Lindenmayer *et al.* (1991), who argue that the then clear-felling rotations would prevent the development of characteristics that make trees suitable nest sites for arboreal marsupials.

Several threatened arboreal marsupials of south-eastern Australian woodlands depend on tree hollows, including the Eastern Pygmy-possum *Cercartetus nanus* (Duncan and Taylor 2001; Menkhorst 1995; Tulloch and Dickman 2006), Brush-tailed Phascogale *Phascogale tapoatafa* (Rhind 2004; van der Ree *et al.* 2006) and Squirrel Glider *Petaurus norfolcensis* (Beyer *et al.* 2008; Department of Sustainability and Environment 2003b; Menkhorst 1995; van der Ree 2002). Beyer *et al.* (2008) also highlighted the issue of the sustainability of suitable den trees, reporting an annual loss on their study sites of 3% of den trees, comparable to the annual loss of 4% of den trees used by the threatened Leadbeater's Possum *Gymnobelideus leadbeateri* in the Victorian Central Highlands (Lindenmayer *et al.* 1997; Lindenmayer *et al.* 1991).

Large trees are known to be important for other woodland mammals. Woodland patches in southern New South Wales are more likely to support populations of Yellow-footed Antechinus *A. flavipes* if they contain, *inter alia*, larger trees of select species (Korodaj 2007). In the box-ironbark woodlands of central Victoria, gullies, which occupy a very limited area in the ecosystem, are known to support significantly greater numbers of some arboreal mammals (e.g. Common Brushtail Possum *Trichosurus vulpecula*, Common Ringtail Possum) compared with non-gully sites; gullies also revealed 53% more trees with hollows in the upper bole and branches, and almost six times more very large trees (Soderquist and Mac Nally 2000), the inference being that hollow-bearing trees are probably the limiting habitat characteristic for these mammals. The importance of such gullies for birds has also been documented (Mac Nally *et al.* 2000b).

Bats comprise over 20% of the Australian mammal species (Van Dyck and Strahan 2008), and they play a significant role in several ecosystem processes — insectivory, pollination, seed dispersal (Law 1996). Their occurrence is largely determined by several key habitat attributes: foliage and canopy spaces, hollows and decorticating bark, and access to water (McElhinny *et al.* 2006). Both empirical and inferential evidence exist for the value of tree hollows to insectivorous bats in south-eastern Australia; hollow-bearing trees are important as roosting, hibernation and maternity sites (Brown *et al.* 1997; Churchill 2008; Herr and Klomp 1999; Law and Anderson 1999; Law 1996; Lumsden *et al.* 2002a; b).

In the woodlands of the Victorian Riverina, insectivorous bats utilise different habitats for roosting and foraging, often commuting large distances between the two types of habitat (Lumsden *et al.* 2002a). Two species, the Lesser Long-eared Bat *Nyctophilus geoffroyi* and Gould's Wattled Bat *Chalinolobus gouldii*, were found to roost, variously, in trees, fallen and decaying timber and under bark, though maternity roosts for both species were predominantly located in large dead trees. The spouts of large River Red Gum *Eucalyptus camaldulensis* trees were especially important as roost sites for male Gould's Wattled Bats (Lumsden *et al.* 2002a; b). In these floodplain forests both species roosted in locations that had greater densities of hollow-bearing trees than were generally available, suggesting roost selectivity by these bats; Lesser Long-eared bats utilised dead hollow-bearing trees and Gould's Wattled Bat, large live trees (Lumsden *et al.* 2002a).

Many species of insectivorous bats of wetter forests in south-eastern Australia (e.g. Highlands Northern Fall, Highlands Southern Fall, Northern Inland Slopes bioregions in Victoria) are known to require hollows in mature trees as roost sites (Law 1996); some of these species (e.g. *Vespadelus* spp.) are also likely to show a high degree of site fidelity, potentially making them more vulnerable to logging activities (Brown and Howley 1990; Churchill 2008; Law 1996).

Mentioned above is the Parks Victoria Ecological Thinning Trial in box-ironbark woodlands of central Victoria (Parks Victoria 2007; 2009), a long-term field-based experimental programme that will evaluate different methods of ecological thinning and the effects they have on the biotic components of the box-ironbark forest ecosystem, including select vertebrate fauna and key habitat characteristics. Mammals (particularly arboreal taxa and bats) and birds are key foci of this study, and benchmark values for their composition and abundance at the experimental sites in these woodlands have been established (Brown and Horrocks 2008). It is too soon to gauge the responses of either the biodiversity or desired habitat characteristics to ecological thinning in this Trial; this should become apparent in years (decades) to come.

4.3.2 Birds

Various estimates have been made of the number of Australian vertebrate species that use tree hollows (e.g. 400 species, Ambrose 1982; 303 species, Gibbons and Lindenmayer 2002). In Victoria, tree hollows are considered essential for 47 bird species (Department of Sustainability and Environment 2007; Emison *et al.* 1987; Menkhorst 1984), which use them primarily for nesting or roosting (Table 3.2). Fourteen of these bird species are listed as threatened (Department of Sustainability and Environment 2007). Many additional species nest on ledges or open hollows (e.g. woodswallows), or use hollows opportunistically. One species (the endangered Swift Parrot) depends on hollows for nesting, but not in Victoria as this migratory species nests only in Tasmania.

The six Victorian owl species (Powerful Owl *Ninox strenua*, Barking Owl *N. connivens*, Sooty Owl *Tyto tenebricosa*, Masked Owl *T. novaehollandiae*, Eastern Barn Owl *T. javanica* and Southern Boobook *N. novaeseelandiae*) all nest mainly in hollows, though some use is made of caves and buildings. The latter four species are also dependent to varying degrees on hollows for daytime roosting (Higgins 1999).

Large forest owls are often considered as 'umbrella' species (sensu Simberloff 1998) in the sense that they occupy large home ranges, are hollow-dependent and prey heavily on arboreal (hollow-dwelling) prey (possums and gliders). They have been used in this way in Victoria, where their conservation depends largely on retention of extensive tracts of old forest (Loyn *et al.* 2001) including abundant tree hollows. Modelling has shown that the probability of detecting a Powerful Owl responded positively to the number of live hollow-bearing trees and the Sooty Owl responded positively to the number of dead hollow-bearing trees at the call playback survey site (Loyn *et al.* 2002).

Powerful Owls occur across most of the bioregions covered by this report with the most significant concentrations in the Victorian Highlands - Southern Fall; Central Victorian Uplands and, to a lesser extent, Goldfields (Victorian Fauna Database, DSE, Emison *et al.* 1987). Barking Owls are scarce in Victoria with clusters of records in the Northern Inland Slopes, Victorian Highlands - Southern Fall and Goldfields bioregions (Victorian Fauna Database, DSE, Emison *et al.* 1987). Sooty Owls favour wetter forests in the eastern half of the state (Victorian Fauna Database, DSE, Emison *et al.* 1987).

Other species that nest in hollows include parrots, cockatoos, owlet-nightjars, kingfishers and a small number of passerines (notably treecreepers and Striated Pardalote *Pardalotus striatus*). Dead trees can provide valuable sources of hollows (e.g. Nelson and Morris 1994), but generally do not remain standing for as long. Studies in forests of Mountain Ash have shown that hollow-dependent birds (and several other bird groups) respond more strongly to numbers of live trees than dead trees (Loyn and Kennedy in press). Their study also showed that the density of old trees was more important than their spatial distribution.

Some bird species require highly specific nest hollow characteristics (McElhinny *et al.* 2006). The dimensions of a hollow can determine the species that may use it. Therefore, a diversity of hollow types is more likely to support a diversity of bird species (McElhinny *et al.* 2006). Small species favour hollows with the smallest entrance they can enter to preclude larger predatory species from access. Similarly, large birds such as owls require large hollows. Lower hollows can lead to greater risk of predation as reported for the near threatened Turquoise Parrot Neophema pulchella, nesting in old hollow fence posts (Quinn and Baker-Gabb 1993).

Hollows may be used by birds for purposes other than nesting. Some owls and Australian owlet-nightjars use hollows for roosting (HANZAB). Treecreepers often roost in crevices in large hollows or fire-scars. Several birds may drink from hollows when they fill with water.

A number of diurnal bird species take prey opportunistically from tree hollows. For example, Laughing Kookaburras *Dacelo novaeguineae* (Victorian Fauna Database, DSE) and Ravens *Corvus* spp. take nestlings (EM pers. obs.) of smaller, hollow-nesting bird or mammal species. Insectivores such as Thornbills *Acanthiza* spp. and omnivores such the Grey Shrike-thrush *Colluricincla harmonica* often forage in hollows seeking invertebrates (EM pers. obs.).

4.3.3 Reptiles

Gibbons and Lindenmayer (2002) estimated that 79 species of reptiles, about 10% of the Australian reptile assemblage, use hollows in Australia. Hollows are used by some reptile taxa as den or nest sites, and by some reptiles as sources of prey (Greer 2006).

In the floodplain forests (Murray Fans bioregion) and woodlands of north-central Victoria (Goldfields, Riverina, Northern Inland Slopes bioregions), reptiles have declined, primarily, as argued by Brown *et al.* (2008), through the broad-scale loss of native vegetation and changing land use. It is not difficult to imagine that the loss of many large trees (and fallen or standing dead timber) across these regions have adversely affected the reptile fauna, especially those taxa that are arboreal or utilise hollow-bearing trees.

Two such threatened taxa in these regions are the Tree Goanna and the Carpet Python (Department of Sustainability and Environment 2003c), both of which utilise hollows in both large logs and large trees (Alexander 1997; Department of Sustainability and Environment 2003d; Greer 2006; Greer 1989; Heard *et al.* 2004; Vincent and Wilson 1999). Other arboreal reptile taxa of these regions that utilise hollow-bearing trees include Carnaby's Wall Skink *Cryptoblepharus carnabyi*, Tree Skink *Egernia striolata*, Marbled Gecko *Christinus marmoratus* (Brown and Bennett 1995; Brown 2002; Brown and Nicholls 1993).

The Tree Goanna also occurs in wetter Victorian forests where it utilises hollow-bearing eucalypts, typically Mountain Ash *Eucalyptus regnans*, as do other reptile taxa, including the Black Rock Skink *Egernia saxatilis*, which has been observed 30 metres above ground on large living Mountain Ash trees (GB pers. obs.), and Spencer's Skink *Pseudemoia spenceri*, which commonly occurs in large colonies on large emergent stags and is significantly associated with numbers of large Mountain Ash trees (Brown and Nelson 1993b).

4.3.4 Amphibians

To our knowledge there have not been any empirical studies on the use of hollow-bearing trees by frogs, although the number of arboreal frog species in south-eastern Australia, principally from the *Litoria* genus, suggests that hollows are used, if only opportunistically. Gibbons and Lindenmayer (2002) nominate 27 Australian arboreal or semi-arboreal frog species that potentially use hollows, and note hollow use by frogs is difficult to detect because of their small size, absence of evidence of hollow use, and a lack of knowledge of their ecology.

In northern Victoria (Murray Fans, Riverina bioregions) Peron's Tree Frog *Litoria peronii* is an arboreal species that is often found under bark and in fissures of large River Red Gum trees (GB pers. obs.) and also in hollows of these floodplain trees (Gibbons and Lindenmayer 2002).

4.3.5 Invertebrates

Limited information is available on tree-hollow use by Australian invertebrates (Gibbons and Lindenmayer 2002), thus we draw on the following international examples. Harvesting may have a negative impact on invertebrate diversity if it results in the future reduction of stags or living trees with hollows. Nilsson and Baranowski (1997) found a greater number of red-listed beetle species in hollow trees from old-growth beech forest in Sweden than in recently (50 – 100 years) disturbed forests. They also observed the red-listed species occurred in low frequencies i.e. only every 20th hollow or dead tree were inhabited by a particular species. This means that a large number of stags and hollow trees need to be retained at a site. The retention of trees with large girths may also be important for beetle conservation and therefore ecological thinning may benefit some species. Rainus (2002) found that species richness for eleven beetle species in Sweden was highest in large trees.

4.4 Flora

The impact of firewood collection and harvesting can affect plant communities directly, through physical damage incurred during the operation, and indirectly, through changes to the ambient or edaphic conditions that plants experience, or through the introduction of competitors and disease (Driscoll *et al.* 2000; Penman *et al.* 2008b). However, despite the volumes of wood harvested from Victoria's forests, little research has been undertaken to quantify the effects that this harvesting is having on the composition and function of forest ecosystems, requiring us to draw heavily on research from other applications. Most of the available research is derived from forestry operations, particularly clearfelling of logging coupes, and, to a lesser extent, heavy silvicultural thinning, and the effects of these operations are expected to be substantially more intensive than those from firewood harvesting. Thus, we must tread cautiously when extrapolating results from other research. An ecological thinning trial was recently initiated by Parks Victoria in Box-Ironbark and Heathy Dry forests from west-central Victoria (Pigott *et al.* 2008), and over the next few years this should provide data that are pertinent to the forests that are experiencing high demand for firewood.

4.4.1 Understorey

The canopy formed by overstorey trees in a forest has a major impact on the conditions experienced by plants at ground level or in subordinate strata, particularly through the interception of light and water and the complexities of plant-plant competition. These effects depend to a large extent on the type of forest, as canopy density varies both spatially and temporally according to the overstorey species present (Belsky *et al.* 1989; Kirkpatrick 1997; Messier *et al.* 1998; Rokich and Bell 1995; Stewart 1988; Turton and Duff 1992) and aridity (Specht 1972; Specht and Morgan 1981).

The creation of canopy gaps by the partial removal of the overstorey leads to localised changes in the ambient environment in which understorey species exist. Gaps or other areas without overstorey generally experience higher photosynthetically-active radiation, higher maximum soil temperatures, higher minimum ground temperatures and decreased water deficit when compared to areas under canopy (Bowman and Kirkpatrick 1986a; Collins *et al.* 1985) (Bauhus *et al.* 2001; Belsky *et al.* 1989; Kirkpatrick 1997; Nunez and Bowman 1986; Rokich and Bell 1995; Stoneman *et al.* 1994). Given the potential differences in ambient conditions between gaps and the surrounding canopy, the creation of additional gaps by firewood harvesting might elicit local responses in understorey vegetation.

Some forest herbs may be adapted to high-intensity light, while others may need low-intensity light to avoid inhibition of photosynthesis. Other herbaceous species display plasticity or flexibility, and are able to adjust both physiologically and physically to a wide range of light regimes (Collins *et al.* 1985). Changes in the amount or wavelengths of light reaching the ground may affect seed germination, as seeds of some species require varying amounts of light for germination while seeds of other species require darkness (Rokich and Bell 1995). The variations in temperature, moisture and light in canopy gaps can affect photosynthesis and assimilation in forest herbs, influencing growth rates, growth form, and even allocation to sexual and asexual reproduction (Collins *et al.* 1985).

The degree to which canopy thinning affects the understorey environment, hence drives species change, differs substantially depending on forest type, the size and nature of the canopy gaps and the individual characteristics of understorey species. In Northern Hemisphere conifer forests, thinning leads to a large increase in the amount of light reaching the light-limited understorey, causing pronounced (although variable) increases in the cover of herbaceous species, particularly grasses (Alaback and Herman 1988; Dodson *et al.* 2007; Laughlin *et al.* 2005; Liira *et al.* 2007; McConnell and Smith 1970; Thomas *et al.* 1999), moving stands closer to older-growth composition (Lindh and Muir 2004) and promoting flowering (Lindh 2008). Shade-intolerant species display improved establishment and growth (Bock and Van Rees 2002). In broadleaved, deciduous forests, ground and shrub layer cover increased significantly with increasing harvest intensity (Fredericksen *et al.* 1999), although shade-tolerant species exhibited reduced growth and increased mortality in full sun treatments (Small and McCarthy 2002). However, changes may be complex and unpredictable, with the same species showing both increases and decreases in response to thinning at different sites (Götmark *et al.* 2005). In South American Lenga Beech *Nothofagus pumilio* forest, tree seedling survival and growth was highest in canopy gaps in mesic forest, but highest under shade in xeric forests (Heinemann and Kitzberger 2006).

In Australia, eucalypt canopies are persistent but often open, with more light reaching the understorey than in many other forest types (Kirkpatrick 1997), reducing the need for understorey plants to be shade-tolerant, and foliage cover tends to reduce from humid to arid zones (Specht 1972; Specht and Morgan 1981). Box-Ironbark and River Red Gum forests, which bear the brunt of firewood collection in Victoria (Driscoll *et al.* 2000), may be considered both relatively dry (Muir *et al.* 1995) and open, and the understorey changes following increased light penetration might therefore be smaller, or substantially slower, than that noted in denser forest types.

At a broader community level, and depending on site conditions, a reduction in the foliage projective cover of the overstorey may be compensated by an increase in the cover of the understorey, as the covers of the two strata in many forest types tend to be inversely related (Specht and Morgan 1981). Previous research suggests that the grassy layer is particularly responsive to change. For example, tree thinning in Narrow-leaved Ironbark *Eucalyptus crebra* woodland in Queensland resulted in a significant increase in herbage biomass (Walker *et al.* 1986). Similarly, thinning in Bimble Box *E. populnea* shrub woodlands led to increasing yields of herbage biomass (Walker *et al.* 1972), as it did in Mulga scrub (Beale 1973), while eucalypt sites in central Queensland produced higher pasture yields when tree basal area was lower (Scanlan and Burrows 1990). The difference between high- and low-basal area sites was more pronounced at sites of lower productivity. In mixed *Eucalyptus* communities in central Queensland, sites with lower tree basal area had increased amounts of grasses such as Black Speargrass *Heteropogon contortus* and Kangaroo Grass *Themeda triandra* than did sites with higher tree basal area (Scanlan and Burrows 1990), while Flooded Gum *Eucalyptus grandis* plantation sites had higher cover of grass under a more severe thinning treatment (Cummings *et al.* 2007).

However, changes are species-specific, and depend on individual habitat preferences. In Silvertop Stringybark *E. laevopinea* open-forest in northern New South Wales, Weeping Grass *Microlaena stipoides* was dominant beneath mature forest canopy, while Cane Wire-grass *Aristida ramosa* (and to a lesser degree Grey Tussock-grass *Poa sieberiana*) was dominant in large open spaces (Gibbs *et al.* 1999). Similarly, the abundance of Weeping Grass was significantly correlated with higher tree density in paddocks (Magcale-Macandog and Whalley 1994). Local frequency and site occurrence of Slender Wallaby-grass *Austrodanthonia racemosa* were both positively correlated with increasing tree cover, as was site occurrence of Velvet Wallaby-grass *Austrodanthonia pilosa* (Scott and Whalley 1982).

Observations by early explorers suggested that woodlands such as Box-Ironbark were originally open, with a highly diverse grassy to shrubby understorey (Calder *et al.* 1994). This suggests that on-going canopy thinning from firewood harvesting may have a positive effect on overall grass cover in that vegetation community.

The same factors that drive the abundance and richness of grasses can combine to drive the abundance and richness of other herbaceous species. In Silvertop Ash *Eucalyptus sieberi* forest in Victoria, thinning promoted the abundance of herbaceous species, particularly Germander Raspwort *Gonocarpus teucrioides*, although changes in total understorey cover, species richness, species diversity or lifeform diversity were not significant (Bauhus *et al.* 2001). Tree thinning in Narrow-leaved Ironbark woodland in Queensland led to a significant increase in herbage biomass and forb density (Walker *et al.* 1986). In contrast, maximum forb richness in Flooded Gum plantation was associated with higher, not lower, canopy cover (Cummings *et al.* 2007). However, no data are available to suggest what the response of forbs will be to thinning in forests such as Box-Ironbark or Red Gum that are most impacted by firewood harvesting.

Many winter-flowering orchids such as Greenhood *Pterostylis*, Midge-orchid *Corunastylis*, Mosquito-orchid *Acianthus* and Gnat-orchid *Cyrtostylis* prefer moister conditions, often under tree cover, and might respond negatively to thinning of the canopy or disturbance of the shrub layer associated with firewood harvesting. However, spring-flowering orchids such as Spider-orchid *Caladenia*, Beard-orchid *Calochilus*, Diuris *Diuris* and Wax-lip Orchid *Glossodia* often prefer drier conditions, and might respond positively to an increased light regime (pers. comm., Mike Duncan, Arthur Rylah Institute). Similarly, in northern hemisphere mixed mesophytic forests, flowering of the herb White Snakeroot *Eupatorium rugosum* was higher in gaps than under the shade of the canopy (Landenberger and Ostergren 2002).

Opportunistic species such as weeds are likely to be favoured in some sites. For example, soil disturbance in Mountain Ash forest led to an initial, abrupt increase in ruderal and weed species after thinning (Peacock 2008) and clearfelling (Appleby 1998), although the absolute cover of weeds remained relatively low. Logging also increased the abundance of weeds (mostly annual grasses and short-lived herbs) in Jarrah forest (Burrows *et al.* 2002). Frequently disturbed areas such as roadsides appear to be an important source of propagules (Appleby 1998), suggesting that regular disturbance and vehicle access associated with firewood cutting might result in an incremental increase in weeds. Weeds are not generally a major feature of Box-Ironbark and similar forests, although a high abundance of weeds is sometimes found in flat moister areas (Arthur Rylah Institute, unpublished data), which are also habitat for Yellow Box *Eucalyptus melliodora*, a preferred firewood species. Disturbance in these moister areas is likely to be more significant in promoting weeds than disturbance on drier slopes or ridges.

The suppression zone resulting from canopy tree roots may extend well out beyond the canopy (Incoll 1979; Lamont 1985; Rotheram 1983), and root competition for water in this zone appears to suppress shrub and overstorey regrowth. This suggests that a more open overstorey might promote the vigour of understorey species, with attendant benefits to ecosystem processes. Nonetheless, responses to canopy thinning by shrubs will be species-specific. In semi-arid Bimble Box woodland in New South Wales, shrubs such as Wilga *Geijera parviflora* and Turkey Bush *Eremophila deserti* grew beneath the canopy, while Mulga and Desert Cassia *Senna artemisioides* grew away from the canopy (Harrington *et al.* 1981). In mixed *Eucalyptus* communities in central Queensland, sites with lower tree basal area had decreased amounts of some native legumes or broad-leaved plants than did sites with higher tree basal area (Scanlan and Burrows 1990). In Flooded Gum plantation, the cover, density and richness of shrubs and woody climbers were lowest in plots with the least canopy (Cummings *et al.* 2007), suggesting regeneration in these species was better under closed canopy.

Anecdotal evidence from early explorers suggested that the shrub layer in forests and woodlands such as Box-Ironbark was well developed, under widely-spaced trees (Calder *et al.* 1994), suggesting that shrub communities in drier forests and woodlands might respond differently to canopy thinning than shrubs in wetter, taller forests. Shrubs might respond positively to thinning in drier forests, particularly in areas that are rocky with lower grass cover. Germination cues will be important. For example, Spreading Wattle *Acacia genistifolia*, Golden Wattle *Acacia pycnantha* and Hedge Wattle *A. paradoxa* all show a strong heat-stimulated germination response (Brown *et al.* 2003), yet persist at low levels (with occasional recruitment) in long-unburnt forest (Arthur Rylah Institute for Environmental Research, unpublished data). The soil disturbance associated with firewood harvesting might encourage some germination (Franco and Morgan 2007).

Finally, the disturbance associated with the firewood harvesting activities will impact directly on plant cover, at least initially, through physical damage to the plants. Disturbed Box-Ironbark sites had lower overall diversity and cover of understorey and ground layer species (Edwards 1997). Four years after logging in Jarrah forest in WA, the total abundance of individual native plants, particularly perennial herbs and sedges, was significantly lower in logged forest patches than in buffer zones (Burrows *et al.* 2002). Felling disturbance in Mountain Ash forest led to significant decreases in tall shrubs and small trees (Peacock 2008). Damage to flowering plants before they have had time to flower and set seed might result in a reduction in the soil seed bank, but no literature was found during this review that was relevant to thinning or firewood extraction activities.

Reseeding species might be less disadvantaged than resprouting species by intensive disturbance. For example, logging followed by slash burning favoured the germination of reseeding species over the growth of resprouting species in dry sclerophyll forest (Penman *et al.* 2008b) and wet forest (Murphy and Ough 1997). Soil disturbance from grading tracks and vehicle movements appear to have facilitated the spread of Hedge Wattle in grassy woodland, particularly in areas of higher soil moisture (Franco and Morgan 2007).

A high proportion of species used resprouting as a regeneration mechanism after fire in Box-Ironbark forest (Orscheg 2006), as did 60 of 66 species in dry sclerophyll foothill forest in north-central Victoria (Tolhurst 1996). By damaging the roots of these resprouting species, intensive harvesting activities may leave them at a competitive disadvantage in the early years after such harvesting. However, the response to logging disturbance is likely to be different to that after fire (Penman *et al.* 2008a), making inferences difficult to make. Data relating to the potential effects of firewood harvesting or canopy thinning on plants with different regeneration strategies were not found during this literature review.

Logging disturbance also results in soil compaction (Edwards 1997; Small and McCarthy 2002), which can have a negative influence on plant growth, although the severity would depend to a large extent on the intensity and frequency of the disturbance. Changes in macroporosity following logging in Mountain Ash forest were not considered severe enough to affect root growth (Rab 2004). No data were found during this literature review on the effects of compaction in dry forests that would be subject to firewood harvesting. Disturbance to the soil crust may also occur, although the impacts may be limited if the soil is relatively dry.

4.4.2 Eucalypt canopy

Thinning of overstorey trees during firewood harvesting operations can affect the growth of remaining trees and the germination and growth of recruits.

Reducing the overall density of canopy trees by thinning (such as regularly undertaken in commercial forestry) should result in a decrease in competition between the remaining trees for water and nutrients, thereby allowing increased growth rates (Department of Natural Resources and Environment. 1999). Of preferred firewood species, such increases in growth rates have been measured in Red Ironbark (Kellas *et al.* 1998; Kellas *et al.* 1982), although increases were more evident in regrowth stems than overwood (Kellas *et al.* 1982).

Tree species recruitment is limited in some forest types by the presence of an intact canopy. For example, adult Alpine Ash (*Eucalyptus delegatensis*) trees, due to their impact on soil moisture, suppress seedlings under their canopies (Bowman and Kirkpatrick 1986a; Bowman and Kirkpatrick 1986b), as do adults of Silvertop Ash (Incoll 1979). Similarly, Jarrah seedlings on sites without overstorey experience smaller soil and leaf water deficits and higher survival than seedlings with the overstorey retained (Stoneman *et al.* 1994). Few eucalypt seedlings were noted in areas where large, mature trees formed a closed canopy, but small seedlings were common in open areas (Gibbs *et al.* 1999). In contrast, regeneration of canopy species in Flooded Gum plantation was higher with increased canopy retention (Cummings *et al.* 2007), suggesting again that response will be species-specific.

In Wandoo *Eucalyptus wandoo* woodland in Western Australia, shrub seedlings were able to establish in the suppression zone around the overstorey trees, but premature death of adult shrubs appeared to occur when shrub roots eventually met the large lateral tree root system (Lamont 1985). Thus, initial establishment by woody recruits following firewood harvesting in some forests may not translate to longer-term increases in cover. However, overstorey recruitment in Box-Ironbark, Grassy Dry and Heathy Dry Forests is a continual process, and does not appear to be inhibited by the relatively low level of shade or the presence of mature trees. Seedlings and juveniles of Long-leaf Box *E. goniocalyx*, Red Stringybark *E. macrorhyncha* and Red Box *E. polyamthemos* are common in these forests, regardless of canopy density, although they may remain suppressed (Arthur Rylah Institute, unpublished data).

Higher cover of *Eucalyptus* species has been noted in sites subject to heavy disturbance (Edwards 1997), suggesting that firewood harvesting may result in an increase in the density of smaller stems. The overall stem densities in forests such as Box-Ironbark are also likely to increase substantially as a result of coppice growth following cutting (Edgar 1958), and the resultant (albeit patchy) denser canopy might affect the understorey as discussed in the previous section.

It is worth noting that recruits of Red Ironbark *E. tricarpa*, a preferred firewood species, are less abundant in areas where it occurs, and this is not surprising given that flowering and seed production in this species tends to be sporadic (Kellas 1991). The germination requirements for this species are poorly understood. Seeds seem to be short-lived and lack dormancy, yet while they germinate readily under laboratory conditions, they do not germinate readily under field conditions (Orscheg 2006). The long-term response of Red Ironbark to continual firewood harvesting is therefore of particular interest, but does not appear to have been the subject of research.

Firewood harvesting can affect overstorey diversity directly through the selective cutting of preferred species (Shahabuddin and Kumar 2007). In Victoria, River Red Gum *E. camaldulensis* is the most popular firewood consumed (Driscoll *et al.* 2000). This tends to occur in relatively monospecific stands, and cutting would alter forest structure more than composition. However, Red Box and Yellow Box, which occur in mixed stands, are the second most common species burned (Driscoll *et al.* 2000), and selective cutting of these species could eventually alter forest composition. Almost one third of Victoria's state forest harvest in 1997-1998 came from the mixed Box-Ironbark forests of the Bendigo Forest Management Area (Driscoll *et al.* 2000), suggesting that these compositional changes may be concentrated in particular areas. Disturbed Box-Ironbark sites are often dominated by a single species (Edwards 1997). The author (AT) has observed areas of the Craigie Forest (near Maryborough) where Red Box existed almost entirely as new coppice growth on stumps, rather than as mature trees. Selective cutting of Yellow Box is of particular concern, as it is generally found in sheltered sites near rivers or flat areas with poorer drainage (Viridans, Victorian Flora Database) and gullies, which have a disproportionate importance in terms of fauna richness and conservation value (Mac Nally *et al.* 2000b).

Interruptions to tree life cycles and life-spans may also occur as a result of selective cutting. Trees must reach a particular age before they set viable seed, and this time-to-maturity has been used extensively for determining successional processes in plant communities following fire (Noble & Slatyer 1981). We note that the Bendigo Forest Management Area specifies a minimum period of 25 years between sawlog harvesting at a site to allow recruitment across all age classes (DSE 2008), but we have not researched the equivalent prescriptions for firewood harvesting in the various regions. If young trees or coppice growth are continually harvested before they have reached a sufficient age to produce viable seed, and if the larger, retained trees eventually become senescent, then the resultant long-term effects might be similar to that experienced by forests that are overdue for a burn. However, no research was found during this review that related to this aspect of harvesting.

In Victoria, 49 plant communities are recognised as potentially threatened by firewood collection, including 23 forest communities, mostly in lower rainfall areas (Driscoll *et al.* 2000). Our analysis indicates that 43 forest or woodland EVCs are potentially affected in the 13 bioregions from which most firewood appears to be harvested, of which 32 are considered to be Endangered or Vulnerable in at least one of those bioregions (see *2.2.1 Vegetation communities*).

4.4.3 Nectar and pollen resources

Nectar and pollen represent important resources upon which many vertebrate and invertebrate fauna species rely. Of course, they are also important to the honey industry. However, the availability of these resources, particularly from canopy species, varies both spatially and temporally (Department of Agriculture 1946; Keatley and Hudson 2007; Keatley *et al.* 2004; Law *et al.* 2000; Wilson 2002).

Flowering of some eucalypt species can occur any time of year, but in general there is a consistent sequential pattern of peak flowering between species (Keatley and Hudson 2007). For example, in Box-Ironbark forests, peak flowering of Yellow Box occurred in November to January (depending on location), followed by Grey Box *Eucalyptus microcarpa* in March, Red Ironbark in June/July, Yellow Gum *E. leucoxylon* in July to September, then Red Box in September to November (Keatley and Hudson 2007). Flowering in forests around Rushworth commenced and peaked 1 to 4 months earlier than flowering in forests around Havelock (further to the south-west) (Keatley and Hudson 2007). Flowering peaks were also skewed in some species, with production in Red Ironbark slowly tapering off after an early peak, but production in Yellow Gum slowly increasing to a late peak (Keatley *et al.* 2004).

Many eucalypt individuals flower only every second year or so, sometimes *en masse*, and flower abundance may vary substantially due to conditions in the current or previous years (Department of Agriculture 1946; Law *et al.* 2000; Wilson 2002). In July 1997, for example, the winter-flowering Red Ironbark was flowering in only 3 of 5 geographic areas, while the percentage of trees flowering in a particular area ranged from 0% to 42% (Wilson and Bennett 1999). Nectar production within and between individual eucalypt trees is equally variable (Law and Chidel 2008).

The flowering patterns and differential responses by individual trees to seasonal conditions suggest that a substantial degree of genetic diversity (and adaptability) exists within species, and the resultant asynchrony in peak flowering patterns ensures that floral resources are available throughout the year. However, selective cutting of species, such as the summer-flowering species Yellow Box and River Red-gum, may negatively influence the distribution, abundance and timing of floral resources (Wilson 2002), with implications for those organisms dependent on them. Yellow Box, which generally flowers *en masse* every second year, is considered by the honey industry to be the most valuable nectar-yielding tree in Victoria (Department of Agriculture 1946), hence forest management prescriptions for the Bendigo Forest Management Area require the retention of all living Yellow Box trees (Department of Sustainability and Environment 2008a). Asynchrony in eucalypt flowering may also help reduce hybridisation between species (Keatley *et al.* 2004).

Little research was found during this literature review that addressed the likely effects of timber harvesting on flowering patterns, floral resources or pollination. In northern New South Wales, time-since-logging was not correlated with the percentage of the canopy in flower, and logging did not generally interrupt flowering cycles (Law *et al.* 2000). Nonetheless, differences were noted between species. For example, Smooth-barked Apple *Angophora costata* had a greater proportion of canopy in flower in recently-logged sites, possible due to reduction in competition, but Grey Ironbark *Eucalyptus siderophloia* and Forest Red Gum *E. tereticornis* tended to flower poorly (Law *et al.* 2000). In Spotted Gum *E. maculata* forest, smaller trees in recently logged forest produced less sugar, and more diluted sugar, than trees in regrowth or mature forest (Law and Chidel 2008). When scaled up to forest stand level, the amount of sugar produced per night in recently logged forest was around one-tenth of that produced in mature forest (Law and Chidel 2008). This corresponds with the observation that nectarivorous birds tend to be more numerous in mature forest than regrowth (Loyn 1980; 1985) and respond positively to numbers of retained live old trees (Loyn and Kennedy in press).

The age of a tree is an important factor influencing eucalypt flowering patterns. Larger trees flower more frequently, more intensely, and for a greater duration than smaller trees, and have bigger canopies that produce more flowers per unit area of canopy (Wilson 2002; Wilson and Bennett 1999). For example, in Spotted Gum forest, a large tree was estimated to have 74 000 flowers, compared to a medium-sized tree with 4 000 flowers (Law and Chidel 2008). This suggests that large trees have a disproportionate importance in eucalypt forests.

In tropical forests, large trees may also, in some instances, contribute more to pollination than small trees (Lourmas *et al.* 2007). However, few data exist on the potential effects of logging or selective harvesting on pollination. Pollen dispersal by insects (and presumably larger vertebrates) may occur over relatively large distances (Lourmas *et al.* 2007), and there may be little impact from a localised reduction in the quantity of individual species. Hybridisation rates in the uncommon Black Gum *E. aggregata* increased with reduced population size, while seed production, germination and seedling survival declined (Field *et al.* 2008). Species targeted for firewood harvesting are considered to be relatively common, and increased hybridization rates and reduced seedling performance are probably unlikely. Nonetheless, if populations of uncommon, non-target canopy or understorey species are reduced by firewood harvesting, increased hybridization (leading to reduced fecundity) in those species remains a possibility. However, no research was found that addressed that issue.

4.4.4 Cryptogams

Cryptogams are plants that reproduce by spores rather than seeds, and include lichens, bryophytes, algae and fungi (Scott *et al.* 1997). Fungi are dealt with in Section 4.6. Despite being important ecologically, their responses to disturbance have been poorly studied in comparison with those of vascular plants.

Lichens in particular play a major role in stabilising the surface and preventing erosion in semi-arid areas (Scott *et al.* 1997), but are vulnerable to the physical impacts associated with firewood harvesting. In Mulga woodland, for example, soil surface features such as lichens and cyanobacterial crusts were not present at firewood sites, despite being common elsewhere (Berg and Dunkerley 2004), rendering surfaces vulnerable to erosion by wind and rain. Lichens are also used as food by invertebrates such as mites or gastropods (slugs and snails), or as protective cover by some insects or their larvae (Scott *et al.* 1997). In sclerophyll forests, where lichens grow on the branches and trunks of many trees (Scott *et al.* 1997), firewood harvesting would result in a localised reduction in the resource that they represent.

Bryophytes (especially mosses) also help to stabilise soil surfaces, and can form a crust in semi-arid areas in conjunction with lichens and algae (Scott *et al.* 1997). They would also be affected by the physical disturbance associated with firewood harvesting. However, while they occur in large amount on trees and logs in wetter forests (Scott *et al.* 1997), they do not appear to be a major feature of woody material in drier forests (see Section 3 above).

CWD is also an important substrate for certain lichen and bryophyte species (Andersson and Hytteborn 1991). International studies have shown that a diversity of decay stages are also important for bryophyte diversity with different guilds forming a successional pathway (Andersson and Hytteborn 1991; Odor *et al.* 2006). Species richness was observed to increase with increasing CWD diameter in semi-natural beech forests in Europe (Odor *et al.* 2006). The limited work that has been conducted in Australia has predominantly focused on wet eucalypt forests in Tasmania. CWD was found to consist of the greatest number of significantly associated bryophyte species than any of the other substrate types. Many of these species were also associated with old growth forest logs. Dead trees or stags however only had one bryophyte species positively associated with it (Turner and Pharo 2005). Some bryophyte species have an obligatory association with CWD and others facultative (Odor *et al.* 2006).

Cryptogams (lichens in particular) are sensitive to changes in light and humidity, and destruction of habitat, especially the protective cover of vascular plants, represents a major threat to them (Scott *et al.* 1997). However, empirical research data are lacking.

4.5 Fungi and microbial organisms

Wood decay is an important contributor to internal tree defect, often in association with termite or borer attack. There are two principal sources of wood decay formation; associated with defective branch ejection and wounding, and linked to stem damage. White and Kile (1991) have demonstrated that stem wounds inflicted during mechanical harvesting operations can lead to the development of substantial columns of decay. They also identified that defect developed more rapidly from closed wounds than open wounds. Other studies have found that these decay columns also often originated from other sources, such as branch stubs and wood-boring insects (Wardlaw 1996).

These pathogens are most active in areas of high rainfall where their impact on wood structure can be considerable (Wardlaw and Neilsen 1999). While some research and reviews of current knowledge of the effect of damage and defect due to thinning and harvesting have been carried out (Dudzinski *et al.* 1992; Kile and Johnson 2000; Old *et al.* 1991; White and Kile 1991), there is still a need for further research (Old *et al.* 1991; White and Kile 1991), particularly in relation to revisiting previously thinned sites and trials (e.g. CSIRO silvertop damage trials).

Fungi help decompose plant material and form symbiotic relationships with higher plants, and in forests and woodlands the number of macrofungi species appears to always exceed the number of vascular plant species (Scott *et al.* 1997). Clearing and alteration of habitats is considered the major threat to this group, either directly or through the reduction in host species (Scott *et al.* 1997). Damaging processes associated with firewood harvesting could include soil compaction, removal of shading cover, loss of mycorrhizal host (plant) or dispersal agent (animal), loss of substrate (dead wood of a certain age or size), homogenisation of forest age, or invasion by exotic taxa.

5 Which communities or species may be affected by firewood activities?

The scale of firewood harvesting or collection varies substantially across Victoria, due to the occurrence or availability of preferred firewood species and demographic issues. In this section we determine the forest types that are most likely to be subjected to firewood activities, and identify vegetation communities or species therein that might be of concern in terms of their biodiversity status. Note that the degree to which these forest types might be affected by firewood collection will vary substantially depending on factors such as their spatial extent or proximity to townships, and we do not claim that firewood activities will always impact on them.

To determine the main Ecological Vegetation Classes (EVCs) that were most likely to be under pressure from licensed firewood harvesting and collection, it was first necessary to identify the Forest Management Areas (FMAs) from where most firewood was sourced. For example, in 1999/2000, the Bendigo FMA accounted for 35.7% of all firewood sold (Sylva Systems Pty Ltd. 2002), followed by Midlands FMA (14.6%) and Mid-Murray FMA (10.5%). All FMAs were plotted in GIS, and colour-coded by firewood volumes (Figure 6.1a), providing a visual guide that allowed the 13 bioregions which supply most of Victoria's firewood to be identified (Figure 6.1b).

A list was then compiled of all EVCs within these 13 bioregions. Wetland, heathland, grassland and other irrelevant EVCs were deleted, leaving only those forest and woodland EVCs in which firewood cutting was likely to occur.

Forty-three EVCs are considered to be subject to firewood harvesting and collection (Table 6.1), although many others are no doubt affected by private or unlicensed collection, including those in areas outside the bioregions chosen for the analysis.

5.1 Threatened EVCs and plant species

5.1.1 Vegetation communities

The Bioregional Conservation Status was determined for the 43 EVCs that were most likely to experience firewood harvesting in the 13 designated bioregions (see Figure 6.1) (http://www.dse.vic.gov.au/dse/nrence.nsf/Home+Page/DSE+Conservation~Home+Page?open) (Table 6.1). Note that the total area of individual EVCs and the extent to which they have been depleted vary between bioregions, and the same EVC may have a different status in a different bioregion.

EVCs of most concern are those that are considered to be Endangered or Vulnerable. Endangered EVCs are those that are contracted to less than 10% of former range; OR less than 10% pre-European extent remains; OR combination of depletion, degradation, current threats and rarity is comparable to the others. Vulnerable EVCs are those where 10 to 30% of pre-European extent remains; OR combination of depletion, degradation, current threats and rarity is comparable. Our analysis indicates that 32 forest or woodland EVCs are considered to be Endangered or Vulnerable in at least one of the 13 defined bioregions (Table 6.1). Only two EVCs (Heathy Dry Forest and Shrubby Riverine Woodland) are considered to be of Least Concern.

A summary is presented in Table 6.2, which shows that the bioregion Northern Inland Slopes has the highest number of endangered EVCs potentially subject to firewood harvesting (10). East Gippsland Uplands has no endangered EVCs likely to be affected.

A list of vegetation communities covered by Victoria's *Flora and Fauna Guarantee Act 1988* (FFG Act) was then consulted to determine if any relevant forest or woodland EVCs were listed (http://www.dse.vic.gov.au/dse/nrenpa.nsf/Home+Page/DSE+Plants~Home+Page?open). These FFG-listed communities are generally more narrowly defined than EVCs, and may therefore be contained within several different EVCs. Similarly, relevant ecological communities included under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (http://www.environment.gov.au/epbc) were identified. These ecological communities also do not align directly with EVCs, but in contrast to FFG-listed vegetation communities are generally broader than EVCs in their definition. Thus, with Commonwealth and state protection acting at community scales higher or lower than EVC scale, it is not possible to generate a simple table that specifies precisely the different levels of protection given to an individual EVC (as is possible with species).

Three ecological communities listed under the EPBC Act (that are likely to be subject to firewood harvesting) occur in and around the bioregions assessed, of which two have affinities with vegetation communities listed under Victoria's FFG Act. At a state level, nine vegetation communities potentially subject to firewood harvesting are listed under Victoria's FFG Act, although only six are likely to be found in the 13 defined bioregions. Six of these FFG-listed vegetation communities have affinities with EPBC-listed ecological communities.

The EPBC-listed Buloke Grassy Woodland occurs in the Riverina and Murray-Darling Depression Bioregions, and is dominated by Buloke *Allocasuarina luehmannii*, and occasionally Slender Cypress Pine *Callitris gracilis* or Grey Box *Eucalyptus microcarpa*. This ecological community has been extensively cleared, although its current exposure to firewood harvesting is unknown. Associated FFG-listed vegetation communities are Grey Box-Buloke Grassy Woodland Community, Semi-arid Herbaceous Pine Woodland Community and Semi-arid Northwest Plains Buloke Grassy Woodlands Community (the latter sometimes with Black Box *E. largiflorens* or Yellow Gum *E. leucoxylon*. The FFG-listed Semi-arid Herbaceous Pine-Buloke Woodland Community and Semi-arid Shrubby Pine-Buloke Woodland Community are also dominated by Cypress Pine and Buloke, but tend to occur in the north-west, outside the seven defined bioregions.

Another EPBC-listed ecological community, Box-Gum Grassy Woodland and Derived Grassland, is affiliated with three Victorian EVCs (Valley Grassy Forest, Plains Grassy Woodland and Grassy Woodland), but not directly with any FFG-listed vegetation community. The overstorey variously consists of White Box *E. albens*, Yellow Box *E. melliodora*, Blakely's Red-gum *E blakelyi* and various other box or stringybark species. This ecological community has also been extensively cleared, and includes several preferred firewood species.

The EPBC-listed Gippsland Red Gum *E. tereticornis* subsp. *mediana* Grassy Woodland and Associated Native Grassland, found on the Gippsland Plains, is dominated by Gippsland Red Gum, but may also include preferred firewood species such as Yellow Box and Red Box *E. polyanthemos*). Officially-identified threats include timber harvesting and firewood collection. In Victoria, the equivalent Forest Red Gum Grassy Woodland Community is listed under the FFG Act.

Red Gum Swamp Community No. 1 and Creekline Grassy Woodland (Goldfields) Community, both dominated by River Red-gum *E. camaldulensis*, are also listed under Victoria's FFG Act. The latter may include Yellow Box and Grey Box. The FFG-listed Western Basalt Plains (River Red Gum) Grassy Woodland Floristic Community 55-04 is found outside the 13 defined bioregions, but may be affected to some degree by past or present firewood harvesting. None of these River Red-Gum vegetation communities correspond to an EPBC-listed ecological community.

5.1.2 Plant species

A list of all plant species recorded in three Victorian bioregions (Goldfields, Victorian Riverina and Murray Fans, Figure 6.1), including their conservation and FFG status, was extracted from the Victorian Flora Information System (Viridans Biological Database). The ten additional bioregions previously used for identification of threatened EVCs were not used, because the inclusion of such a broad range of vegetation types (that included coastal, Mallee, and montane to alpine) led to an unmanageable number of irrelevant species. In any event, these three bioregions account for up to two-thirds of the firewood harvested in Victoria. These data were then vetted to ensure that the list contained only those plant species likely to be in vegetation types (forests or woodlands) that were likely to be subject to firewood harvesting. Species listed under the Commonwealth's EPBC Act were identified as for EVCs.

Vascular plant species listed under Victoria's FFG Act or the Commonwealth's EPBC Act, that occur in forests or woodlands of concern, are presented in Table 6.3, while a full list of species with a rare or threatened status is presented in the Appendix. Note that we make no claims about the extent to which individual species might be threatened by firewood harvesting activities, nor have we considered the mechanisms by which these plant species would be affected; we have simply generated a list of endangered species of which we should be mindful.

Within the forests and woodlands of the three defined bioregions, 58 vascular plant species are listed under the EPBC Act, FFG Act, or both. In summary, 23 EPBC-listed and 55 FFG-listed species are in forests or woodlands potentially subject to firewood harvesting (Table 6.4). Twelve and 36 of these species are considered endangered in Australia and Victoria, respectively. However, the total number of potentially threatened species may be substantially higher, as an additional 10 endangered and 29 vulnerable species are not listed under the EPBC or FFG Acts (Appendix 2). A further 20 species are poorly known, but likely to be endangered, vulnerable or rare.

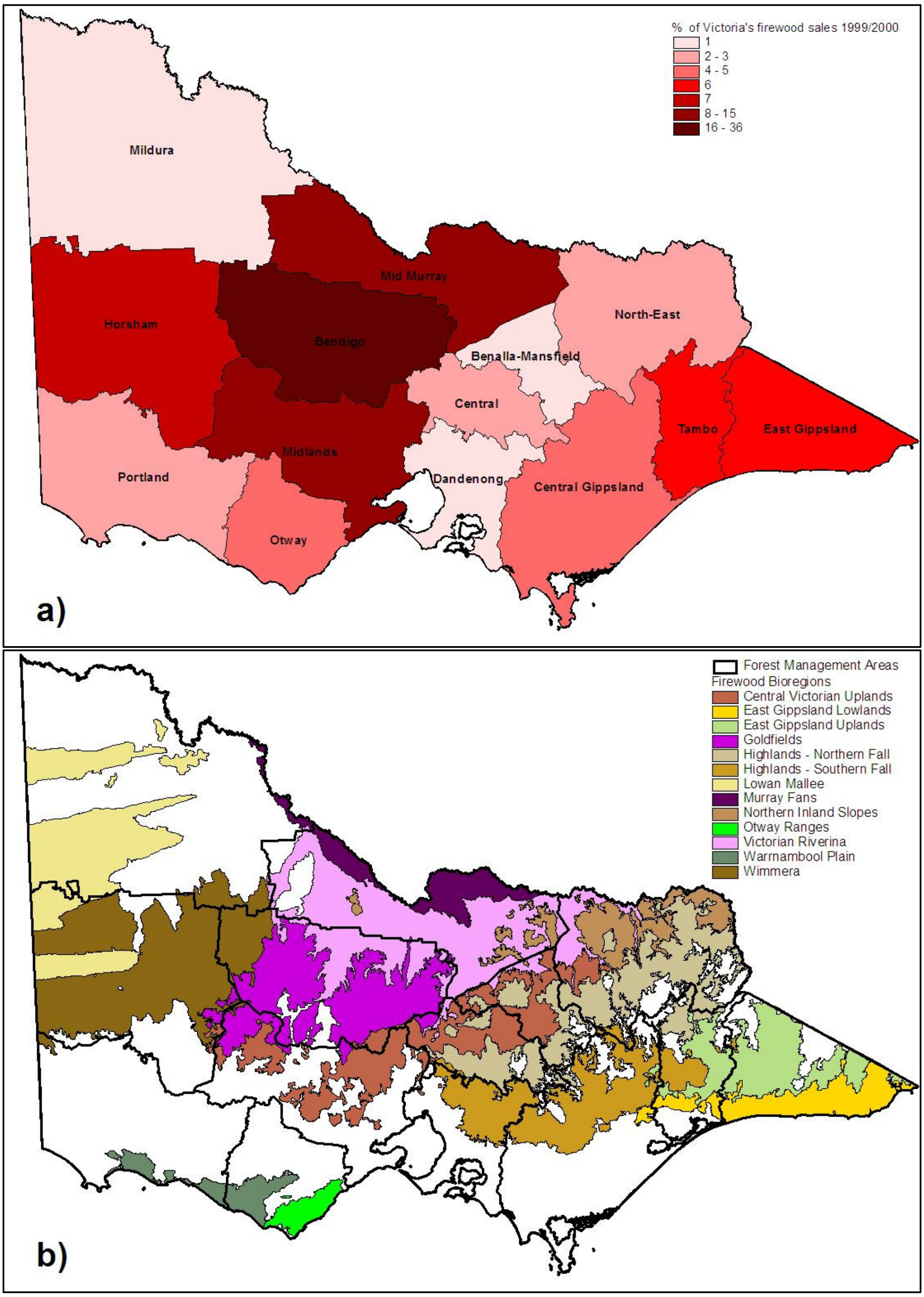


Figure 5.1 **Determination of bioregions. a) Forest Management Areas by firewood volume. b) Bioregions most relevant to this study.**

Table 5.1 Bioregional conservation status of EVCs likely to be subject to firewood harvesting.

Bioregions: CVU Central Victorian Uplands; GO Goldfields; HN Highlands - Northern Fall; HS Highlands - Southern Fall; MF Murray Fans; NIS Northern Inland Slopes; VR Victorian Riverina; WI Wimmera; LM Lowan Mallee; EGU East Gippsland Uplands; EGL East Gippsland Lowlands; OR Otway ranges; WP Warrnambool Plain.

Conservation Status: E Endangered; V Vulnerable; D Depleted; R rare; L Least concern.

EVC No.	EVC Name	CVU	GO	HN	HS	MF	NIS	VR	WI	LM	EGU	EGL	OR	WP
16	Lowland Forest	L		L	L								D	V
20	Heathy Dry Forest	L	L	L	L		L	L			L	L		
21	Shrubby Dry Forest	L	V	L	L		L	V			L	L	L	
22	Grassy Dry Forest	D	D	L	L		D	D	D		L	L	D	
23	Herb-rich Foothill Forest	D	D	L	L		L	D			L	L	D	V
24	Foothill Box Ironbark Forest										V			
45	Shrubby Foothill Forest	L		D	L						L		L	D
47	Valley Grassy Forest	V	V	V	V		E	V			D	D		
55	Plains Grassy Woodland	E	E	E	E		E	E	E			E		E
56	Floodplain Riparian Woodland	E	E	E	E	D	E	V	E					
61	Box Ironbark Forest	V	D		V		V	V	D					
66	Low Rises Woodland					E		V	E	E				
68	Creekline Grassy Woodland	E	E	E	E	E	E	E	E					
69	Metamorphic Slopes Shrubby Woodland		D						D					
70	Hillcrest Herb-rich Woodland	D	D						D					
71	Hills Herb-rich Woodland	V	D						V					
80	Spring Soak Woodland	E					E	V						
103	Riverine Chenopod Woodland					E	V	V	E	D				
106	Grassy Riverine Forest					D		D						

127	Valley Heathy Forest	V	E	E	V			E			V			
128	Grassy Forest	V			V								E	
151	Plains Grassy Forest				E							E		
168	Drainage-line Aggregate	E				V	E	E						
169	Dry Valley Forest			V	V						V	V		
175	Grassy Woodland	E	V	D	D	E	E	E	E		D	D	E	E
177	Valley Slopes Dry Forest	L			L						R	R		
198	Sedgy Riparian Woodland	D	V										V	E
282	Shrubby Woodland	R	L						L					
295	Riverine Grassy Woodland		V			V	E	V		D				
641	Riparian Woodland	E	E					E						
652	Lunette Woodland							E	E					
659	Plains Riparian Shrubby Woodland								V					
663	Black Box Lignum Woodland								E					
679	Drainage-line Woodland		E											
704	Lateritic Woodland		E						V					
793	Damp Heathy Woodland				D									
803	Plains Woodland	E	E			E	E	E	E	E				
813	Intermittent Swampy Woodland					D		D	V	V				
814	Riverine Swamp Forest					D		D						
815	Riverine Swampy Woodland		V			V	E	V						
816	Sedgy Riverine Forest					D		V						
818	Shrubby Riverine Woodland					L								
823	Lignum Swampy Woodland					V	V	V	V	D				

Table 5.2 Summary of bioregional conservation status of EVCs likely to be subject to firewood harvesting.

Bioregions: CVU Central Victorian Uplands; Gold Goldfields; H-NF Highlands - Northern Fall H-SF Highlands - Southern Fall; MF Murray Fans; NIS Northern Inland Slopes; VR Victorian Riverina.

Bioregion	Endangered	Vulnerable	Depleted	Rare	Least Concern
Central Victorian Uplands	8	5	4	1	5
Goldfields	8	6	6	0	2
Highlands - Northern Fall	4	2	2	0	5
Highlands - Southern Fall	4	5	2	0	7
Murray Fans	5	4	5	0	1
Northern Inland Slopes	10	3	1	0	3
Victorian Riverina	8	11	5	0	1
Wimmera	9	5	4	0	1
Lowan Mallee	2	1	3	0	0
East Gippsland Uplands	0	3	2	1	5
East Gippsland Lowlands	2	1	2	1	4
Otway Ranges	2	1	3	0	2
Warrnambool Plain	3	2	1	0	0

Table 5.3 EPBC or FFG-listed vascular plant species from forests and woodlands in three key bioregions likely to be subject to firewood harvesting.

EPBC (Australian Threatened) Status: E Endangered; V Vulnerable. FFG Status: f = listed. Victorian (Rare or Threatened) Status: e endangered; v vulnerable; r rare.

DICOTYLEDONS	Common name	EPBC	FFG	Vic
Acacia deanei subsp*. deanei*	Deane's wattle		f	e
Acacia omalophylla	Yarran Wattle		f	e
Allocasuarina luehmannii	Buloke		f	
Brachyscome chrysoglossa	Yellow-tongue Daisy		f	v
Brachyscome gracilis	Dookie Daisy		f	v
Brachyscome muelleroides	Mueller Daisy	V	f	e
Cullen tenax	Tough Scurf-pea		f	e
Discaria pubescens	Australian Anchor Plant		f	r
Dodonaea procumbens	Trailing Hop-bush	V		v
Eucalyptus aggregata	Black Gum		f	e
Eucalyptus alligatrix subsp*. limaensis*	Lima Stringybark	V	f	e
Eucalyptus froggattii	Kamarooka Mallee		f	r
Euphrasia collina subsp*. muelleri*	Purple Eyebright	E	f	e
Euphrasia scabra	Rough Eyebright		f	e
Geijera parviflora	Wilga		f	e

Glycine canescens	Silky Glycine		f	e
Glycine latrobeana	Clover Glycine	V	f	v
Goodenia macbarronii	Narrow Goodenia		f	v
Grevillea floripendula	Ben Major Grevillea	V	f	v
Hibbertia humifusa subsp*. erigens*	Euroa Guinea-flower	V	f	v
Lepidium pseudopapillosum	Erect Peppercress	V	f	e
Olearia pannosa subsp*. cardiophylla*	Velvet Daisy-bush		f	v
Philotheca difformis subsp*. difformis*	Small-leaf Wax-flower		f	e
Ptilotus erubescens	Hairy Tails		f	
Pultenaea graveolens	Scented Bush-pea		f	v
Pultenaea lapidosa	Stony Bush-pea		f	v
Santalum lanceolatum	Northern Sandalwood		f	e
Swainsona adenophylla	Violet Swainson-pea		f	e
Swainsona galegifolia	Smooth Darling-pea		f	e
Swainsona recta	Mountain Swainson-pea	E	f	e
Swainsona sericea	Silky Swainson-pea		f	v
Swainsona swainsonioides	Downy Swainson-pea		f	e
Thesium australe	Austral Toad-flax	V	f	v
Westringia crassifolia	Whipstick Westringia	E	f	e
Zieria aspalathoides subsp*. aspalathoides*	Whorled Zieria		f	v

MONOCOTYLEDONS	**Common name**	**EPBC**	**FFG**	**Vic**
Acianthus collinus	Hooded Mosquito-orchid		f	v
Caladenia audasii	McIvor Spider-orchid	E	f	e
Caladenia cruciformis	Red-cross Spider-orchid		f	e
Caladenia fulva	Tawny Spider-orchid	E	f	e
Caladenia ornata	Ornate Pink-fingers	V		v
Caladenia rosella	Little Pink Spider-orchid	E	f	e
Caladenia sp. aff. *fragrantissima* (Central	Bendigo Spider-orchid		f	e
Caladenia toxochila	Bow-lip Spider-orchid		f	v
Caladenia versicolor	Candy Spider-orchid	V	f	e
Caladenia xanthochila	Yellow-lip Spider-orchid	E	f	e
Calochilus richiae	Bald-tip Beard-orchid	E	f	e
Dianella amoena	Matted Flax-lily	E		e
Diuris dendrobioides	Wedge Diuris		f	e
Diuris palustris	Swamp Diuris		f	v
Diuris punctata var. *punctata*	Purple Diuris		f	v
Diuris tricolor	Painted Diuris		f	e
Prasophyllum hygrophilum	Swamp Leek-orchid		f	e
Prasophyllum sp. aff*. fitzgeraldii A*	Pink-lip Leek-orchid		f	e
Prasophyllum subbisectum	Pomonal Leek-orchid	E	f	e
Pterostylis despectans	Lowly Greenhood	E	f	e
Pterostylis woollsii	Long-tail Greenhood		f	e
Thelymitra epipactoides	Metallic Sun-orchid	E	f	e
Thelymitra mackibbinii	Brilliant Sun-orchid	V	f	e

Table 5.4 Summary of listed rare and threatened species potentially affected by firewood harvesting in three key bioregions.

Species that are Endangered or Vulnerable in Victoria, or listed under the Commonwealth EPBC Act, are not necessarily listed under Victoria's FFG Act, and *vice versa*.

Category	**Australia**	**Victoria**
Endangered	12	36
Vulnerable	11	18
Total EPBC-listed (Australia)	23	
Total FFG-listed (Victoria)		55*

6 Knowledge gaps

Our report confirms the findings of several relatively recent reviews on the ecological impacts of firewood harvesting at the national and state level (e.g. Australian and New Zealand Environment and Conservation Council 2001a; Driscoll *et al.* 2000; Grove *et al.* 2002; Lindenmayer *et al.* 2002) — that few studies have examined the direct impacts of firewood removal and harvesting on the diversity of flora and fauna and ecosystem processes, such as soil nutrient turnover. Notable exceptions include the investigations of saproxylic invertebrates at the Warra field site in Tasmania (e.g. Grove 2002b; Grove and Bashford 2003; Yee 2005; Yee *et al.* 2006) and the vertebrate and invertebrate work carried out in the Victorian River Red Gum forests in northern Victoria (e.g. Ballinger *et al.* 2003; Mac Nally 2006; Mac Nally *et al.* 2002a; Mac Nally and Horrocks 2008; Mac Nally *et al.* 2001).

Most research has concentrated on the moist forests of eastern and south-eastern Australia where CWD production is higher, though the impacts on biodiversity and ecosystem processes are arguably less than those in woodlands — more research is required in these drier, less productive forests. There has been a tendency to utilise anecdotal observations and inferential evidence in the absence of empirical data and to conclude that particular taxa are likely to decline if this habitat resource was removed (Driscoll *et al.* 2000; Lindenmayer *et al.* 2002). Driscoll *et al.* (2000) summarised the major gaps in knowledge about the impacts of firewood harvesting in Australia, though their focus was broader than ours and included the extent (i.e. amount of firewood used, its geographical source and the tree species taken) of harvesting firewood across Australia. We suggest the following as key research areas because information for each is lacking, particularly in dry forests and woodlands:

- The historical and current abundances of CWD, rates of accumulation and decay and sustainable rates at which to harvest it in different vegetation communities
- The abundance of CWD required to conserve particular fauna species, particularly terrestrial taxa that utilise CWD
- The features of CWD (e.g. decay stage, presence of hollows etc.) required to conserve particular wildlife species
- The impacts of firewood removal on less-researched taxa, such as invertebrates, fungi, and cryptogams (algae, lichens, mosses, ferns)
- The impact of fire on CWD decomposition is not well known. Some research suggests that charring slows down decomposition while other work suggests it increases it (Mackensen and Bauhus 1999)
- The mechanisms that accelerate the development of firewood timber species and the characteristics deemed desirable for biodiversity (e.g. hollows)

Little information exists on the contribution by CWD to vegetation structure and processes, and existing research focuses almost exclusively on wet forests. Research areas that should be addressed for drier forests include:

- The inter-relationships between CWD, mycorrhizal fungi and understorey plant species
- The role of CWD in providing microsites for seedling germination and survival

- The contribution of CWD to weed establishment and abundance

The physical disturbance associated with timber harvesting has been researched to a small degree in wetter, commercial forests, but little information exists on the effects of harvesting disturbance in drier forests. Research should determine:

- The degree of soil compaction associated with firewood harvesting, and the implications for seedling germination and survival, and plant growth rates
- Effects of soil compaction on water infiltration, run-off and erosion
- Differential impacts of disturbance on reseeding and resprouting species

The canopy formed by overstorey trees has a major impact on the conditions experienced by subordinate strata. Those conditions are likely to be altered, at least in the short-medium term, by the thinning associated with firewood harvesting, and this has implications in turn for fauna species. However, little research exists on the effects of thinning, either for commercial or ecological reasons, particularly in relation to drier forests. Areas for potential research include:

- Effects of canopy thinning on understorey vegetation composition and structure, including weeds
- Effects of canopy thinning on threatened species, such as winter-flowering orchids
- Effects of canopy thinning on flowering and nectar production
- Effects of canopy thinning on overstorey recruitment

Nectar and pollen represent important resources, not only for recruitment and persistence of plant species, but also for fauna. However, the degree to which timber harvesting will affect these resources is largely unknown. Research should determine:

- Peak flowering and sugar production times for all key firewood tree species
- The effects of firewood harvesting on the volume and timing of nectar production, total nectar availability and quality
- Pollination distances for key firewood species and the likely effects of decreases in mature tree density. This includes hybridisation rates, and changes in seed production and viability.

References

The references listed below have either been cited in this report or they are otherwise considered useful because they provide information relevant to this report.

Abensperg-Traun M, De Boer ES (1990) Species abundance and habitat differences in biomass of subterranean termites (Isoptera) in the wheatbelt of Western Australia. *Australian Journal of Ecology* **15**, 219-226.

Aigner PA, Block WM, Morrison ML (1998) Effect of firewood harvesting on birds in a California oak-pine woodland. *Journal of Wildlife Management* **62**, 485-496.

Alaback PB, Herman FR (1988) Long-term response of understory vegetation to stand density in *Picea-Tsuga* forests. *Canadian Journal Forest Research* **18**, 1522-30.

Alexander JSA (1997) 'Threatened hollow-dependent fauna in Box-Ironbark forests of Victoria: Bendigo Forest Management Area.' Department of Natural Resources and Environment, East Melbourne, Victoria.

Alinvi O, Ball JP, Danell K, Hjalten J, Pettersson RB (2007) Sampling saproxylic beetle assemblages in dead wood logs: comparing window and elector traps to traditional bark sieving and a refinement. *Journal of Insect Conservation* **11**, 99-112.

Alsfeld AJ, Bowman JL, Deller-Jacobs A (2009) Effects of woody debris, microtopography, and organic matter amendments on the biotic community of constructed depressional wetlands. *Biological Conservation* **142**, 247-255.

Amaranthus M, Trappe JM, Bednar L, Arthur D (1994) Hypogeous fungal production in mature Douglas-fir forest fragments and surrounding plantations and its relation to coarse woody debris and animal mycophagy. *Canadian Journal Forest Research* **24**, 2157-2165.

Ambrose GJ (1982) An ecological and behavioural study of vertebrates using hollows in eucalypt branches. Ph.D. thesis, La Trobe University. Bundoora, Victoria.

Andersson LI, Hytteborn H (1991) Bryophytes and decaying wood - a comparison between managed and natural forest. *Holarctic Ecology* **14**, 121-130.

Andrew N, Rodgerson L, York A (2000) Frequent fuel-reduction burning: the role of logs and associated leaf litter in the conservation of ant biodiversity. *Austral Ecology* **25**, 99-107.

Anstis M (2002) 'Tadpoles of South-eastern Australia: A Guide with Keys.' (Reed New Holland: Sydney)

Appleby MWA (1998) The incidence of exotic species following clearfelling of *Eucalyptus regnans* forest in the Central Highlands, Victoria. *Australian Journal of Ecology* **23**, 457-465.

Araya K (1993) Relationship between the decay types of dead wood and occurrence of Lucanid beetles (Coleoptera: Lucanidae). *Applied Entomology and Zoology* **28**, 27-33.

Ashton DH (1981) Fire in tall open-forests (wet sclerophyll forests). In 'Fire and the Australian Biota'. (Eds AM Gill, RH Groves and IR Noble) pp. 339-366. (Australian Academy of Science: Canberra)

Ashton DH (2000) The environment and plant ecology of the Hume Range, Central Victoria. *Proceedings of the Royal Society of Victoria* **112**, 185-272.

Attiwill PM, Polglase PJ, Weston CJ, Adams MA (1996) Nutrient cycling in forests of south-eastern Australia. In 'Nutrition of Eucalypts'. (Eds PM Attiwill and MA Adams). (CSIRO Publishing: Melbourne)

Australian and New Zealand Environment and Conservation Council (2001) 'A national approach to firewood collection and use in Australia.' ANZECC, Canberra.

Australian and New Zealand Environment and Conservation Council (2001) 'Review of the National Strategy for the Conservation of Australia's Biological Diversity.' (ANZECC: Canberra)

Australian Rainforest Conservation Society (1999) 'South-east Queensland Forest Facts Information Sheet No. 4.4: Habitat trees.' (ARCS: Bardon, Queensland). www.rainforest.org.au/Habitat_trees.pdf

Ball IR, Lindenmayer DB, Possingham HP (1999) A tree hollow dynamics simulation model. *Forest Ecology and Management* **123**, 179-194.

Ballinger A, Mac Nally R, Lake PS (2003) The effects of coarse woody debris and flooding on terrestrial invertebrate assemblages in river red gum *Eucalyptus camaldulensis* (Dehnh) floodplain forest. In 'Fifth invertebrate Biodiversity and Conservation Conference'. (South Australian Museum: Adelaide, SA)

Banks LM, Bennett AF (2003) Distribution of logs in a dry sclerophyll forest, Brisbane Ranges, Victoria. *The Victorian Naturalist* **120**, 55-60.

Barrett DJ (2002) Steady state turnover time of carbon in the Australian terrestrial biosphere. *Global Biogeochemical Cycles* **16**, 1-21.

Bate LJ, Torgersen TR, Wisdom MJ, Garton EO (2004) Performance of sampling methods to estimate log characteristics for wildlife. *Forest Ecology and Management* **199**, 83-102.

Bauhus J, Aubin I, Messier C, Connell M (2001) Composition, structure, light attenuation and nutrient content of the understorey vegetation in a *Eucalyptus sieberi* regrowth stand 6 years after thinning and fertilisation. *Forest Ecology and Management* **144**, 275-86.

Bauhus J, Khanna PK, Hopmans P, Ludwig B, Weston C. (2003) Evaluation of soil organic matter as a meaningful indicator of important soil properties and processes in native forest ecosystems. FWPRDC Report PN99.803.

Beale IF (1973) Tree density effects on yields of herbage and tree components in south west Queensland mulga (*Acacia aneura* F. Muell.) scrub. *Tropical Grasslands* **7**, 135-42.

Belcher CA (2004) The largest surviving marsupial carnivore on mainland Australia: the tiger or spotted-tail quoll *Dasyurus maculatus*, a nationally threatened, forest-dependent species. In 'Conservation of Australia's Forest Fauna'. (Ed. D Lunney) pp. 612-623. (Royal Zoological Society of New South Wales: Sydney: Sydney)

Belsky AJ, Amundson RG, Duxbury JM, Riha S, J., Ali AR, Mwonga SM (1989) The effects of trees on their physical, chemical, and biological environments in a semi-arid savanna in Kenya. *Journal of Applied Ecology* **26**, 1005-24.

Bengtsson J, Persson T, Lundkvist H (1997) Long-term effects of logging residue addition and removal on macroarthropods and enchytraeids. *Journal of Applied Ecology* **34**, 1014-1022.

Bennett A, Brown G, Lumsden L, Hespe D, Krasna S, Silins J (1998) 'Fragments For the Future. Wildlife in the Victorian Riverina (the Northern Plains).' (Department of Natural Resources and Environment: East Melbourne)

Bennett A, Mac Nally R, Yen AL (1999) 'Extinction Processes and Fauna Conservation in Remnant Box-Ironbark Woodlands.' Final report to Land and Water Resources R & D Corporation and Environment Australia.

Bennett AF (1993) Microhabitat use by the long-nosed potoroo *Potorous tridactylus* and other small mammals in remnant forest vegetation of south-west Victoria. *Wildlife Research* **20**, 267-285.

Bennett AF (2002) 'Ecological management strategy. Box-Ironbark woodlands. A scoping paper.' School of Ecology and Environment, Deakin University, Burwood.

Bennett AF, Lumsden LF, Alexander JSA, Duncan PE, Johnson PG, Robertson P, Silveira CE (1991) Habitat use by arboreal mammals along an environmental gradient in north-eastern Victoria. *Wildlife Research* **18**, 125-146.

Bennett AF, Lumsden LF, Nicholls AO (1994) Tree hollows as a resource for wildlife in remnant woodlands: spatial and temporal patterns across the northern plains of Victoria, Australia. *Pacific Conservation Biology* **1**, 222-235.

Bennett LT, Adams MA (2004) Ecological effects of harvesting in Victoria's native forests: quantification of research outputs. *Australian Forestry* **67**, 212-221.

Berg SS, Dunkerley DL (2004) Patterned Mulga near Alice Springs, central Australia, and the potential threat of firewood collection on this vegetation community. *Journal of Arid Environments* **59**, 313-350.

Beyer GL, Goldingay RL, Sharpe DJ (2008) The characteristics of squirrel glider (*Petaurus norfolcensis*) den trees in subtropical Australia. *Australian Journal of Zoology* **56**, 13-21.

Bilby RE, Sullivan K, Duncan SH (1989) The generation and fate of road surface sediment in forested watersheds in southwestern Washington. *Forest Science* **3**, 453-468.

Bock MD, Van Rees KCJ (2002) Forest harvesting impacts on soil properties and vegetation communities in the Northwest Territories. *Canadian Journal Forest Research* **32**, 713-724.

Bowman DMJS, Kirkpatrick JB (1986) Establishment, suppression and growth of *Eucalyptus delegatensis* R. T. Baker in multiaged forests. II. Sapling growth and its environmental correlates. *Australian Journal of Botany* **34**, 73-80.

Bowman DMJS, Kirkpatrick JB (1986) Establishment, suppression and growth of *Eucalyptus delegatensis* R. T. Baker in multiaged forests. III. Intraspecific allelopathy, competition between adult and juvenile for moisture and nutrients, and frost damage to seedlings. *Australian Journal of Botany* **34**, 81-94.

Bowman JC, Sleep D, Forbes GJ, Edwards M (2000) The association of small mammals with coarse woody debris at log and stand scales. *Forest Ecology and Management* **129**, 119-124.

Bragg DC, Kershner JL (1999) Coarse woody debris in riparian zones; opportunity for interdisciplinary interaction. *Journal of Forestry* **97**, 30-35.

Brais S, Pare D, Camire C, Rochon P, Vasseur C (2002) Nitrogen net mineralization and dynamics following whole-tree harvesting and winter windrowing on clayey sites of northwestern Quebec. *Forest Ecology and Management* **157**, 119-130.

Braithwaite RW (1979) Social dominance and habitat utilisation in *Antechinus stuartii* (Marsupialia). *Australian Journal of Zoology* **27**, 517-528.

Braithwaite RW, Gullan PK (1978) Habitat selection by small mammals in a Victorian heathland. *Australian Journal of Ecology* **3**, 109-127.

Bride TF (1898) 'Letters from Victorian pioneers. Republished 1983.' (Currey O'Neill: Melbourne, Victoria)

Brough Smyth R (1878) 'The aborigines of Victoria with notes relating to the habits of the natives of other parts of Australia and Tasmania.' John Ferres, Government Printer, Melbourne.

Brown G, Bennett A (1995) 'Reptiles in rural environments. The distribution, habitat requirements and conservation status of the reptile fauna of the Murray-Darling area in Victoria. A report to the Murray-Darling Basin Commission.' Department of Conservation and Natural Resources, Flora and Fauna Branch.

Brown G, Cunningham J, Neyland M (2001) 'Thinning Regrowth Eucalypts, Native Forest Silviculture ' Forestry Tasmania.

Brown GW (2001) The influence of habitat disturbance on reptiles in a Box-Ironbark eucalypt forest of south-eastern Australia. *Biodiversity and Conservation* **10**, 161-176.

Brown GW (2002) The distribution and conservation status of the reptile fauna of the Murray River region in Victoria. *The Victorian Naturalist* **119**, 133-143.

Brown GW, Bennett AF, Potts JM (2008) Regional faunal decline - reptile occurrence in fragmented rural landscapes of south-eastern Australia. *Wildlife Research* **35**, 8-18.

Brown GW, Horrocks GF (2008) 'Parks Victoria Box-Ironbark Ecological Thinning Trial. Phase 1 Final Report to Parks Victoria — Vertebrate Fauna.' Arthur Rylah Institute for Environmental Research, Victorian Department of Sustainability and Environment, Heidelberg, Victoria.

Brown GW, Howley ST (1990) The bat fauna (Chiroptera: Vespertilionidae) of the Acheron Valley, Victoria. *Australian Mammalogy* **13** 65-70.

Brown GW, Nelson JL (1993) 'Habitat utilisation by heliothermic reptiles of different successional stages of *Eucalyptus regnans* Mountain Ash forest in the Central Highlands, Victoria.' Department of Conservation and Natural Resources V.S.P Technical Report, No. 17, Melbourne, Victoria.

Brown GW, Nelson JL (1993) Influence of successional stage of *Eucalyptus regnans* (Mountain Ash) on habitat use by reptiles in the Central Highlands of Australia. *Australian Journal of Ecology* **18**, 405-418.

Brown GW, Nelson JL, Cherry KA (1997) The influence of habitat structure on insectivorous bat activity in montane ash forests of the Central Highlands, Victoria. *Australian Forestry* **60**, 138-146.

Brown GW, Nicholls AO (1993) Comparative census techniques and modelling of habitat utilization by reptiles in northern Victoria. In 'Herpetology in Australia. A Diverse Discipline'. (Eds D Lunney and D Ayers) pp. 283-290. (Surrey Beatty & Sons Pty Ltd: Chipping Norton)

Brown J, N.J. E, Miller BP (2003) Seed production and germination in two rare and three common co-occurring *Acacia* species from south-east Australia. *Austral Ecology* **28**, 271-280.

Brown JK, Reinhardt ED, Kramer KA (2003) 'Coarse woody debris: Managing benefits and fire hazard in the recovering forest.' United States Department of Agriculture, Rocky Mountain.

Brown S, Mo J, McPherson JK, Bell DT (1996) Decomposition of woody debris in Western Australian forests. *Canadian Journal Forest Research* **26**, 954-956.

Buckley AJ, Corkish NL (1991) 'Fire hazard and prescribed burning of thinning slash in eucalypt regrowth forest.' Department of Conservation and Environment, Fire Management Branch.

Buddle CM (2001) Spiders (Araneae) associated with down woody material in a deciduous forest in central Alberta, Canada. *Agricultural and Forest Entomology* **3**, 241-251.

Buffum B, Gratzer G, Tenzin Y (2008) The sustainability of selection cutting in a late successional broadleaved community forest in Bhutan. *Forest Ecology and Management* **256**, 2084-2091.

Bull EL (2002) The value of coarse woody debris to vertebrates in the Pacific Northwest. In 'Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, November 2-4, 1999 Reno, Nevada '. (Eds WF Laudenslayer Jr., PJ Shea, BE Valentine, CP Weatherspoon and TE Lisle) pp. 171-178. (USDA Forest Service)

Bull EL, Parks CG, Torgersen TR (1997) 'Trees and logs important to wildlife in the interior Columbia River Basin.' US Department of Agriculture, Forest Service, Pacific NorthWest Research Station, Portland.

Bull EL, Wales BC (2001) Effects of disturbance on birds of conservation concern in eastern Oregon and Washington. *Northwest Science* **75**, 166-173.

Burrow N, (1994) Experimental development of a fire management model for Jarrah (*Eucalyptus marginata*) forest, PhD thesis, Dept. Forestry, ANU

Burrow N, (1987) Fire caused bole damage to Jarrah (*Eucalyptus marginata*) and Marri (*Eucalyptus calophylla*), Research Paper No. 3, Dept. Conservation and Land Management, WA

Burrows ND, Ward B, Cranfield R (2002) Short-term impacts of logging on understorey vegetation in a jarrah forest. *Australian Forestry* **65**, 47-58.

Buse J, Schroder B, Assmann T (2007) Modelling habitat and spatial distribution of an endangered longhorn beetle - A case study for saproxylic insect conservation. *Biological Conservation* **137**, 372-381.

Butts SR, McComb WC (2000) Associations of forest-floor vertebrates with coarse woody debris in managed forests of western Oregon. *Journal of Wildlife Management* **64**, 95-104.

Calder DM, Calder J, McCann IR (1994) 'The Forgotten Forests: a Field Guide to Victoria's Box and Ironbark Country.' (National Parks Association: Melbourne)

Campbell AJ, Tanton MT (1981) Effects of fire on the invertebrate fauna of soil and litter of a eucalypt forest. In 'Fire and the Australian Biota'. (Eds AM Gill, JC Woinarski and A York) pp. 215 - 241. (Australian Academy of Science: Canberra)

Catling PC, Burt RJ, Forrester RI (2000) Models of the distribution and abundance of ground-dwelling mammals in the eucalypt forests of north-eastern New South Wales in relation to habitat variables. *Wildlife Research* **27**, 639-654.

Chambers J, Wilson JC, Williamson I (2006) Soil pH influences embryonic survival in *Pseudophryne bibronii* (Anura: Myobatrachidae). *Austral Ecology* **31**, 68-75.

Cheney NP, (1990) Fuel load or fuel structure: Discussion paper for RWG 6, unpublished paper presented to AFCRWG 6, Fire Management meeting, Victor Harbour, South Australia, 1990

Cheney NP, Raison RJ, Khanna PK (1980) Release of carbon to the atmosphere in Australian vegetation fires. In 'Carbon Dioxide and Climate: Australian research'. (Ed. GI Pearman) pp. 153-158. (Australian Academy of Science: Canberra)

Cheney NP, Gould JS, Hutchings PT (1990) Sampling of available fuel and damage to trees retained after thinning and burning. Management of Eucalypt Regrowth in East Gippsland, Techical Report No. 12, DCE and CSIRO. (unpubl.)

Chettri N, Sharma E, Deb DC, Sundriyal RC (2002) Impact of firewood extraction on tree structure, regeneration and woody biomass productivity in a trekking corridor of the Sikkim Himalaya. *Mountain Research and Development* **22**, 150-158.

Christidis L, Boles WE (2008) 'Systematics and Taxonomy of Australian Birds.' (CSIRO Publishing: Melbourne, Victoria)

Churchill S (2008) 'Australian Bats. Second edition.' (Jacana Books: Crows Nest, NSW)

Claridge AW (1988) The diet and ecology of the Southern Brown and Long-nosed Bandicoots in south-eastern New South Wales. M.Sc. thesis, Australian National University. Canberra, ACT.

Claridge AW, Barry SC (2000) Factors influencing the distribution of medium-sized ground-dwelling mammals in southeastern mainland Australia. *Austral Ecology* **25**, 676-688.

Claridge AW, Barry SC, Cork SJ, Trappe JM (2000) Diversity and habitat relationships of hypogeous fungi. II. Factors influencing the occurrence and number of taxa. *Biodiversity and Conservation* **9**, 175-199.

Claridge AW, Lindenmayer DB (1998) Consumption of hypogeous fungi by the mountain brushtail possum (*Trichosurus caninus*) in eastern Australia. *Mycological Research* **102**, 269-272.

Cogger HG (2000) 'Reptiles and Amphibians of Australia.' (Reed New Holland: Sydney)

Collins BS, Dunne KP, Pickett STA (1985) Responses of forest herbs to canopy gaps. In 'The Ecology of Natural Disturbance and Patch Dynamics'. (Eds STA Pickett and PS White) pp. 217-34. (Academic Press: Orlando)

Connell MJ (2005) 'Report on growth and yield for use in developing the VicForests Thinning Strategy.' VicForests, Melbourne, Victoria.

Constantini A, Loch RJ, Connolly RD, Garthe R (1999) Sediment generation from forest roads: bed and eroded sediment size distributions, and runoff management strategies. *Australian Journal of Soil Research* **37**, 947-964.

Cornish PM (2001) The effects of roading, harvesting and forest regeneration on streamwater turbidity levels in a moist eucalypt forest. *Forest Ecology and Management* **152**, 293-312.

Costantini A, Grimmett JL, Dunn GM (1997) Towards sustainable management of forest plantations in south-east Queensland. I: Logging and understorey residue management between rotations in steep country *Araucaria cunninghamii* plantations. *Australian Forestry* **60**, 218-225.

Couper PJ (1995) Communal nesting in the small skink, *Lampropholis adonis*. *Memoirs of the Queensland Museum* **38**, 382.

Craig MD, Withers PC, Bradshaw DS (2007) Diet of *Ctenotus xenopleura* (Reptilia: Scincidae) in the southern Goldfields of Western Australia. *Australian Zoologist* **34**, 89 - 91.

Croke JC, Hairsine PB, Fogarty P (1999) Sediment production, storage and redistribution on logged hillslopes. *Hydrological Processes* **13**, 2705-2720.

Crook DA, Robertson AI (1999) Relationship between riverine fish and woody debris: implications for lowland rivers. *Marine Freshwater Research* **50**, 941-853.

Cummings J, Reid N (2008) Stand-level management of plantations to improve biodiversity values. *Biodiversity and Conservation* **17**, 1187-1211.

Cummings J, Reid N, Davies I, Grant C (2007) Experimental manipulation of restoration barriers in abandoned eucalypt plantations. *Restoration Ecology* **15**, 156-167.

Cunningham RB, Lindenmayer DB, Crane M, Michael D, MacGregor C (2007) Reptile and arboreal marsupial response to replanted vegetation in agricultural landscapes. *Ecological Applications* **17**, 609-619.

Cunningham SC, Mac Nally R, White M, Read J, Baker PJ, Thomson J, Griffioen P (2007) 'Mapping the current condition of River Red Gum (*Eucalyptus camaldulensis* Dehnh.) stands along the Victorian Murray River floodplain. A report to the northern Victorian Catchment Management Authorities and the Department of Sustainability and Environment.' Australian Centre for Biodiversity, School of Biological Sciences, Monash University, and the Arthur Rylah Institute for Environmental Research.

Cunningham SC, Read J, Baker PJ, Mac Nally R (2007) Quantitative assessment of tree condition and its relationship to physiological stress in stands of *Eucalyptus camaldulensis* (Myrtaceae) in southeastern Australia. *Australian Journal of Botany* **55**.

Date EM, Ford HA, Recher HF (2002) Impacts of logging, fire and grazing regimes on bird species assemblages of the Pilliga woodlands of New South Wales. *Pacific Conservation Biology* **8**, 177-195.

Davidson NJ, Close DC, Battaglia M, Churchill K, Ottenschlaeger M, Watson T, Bruce J (2007) Eucalypt health and agricultural land management within bushland remnants in the Midlands of Tasmania, Australia. *Biological Conservation* **139**, 439-446.

Davies N (1953) 'Investigations on the Soil and Water Relations of the River Red Gum Forests - Final Report. Murray Management Survey.' Forestry Commission of New South Wales, Resources Branch.

de Maynadier PG, Hunter Jr. ML (1995) The relationship between forest management and amphibian ecology: a review of the North American literature. *Environmental Review* **3**, 230-261.

Delaney M, Brown S, Lugo AE, Torres-Lezama A, Bello Quintero N (1998) The quantity and turnover of dead wood in permanent forest plots in six life zones of Venezuela. *Biotropica* **30**, 2-11.

Department of Agriculture (1946) 'Honey Flora of Victoria.' Department of Agriculture, Victoria.

Department of Environment and Climate Change (2008) 'Removal of dead wood and dead trees - key threatening process listing.' (DECC: Sydney, NSW). http://www.environment.nsw.gov.au/determinations/DeadwoodRemovalKtp.htm.

Department of Natural Resources and Environment (1998) 'Box-ironbark Timber Assessment Project: Bendigo Forest Management Area and Pyrenees Ranges.' NRE, Melbourne, Victoria.

Department of Natural Resources and Environment (2001) 'Proposed Forest Management Plan for the Mid-Murray Forest Management Area.' DNRE, Melbourne, Victoria.

Department of Natural Resources and Environment (2002) 'Community firewood supplies from public land in the Box-Ironbark study area: reference document.' NRE, East Melbourne, Victoria.

Department of Natural Resources and Environment (2002) 'Victorian firewood strategy. Discussion paper.' NRE, East Melbourne, Victoria.

Department of Natural Resources and Environment. (1999) 'Treatment of Non-Merchantable Trees. Native Forest Silviculture Guideline No. 12.' Forests Service, DNRE, Victoria.

Department of Natural Resources and Environment. (2002) 'Community firewood supplies from public land in the Box-Ironbark study area: reference document.' NRE, East Melbourne, Victoria.

Department of Sustainability and Environment, Victoria (DSE) (2003). Ecological effects of repeated low-intensity fire in a mixed eucalypt foothill forest in south-eastern Australia: Summary report (1984-1999). DSE, Fire Management. Research Report No. 57. 86 pp.

Department of Sustainability and Environment (2003) 'Action Statement No. 70 Large Ant-blue Butterfly *Acrodipsas brisbanensis*.' (DSE: East Melbourne). http://www.dse.vic.gov.au/dse/.

Department of Sustainability and Environment (2003) 'Action Statement No. 166 Squirrel Glider *Petaurus norfolcensis*.' (DSE: East Melbourne, Victoria). http://www.dse.vic.gov.au/dse/.

Department of Sustainability and Environment (2003) 'Action Statement No. 175 Inland Carpet Python *Morelia spilota metcalfei*.' (DSE: East Melbourne, Victoria). http://www.dse.vic.gov.au/dse/.

Department of Sustainability and Environment (2003) 'Action Statement No. 192. Loss of hollow-bearing trees from Victorian native forests and woodlands.' (DSE: East Melbourne, Victoria). http://www.dse.vic.gov.au.

Department of Sustainability and Environment (2003) 'Forest products from the State forest around Portland and Horsham: have your say discussion papers. No. 2.' (DSE: East Melbourne, Victoria). www.land.vic.gov.au/CA256F310024B628/0/4C48C394599F72CFCA25727A001B5E70/$File/Forest+prod.

Department of Sustainability and Environment (2003) 'Investigation into domestic firewood issues in Box ironbark forest.' DSE, East Melbourne, Victoria.

Department of Sustainability and Environment (2004) 'Firewood collection in Victoria.' DSE, Melbourne, Victoria.

Department of Sustainability and Environment (2004) 'Vegetation Quality Assessment Manual. Guidelines for applying the Habitat Hectares scoring method. Version 1.3.' (Victorian Government, DSE: East Melbourne, Victoria). http://www.dse.vic.gov.au/dse/.

Department of Sustainability and Environment (2006) 'Forest Factsheet: Forestry in the box-ironbark Bendigo Forest Management Area.' Victorian Government, DSE, East Melbourne, Victoria.

Department of Sustainability and Environment (2006) 'Vegetation Gain Approach - Technical basis for calculating gains through improved native vegetation and management.' Victorian Government, DSE, East Melbourne, Victoria.

Department of Sustainability and Environment (2007) 'Advisory List of Threatened Vertebrate Fauna in Victoria – 2007.' (DSE: East Melbourne, Victoria)

Department of Sustainability and Environment (2008) 'Bendigo Forest Management Area. Shaping our forests future. Prescriptions to maintain habitat in timber harvesting areas. Field guide brochure.' Department of Sustainability and Environment, Victoria.

Department of Sustainability and Environment (2008) 'Bendigo Forest Management Area: Wood Utilisation Plan, 2008/09-2010/11.' DSE, Melbourne, Victoria.

Department of Sustainability and Environment (2008) 'Department of Sustainability and Environment. Flora and Fauna Guarantee Act - listed taxa, communities and potentially threatening processes.' (DSE: East Melbourne, Victoria). http://www.dse.vic.gov.au/dse/.

Department of Sustainability and Environment (2008) 'Ecological Vegetation Class (EVC) benchmarks for each bioregion.' (DSE: East Melbourne, Victoria). http://www.dse.vic.gov.au/.

Department of Sustainability and Environment (2008) 'Mid Murray Forest Management Area: Wood Utilisation Plan, 2008/09.' DSE, Melbourne, Victoria.

Department of Sustainability and Environment (2008) 'Midlands Forest Management Area: Wood Utilisation Plan, 2008/09-2010/11.' DSE, Melbourne, Victoria.

Department of Sustainability and Environment (2009 in prep.) 'Low Elevation Mixed Species in Victoria's State Forests: silvicultural reference manual No. 3.' DSE, Melbourne, Victoria.

Department of Sustainability and Environment (2009) 'Proposed Wood Utilisation Plan: Midlands Forest Management Area.' DSE, Melbourne, Victoria.

Department of Sustainability and Environment. (2003) 'Forest products from the State forest around Portland and Horsham: have your say discussion papers.' DSE, East Melbourne, Victoria.

Department of Sustainability and Environment. (2003) 'Investigation into domestic firewood issues in box-ironbark forest.' DSE, East Melbourne, Victoria.

Department of the Environment Water Heritage and the Arts (2005) 'Bush stone-curlew *Burhinus grallarius*. Threatened Species Day fact sheet.' (DEWHA: Canberra, ACT). http://www.environment.gov.au/biodiversity/threatened/publications/tsd05bush-stone-curlew.html.

Department of the Environment Water Heritage and the Arts (2008) 'Environment Protection and Biodiversity Conservation Act 1999.' (DEWHA: Canberra, ACT). http://www.environment.gov.au/epbc/index.html.

Dexter BD (1968) 'Flooding and regeneration of river red gum, *Eucalyptus camaldulensis* Dehn.' Forests Commission of Victoria, Melbourne.

Dexter BD (1970) Regeneration of river red gum, *Eucalyptus camaldulensis*, Dehn. M.Sc.For. thesis, University of Melbourne. Melbourne, Victoria.

Dexter BD (1978) Silviculture of the river red gum forests of the central Murray floodplain. *Proceedings of the Royal Society of Victoria* **90**, 175-192.

Dexter BD, Rose HJ, Davies N (1986) River regulation and associated forest management problems in the River Murray red gum forests. *Australian Forestry* **49**, 16-27.

Di Stefano J (2002) River red gum (*Eucalyptus camaldulensis*): a review of ecosystem processes, seedling regeneration and silvicultural practice. *Australian Forestry* **65**, 14-22.

Dickman CR (1980) Ecological studies of *Antechinus stuartii* and *Antechinus flavipes* (Marsupialia: Dasyuridae) in open forest and woodland habitats. *Australian Zoologist* **20**, 433-446.

Dickman CR (1991) Use of trees by ground-dwelling mammals: implications for management. In 'Conservation of Australia's Forest Fauna'. (Ed. DE Lunney) pp. 125-136. (Royal Society of New South Wales: Mosman)

Dickman CR, Steeves TE (2004) Use of habitat by mammals in eastern Australian forests: are common species important in forest management? In 'Conservation of Australia's Forest Fauna (second edition)'. (Ed. D Lunney) pp. 761-773. (Royal Zoological Society of Australia: Mossman, New South Wales)

Dignan P (1999) Tracing sediment flows into buffers. In 'Proceedings of the Second Forest Erosion Workshop: Forest Management for Water Quality and Quantity'. Canberra. (Eds J Croke and P Lane) pp. 27-29. (Cooperative Research Centre for Catchment Hydrology)

Dignan P, Bren L (2003) A study of the effect of logging on the understorey light environment in riparian buffer strips in a south-east Australian forest. *Forest Ecology and Management* **172**, 161-172.

Dodson EK, Metlen KL, Fiedler CE (2007) Common and uncommon understory species differentially respond to restoration treatments in ponderosa pine/Douglas-fir forests, Montana. *Restoration Ecology* **15**, 696-708.

Driscoll D, Milkovits G, Freudenberger D (2000) 'Impact and Use of Firewood in Australia.' (Australian Department of the Environment, Water, Heritage and the Arts: Canberra, ACT). http://www.deh.gov.au/land/publications/firewood-impacts/.

Du Plessis MA (1995) The effect of firewood removal on the diversity of some cavity-using birds and mammals in South Africa. *Biological Conservation* **74**, 77-82.

Dudzinski MJ, Old KM, Gibbs RJ (1992) 'Minor Stem Damage to Silvertop Ash from Thinning Operations: Report to the Department of Conservation and Environment, Victoria.' CSIRO Division of Forestry, Canberra, ACT.

Duncan AMR, Taylor RJ (2001) Occurrence of pygmy possums, *Cercartetus lepidus* and *C. nanus,* and their nest sites in logged and unlogged dry and wet eucalypt forest in Tasmania. *Australian Forestry* **64**, 159-164.

Edgar WJ (1958) 'Working Plan for the Chiltern Forests.' Forests Commission, Victoria (Manuscript NPS Files).

Edwards A (1997) The effect of disturbance to understorey components of remnant woodlands. The Box-Ironbark system. B.Sc. (Hons) thesis, Deakin University. Melbourne.

EhnstroÌm B (2001) Leaving dead wood for insects in boreal forests - suggestions for the future. *Scandinavian Journal of Forest Research* **16**, 91-98.

Emison WB, Beardsell CM, Norman FI, Loyn RH, Bennett SC (1987) 'Atlas of Victorian Birds.' (Department of Conservation, Forests and Lands and Royal Australasian Ornithologists Union: Melbourne)

Environment Conservation Council (1997) 'Box-Ironbark Forests and Woodlands Investigation. Resources and Issues Report.' ECC, Fitzroy, Victoria.

Environment Conservation Council (2001) 'Box-Ironbark Forests and Woodlands Investigation. Final Report.' ECC, East Melbourne.

Fagg PC (2006) 'Thinning of Ash Eucalypt Regrowth.' Land and Natural Resources Div., Department of Sustainability and Environment, Melbourne, Victoria.

Fagg PC, Bates P (2009) 'Thinning of Box-ironbark forests.' Natural Resources Div., Department of Sustainability and Environment, Melbourne, Victoria.

Field DL, Ayre DJ, Whelan RJ, Young AG (2008) Relative frequency of sympatric species influences rates of interspecific hybridization, seed production and seedling performance in the uncommon *Eucalyptus aggregata*. *Journal of Ecology* **96**, 1198-1210.

Finkral AJ, Evans AM (2008) The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. *Forest Ecology and Management* **255**, 2743-2750.

Fischer J, Lindenmayer D, Cowling A (2003) Habitat models for the four-fingered skink (*Carlia tetradactyla*) at the microhabitat and landscape scale. *Wildlife Research* **30**, 495-504.

Flinn D, Squire R, Wareing K (2001) 'A review of native forest management in Victoria since World War II from a carbon accounting perspective.' Report to the Australian Greenhouse Office.

Flint A, Fagg PC (2007) 'Mountain Ash in Victoria's State Forests. Silviculture Reference Manual No. 1.' Department of Sustainability & Environment, Melbourne, Victoria.

Foltz RB (1996) Traffic and no-traffic on an aggregate surface road: sediment production differences. In 'Food and Agriculture Organisation (FAO) Seminar on Environmentally Sound Forest Road and Wood Transport'. pp. 195-204. (Sinaia, Romania)

Forestry Commission of NSW (1984) 'Notes on the Silviculture of Major Forest Types. 5. River Red Gum Types.' FCNSW, Sydney, NSW.

France RL (1997) Macroinvertebrate colonization of woody debris in Canadian Shield lakes following riparian clearcutting. *Conservation Biology* **11**, 513-521.

Franco JA, Morgan JW (2007) Using historical records, aerial photography and dendroecological methods to determine vegetation changes in a grassy woodland since European settlement. *Australian Journal of Botany* **55**, 1-9.

Franklin JF, Sugart HH, Harmon ME (1987) Tree death as an ecological process. *Bioscience* **37**, 550-556.

Fredericksen TS, Ross BD, Hoffman W, Morrison ML, Beyea J, Johnson BN, Lester MB, Ross E (1999) Short-term understory plant community responses to timber-harvesting intensity on non-industrial private forestlands in Pennsylvania. *Forest Ecology and Management* **116**, 129-139.

Freudenberger D, Cawsey EM, Stol J, West PW (2004) 'Sustainable Firewood Supply in the Murray-Darling Basin.' CSIRO Sustainable Ecosystems, Canberra.

Friend G, Wayne A (2003) Relationships between mammals and fire in south-western Australian ecosystems: what we know and what we need to know. In 'Fire in south-western Australian ecosystems: Impacts and management'. (Eds I Abbott and ND Burrows) pp. 363-380. (Backhuys Publishers: Leiden)

Garnett ST, Crowley GM (2000) 'The Action Plan for Australian Birds.' (Environment Australia: Canberra)

Gibb H, Hjalten J, Ball JP, Atlegrim O, Pettersson RB, Hilszczanski J, Johansson T, K. D (2006) Effects of landscape composition and substrate availability on saproxylic beetles in boreal forests: a study using experimental logs for monitoring assemblages. *Ecography* **29**, 191-204.

Gibbens J (1997) Ants and termites as indicators of habitat disturbance in Box-Ironbark forest. B.Sc. (Hons) thesis, University of Melbourne. Melbourne.

Gibbens J (2000) Changes in ant and termite activity and community structure as indicators of ground layer disturbance in box-ironbark forest. *The Victorian Naturalist* **117**, 124-130.

Gibbons P, Lindenmayer DB (1997) Developing tree retention strategies for hollow-dependent arboreal marsupials in the wood-production eucalypt forests of eastern Australia. *Australian Forestry* **60**, 29-45.

Gibbons P, Lindenmayer DB (2002) 'Tree hollows and wildlife conservation in Australia.' (CSIRO Publishing: Collingwood)

Gibbons P, Lindenmayer DB, Barry SC, Tanton MT (2000) The effects of slash burning on the mortality and collapse of trees retained on logged sites in south-eastern Australia. *Forest Ecology and Management* **139**, 51-61.

Gibbons P, Lindenmayer DB, Barry SC, Tanton MT (2002) Hollow selection by vertebrate fauna in forests of southeastern Australia and implications for forest management. *Biological Conservation* **103**, 1-12.

Gibbs L, Reid N, Whalley RDE (1999) Relationships between tree cover and grass dominance in a grazed temperate stringybark (*Eucalyptus laevopinea*) open-forest. *Australian Journal of Botany* **47**, 49-60.

Gill AM (1981) Adaptive responses of Australian vascular plant species to fires. In 'Fire and the Australian Biota'. (Eds AM Gill, RH Groves and IR Noble) pp. 243-272. (Australian Academy of Science Canberra)

Gill AM, Ashton DH, (1968) The role of bark type in relative tolerance to fire of three central Victorian eucalypts. Aust. J. Bot., 1968, 16, 491-8

Goldingay R, Daly G, Lemckert F (1996) Assessing the impacts of logging on reptiles and frogs in the montane forests of New South Wales. *Wildlife Research* **23**, 495-510.

Goodall K, Mathieson M, Smith GC (2004) 'Identification of species and functional groups that give early warning of environmental change (indicator 1.2): Part E1, a retrospective analysis of ground dwelling reptile assemblages in relation to selective timber harvesting, in dry sclerophyll forest of south-eastern Queensland ' Forest and Wood Products Research and Development Corporation, Melbourne, Vic.

Goodall K, Mathieson M, Smith GC (2004) 'Identification of species and functional groups that give early warning of environmental change (indicator 1.2): Part E2, avian assemblages of selectively harvested dry sclerophyll forests, South-East Queensland ' Forest and Wood Products Research and Development Corporation, Melbourne, Vic.

Götmark F, Paltto H, Nordén B, Götmark E (2005) Evaluating partial cutting in broadleaved temperate forest under strong experimental control: short-term effects on herbaceous plants. *Forest Ecology and Management* **214**, 124-141.

Grayson RB, Haydon SR, Jayasuriya MDA, Finlayson BL (1993) Water quality in Mountain Ash forests - separating the impacts of roads from those of logging operations. *Journal of Hydrology* **150**, 459-480.

Greer A (2006) 'Encyclopedia of Australian reptiles. Australian Museum online.' (Australian Museum: Sydney, NSW). http://austmus.gov.au/herpetology/research/#encyclopedia.

Greer AE (1989) 'The Biology and Evolution of Australian Lizards.' (Surrey Beatty & Sons: Chipping Norton)

Gregory KJ, Davis RJ (1992) Coarse woody debris in stream channels in relation to river channel management in woodland areas. *Regulated Rivers: Research & Management* **7**, 117-136.

Grierson PF, Adams MA, Attiwill PM (1992) Estimates of carbon storage in the above-ground biomass of Victoria's forests. *Australian Journal of Botany* **40**, 631-640.

Grove DJ, Tucker NJ (2000) Importance of mature timber habitat in forest management and restoration: What can insects tell us? *Ecological Management and Restoration* **1**, 62-64.

Grove SJ (2001) Extent and composition of dead wood in Australian lowland tropical rainforest with different management histories. *Forest Ecology and Management* **154**, 35-53.

Grove SJ (2002) Saproxylic insect ecology and the sustainable management of forests. *Annual Review of Ecology and Systematics* **33**, 1-23.

Grove SJ (2002) The influence of forest management history on the integrity of the saproxylic beetle fauna in an Australian lowland tropical rainforest. *Biological Conservation* **104**, 149-171.

Grove SJ, Bashford R (2003) Beetle assemblages from the Warra log-decay project: insights from the first year of sampling. *Tasforests*, 117-129.

Grove SJ, Meggs J (2003) Coarse woody debris, biodiversity and management: a review with particular reference to Tasmanian wet eucalypt forests. *Australian Forestry* **66**, 258-272.

Grove SJ, Meggs J, Goodwin A (2002) 'A review of biodiversity conservation issues relating to coarse woody debris management in wet eucalypt production forests of Tasmania.' Division of Forest Research and Development, Forestry Tasmania, Hobart.

Grove SJ, Stork NE (1999) The conservation of saproxylic insects in tropical forests: a research agenda. *Journal of Insect Conservation* **3**, 67-74.

Gunnarsson B, Nitterus K, Wirdenas P (2004) Effects of logging residue removal on ground-active beetles in temperate forests. *Forest Ecology and Management* **201**, 229-239.

Gunning R (2000) 'Invertebrates which are threatened by the removal of dead wood.' New South Wales Scientific Committee.

Guo LB, Bek E, Gifford RM (2006) Woody debris in a 16-year old *Pinus radiata* plantation in Australia: Mass, carbon and nitrogen stocks and turnover. *Forest Ecology and Management* **228**, 145-151.

Hairsine PB, Croke JC, Mathews H, Fogarty P, Mockler SP (2002) Modelling plumes of overland flow from roads and logging tracks. *Hydrological Processes* **16**, 2311-2327.

Halstead-Smith J (1999) The use of coarse woody debris by ground-dwelling small mammals. B.Sc. (Hons) thesis, Monash University. Clayton, Victoria.

Hannah D, Woinarski JCZ, Catterall CP, McCosker JC, Thurgate NY, Fensham RJ (2007) Impacts of clearing, fragmentation and disturbance on the bird fauna of Eucalypt savanna woodlands in central Queensland, Australia. *Austral Ecology* **32**, 261-276.

Harmon ME, Franklin JF*, et al.* (1986) Ecology of coarse woody debris in temperate ecosystems. In 'Advances in Ecological Research'. (Eds A MacFadyen and ED Ford) pp. 133-302. (Academic Press: London)

Harper MJ (2005) Home range and den use of common brushtail possums (*Trichosurus vulpecula*) in urban forest remnants. *Wildlife Research* **32**, 681-687.

Harrington GN, Dawes GT, Ludwig JA (1981) An analysis of the vegetation pattern in a semi-arid *Eucalyptus populnea* woodland in north-west New South Wales. *Australian Journal of Ecology* **6**, 279-87.

Hart DM (1995) Litterfall and decomposition in the Pilliga State Forests, New South Wales, Australia. *Australian Journal of Ecology* **20**, 266-272.

Heard GW, Black D, Robertson P (2004) Habitat use by the inland carpet python (*Morelia spilota metcalfei*: Pythonidae): Seasonal relationships with habitat structure and prey distribution in a rural landscape. *Austral Ecology* **29**, 446-460.

Hegetschweiler KT, van Loon N, Ryser A, Rusterholz HP, Baur B (2009) Effects of fireplace use on forest vegetation and amount of woody debris in suburban forests in northwestern Switzerland. *Environmental Management* **43**, 1-12.

Heinemann K, Kitzberger T (2006) Effects of position, understorey vegetation and coarse woody debris on tree regeneration in two environmentally contrasting forests of north-western Patagonia: A manipulative approach. *Journal of Biogeography* **33**, 1357-1367.

Helmus MR, Sass GG (2008) The rapid effects of a whole-lake reduction of coarse woody debris on fish and benthic macroinvertebrates. *Freshwater Biology* **53**, 1423-1433.

Henle K (1989) Ecological segregation in an assemblage of diurnal lizards in arid Australia. *Acta Oecologica, Oecol. Gener.* **10**, 19-35.

Herr A, Klomp NI (1999) Preliminary investigation of roosting habitat preferences of the large forest bat *Vespadelus darlingtoni* (Chiroptera, Vespertilionidae). *Pacific Conservation Biology* **5**, 208-213.

Higgins PJ (1999) (Ed.) 'Handbook of Australian, New Zealand and Antarctic Birds. Volume 4: Parrots to Dollarbird.' (Oxford University Press: Melbourne)

Hjalten J, Johansson T, Alinvi O, Danell JP, Ball IR, Pettersson RB, Gibb H, Hilszczanski J (2007) The importance of substrate type, shading and scorching for the attractiveness of dead wood to saproxylic beetles. *Basic and applied ecology* **8**, 364-376.

Hopkins AJM, Harrison KS, Grove SJ, Wardlaw TJ, Mohammed CL (2005) Wood-decay fungi and saproxylic beetles associated with living *Eucalyptus obliqua* trees: early results from studies at the Warra LTER Site, Tasmania. *Tasforests* **16**, 111-126.

Hopmans P, Bauhus J, Khanna P, Weston C (2005) Carbon and Nitrogen in forest soils: Potential indicators for sustainable management of eucalypt forests in south-eastern Australia. *Forest Ecology and Management*, vol 220, 1-3, pp 75-87.

Hopmans P, Elms SR (in press, 2009) Changes in total carbon and nutrients in soil profiles and accumulation in biomass after a 30-year rotation of *Pinus radiata* on podzolized sands: impacts of intensive harvesting on soil resources. *Forest Ecology and Management*.

Horskins K, Turner VB (1999) Resource use and foraging patterns of honeybees, *Apis mellifera*, and native insects on flowers of *Eucalyptus costata*. *Australian Journal of Ecology* **24**, 221-227.

House SM (1997) Reproductive biology of eucalypts. In 'Eucalypt Ecology'. (Eds JE Williams and CZ Woinarski) pp. 30-55. (Cambridge University Press: Cambridge)

House SM, (1992) Population density and fruit set in three dioecious tree species in Australian tropical rainforest. *Journal of Ecology* **80**, 57-69.

Humphries RK (1992) 'The effects of single spring and autumn prescribed fires on reptile population in wombat state forest.' Department of Conservation and Environment, Victoria.

Huxtable D (1987) 'The environmental impact of firewood collection for campfires, and appropriate management strategies.' South Australian College of Advanced Education, Salisbury, South Australia.

Incoll WD (1979) Effect of overwood trees on growth of young stands of *Eucalyptus sieberi*. *Australian Forestry* **42**, 110-6.

Incol WD, (1981) Effects of wildfire on survival, growth, form and defect in *Eucalyptus obliqua* and *E. sieberi* forests. Forests Commission of Victoria, RBR No. 180 (unpublished report)

Incoll WD (1981) 'Effects of thinning and initial stocking on growth of *Eucalyptus camaldulensis*.' Forests Commission Victoria, Melbourne, Victoria.

Ingram JC, Whittaker RJ, Dawson TP (2005) Tree structure and diversity in human-impacted littoral forests, Madagascar. *Environmental Management* **35**, 779-798.

IUCN (2008) '2008 IUCN Red List of Threatened Species.' (International Union for Conservation of Nature and Natural Resources Species Survival Commission: Cambridge, United Kingdom). http://www.iucnredlist.org.

Jabin M, Mohr D, Kappes H, Topp W (2004) Influence of deadwood on density of soil macro-arthropods in a managed oak-beech forest. *Forest Ecology and Management* **194**, 61-69.

Jacobs MR (1955) Growth habits of the eucalypts. Comm. For. And Tim. Bur., Canberra. 262 pp.

Jones ME, Oakwood M, Belcher CA, Morris K, Murray AJ, Woolley PA, Firestone KB, Johnson B, Burnett S (2003) Carnivore concerns: problems, issues and solutions for conserving Australia's marsupial carnivores. In 'Predators with Pouches: the Biology of Carnivorous Marsupials'. (Eds ME Jones, CR Dickman and M Archer) pp. 422-434. (CSIRO Publishing: Melbourne)

Jonsell M, Weslien J, Ehnstrom B (1998) Substrate requirements of red-listed saproxylic invertebrates in Sweden. *Biodiversity and Conservation* **7**.

Kanowski J, Catterall CP, Wardell-Johnson GW, Proctor H, Reis T (2003) Development of forest structure on cleared rainforest land in eastern Australia under different styles of reforestation. *Forest Ecology and Management* **183**, 265-280.

Kanowski JJ, Reis TM, Catterall CP, Piper SD (2006) Factors affecting the use of reforested sites by reptiles in cleared rainforest landscapes in tropical and subtropical Australia. *Restoration Ecology* **14**, 67-76.

Kavanagh RP, Debus S, Tweedie T, Webster R (1995) Distribution of nocturnal forest birds and mammals in north-eastern New South Wales: relationships with environmental variables and management history. *Wildlife Research* **22**, 359-377.

Kavanagh RP, Stanton MA (2003) Bird population recovery 22 years after intensive logging near Eden, New South Wales. *Emu* **103**, 221-231.

Kavanagh RP, Stanton MA (2005) Vertebrate species assemblages and species sensitivity to logging in the forests of north-eastern New South Wales. *Forest Ecology and Management* **209**, 309-341.

Kavanagh RP, Webb GA (1998) Effects of variable-intensity logging on mammals, reptiles and amphibians at Waratah Creek, eastern New South Wales. *Pacific Conservation Biology* **4**, 326-347.

Keatley MR, Hudson IL (2007) A comparison of long-term flowering patterns of Box-Ironbark species in Havelock and Rushworth forests. *Environmental Modeling and Assessment* **12**, 279-292.

Keatley MR, Hudson IL, Fletcher TD (2004) Long-term flowering synchrony of box-ironbark eucalypts. *Australian Journal of Botany* **52**, 47-54.

Kellas JD (1991) Management of the dry sclerophyll forests in Victoria. 2. Box-Ironbark forests. In 'Forest Management in Australia'. (Eds FH McKinnell, ER Hopkins and JED Fox) pp. 163-169. (Surrey Beatty & Sons: NSW)

Kellas JD, Oswin DA, Ashton AK (1998) 'Growth of Red Ironbark between 1972 and 1995 on research plots in the Heathcote Forest. Research Report No. 363.' Forests Service, Department of Natural Resources and Environment, Melbourne, Victoria.

Kellas JD, Incoll WD, Squire RO (1984) Reduction in basal area increment of Eucalyptus oblique following crown scorch. Aust. For. 47: 179-183.

Kellas JD, Owen JV, Squire RO (1982) 'Response of *Eucalyptus sideroxylon* to release from competition in an irregular stand.' Forests Commission Victoria, 29, Melbourne, Victoria.

Kerruish CM, Rawlins WHM (1991) 'The Young Eucalypt Report - some management options for Australia's regrowth forests.' (CSIRO Publications: Melbourne, Victoria)

Kile GA, Johnson GC (2000) Stem and butt rot of eucalypts. In 'Disease and Pathogens of Eucalypts'. (Eds PJ Keane, GA Kile, FD Podger and BN Brown) pp. 307-338. (CSIRO Publishing: Australia)

Kirby KJ, Reid CM, Thomas RC, Goldsmith FB (1998) Preliminary estimates of fallen dead wood and standing dead trees in managed and unmanaged forests in Britain. *Journal of Applied Ecology* **35**, 148-155.

Kirkpatrick JB (1997) Vascular plant-eucalypt interactions. In 'Eucalypt Ecology: Individuals to Ecosystems'. (Eds JE Williams and JCZ Woinarski) pp. 227-45. (Cambridge University Press: Cambridge)

Kirkpatrick JB (1999) The characteristics and management problems of the vegetation and flora of the Huntingfield area, Southern Tasmania. *Proceedings of the Royal Society of Tasmania* **133**, 23-28.

Korodaj T (2007) Determinants of Antechinus occurrence in a fragmented landscape: dead wood matters. Honours thesis, Charles Sturt University. Albury, NSW.

Krzyszowska-Waitkus A, Vance GF, Preston CM (2006) Influence of coarse wood and fine litter on forest organic matter composition. *Canadian Journal of Soil Science* **86**, 35-46.

Kueppers LM, Southon J, Baer P, Harte J (2004) Dead wood biomass and turnover time, measured by radiocarbon, along a subalpine gradient. *Oecologia* **141**, 641-651.

Kuffer N, Senn-Irlet B (2005) Influence of forest management on the species richness and composition of wood-inhabiting basidiomycetes in Swiss forests. *Biodiversity and Conservation* **14**, 2419-2435.

Kumar R, Shahabuddin G (2005) Effects of biomass extraction on vegetation structure, diversity and composition of forests in Sariska Tiger Reserve, India. *Environmental Conservation* **32**, 248-259.

Kutt AS (1993) Initial observations on the effect of thinning eucalypt regrowth on heliothermic skinks in lowland forest, East Gippsland Victoria. In 'Herpetology in Australia: A diverse discipline'. (Eds D Lunney and D Ayers) pp. 187-196. (Royal Zoological Society: Sydney)

Lada H, Mac Nally R, Taylor AC (2008) Responses of a carnivorous marsupial (*Antechinus flavipes*) to local habitat factors in two forest types. *Journal of Mammalogy* **89**, 398-407.

Lada H, Thomson JR, Mac Nally R, Horrocks G, Taylor AC (2007) Evaluating simultaneous impacts on three anthropogenic effects on a flood plain-dwelling marsupial *Antechinus flavipes*. *Biological Conservation* **134**, 527-536.

Lamb D, Lyon R, Smith A, Wilkinson G (1998) 'Managing habitat trees in Queensland forests.' Department of Natural Resources, Brisbane.

Lamont B (1985) Gradient and zonal analysis of understorey suppression by *Eucalyptus wandoo*. *Vegetatio* **63**, 49-66.

Landenberger RE, Ostergren DA (2002) *Eupatorium rugosum* (Asteraceae) flowering as an indicator of edge effect from clearcutting in mixed mesophytic forest. *Forest Ecology and Management* **155**.

Laudenslayer Jr. WF, Shea PJ, Valentine BE, Weatherspoon CP, Lisle TE (2002) 'Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, November 2-4, 1999 Reno, Nevada.' Pacific Southwest Research Station, USDA Forest Service.

Laughlin DC, Bakker JD, Fule PZ (2005) Understorey plant community structure in lower montane and subalpine forests, Grand Canyon National Park, USA. *Journal of Biogeography* **32**, 2083-2102.

Lauren A, Sikanen L, Asikainen A, Koivusalo H, Palviainen M, Kokkonen T, Kellomaki S, Finer L (2008) Impacts of logging residue and stump removal on nitrogen export to a stream: A modelling approach. *Scandinavian Journal of Forest Research* **23**, 227-235.

Laven NH, Mac Nally R (1998) Association of birds with fallen timber in box-ironbark forest of central Victoria. *Corella* **22**, 56-60.

Law B, Anderson J (1999) A survey for the Southern Myotis *Myotis macropus* (Vespertilionidae) and other bat species in the River Red Gum *Eucalyptus camaldulensis* forests of the Murray River, New South Wales. *Australian Zoologist* **31**, 166-174.

Law B, Mackowski C, Schoer L, Tweedie T (2000) Flowering phenology of myrtaceous trees and their relation to climatic, environmental and disturbance variables in northern New South Wales. *Austral Ecology* **25**, 160-178.

Law BS (1996) The ecology of bats in south-eastern Australian forests and potential impacts of forestry practices: a review. *Pacific Conservation Biology* **2**, 363-374.

Law BS, Anderson J (2000) Roost preferences and foraging ranges of the eastern forest bat *Vespadelus pumilus* under two disturbance histories in northern New South Wales, Australia. *Austral Ecology* **25**, 352-367.

Law BS, Chidel M (2008) Quantifying the canopy nectar resource and the impact of logging and climate in spotted gum *Corymbia maculata*. *Austral Ecology* **33**, 999-1014.

Lee PC, Crites S, Niefeld M, Nguyen HV, Stelfox JB (1997) Characteristics and origins of deadwood material in aspen dominated boreal forest. *Ecological Applications* **7**, 691-701.

Lester RE, Boulton AJ (2008) Rehabilitating agricultural streams in Australia with wood: A review. *Environmental Management* **42**, 310-326.

Lester RE, Wright W, Jones-Lennon M (2007) Does adding wood to agricultural streams enhance biodiversity? An experimental approach. *Marine and Freshwater Research* **58**, 687-698.

Liira J, Sepp T, Parrest O (2007) The forest structure and ecosystem quality in conditions of anthropogenic disturbance along productivity gradient. *Forest Ecology and Management* **250**, 34-46.

Lindenmayer D (1992) 'The ecology and habitat requirements of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria: a summary of studies.' Victorian Department of Conservation and Environment, East Melbourne, Victoria.

Lindenmayer D (1996) 'Wildlife and Woodchips: Leadbeater's Possum, a Test Case for Sustainable Forestry.' (University of NSW Press: Sydney)

Lindenmayer D, Hobbs RJ*, et al.* (2008) A checklist for ecological management of landscapes for conservation. *Ecology Letters* **11**, 78-91.

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

Lindenmayer DB (1994) Timber harvesting impacts on wildlife: implications for ecologically sustainable forest use. *Australian Journal of Environmental Management* **1**, 56-68.

Lindenmayer DB (1997) Differences in the biology and ecology of arboreal marsupials in forests of southeastern Australia. *Journal of Mammalogy* **78**, 1117-1127.

Lindenmayer DB (2007) 'The variable retention harvest system and its implications for biodiversity in the Mountain Ash forests of the Central Highlands of Victoria. Report prepared for the Department of Primary Industries - Victoria.' ANU College of Science, 2, Canberra, ACT.

Lindenmayer DB, Claridge AW, Gilmore AM, Michael D, Lindenmayer BD (2002) The ecological roles of logs in Australian forests and the potential impacts of harvesting intensification on log-using biota. *Pacific Conservation Biology* **8**, 121-140.

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, Tanton MT, Smith AP, Nix HA (1991) 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, Fischer J (2006) 'Habitat Fragmentation and Landscape Change. An Ecological and Conservation Synthesis.' (CSIRO: Collingwood)

Lindenmayer DB, Franklin JF, Fischer J (2006) General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biological Conservation* **131**, 433-445.

Lindenmayer DB, Hobbs RJ (2004) Fauna conservation in Australian plantation forests - A review. *Biological Conservation* **119**, 151-168.

Lindenmayer DB, Incoll RD, Cunningham RB, Donnelly CF (1999) Attributes of logs on the floor of Australian Mountain Ash (*Eucalyptus regnans*) forests of different ages. *Forest Ecology and Management* **123**, 195-203.

Lindenmayer DB, MacGregor C, Welsh A, Donnelly CF, Brown D (2008) The use of hollows and dreys by the common ringtail possum (*Pseudocheirus peregrinus*) in different vegetation types. *Australian Journal of Zoology* **56**, 1-11.

Lindenmayer DB, Margules CR, Botkin DB (2000) Indicators of biodiversity for ecologically sustainable forest management. *Conservation Biology* **14**, 941-950.

Lindenmayer DB, Tanton MT, Norton TW (1990) 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, Welsh A, Donnelly CF (1998) The use of nest trees by the mountain brushtail possum (*Trichosurus caninus*) (Phalangeridae: Marsupialia). V. Synthesis of studies. *Wildlife Research* **25**, 627-634.

Lindh BC (2008) Flowering of understory herbs following thinning in the western Cascades, Oregon. *Forest Ecology and Management* **256**, 929-936.

Lindh BC, Muir PS (2004) Understory vegetation in young Douglas-fir forests: does thinning help restore old-growth composition? *Forest Ecology and Management* **192**, 285-296.

Lohmus A (2005) Are timber harvesting and conservation of nest sites of forest-dwelling raptors always mutually exclusive? *Animal Conservation* **8**, 443-450.

Lohr SM, Gauthreaux SA, Kilgo JC (2002) Importance of coarse woody debris to avian communities in loblolly pine forests. *Conservation Biology* **16**, 767-777.

Lonsdale D, Pautasso M, Holdenrieder O (2008) Wood-decaying fungi in the forest: conservation needs and management options. *European Journal of Forest Management* **127**, 1-22.

Lourmas M, Kjellberg F, Dessard H, Joly HI, Chevallier M-H (2007) Reduced density due to logging and its consequences on mating system and pollen flow in the African mahogany *Entandrophragma cylindricum*. *Heredity* **99**, 151-160.

Loyn RH (1980) Bird populations in a mixed eucalypt forest used for production of wood in Gippsland, Victoria. *Emu* **80**, 145-56.

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

Loyn RH, Kennedy SJ (in press) Designing old ash forest for the future: old trees as habitat for birds in forests of Mountain Ash *Eucalyptus regnans*. *Forest Ecology & Management*.

Loyn RH, Lumsden LF, Ward KA (2002) Vertebrate fauna of the Barmah Forest, a large forest of River Red Gum *Eucalyptus camaldulensis* on the floodplain of the Murray River. *The Victorian Naturalist* **119**, 115-132.

Loyn RH, McNabb EG, Volodina L, Willig R (2001) Modelling landscape distributions of large forest owls as applied to managing forests in north-east Victoria, Australia. *Biological Conservation* **97**, 361-376.

Loyn RH, McNabb EG, Volodina L, Willig R (2002) Modelling distributions of large forest owls as a conservation tool in forest management: a case study from Victoria, south-eastern Australia. In 'Ecology and Conservation of Owls'. (Eds I Newton, R Kavanagh, J Olsen and I Taylor) pp. 242-254. (CSIRO Publishing: Melbourne, Victoria)

Ludwig B, Khanna PK, Raison RJ, Jacobsen K (1997) Modelling changes in carbon composition of a soil after clearfelling a eucalypt forest in East Gippsland. *Geoderma* **80**, 95-116.

Luke RH, McArthur AG, (1978) Bushfires in Australia, Australian Government Publishing Service, Canberra

Lumsden LF, Bennett AF, Silins JE (2002) Location of roosts of the lesser long-eared bat *Nyctophilus geoffroyi* and Gould's wattled bat *Chalinolobus gouldii* in a fragmented landscape in south-eastern Australia. *Biological Conservation* **106**, 237-249.

Lumsden LF, Bennett AF, Silins JE (2002) Selection of roost sites by the lesser long-eared bat (*Nyctophilus geoffroyi*) and Gould's wattled bat (*Chalinolobus gouldii*) in south-eastern Australia. *Journal of Zoology, London* **257**, 207-218.

Lunney D (1991) (Ed.)^(Eds) 'Conservation of Australia's Forest Fauna.' (Royal Zoological Society of Australia: Mossman)

Lunney D (2004) (Ed.)^(Eds) 'Conservation of Australia's Forest Fauna (second edition).' (Royal Zoological Society of Australia: Mossman, New South Wales)

Mac Nally R (1999) Ecological significance of coarse woody debris on floodplains. In 'Riverine Environment Forum, 4th'. (Murray Darling Basin Commission: Hahndorf, SA)

Mac Nally R (2006) Longer-term response to experimental manipulation of fallen timber on forest floors of floodplain forest in south-eastern Australia. *Forest Ecology and Management* **229**, 155-160.

Mac Nally R, Ballinger A, Horrocks G (2002) Habitat change in River Red Gum floodplains: depletion of fallen timber and impacts on biodiversity. *The Victorian Naturalist* **119**, 107-113.

Mac Nally R, Bennett AF (1997) Species-specific predictions of the impact of habitat fragmentation: local extinction of birds in the Box-Ironbark forests of central Victoria, Australia. *Biological Conservation* **82**, 147-155.

Mac Nally R, Bennett AF, Horrocks G (2000) Forecasting the impacts of habitat fragmentation. Evaluation of species-specific predictions of the impact of habitat fragmentation on birds in the box-ironbark forests of central Victoria, Australia. *Biological Conservation* **95**, 7-29.

Mac Nally R, Brown GW (2001) Reptiles and habitat fragmentation in the box-ironbark forests of central Victoria, Australia: predictions, compositional change and faunal nestedness. *Oecologia* **128**, 116-125.

Mac Nally R, Horrocks G (2002) Habitat change and restoration: responses of a floodplain forest-floor mammal species to manipulations of fallen timber in forests. *Animal Biodiversity Conservation* **1**, 42-51.

Mac Nally R, Horrocks G (2002) Relative influences of patch, landscape and historical factors on birds in an Australian fragmented landscape. *Journal of Biogeography* **29**, 395-410.

Mac Nally R, Horrocks G (2008) Longer-term responses of a floodplain-dwelling marsupial to experimental manipulation of fallen timber loads. *Basic and Applied Ecology* **9**, 458-465.

Mac Nally R, Horrocks G, Bennett AF (2002) Nestedness in fragmented landscapes: birds of the box-ironbark forests of south-eastern Australia. *Ecography* **25**, 651-660.

Mac Nally R, Horrocks G, Pettifer L (2002) Experimental evidence for potential beneficial effects of fallen timber in forests *Ecological Applications* **12**, 1588-1594.

Mac Nally R, Horrocks GF (2007) Inducing whole-assemblage change by experimental manipulation of habitat structure. *Journal of Animal Ecology* **76**, 643–650.

Mac Nally R, Parkinson A, Horrocks G, Conole L, Tzaros C (2001) Relationships between terrestrial vertebrate diversity, abundance and availability of coarse woody debris on south-eastern Australian floodplains. *Biological Conservation* **99**, 191-205.

Mac Nally R, Parkinson A, Horrocks G, Conole L, Young M, Tzaros C, Koehn J, Lieschke J, Nicol S (2000) 'Ecological significance of coarse woody debris on south-eastern Australian floodplains. Report No. R7007.' Murray-Darling Basin Commission.

Mac Nally R, Parkinson A, Horrocks G, Young M (2002) Current loads of coarse woody debris on southeastern Australian floodplains: evaluation of change and implications for restoration. *Restoration Ecology* **10**, 627-635.

Mac Nally R, Soderquist TR, Tzaros C (2000) The conservation value of mesic gullies in dry forest landscapes: avian assemblages in the box-ironbark ecosystem of southern Australia. *Biological Conservation* **93**, 293-302.

MacHunter J, Menkhorst P (2008) 'Workshop proceedings integrating fauna in fire planning.' Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria.

Mackensen J, Bauhus J (1999) 'The decay of coarse woody debris. National Carbon Accounting System Technical Report No. 6.' (Australian Greenhouse Office: Canberra, ACT). http://www.climatechange.gov.au/ncas/reports/tech06.html.

Mackensen J, Bauhus J, Webber E (2003) Decomposition rates of coarse woody debris: a review with particular emphasis on Australian tree species. *Australian Journal of Botany* **51**, 27-37.

Mackowski CM (1984) The ontogeny of hollows in blackbutt (*Eucalyptus pilularis*) and its relevance to the management of forests for possums, gliders and timber. In 'Possums and Gliders.' (Eds AP Smith and ID Hume.) pp. 553-567. (Australian Mammal Society: Sydney)

Magcale-Macandog DB, Whalley RDB (1994) Factors affecting the distribution and abundance of *Microlaena stipoides* (Labill.) R. BR. on the Northern Tablelands of New South Wales. *Rangeland Journal* **16**.

Manning AD, Lindenmayer DB, Cunningham RB (2007) A study of coarse woody debris volumes in two box-gum grassy woodland reserves in the Australian Capital Territory. *Ecological Management and Restoration* **8**, 221 - 224.

Maser C, Anderson RG, Cromack KJ, Williams JT, Martin RE (1979) Dead and down woody material. In 'Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. USDA Agricultural handbook 553'. (Ed. JW Thomas) pp. 78-95. (USDA Forest Service: Washington D.C., USA)

Maser C, Cline SP, Cromack KJ, Trappe JM, Hansen E (1988) 'What we know about large trees that fall to the forest floor. From Forest to the sea: a story of fallen trees.' U.S. Department of Agriculture, Forest Service, PNW-GTR-229, Oregon.

Mather PB (1989) A comparison of the normal habitats of skinks of three electrophoretically distinguishable forms of *Lampropholis delicata* (Lacertilia: Scincidae) in South-eastern Queensland. *Australian Wildlife Research* **16**, 159-165.

McArthur AG (1968) The fire resistance of eucalypts. *Proceedings of the Ecological Society of Australia* **3**, 83-90.

McCarthy GJ, Tolhurst KG, Wouters M (2003) 'Prediction of fire fighting resources for suppression operations in Victoria's parks and forests: Research Report No. 56.' Forest Science Centre, Orbost, Creswick and Mildura.

McCaw WL, Neal JE, Smith RH (2002) Stand characteristics and fuel accumulation in a sequence of even-aged Karri (*Eucalyptus diversicolor*) stands in south-west Western Australia. *Forest Ecology and Management* **158**, 263-271.

McCaw L, Hagen R, Gould J (2001) Managing fire in regrowth eucalypt forests. Chap. 13, **In** Connell MJ, Raison RJ, Brown AG (eds) (2001) Intensive management of regrowth forest for wood production in Australia. Proc. National Workshop, Orbost, May 1999.

McCay TS, Hanula JL, Loeb SC, Lohr SM, McMinn JW, Wright-Miley BD (2002) The role of coarse woody debris in southeastern pine forests: preliminary results from a large-scale experiment. In 'Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, November 2-4, 1999 Reno, Nevada'. (Eds WF Laudenslayer Jr., PJ Shea, BE Valentine, CP Weatherspoon and TE Lisle) pp. 135-144. (USDA Forest Service)

McCay TS, Komoroski MJ (2004) Demographic responses of shrews to removal of coarse woody debris in a managed pine forest. *Forest Ecology and Management* **189**, 387-395.

McComb W, Lindenmayer D (1999) Dying, dead and down trees. In 'Maintaining biodiversity in forest ecosystems'. (Ed. MJ Hunter) pp. 335-372. (Cambridge University Press: Cambridge, UK)

McConnell BR, Smith JG (1970) Response of understory vegetation to ponderosa pine thinning in eastern Washington. *Journal of Range Management* **23**, 208-12.

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

McIver JD, Starr L (2001) A literature review on the environmental effects of postfire logging. *Western Journal of Applied Forestry* **16**, 159-168.

McKenny HJA, Kirkpatrick JB (1999) The role of fallen logs in the regeneration of tree species in Tasmanian mixed forest. *Australian Journal of Botany* **47**, 745-753.

McKenzie N, Ryan P, Fogarty P, Wood P (2000) 'Sampling, measurement and analytical protocols for carbon estimation in soil, litter and coarse woody debris.' Australian Greenhouse Office, Canberra.

Meggs JM (1996) 'Pilot study of the effects of modern logging practices on the decaying-log habitat in wet Eucalypt forest in south-east Tasmania: report to the Tasmanian RFA.' Forestry Tasmania, Hobart.

Meggs JM, Munks SA (2003) Distribution, habitat characteristics and conservation requirements of a forest-dependent threatened invertebrate *Journal of Insect Conservation* **7**, 137-152.

Meggs JM, Taylor RJ (1999) Distribution and conservation status of the of the Mt Mangana stag beetle, *Lissotes menalcas* (Coleoptera: Lucanidae). *Proceedings of the Royal Society of Tasmania* **133**, 23-28.

Melville J, Swain R (1997) Spatial separation in two sympatric skinks, *Niveoscincus microlepidotus* and *N. metallicus*, from Tasmania. *Herpetologica* **53**, 126-132.

Menkhorst PW (1984) The use of nestboxes by forest vertebrates in Gippsland: acceptance, preference and demand. *Australian Wildlife Research* **11**, 255-264.

Menkhorst PW (1995) 'Mammals of Victoria: Distribution, Ecology and Conservation.' (Oxford University Press: Oxford)

Mesibov R (1988) 'Log invertebrate project.' Forestry Tasmania, Hobart, Tasmania, Australia.

Messier C, Parent S, Bergeron Y (1998) Effects of overstory and understory vegetation on the understory light environment in mixed boreal forests. *Journal of Vegetation Science* **9**, 511-20.

Michael D (2001) Vertebrate fauna in a semi-arid grassland at Terrick Terrick National Park, Victoria: distributions, habitat preferences and use of experimental refuges. B.Sc. (Hons) thesis, Charles Sturt University. Albury.

Michael DR, Lunt ID, Robinson WA (2003) Terrestrial vertebrate fauna of grasslands and grassy woodlands in Terrick Terrick National Park, northern Victoria. *The Victorian Naturalist* **120**, 164-171.

Michael DR, Lunt ID, Robinson WA (2004) Enhancing fauna habitat in grazed native grasslands and woodlands: use of artificially placed log refuges by fauna. *Wildlife Research* **31**, 65-71.

Michaels K, Bornemissza G (1999) Effects of clearfell harvesting on lucanid beetles (Coleoptera: Lucanidae) in wet and dry sclerophyll forests in Tasmania. *Journal of Insect Conservation* **3**, 85-95.

Milton SJ (1991) Estimated woody litterfall in broadleaved, evergreen forest, Southern Cape, South Africa. *Suid-Afrikaanse Bosboutydskrif* **58**, 29-32.

Mitchell TL (1839) 'Three expeditions into the interior of eastern Australia. Facsimile edition, Libraries Board of South Australia, Adelaide, 1965.' (T. and W. Boone: London)

Motha JA, Wallbrink PJ, Hairsine PB, Grayson RB (2003) Determining the sources of suspended sediment in a forested catchment in southeastern Australia. *Water Resources Research* **39**, 1056.

Muir AM, Edwards SA, Dickens MJ (1995) 'Description and conservation status of the vegetation of the box-ironbark ecosystem in Victoria.' Department of Conservation and Natural Resources, 136, East Melbourne, Victoria.

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

Murphy S, Forrester DI (2009 in prep.) 'Growth of retained trees and coppice in a *Eucalyptus tricarpa* thinning trial.' Department of Sustainability and Environment, Melbourne, Victoria.

Neagle N (1994) 'The environmental impact and ecological sustainability of woodcutting in South Australia.'

Nelson JL, Morris BJ (1994) Nesting requirements of the Yellow-tailed Black-cockatoo, *Calyptorhynchus funereus*, in *Eucalyptus regnans* forest, and implications for forest management. *Wildlife Research* **21**, 267-278.

Neumann FG (1991) Responses of litter arthropods to major natural or artificial ecological disturbances in mountain ash forest. *Australian Journal of Ecology* **16**, 19-32.

New South Wales Department of Environment and Climate Change (2003) 'Threatened Species Information. Removal of Dead Wood as a key threatening process - an overview ' (DECC: Hurstville, NSW). http://www.environment.nsw.gov.au/resources/nature/factsheetKtpDeadwoodRemoval.pdf.

New South Wales Department of Environment and Climate Change (2009) 'Removal of dead wood and dead trees - key threatening process listing. NSW Scientific Committee - final determination.' (NSW DECC: Sydney). http://www.environment.nsw.gov.au/determinations/DeadwoodRemovalKtp.htm.

Newman LA (1961) 'The Box-Ironbark Forests of Victoria, Australia.' Forests Commission of Victoria.

Nilsson SG, Baranowski R (1997) Habitat predictability and the occurrence of wood beetles in old-growth forests. *Ecography* **20**, 491-498.

Nitterus K, Gunnarsson B (2006) Effect of microhabitat complexity on the local distribution of arthropods in clear-cuts. *Environmental Entomology* **35**, 1324-1333.

Noble IR, Slatyer RO (1981) Concepts and models of succession in vascular plant communities subject to recurrent fires. In 'Fire and the Australian Biota'. (Eds AM Gill, RH Groves and IR Noble) pp. 311-335. (Australian Academy of Science: Canberra)

Norden B, Gotmark F, Ryberg M, Paltto H, Allmer J (2008) Partial cutting reduces species richness of fungi on woody debris in oak-rich forests. *Canadian Journal of Forest Research* **38**, 1807-1816.

North East Catchment Management Authority (2004) 'North east Victorian firewood strategy.' NECMA, Wodonga, Victoria.

Nunez M, Bowman DMJS (1986) Nocturnal cooling in a high altitude stand of *Eucalyptus delegatensis* as related to stand density. *Australian Forest Research* **16**, 185-97.

O'Connell AM and Grove TS (1996) Biomass production, nutrient uptake and nutrient cycling in the jarrah (Eucalyptus marginate) and Karri (Eucalyptus diversicolor) forests of south-western Australia. In 'Nutrition of Eucalypts'. (Eds PM Attiwill and MA Adams). (CSIRO Publishing: Melbourne)

O'Connell AM (1997) Decomposition of slash residues in thinned regrowth eucalypt forest in Western Australia. *Applied Ecology* **34**, 322-321.

O'Connell AM, Grove TS, Mendham DS, Rance SJ (2004) Impact of harvest residue management on soil nitrogen dynamics in *Eucalyptus globulus* plantations in south western Australia. *Soil Biology and Biochemistry* **36**, 39-48.

Odor P, Heilmann-Clausem J*, et al.* (2006) Diversity of dead wood inhabiting fungi and bryophytes in semi-natural beech forests in Europe. *Biological Conservation* **131**, 58-71.

Old KM, Dudzinski MJ, Gibbs RJ, Kubono T (1991) 'Stem Degrade Following Harvesting Damage: Interim report on Collaborative Silvicultural Systems Research in East Gippsland between CSIRO and the Victorian Department of Conservation and Environment.' CSIRO Division of Forestry, Canberra, Australia.

Orscheg CK (2006) An investigation of selected ecological processes in ironbark communities of the Victorian box-ironbark system. Ph.D. thesis, The University of Melbourne. Melbourne, Victoria.

Owens AK, Moseley KR, McCay TS, Castleberry SB, Kilgo JC, Ford WM (2008) Amphibian and reptile community response to coarse woody debris manipulations in upland loblolly pine (*Pinus taeda*) forests. *Forest Ecology and Management* **256**, 2078-2083.

Paine TD, Millar JG, Paine EO, Hanks LM (2001) Influence of host log age and refuge from natural enemies on colonization and survival of *Phoracantha semipunctata*. *Entomologia Experimentalis et Applicata* **98**, 157-163.

Parkes D, Newell G, Cheal D (2003) Assessing the quality of native vegetation: the 'habitat hectare' approach. *Ecological Management and Restoration* **4 (Supplement)**, S29-S38.

Parks Victoria (2007) 'Box-Ironbark Ecological Thinning Trial - Unpublished Draft Progress Report.' Parks Victoria, Melbourne, Victoria.

Parks Victoria (2009) 'Box-Ironbark Ecological Management Strategy & Ecological Thinning.' (Parks Victoria: Melbourne). http://www.parkweb.vic.gov.au/.

Paul K, Booth T, Elliot A, Jovanovic T, Polglase P, Kirschbaum M (2003) 'Life cycle assessment of greenhouse gas emissions from domestic woodheating.' Department of the Environment and Heritage, Canberra, ACT.

Peacock RJ (2008) 'Vegetation Biodiversity Response of Eucalyptus Regrowth Forest to Thinning and Grazing.' Rural Industries Research and Development Corporation, Barton, ACT.

Pengilley RK (1971) The food of some Australian anurans (Amphibia). *Journal of Zoology London* **163**, 93-103.

Penman TD, Binns DL, Kavanagh RP (2008) Quantifying successional changes in response to forest disturbances. *Applied Vegetation Science* **11**, 261-268.

Penman TD, Binns DL, Shiels RJ, Allen RM, Kavanagh RP (2008) Changes in understorey plant species richness following logging and prescribed burning in shrubby dry sclerophyll forests of south-eastern Australia. *Austral Ecology* **33**, 197-210.

Penttila R, Lindgren M, Miettinene O, Rita H, Hanski I (2006) Consequences of forest fragmentation for polyporous fungi at two spatial scales. *Oikos* **114**, 225-240.

Perez-Batallon P, Ouro G, Macias F, Merino A (2001) Initial mineralization of organic matter in a forest plantation soil following different logging residue management techniques. *Annals of Forest Science* **58**, 807-818.

Pigott JP, Brown GW, Gibson MS, Palmer GC, Tolsma AD, Wright JR, Yen A (2008) 'Box-Ironbark Ecological Thinning Trial Field Guide: Documentation of Methods and Monitoring Framework. Revised pre-publication edition.' Parks and Marine Division, Parks Victoria, Melbourne.

Pook EW, Gill AM, Moore PHR (1997) Long-term variation of litter fall, canopy leaf area and flowering in a *Eucalyptus marginata* forest on the south coast of New South Wales. *Australian Journal of Botany* **45**, 737-755.

Porter R (1993) A record of communal egg-laying in the skink *Carlia tetradactyla*. *Memorial Queensland Museum* **33**, 60.

Quinn BR, Baker-Gabb DJ (1993) 'Conservation and management of the Turquoise Parrot *Neophema pulchella* in north-east Victoria.' ARI, 125, Heidelberg, Victoria.

Rab MA (2004) Recovery of soil physical properties from compaction and soil profile disturbance caused by logging of native forests in Victorian Central Highlands, Australia. *Forest Ecology and Management* **191**, 329-340.

Rab A, Bradshaw J, Campbell R, Murphy S, (2005). Review of factors affecting disturbance, compaction and trafficability of soils with particular reference to timber harvesting in the forests of south-west Western Australia. SFM Tech. Report No. 2, Department of Conservation and Land Management.

Radder RS, Shine R (2007) Why do female lizards lay their eggs in communal nests? *Journal of Animal Ecology* **76**, 881-887.

Raison RJ, Kirschbaum MUF, McCormack RJ, Attiwill PM, Richardson AMM, (2002) Review of the science relevant to the sustainable use of forest harvesting residues for energy production in Tasmania. CSIRO Report for Forestry Tasmania, National Power, John Holland Development and Investments.

Ranius T (2002) Influence of stand age and quality of tree hollows on saproxylic beetles in Sweden. *Biological Conservation* **103**, 85-91.

Ranius T, Kindvall O (2004) Modelling the amount of coarse woody debris produced by the new biodiversity-oriented silvicultural practices in Sweden. *Biological Conservation* **119**, 51-59.

Rawlinson PA (1981) Conservation of Australian amphibian and reptile communities. In 'Proceedings of the Melbourne Herpetological Symposium. 19th-21st May 1980'. Royal Zoological gardens Australia. (Eds CB Banks and AA Martin) pp. 127-138. (Zoological Board of Victoria)

Recher H (1991) The conservation and management of eucalypt forest birds: resource requirements for nesting and foraging. In 'Conservation of Australia's forest fauna'. (Ed. D Lunney) pp. 25-34. (The Royal Zoological Society of New South Wales: Mosman)

Recher HF (2004) Eucalypt forest birds: the role of nesting and foraging sources in conservation and management. In 'Conservation of Australia's forest fauna, 2nd edition'. (Ed. D Lunney) pp. 23-35. (Royal Zoological Society of New South Wales: Sydney, NSW)

Reid LM, Dunne T (1984) Sediment production from forest road surfaces. *Water Resources Research* **20**, 1753-1761.

Rhind SG (2004) Direct impacts of logging and forest management on the brush-tailed phascogale *Phascogale tapoatafa* and other arboreal marsupials in a jarrah forest of Western Australia. In 'Conservation of Australia's Forest Fauna (second edition)'. (Ed. D Lunney) pp. 639-655. (Royal Zoological Society of Australia: Mossman, New South Wales)

Robinson RT (1997) Dynamics of coarse woody debris in floodplain forests: impact of forest management and flood frequency. B.Sc. (Hons) thesis, Charles Sturt University. Wagga Wagga, NSW.

Rokich DP, Bell DT (1995) Light quality and intensity effects on the germination of species from the jarrah (*Eucalyptus marginata*) forest of Western Australia. *Australian Journal of Botany* **43**, 169-79.

Rosenberg O, Jacobson S (2004) Effects of repeated slash removal in thinned stands on soil chemistry and understorey vegetation. *Silva Fennica* **38**, 133-142.

Rotheram I (1983) Suppression of growth of surrounding regeneration by veteran trees of karri (*Eucalyptus diversicolor*). *Australian Forestry* **46**, 8-13.

Roxburgh SH, Wood SW, Mackey BG, Woldendorp G, Gibbons P (2006) Assessing the carbon sequestration potential of managed forests: a case study from temperate Australia. *Journal of Applied Ecology* **43**, 1149-1159.

Salvidio S (2009) Detecting amphibian population cycles: The importance of appropriate statistical analyses. *Biological Conservation* **142**, 455-461.

Scanlan JC, Burrows WH (1990) Woody overstorey impact on herbaceous understorey in *Eucalyptus* spp. communities in central Queensland. *Australian Journal of Ecology* **15**, 191-7.

Schiegg K (2000) Effects of dead wood volume and connectivity on saproxylic insect species diversity. *Ecoscience* **7**, 290-298.

Schmuki C, Vorburger C, Runciman D, Maceachern S, Sunnucks P (2006) When log-dwellers meet loggers: impacts of forest fragmentation on two endemic log-dwelling beetles in southeastern Australia. *Molecular Ecology* **15**, 1481-1492.

Scott AW, Whalley RDB (1982) The distribution and abundance of species of *Danthonia* DC on the New England Tablelands (Australia). *Australian Journal of Ecology* **7**, 239-48.

Scott GAM, Entwisle TJ, May TW, Stevens GN (1997) 'A conservation overview of Australian non-marine lichens, bryophytes, algae and fungi.' Environment Australia, Canberra.

Scotts DJ (1991) Old-growth forests: their ecological characteristics and value to forest-dependent vertebrate fauna of south-east Australia. In 'Conservation of Australia's forest fauna'. (Ed. D Lunney) pp. 147-159. (The Royal Zoological Society of NSW: Sydney)

Scotts DJ, Seebeck JH (1989) 'Ecology of *Potorous longipes* (Marsupialia: Potoroidae); and preliminary recommendations for management of its habitat in Victoria.' Arthur Rylah Institute for Environmental Research, 62, Heidelberg, Victoria.

Sebire I, Fagg PC (1997) 'Thinning of Mixed Species Regrowth.' Forests Service, Department Natural Resources and Environment, Melbourne, Victoria.

Shahabuddin G, Kumar R (2007) Effects of extractive disturbance on bird assemblages, vegetation structure and floristics in tropical scrub forest, Sariska Tiger Reserve, India. *Forest Ecology and Management* **246**, 175-185.

Sheridan GJ, Noske P, Whipp RK, Wijesinghhe N (2005) The effect of truck traffic and road water content on sediment delivery from unpaved forest roads. *Hydrologic Processes* **20**, 1683-1699.

Sheridan GJ, Noske PJ (2006) A quantitative study of sediment delivery and stream pollution from different forest road types. *Hydrological Processes* **21**, 387-398.

Sheridan GJ, Noske PJ (2007) Catchment scale contribution of forest roads to stream exports of sediment, phosphorus, and nitrogen. *Hydrological Processes* **21**, 3107-3122.

Simberloff D (1998) Flagships, umbrellas, and keystones: Is single-species management passé in the landscape era? *Biological Conservation* **83**, 247-257.

Small CJ, McCarthy BC (2002) Effects of simulated post-harvest light availability and soil compaction on deciduous forest herbs. *Canadian Journal of Forest Research* **32**, 1753-1762.

Smith AP, Wellham GS, Green SW (1989) Seasonal foraging activity and microhabitat selection by echidnas (*Tachyglossus aculeatus*) on the New England tablelands. *Australian Journal of Ecology* **14**, 457-66.

Soderquist TR (1999) 'Tree hollows in the box-ironbark forest. Analyses of ecological data from the box-ironbark timber assessment in the Bendigo Forest Management Area and the

Pyrenees Ranges.' Department of Natural Resources and Environment, East Melbourne, Victoria.

Soderquist TR, Mac Nally R (2000) The conservation value of mesic gullies in dry forest landscapes: mammal populations in the box-ironbark ecosystem of southern Australia. *Biological Conservation* **93**, 281-291.

Sollins P, Cline SP, Verhoeven T, Sachs D, Spycher G (1987) Patterns of log decay in old-growth Douglas fir forests. *Canadian Journal Forestry Research* **17**, 1585-1595.

Spargo S, Katos G, Quint T (2002) 'Box-Ironbark firewood usage and collection study.' Victorian Department of Natural Resources and Environment, East Melbourne, Victoria.

Specht RL (1972) Water use by perennial evergreen plant communities in Australia and Papua New Guinea. *Australian Journal of Botany* **20**, 273-99.

Specht RL, Morgan DG (1981) The balance between the foliage projective covers of overstorey and understorey strata in Australian vegetation. *Australian Journal of Ecology* **6**, 193-202.

Statham HL, Harden RH (1982) Habitat utilisation of *Antechinus stuartii* (Marsupialia) at Petroi, northern New South Wales. In 'Carnivorous Marsupials'. (Ed. M Archer) pp. 165-185. (Surrey Beatty & Sons: Chipping Norton)

Stevens V (1997) 'The ecological role of coarse woody debris: an overview of the ecological importance of CWD in BC forests.' Research Branch, British Columbia Ministry of Forests, Victoria, British Columbia.

Stewart GH (1988) The influence of canopy cover on understorey development in forests of the western Cascade Range, Oregon, USA. *Vegetatio* **76**, 79-88.

Stewart HTL, Flinn DW (1985) Nutrient losses from broadcast burning of Eucalyptus debris in North-east Victoria. *Australian Forest Research* **15**, 321-332.

Stewart HTL, Woodman M (1982) 'Estimating the weight of woody eucalypt debris following clearing for pine establishment.' Forests Commission Victoria.

Stoneman GL, Dell B, Turner NC (1994) Mortality of *Eucalyptus marginata* (jarrah) seedlings in Mediterranean-climate forest in response to overstorey, site, seedbed, fertilizer application and grazing. *Australian Journal of Ecology* **19**, 103-9.

Stubbings A (2003) Effects of fire season and frequency on the availability of logs on the forest floor as habitat, in Wombat State Forest, Victoria. B.Sc. For. (Hons) thesis, University of Melbourne. Creswick.

Sullivan TP, Sullivan DS, Lindgren PMF, Ransome DB (2007) Long-term responses of ecosystem components to stand thinning in young lodgepole pine forest: IV. Relative habitat use by mammalian herbivores. *Forest Ecology and Management* **240**, 32-41.

Sumner J, Moritz C, Shine R (1999) Shrinking forest shrinks skink: morphological change in response to rainforest fragmentation in the prickly forest skink (*Gnypetoscincus queenslandiae*). *Biological Conservation* **91**, 159-167.

Sylva Systems Pty Ltd (2007) 'Firewood resource analysis: demand and supply (2007). Report to the Department of Sustainability and Environment.' Sylva Systems Pty Ltd, Warragul, Victoria.

Sylva Systems Pty Ltd. (2002) 'Victorian firewood strategy: discussion paper.' Sylva Systems Pty Ltd, Warragul, Victoria.

Tabor J, McElhinny C, Hickey J, Wood J (2007) Colonisation of clearfelled coupes by rainforest tree species from mature mixed forest edges, Tasmania, Australia. *Forest Ecology and Management* **240**, 13-23.

Tarrega R, Calvo L, Marcos E, Taboada A (2006) Forest structure and understory diversity in *Quercus pyrenaica* communities with different human uses and disturbances. *Forest Ecology and Management* **227**, 50-58.

Tasker EM, Bradstock RA (2006) Influence of cattle grazing practices on forest understorey structure in north-eastern New South Wales. *Austral Ecology* **31**, 490-502.

Tasmanian Conservation Trust (2002) Adelaide Firewood Conference 2002: No Smoke Without Fire.

Tasmanian Conservation Trust (2002) Armidale Firewood Conference 2001: Burning Issues. Armidale

Tasmanian Conservation Trust (2002) Bendigo Firewood Conference 2001:Burning Issues. Bendigo

Tasmanian Conservation Trust (2002) Launceston Firewood Conference 2001. Firewood: A Biodiversity, Consumer and Human Health Issue. Launceston

Taylor RJ (1990) Occurrence of log-dwelling invertebrates in regeneration and old-growth wet sclerophyll forest in southern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **124**, 27-34.

Thomas SC, Halpern CB, Falk DA, Liguori DA, Austin KA (1999) Plant diversity in managed forests: understorey responses to thinning and fertilization. *Ecological Applications* **9**, 864-79.

Todd JJ, Horwitz PHJ (1990) Spreading insects through firewood collection in Tasmania. *Australian Forestry* **53**, 154-159.

Tolhurst K, Catchpole W, Gould J (2004) Coarse Fuel Consumption Experiment - Tumbarumba. In.

Tolhurst KG (1996) Effects of fuel reduction burning on fuel loads in a dry sclerophyll forest. In 'Biodiversity and Fire: The effects and effectiveness of fire management. Proceedings of the conference held 8-9 October 1994, Footscray, Melbourne' pp. 17-20. (Department of the Environment, Sport and Territories, Canberra)

Tolhurst KG, Anderson WR, Gould J (2006) Woody fuel consumption experiments in an undisturbed forest. In 'Proceedings of the 5th International conference on Forest Fire Research'. (Ed. DX Viegas) pp. 1-14. (Elsevier: Amsterdam, Netherlands)

Tolhurst KG, Flinn DW, Loyn RH, Wilson AG, Foletta I (1992) 'Ecological effects of fuel reduction burning in dry sclerophyll forest: a summary of principal research findings and their management implications.' Forest Research Centre, Department of Conservation and Environment, Melbourne.

Tolhurst, K.G. and Cheney, N.P. (1999). Synopsis of the knowledge used in prescribed burning in Victoria. Department of Natural Resources and Environment, Fire Management. 97 pp.

Tongway DJ, Ludwig JA (1989) Mulga log mounds: Fertile patches in the semi-arid woodlands of eastern Australia. *Australian Journal of Ecology* **14**, 263-268.

Tongway DJ, Ludwig JA (1996) Rehabilitation of semi-arid landscapes in Australia. 1. Restoring reproductive patches. *Restoration Ecology* **4**, 388-397.

TQA Research (2002) 'Box-Ironbark firewood usage and collection study. Report to the Victorian Department of Natural Resources and Environment.' TQA Research, Sandringham, Victoria.

Traill BJ (1991) Box-Ironbark forests: tree hollows, wildlife and management. In 'Conservation of Australia's forest fauna.' (Ed. D Lunney) pp. 119-23. (Royal Zoological Society of New South Wales: Mosman)

Tulloch AI, Dickman CR (2006) Floristic and structural components of habitat use by the eastern pygmy-possum (*Cercartetus nanus*) in burnt and unburnt habitats. *Wildlife Research* **33**, 627-637.

Turner PA, Pharo EJ (2005) Influence of substrate type and forest age on bryophyte species distribution in Tasmanian mixed forest. *The Bryologist* **108**, 67-85.

Turton SM, Duff GA (1992) Light environments and floristic composition across an open forest-rainforest boundary in northeastern Queensland. *Australian Journal of Ecology* **17**, 412-23.

Tzaros C (2005) 'Wildlife of the Box-Ironbark Country.' (CSIRO Publishing: Collingwood, Australia)

Ucitel D, Christian DP, Graham JM (2003) Vole use of coarse woody debris and implications for habitat and fuel management. *Journal of Wildlife Management* **67**, 65-72.

van der Ree R (2002) The population ecology of the squirrel glider (*Petaurus norfolcensis*) within a network of remnant linear habitats. *Wildlife Research* **29**, 329-340.

van der Ree R, Bennett AF, Soderquist TR (2006) Nest-tree selection by the threatened brush-tailed phascogale (*Phascogale tapoatafa*) (Marsupialia: Dasyuridae) in a highly fragmented agricultural landscape. *Wildlife Research* **33**, 113-119.

Van Dyck S, Strahan R (2008) (Ed.)^(Eds) 'The Mammals of Australia. Third edition.' (Reed New Holland: Sydney)

Varady-Szabo H, Buddle CM (2006) On the relationships between ground-dwelling spider (Araneae) assemblages and dead wood in a northern sugar maple forest. *Biodiversity and Conservation* **15**, 4119 - 4141.

Vearing L (2000) The formation of tree hollows in the box and ironbark forests of central Victoria. Unpublished discussion paper. In. (Department of Natural Resources and Environment: Bendigo, Victoria)

Venosta M (2001) Forest structure and ecological management in Victoria's box-ironbark forests. B.Sc. (Hons) thesis, Deakin University. Burwood, Victoria.

Vesk PA, Mac Nally R (2006) The clock is ticking—Revegetation and habitat for birds and arboreal mammals in rural landscapes of southern Australia. *Agriculture, Ecosystems and Environment* **112**, 356-366.

Victorian Environmental Assessment Council (2001) 'Final Report. Box-Ironbark Forests and Woodlands Investigation.' VEAC, Melbourne, Victoria.

Vincent M, Wilson S (1999) 'Australian Goannas.' (New Holland Publishers: Sydney)

Walker J, Moore RM, Robertson JA (1972) Herbage response to tree and shrub thinning in *Eucalyptus populnea* shrub woodlands. *Australian Journal of Agricultural Research* **23**, 405-10.

Walker J, Robertson JA, Penridge LK (1986) Herbage response to tree thinning in a *Eucalyptus crebra* woodland. *Australian Journal of Ecology* **11**, 134-40.

Wardell-Johnson GW, Williams MR, Mellican AE, Annells A (2007) Floristic patterns and disturbance history in karri (Eucalyptus diversicolor: Myrtaceae) forest, south-western Australia: 2. Origin, growth form and fire response. *Acta Oecologica* **31**, 137-150.

Wardlaw TJ (1996) The origin and extent of discolouration and decay in stems of young regrowth eucalypts in southern Tasmania. *Canadian Journal of Forest Research* **26**, 1-8.

Wardlaw TJ, Neilsen WA (1999) Decay and other defects associated with pruned branches of *Eucalyptus nitens*. *Tasforest* **11**, 49-58.

Watt A (1991) The ecology of three species of *Antechinus* (Marsupialia: Dasyuridae) in upland rainforests of north-east Queensland. Ph.D. thesis, James Cook University of North Queensland. Townsville.

Webb AA, Erskine WD (2003) Distribution, recruitment, and geomorphic significance of large woody debris in an alluvial forest stream: Tonghi Creek, southeastern Australia. *Geomorphology* **51**, 109-126.

Webb GA (1985) Habitat use and activity patterns in some southeastern Australian skinks. In 'Biology of Australasian frogs and reptiles'. (Eds G Grigg, R Shine and H Ehmann) pp. 23-30. (Surrey Beatty & Sons Pty Ltd: Chipping Norton, NSW)

Wei X, Kimmins JP, Peel K, Steen O (1997) Mass and nutrients in woody debris in harvested and wildfire-killed lodgepole pine forests in the central interior of British Columbia. *Canadian Journal of Forest Research* **27**, 148-155.

Wells R (1981) Utilisation of the same site for communal egg-laying by *Lampropholis delicata* and *L. guichenoti*. *Australian Journal of Herpetology* **1**, 35-36.

West PW, Cawsey EM, Stol J, Freudenberger D (2008) Firewood harvest from forests of the Murray-Darling Basin, Australia. Part 1: Long-term, sustainable supply available from native forests. *Biomass and Bioenergy* **32**, 1206-1219.

West PW, Cawsey EM, Stol J, Freudenberger D (2008) Firewood harvest from forests of the Murray-Darling Basin, Australia. Part 2: Plantation resource required to supply present demand. *Biomass and Bioenergy* **32**, 1220-1226.

White DA, Kile GA (1991) Thinning damage and defect in regrowth eucalypts. In 'The Young Eucalypt Report some management options for Australia's regrowth forest'. (Eds CM Kerruish and WHM Rawlins). (CSIRO Publishing: Melbourne)

Whitford KR, Williams MR (2001) Survival of jarrah (*Eucalyptus marginata* Sm.) and marri (*Corymbia calophylla* Lindl.) habitat trees retained after logging. *Forest Ecology and Management* **146**, 181-197.

Wikars L (2002) Dependence of fire in wood-living insects: an experiment with burned and unburned spruce and birch logs. *Journal of Insect Conservation* **6**, 1-12.

Wilkinson DA, Grigg GC, Beard LA (1998) Shelter selection and home range of echidnas, *Tachyglossus aculeatus*, in the highlands of south-east Queensland. *Wildlife Research* **25**, 219-232.

Williams MR, Faunt K (1997) Factors affecting the abundance of hollows in logs in jarrah forest of south-western Australia. *Forest Ecology and Management* **95**, 153-160.

Wilson J (2002) Flowering ecology of a box-ironbark eucalyptus community. Ph.D. thesis, Deakin University. Burwood, Melbourne.

Wilson J, Bennett AF (1999) Patchiness of a floral resource: flowering of Red ironbark *Eucalyptus tricarpa* in a Box and Ironbark forest. *The Victorian Naturalist* **116**, 48-53.

Wilson S, Swan G (2008) 'A Complete Guide to Reptiles of Australia. Second edition.' (New Holland Publishers (Australia): Sydney)

Woldendorp G, Keenan RJ (2005) Coarse woody debris in Australian forest ecosystems: a review. *Austral Ecology* **30**, 834-843.

Woldendorp G, Keenan RJ, Ryan MF (2002) 'Coarse Woody Debris in Australian Forest Ecosystems. A Report for the National Greenhouse Strategy, Module 6.6 (Criteria and Indicators of Sustainable Forest Management), April 2002.' Bureau of Rural Sciences, Canberra.

Woldendorp G, Keenan RJ, Spencer RD (2004) Analysis of sampling methods for coarse woody debris. *Forest Ecology and Management* **198**, 133-148.

Woldendorp G, Spencer RD, Keenan RJ, Barry S (2002) 'An analysis of sampling methods for coarse woody debris in Australian forest ecosystems.' Bureau of Rural Sciences, Canberra.

Woodgate, P.W., Peel, W.D., Ritman, K.T., Coram, J.E., Brady, A., Rule, A.J. and Banks, J.C.G. (1994). A study of the old-growth forests of East Gippsland. Department of Conservation and Natural Resources, Victoria. 223 pp.

Woodruff DS (1976) Courtship, reproductive rates, and mating system in three Australian *Pseudophryne* (Amphibia, Anura, Leptodactylidae). *Journal of Herpetology* **10**, 313-318.

Woodruff DS (1976) Embryonic mortality in *Pseudophryne* (Anura: Leptodactylidae). *Copeia* **1976**, 445-449.

Woods PV, Raison RJ (1983) Decomposition of litter in sub-alpine forests of *Eucalyptus delegatensis*, *E. pauciflora* and *E. dives*. *Australian Journal of Ecology* **8**, 287-299.

Yee M (2005) The ecology and habitat requirements of saproxylic beetles native to Tasmanian wet eucalypt forests: potential impacts of commercial forestry practices. Ph.D. thesis, University of Tasmania. Hobart.

Yee M, Grove SJ, Richardson AM, Mohammed C (2006) Brown rot in inner heartwood: why large logs support characteristic saproxylic beetle assemblages of conservation concern. In 'Insect biodiversity and dead wood: proceedings of a symposium for the 22nd International Congress of Entomology. General Technical Report. SRS-93. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station.' (Eds SJ Grove and JL Hanula) p. 109

Yee M, Yuan Z-Q, Mohammed C (2001) Not just waste wood: decaying logs as key habitats in Tasmania's wet sclerophyll *Eucalyptus obliqua* production forests: the ecology of large and small logs compared. *Tasforests* **13**, 119-128.

Yen AL (2003) 'Invertebrates of coarse woody debris in River Red Gum forests in southern New South Wales: a scoping study. Unpublished report to the New South Wales Red Gum Industry Strategy.' Firewood and Log Residue Working Group Inc.

Yoshimura M (2008) Impact of secondary forest management on ant assemblage composition in the temperate region in Japan. In 'Journal of Insect Conservation'. pp. 1-6. (Springer Netherlands)

Appendix 1

Vertebrate taxa for each of the select Victorian bioregions, compiled from the Atlas of Victorian Wildlife (DSE database), January 2009.

Victorian (Vict Cons and FFG code) and national (EPBC) threatened status* are shown, along with use of CWD and hollow-bearing trees (B = basking, F = foraging, N = nesting, S = shelter). Genera are arranged alphabetically within Family and Families are arranged taxonomically within Order. Only extant non-vagrant Victorian native taxa are included.

			Bioregion												
			Murray Fans	Victorian Riverina	Goldfields	Central Victorian Uplands	Northern Inland Slopes	Highlands Northern Fall	Highlands Southern Fall	EPBC	Cons. Vict.	FFG	Logs/CWD	Hollow-bearing trees	Type of hollow^
MAMMALS															
Ornithorhynchidae	Platypus	*Ornithorhynchus anatinus*	√	√	√	√	√	√	√						
Tachyglossidae	Short-beaked Echidna	*Tachyglossus aculeatus*	√	√	√	√	√	√	√						
Dasyuridae	Agile Antechinus	*Antechinus agilis*		√	√	√	√	√	√				FNS	FNS	H
	Yellow-footed Antechinus	*Antechinus flavipes*	√	√	√	√	√	√					FNS	FNS	H
	Swamp Antechinus	*Antechinus minimus*							√		NT	L			
	Dusky Antechinus	*Antechinus swainsonii*				√		√	√				FNS		
	Brush-tailed Phascogale	*Phascogale tapoatafa*		√	√	√	√	√	√		VU	L	FNS	FNS	H
	Spot-tailed Quoll	*Dasyurus maculatus*		√	√	√	√	√	√	EN	EN	L	FNS	FNS	H
	Fat-tailed Dunnart	*Sminthopsis crassicaudata*	√	√	√	√	√				NT		FNS		
	White-footed Dunnart	*Sminthopsis leucopus*						√	√		NT	L	FNS		
	Common Dunnart	*Sminthopsis murina*		√	√	√		√	√		VU		FS		
Peramelidae	Southern Brown Bandicoot	*Isoodon obesulus obesulus*			√	√			√	EN	NT				
	Eastern Barred Bandicoot	*Perameles gunnii*				√				EN	CR	L			
	Long-nosed Bandicoot	*Perameles nasuta*		√		√	√	√	√						
Phascolarctidae	Koala	*Phascolarctos cinereus*	√	√	√	√	√	√	√						
Vombatidae	Common Wombat	*Vombatus ursinus*	√	√	√	√	√	√	√						
Petauridae	Leadbeater's Possum	*Gymnobelideus leadbeateri*						√	√					FNS	H
	Yellow-bellied Glider	*Petaurus australis*				√		√	√					FNS	H
	Sugar Glider	*Petaurus breviceps*	√	√	√	√	√	√	√				NS	FNS	H
	Squirrel Glider	*Petaurus norfolcensis*	√	√	√	√	√				EN	L	NS	FNS	H
Pseudocheiridae	Common Ringtail Possum	*Pseudocheirus peregrinus*	√	√	√	√	√	√	√					NS	[H]
	Greater Glider	*Petauroides volans*		√		√	√	√	√					FNS	H
Acrobatidae	Feathertail Glider	*Acrobates pygmaeus*	√	√	√	√	√	√	√				FNS	FNS	H
Phalangeridae	Mountain Brushtail Possum	*Trichosurus cunninghami*			√	√	√	√	√				NS	FNS	H
	Common Brushtail Possum	*Trichosurus vulpecula*	√	√	√	√	√	√	√				FNS	FNS	H
Potoroidae	Long-footed Potoroo	*Potorous longipes*						√	√						
Macropodidae	Western Grey Kangaroo	*Macropus fuliginosus*	√	√	√	√									
	Eastern Grey Kangaroo	*Macropus giganteus*	√	√	√	√	√	√	√						
	Eastern Wallaroo	*Macropus robustus robustus*					√	√			EN	L			
	Red-necked Wallaby	*Macropus rufogriseus*				√	√	√							
	Tammar Wallaby	*Macropus eugenii*			√										
	Brush-tailed Rock-wallaby	*Petrogale penicillata*						√							
	Black Wallaby	*Wallabia bicolor*	√	√	√	√	√	√	√	VU	CR	L			
Pteropodidae	Grey-headed Flying-fox	*Pteropus poliocephalus*		√	√	√			√	VU	VU	L			
	Little Red Flying-fox	*Pteropus scapulatus*	√	√	√		√								
Rhinolophidae	Eastern Horseshoe Bat	*Rhinolophus megaphyllus*				√		√	√		VU	L			
Emballonuridae	Yellow-bellied Sheathtail Bat	*Saccolaimus flaviventris*							√			L		S	H
Molossidae	Freetail Bat (eastern form)	*Mormopterus* sp. EG	√	√	√	√	√		√					SN	H
	Southern Freetail Bat (long penis)	*Mormopterus* sp. 1	√	√	√	√	√	√	√					SN	H

	White-striped Freetail Bat	*Tadarida australis*	√	√	√	√	√	√	√					SN	H
Vespertilionidae	Gould's Wattled Bat	*Chalinolobus gouldii*	√	√	√	√	√	√	√				NS	NS	H
	Chocolate Wattled Bat	*Chalinolobus morio*	√	√	√	√	√	√	√				NS	NS	H
	Eastern False Pipistrelle	*Falsistrellus tasmaniensis*			√	√	√	√	√				NS	NS	H
	Common Bent-wing Bat	*Miniopterus schreibersii (group)*			√	√	√	√	√			L			
	Southern Myotis	*Myotis macropus*	√	√	√		√	√	√		NT		NS	NS	H
	Lesser Long-eared Bat	*Nyctophilus geoffroyi*	√	√	√	√	√	√	√				NS	NS	H
	Gould's Long-eared Bat	*Nyctophilus gouldi*	√	√	√	√	√	√	√				NS	NS	H
	Greater Long-eared Bat	*Nyctophilus timoriensis*		√						VU	VU	L	NS	NS	H
	Inland Broad-nosed Bat	*Scotorepens balstoni*	√	√	√	√	√						NS	NS	H
	Eastern Broad-nosed Bat	*Scotorepens orion*					√	√	√				NS	NS	H
	Large Forest Bat	*Vespadelus darlingtoni*	√	√	√	√	√	√	√				NS	NS	H
	Southern Forest Bat	*Vespadelus regulus*	√	√	√	√	√	√	√				NS	NS	H
	Little Forest Bat	*Vespadelus vulturnus*	√	√	√		√	√	√				NS	NS	H
Muridae	Water Rat	*Hydromys chrysogaster*	√	√	√	√	√	√	√						
	Broad-toothed Rat	*Mastacomys fuscus*						√	√		DD				
	Smoky Mouse	*Pseudomys fumeus*						√	√	EN	CR	L			
	Bush Rat	*Rattus fuscipes*		√	√	√	√	√	√						
	Swamp Rat	*Rattus lutreolus*			√	√		√	√						
Canidae	Dingo	*Canis lupus dingo*				√		√	√		NT				
BIRDS															
Casuariidae	Emu	*Dromaius novaehollandiae*	√	√	√	√	√	√	√						
Megapodiidae	Malleefowl	*Leipoa ocellata*			√					VU	EN	L			
Phasianidae	Stubble Quail	*Coturnix pectoralis*	√	√	√	√	√	√	√						
	Brown Quail	*Coturnix ypsilophora*	√	√	√	√	√	√	√		NT				
	King Quail	*Excalfactoria chinensis*		√		√					EN	L			
Anseranatidae	Magpie Goose	*Anseranas semipalmata*	√	√	√	√					NT	L			
Anatidae	Chestnut Teal	*Anas castanea*	√	√	√	√	√	√	√					N	[H]
	Grey Teal	*Anas gracilis*	√	√	√	√	√	√	√					N	[H]
	Australasian Shoveler	*Anas rhynchotis*	√	√	√	√	√	√	√		VU				
	Pacific Black Duck	*Anas superciliosa*	√	√	√	√	√	√	√					N	[H]
	Hardhead	*Aythya australis*	√	√	√	√	√	√	√		VU				
	Musk Duck	*Biziura lobata*	√	√	√	√	√	√	√		VU				
	Cape Barren Goose	*Cereopsis novaehollandiae*		√		√					NT				
	Australian Wood Duck	*Chenonetta jubata*	√	√	√	√	√	√	√					N	H
	Black Swan	*Cygnus atratus*	√	√	√	√	√	√	√						
	Plumed Whistling-Duck	*Dendrocygna eytoni*	√	√	√	√	√		√						
	Pink-eared Duck	*Malacorhynchus membranaceus*	√	√	√	√	√	√	√					N	[H]
	Blue-billed Duck	*Oxyura australis*	√	√	√	√	√	√	√		EN	L			
	Freckled Duck	*Stictonetta naevosa*	√	√	√	√	√		√		EN	L			
	Australian Shelduck	*Tadorna tadornoides*	√	√	√	√	√	√	√				N	N	[H]
Podicipedidae	Great Crested Grebe	*Podiceps cristatus*	√	√	√	√	√	√	√						
	Hoary-headed Grebe	*Poliocephalus poliocephalus*	√	√	√	√	√	√	√						
	Australasian Grebe	*Tachybaptus novaehollandiae*	√	√	√	√	√	√	√						
Columbidae	White-headed Pigeon	*Columba leucomela*				√			√						
	Diamond Dove	*Geopelia cuneata*	√	√	√	√	√		√		NT	L			
	Bar-shouldered Dove	*Geopelia humeralis*		√											
	Peaceful Dove	*Geopelia striata*	√	√	√	√	√	√	√						
	Wonga Pigeon	*Leucosarcia melanoleuca*		√		√	√	√	√						
	Brown Cuckoo-Dove	*Macropygia amboinensis*	√						√						
	Crested Pigeon	*Ocyphaps lophotes*	√	√	√	√	√	√	√						
	Common Bronzewing	*Phaps chalcoptera*	√	√	√	√	√	√	√						

	Brush Bronzewing	*Phaps elegans*			√	√	√	√	√					
Podargidae	Tawny Frogmouth	*Podargus strigoides*	√	√	√	√	√	√	√					
Eurostopodidae	White-throated Nightjar	*Eurostopodus mystacalis*		√	√	√	√	√	√					
	Spotted Nightjar	*Eurostopodus argus*	√	√	√		√		√					
Aegothelidae	Australian Owlet-nightjar	*Aegotheles cristatus*	√	√	√	√	√	√	√			NS	NS	H
Apodidae	White-throated Needletail	*Hirundapus caudacutus*	√	√	√	√	√	√	√					
	Fork-tailed Swift	*Apus pacificus*	√	√	√	√	√	√	√					
Anhingidae	Darter	*Anhinga novaehollandiae*	√	√	√	√	√	√	√					
Phalacrocoracidae	Little Pied Cormorant	*Microcarbo melanoleucos*	√	√	√	√	√	√	√					
	Great Cormorant	*Phalacrocorax carbo*	√	√	√	√	√	√	√					
	Little Black Cormorant	*Phalacrocorax sulcirostris*	√	√	√	√	√	√	√					
	Pied Cormorant	*Phalacrocorax varius*	√	√	√	√	√	√	√	NT				
Pelecanidae	Australian Pelican	*Pelecanus conspicillatus*	√	√	√	√	√	√	√					
Ardeidae	Cattle Egret	*Ardea ibis*	√	√	√	√	√	√	√					
	Intermediate Egret	*Ardea intermedia*	√	√	√	√	√	√	√	CR	L			
	Eastern Great Egret	*Ardea modesta*	√	√	√	√	√	√	√	VU	L			
	White-necked Heron	*Ardea pacifica*	√	√	√	√	√	√	√					
	Australasian Bittern	*Botaurus poiciloptilus*	√	√	√	√	√	√	√	EN	L			
	Little Egret	*Egretta garzetta*	√	√	√	√	√		√	EN	L			
	White-faced Heron	*Egretta novaehollandiae*	√	√	√	√	√	√	√					
	Australian Little Bittern	*Ixobrychus dubius*	√	√	√	√			√	EN	L			
	Nankeen Night Heron	*Nycticorax caledonicus*	√	√	√	√	√	√	√	NT				
Threskiornithidae	Yellow-billed Spoonbill	*Platalea flavipes*	√	√	√	√	√	√	√					
	Royal Spoonbill	*Platalea regia*	√	√	√	√	√	√	√	VU				
	Glossy Ibis	*Plegadis falcinellus*	√	√	√	√	√	√	√	NT				
	Australian White Ibis	*Threskiornis molucca*	√	√	√	√	√	√	√					
	Straw-necked Ibis	*Threskiornis spinicollis*	√	√	√	√	√	√	√					
Accipitridae	Collared Sparrowhawk	*Accipiter cirrhocephalus*	√	√	√	√	√	√	√					
	Brown Goshawk	*Accipiter fasciatus*	√	√	√	√	√	√	√					
	Grey Goshawk	*Accipiter novaehollandiae*	√	√	√	√		√	√	VU	L			
	Wedge-tailed Eagle	*Aquila audax*	√	√	√	√	√	√	√					
	Swamp Harrier	*Circus approximans*	√	√	√	√	√	√	√					
	Spotted Harrier	*Circus assimilis*	√	√	√	√	√		√	NT				
	Black-shouldered Kite	*Elanus axillaris*	√	√	√	√	√	√	√					
	Letter-winged Kite	*Elanus scriptus*		√			√		√					
	White-bellied Sea-Eagle	*Haliaeetus leucogaster*	√	√	√	√	√	√	√	VU	L			
	Whistling Kite	*Haliastur sphenurus*	√	√	√	√	√	√	√					
	Black-breasted Buzzard	*Hamirostra melanosternon*	√	√	√									
	Little Eagle	*Hieraaetus morphnoides*	√	√	√	√	√	√	√					
	Square-tailed Kite	*Lophoictinia isura*	√	√	√	√	√	√	√	VU	L			
	Black Kite	*Milvus migrans*	√	√	√	√	√	√	√					
	Eastern Osprey	*Pandion cristatus*	√											
Falconidae	Brown Falcon	*Falco berigora*	√	√	√	√	√	√	√				N	L
	Nankeen Kestrel	*Falco cenchroides*	√	√	√	√	√	√	√				N	L
	Grey Falcon	*Falco hypoleucos*	√	√	√		√			EN	L			
	Australian Hobby	*Falco longipennis*	√	√	√	√	√	√	√					
	Peregrine Falcon	*Falco peregrinus*	√	√	√	√	√	√	√				N	L
	Black Falcon	*Falco subniger*	√	√	√	√	√	√	√	VU				
Gruidae	Brolga	*Grus rubicunda*	√	√	√	√	√	√		VU	L			
Rallidae	Eurasian Coot	*Fulica atra*	√	√	√	√	√	√	√					
	Dusky Moorhen	*Gallinula tenebrosa*	√	√	√	√	√	√	√					
	Buff-banded Rail	*Gallirallus philippensis*	√	√	√	√	√	√	√					
	Lewin's Rail	*Lewinia pectoralis*	√		√	√	√		√	VU	L			

	Purple Swamphen	*Porphyrio porphyrio*	√	√	√	√	√	√	√				
	Australian Spotted Crake	*Porzana fluminea*	√	√	√	√	√		√				
	Baillon's Crake	*Porzana pusilla*	√	√	√	√	√		√		VU	L	
	Spotless Crake	*Porzana tabuensis*	√	√	√	√	√		√				
	Black-tailed Native-hen	*Tribonyx ventralis*	√	√	√	√	√	√	√				
Otididae	Australian Bustard	*Ardeotis australis*	√	√		√					CR	L	
Burhinidae	Bush Stone-curlew	*Burhinus grallarius*	√	√	√	√	√	√	√		EN	L	FNS
Recurvirostridae	Banded Stilt	*Cladorhynchus leucephalus*	√	√	√								
	Black-winged Stilt	*Himantopus himantopus*	√	√	√	√	√		√				
	Red-necked Avocet	*Recurvirostra novaehollandiae*	√	√	√				√				
Charadriidae	Inland Dotterel	*Charadrius australis*		√	√						VU		
	Double-banded Plover	*Charadrius bicinctus*	√	√	√	√							
	Greater Sand Plover	*Charadrius leschenaultii*		√							VU		
	Red-capped Plover	*Charadrius ruficapillus*	√	√	√	√	√						
	Oriental Plover	*Charadrius veredus*		√									
	Black-fronted Dotterel	*Elseyornis melanops*	√	√	√	√	√	√	√				
	Red-kneed Dotterel	*Erythrogonys cinctus*	√	√	√	√	√	√	√				
	Pacific Golden Plover	*Pluvialis fulva*	√	√							NT		
	Masked Lapwing	*Vanellus miles*	√	√	√	√	√	√	√				
	Banded Lapwing	*Vanellus tricolor*	√	√	√	√	√	√	√				
Pedionomidae	Plains-wanderer	*Pedionomus torquatus*	√	√	√	√	√		√	VU	CR	L	
Rostratulidae	Australian Painted Snipe	*Rostratula australis*	√	√		√			√	VU	CR	L	
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*		√	√				√		VU		
	Ruddy Turnstone	*Arenaria interpres*	√	√									
	Sharp-tailed Sandpiper	*Calidris acuminata*	√	√	√		√		√				
	Red Knot	*Calidris canutus*	√	√							NT		
	Curlew Sandpiper	*Calidris ferruginea*	√	√									
	Pectoral Sandpiper	*Calidris melanotos*		√	√						NT		
	Little Stint	*Calidris minuta*		√									
	Red-necked Stint	*Calidris ruficollis*	√	√	√	√			√				
	Long-toed Stint	*Calidris subminuta*		√							NT		
	Great Knot	*Calidris tenuirostris*		√							EN	L	
	Latham's Snipe	*Gallinago hardwickii*	√	√	√	√	√	√	√		NT		
	Asian Dowitcher	*Limnodromus semipalmatus*						√					
	Bar-tailed Godwit	*Limosa lapponica*	√	√					√				
	Black-tailed Godwit	*Limosa limosa*		√							VU		
	Eastern Curlew	*Numenius madagascariensis*		√	√						NT		
	Little Curlew	*Numenius minutus*		√									
	Red-necked Phalarope	*Phalaropus lobatus*		√			√						
	Ruff	*Philomachus pugnax*		√									
	Wood Sandpiper	*Tringa glareola*		√	√				√		VU		
	Common Greenshank	*Tringa nebularia*	√	√	√		√		√				
	Marsh Sandpiper	*Tringa stagnatilis*	√	√	√	√			√				
Turnicidae	Red-backed Button-quail	*Turnix maculosus*			√								
	Red-chested Button-quail	*Turnix pyrrhothorax*	√	√			√				VU	L	
	Painted Button-quail	*Turnix varius*	√	√	√	√	√	√	√				
	Little Button-quail	*Turnix velox*	√	√	√	√	√		√		NT		
Glareolidae	Oriental Pratincole	*Glareola maldivarum*		√									
	Australian Pratincole	*Stiltia isabella*	√	√							NT		
Laridae	Whiskered Tern	*Chlidonias hybridus*	√	√	√	√	√		√		NT		
	White-winged Black Tern	*Chlidonias leucopterus*	√	√							NT		
	Silver Gull	*Chroicocephalus novaehollandiae*	√	√	√	√	√	√	√				
	Gull-billed Tern	*Gelochelidon nilotica*	√	√		√		√			EN	L	

	Caspian Tern	*Hydroprogne caspia*	√	√	√	√		√	√		NT	L			
Cacatuidae	Sulphur-crested Cockatoo	*Cacatua galerita*	√	√	√	√	√	√	√					N	H
	Little Corella	*Cacatua sanguinea*	√	√	√	√	√	√	√					N	H
	Long-billed Corella	*Cacatua tenuirostris*	√	√	√	√	√	√	√					N	H
	Gang-gang Cockatoo	*Callocephalon fimbriatum*	√	√	√	√	√	√	√					N	H
	Yellow-tailed Black-Cockatoo	*Calyptorhynchus funereus*	√	√	√	√	√	√	√					N	H
	Glossy Black-Cockatoo	*Calyptorhynchus lathami*		√							VU	L		N	H
	Galah	*Eolophus roseicapilla*	√	√	√	√	√	√	√					N	H
	Major Mitchell's Cockatoo	*Lophocroa leadbeateri*	√	√		√			√		VU	L		N	H
	Cockatiel	*Nymphicus hollandicus*	√	√	√	√	√		√					N	H
Psittacidae	Australian King-Parrot	*Alisterus scapularis*	√	√	√	√	√	√	√					N	H
	Australian Ringneck	*Barnardius zonarius zonarius*	√	√	√	√	√	√	√					N	H
	Musk Lorikeet	*Glossopsitta concinna*	√	√	√	√	√	√	√					N	H
	Purple-crowned Lorikeet	*Glossopsitta porphyrocephala*	√	√	√	√	√	√	√					N	H
	Little Lorikeet	*Glossopsitta pusilla*		√	√	√	√	√	√					N	H
	Swift Parrot	*Lathamus discolor*		√	√	√	√	√	√	EN	EN	L		N^{+}	H
	Budgerigar	*Melopsittacus undulatus*	√	√	√	√	√		√					N	H
	Blue-winged Parrot	*Neophema chrysostoma*	√	√	√	√	√	√	√					N	H
	Elegant Parrot	*Neophema elegans*		√	√	√					VU			N	H
	Turquoise Parrot	*Neophema pulchella*	√	√	√	√	√	√	√		NT	L		N	H
	Blue Bonnet	*Northiella haematogaster*	√	√										N	H
	Pale-headed Rosella	*Platycercus adscitus*		√	√	√								N	H
	Crimson Rosella	*Platycercus elegans elegans*	√	√	√	√	√	√	√					N	H
	Eastern Rosella	*Platycercus eximius*	√	√	√	√	√	√	√					N	H
	Regent Parrot	*Polytelis anthopeplus*	√	√	√					VU	VU	L		N	H
	Superb Parrot	*Polytelis swainsonii*	√	√	√		√		√	VU	EN	L		N	H
	Red-rumped Parrot	*Psephotus haematonotus*	√	√	√	√	√	√	√					N	H
	Mulga Parrot	*Psephotus varius*	√											N	H
	Scaly-breasted Lorikeet	*Trichoglossus chlorolepidotus*			√				√					N	H
	Rainbow Lorikeet	*Trichoglossus haematodus*	√	√	√	√		√	√					N	H
Cuculidae	Fan-tailed Cuckoo	*Cacomantis flabelliformis*	√	√	√	√	√	√	√						
	Pallid Cuckoo	*Cacomantis pallidus*	√	√	√	√	√	√	√						
	Brush Cuckoo	*Cacomantis variolosus*	√	√	√	√	√	√	√						
	Horsfield's Bronze-Cuckoo	*Chalcites basalis*	√	√	√	√	√	√	√						
	Shining Bronze-Cuckoo	*Chalcites lucidus*	√	√	√	√	√	√	√						
	Black-eared Cuckoo	*Chalcites osculans*	√	√	√	√	√	√	√		NT				
Strigidae	Barking Owl	*Ninox connivens*	√	√	√	√	√	√	√		EN	L		N	H
	Southern Boobook	*Ninox novaeseelandiae*	√	√	√	√	√	√	√					NS	H
	Powerful Owl	*Ninox strenua*	√	√	√	√	√	√	√		VU	L		N	H
Tytonidae	Eastern Barn Owl	*Tyto javanica*	√	√	√	√	√		√					NS	H
	Masked Owl	*Tyto novaehollandiae*	√		√	√		√	√		EN	L		NS	H
	Sooty Owl	*Tyto tenebricosa*						√	√		VU	L		NS	H
Alcedinidae	Azure Kingfisher	*Ceyx azureus*	√	√	√	√	√	√	√		NT				
Halcyonidae	Laughing Kookaburra	*Dacelo novaeguineae*	√	√	√	√	√	√	√				F	FN	H
	Red-backed Kingfisher	*Todiramphus pyrrhopygia*	√	√	√	√	√				NT				
	Sacred Kingfisher	*Todiramphus sanctus*	√	√	√	√	√	√	√					N	H
Meropidae	Rainbow Bee-eater	*Merops ornatus*	√	√	√	√	√	√	√						
Coraciidae	Dollarbird	*Eurystomus orientalis*	√	√	√	√	√	√	√					N	H
Menuridae	Superb Lyrebird	*Menura novaehollandiae*		√		√	√	√	√						
Climacteridae	Red-browed Treecreeper	*Climacteris erythrops*		√		√	√	√	√				F	FNS	H
	Brown Treecreeper (south-eastern ssp.)	*Climacteris picumnus victoriae*	√	√	√	√	√	√	√		NT		F	FNS	H
	White-throated Treecreeper	*Cormobates leucophaeus*	√	√	√	√	√	√	√				F	FNS	H
Ptilonorhynchidae	Satin Bowerbird	*Ptilonorhynchus violaceus*		√		√	√	√	√						

Maluridae	Superb Fairy-wren	*Malurus cyaneus*	√	√	√	√	√	√	√						
	Variegated Fairy-wren	*Malurus lamberti*	√	√	√		√								
	White-winged Fairy-wren	*Malurus leucopterus*	√	√											
	Splendid Fairy-wren	*Malurus splendens*		√											
	Southern Emu-wren	*Stipiturus malachurus*							√						
Acanthizidae	Inland Thornbill	*Acanthiza apicalis*	√	√	√		√								
	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	√	√	√	√	√	√	√						
	Striated Thornbill	*Acanthiza lineata*	√	√	√	√	√	√	√						
	Yellow Thornbill	*Acanthiza nana*	√	√	√	√	√	√	√						
	Brown Thornbill	*Acanthiza pusilla*	√	√	√	√	√	√	√						
	Buff-rumped Thornbill	*Acanthiza reguloides*	√	√	√	√	√	√	√					N	L
	Chestnut-rumped Thornbill	*Acanthiza uropygialis*	√	√	√	√	√	√						N	H
	Southern Whiteface	*Aphelocephala leucopsis*	√	√	√	√	√	√						N	H
	Rufous Fieldwren	*Calamanthus campestris*		√							NT				
	Shy Heathwren	*Calamanthus cautus*		√	√										
	Striated Fieldwren	*Calamanthus fuliginosus*		√		√			√						
	Chestnut-rumped Heathwren	*Calamanthus pyrrhopygia*		√	√	√	√		√		VU	L			
	Speckled Warbler	*Chthonicola sagittata*		√	√	√	√	√	√		VU	L	FN		
	White-throated Gerygone	*Gerygone albogularis*		√	√	√	√	√	√						
	Western Gerygone	*Gerygone fusca*	√	√	√	√	√	√	√						
	Brown Gerygone	*Gerygone mouki*		√					√						
	Pilotbird	*Pycnoptilus floccosus*		√		√	√	√	√						
	White-browed Scrubwren	*Sericornis frontalis*	√	√	√	√	√	√	√						
	Large-billed Scrubwren	*Sericornis magnirostris*						√	√						
	Weebill	*Smicrornis brevirostris*	√	√	√	√	√	√	√						
Pardalotidae	Spotted Pardalote	*Pardalotus punctatus*	√	√	√	√	√	√	√				N		
	Striated Pardalote	*Pardalotus striatus*	√	√	√	√	√	√	√				N	N	H
Meliphagidae	Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	√	√	√	√	√		√						
	Eastern Spinebill	*Acanthorhynchus tenuirostris*		√	√	√	√	√	√						
	Red Wattlebird	*Anthochaera carunculata*	√	√	√	√	√	√	√						
	Little Wattlebird	*Anthochaera chrysoptera*	√	√	√	√	√	√	√						
	Regent Honeyeater	*Anthochaera phrygia*		√	√	√	√	√	√	EN	CR	L			
	Pied Honeyeater	*Certhionyx variegatus*					√								
	Blue-faced Honeyeater	*Entomyzon cyanotis*	√	√	√	√	√								
	White-fronted Chat	*Epthianura albifrons*	√	√	√	√	√	√	√						
	Orange Chat	*Epthianura aurifrons*	√	√											
	Crimson Chat	*Epthianura tricolor*		√			√								
	Tawny-crowned Honeyeater	*Glyciphila melanops*			√	√	√		√						
	Painted Honeyeater	*Grantiella picta*	√	√	√	√	√	√	√		VU	L			
	Yellow-faced Honeyeater	*Lichenostomus chrysops*		√	√	√	√	√	√						
	Purple-gaped Honeyeater	*Lichenostomus cratitius*		√	√						VU				
	Fuscous Honeyeater	*Lichenostomus fuscus*	√	√	√	√	√	√	√						
	White-eared Honeyeater	*Lichenostomus leucotis*	√	√	√	√	√	√	√						
	Yellow-tufted Honeyeater	*Lichenostomus melanops*		√	√	√	√	√	√						
	Yellow-plumed Honeyeater	*Lichenostomus ornatus*	√	√	√	√	√								
	White-plumed Honeyeater	*Lichenostomus penicillatus*	√	√	√	√	√	√	√						
	Singing Honeyeater	*Lichenostomus virescens*	√	√	√	√	√	√	√						
	Yellow-throated Miner	*Manorina flavigula*	√	√											
	Noisy Miner	*Manorina melanocephala*	√	√	√	√	√	√	√						
	Bell Miner	*Manorina melanophrys*		√	√	√	√	√	√						
	Lewin's Honeyeater	*Meliphaga lewinii*						√	√						
	Brown-headed Honeyeater	*Melithreptus brevirostris*	√	√	√	√	√	√	√						
	Black-chinned Honeyeater	*Melithreptus gularis*	√	√	√	√	√	√	√		NT				

	White-naped Honeyeater	*Melithreptus lunatus*	√	√	√	√	√	√	√					
	Scarlet Honeyeater	*Myzomela sanguinolenta*			√	√			√					
	Little Friarbird	*Philemon citreogularis*	√	√	√	√	√	√	√					
	Noisy Friarbird	*Philemon corniculatus*	√	√	√	√	√	√	√					
	New Holland Honeyeater	*Phylidonyris novaehollandiae*	√	√	√	√	√	√	√					
	Crescent Honeyeater	*Phylidonyris pyrrhopterus*		√	√	√	√	√	√					
	Striped Honeyeater	*Plectorhyncha lanceolata*	√	√	√									
	White-fronted Honeyeater	*Pumella albifrons*	√	√	√	√	√		√					
	Black Honeyeater	*Sugamel niger*		√	√	√	√		√					
Pomatostomidae	Chestnut-crowned Babbler	*Pomatostomus ruficeps*					√							
	White-browed Babbler	*Pomatostomus superciliosus*	√	√	√	√	√	√						
	Grey-crowned Babbler	*Pomatostomus temporalis*	√	√	√	√	√	√	√	EN	L			
Eupetidae	Spotted Quail-thrush	*Cinclosoma punctatum*		√	√	√	√	√	√	NT				
	Eastern Whipbird	*Psophodes olivaceus*		√		√	√	√	√					
Neosittidae	Varied Sittella	*Daphoenositta chrysoptera*	√	√	√	√	√	√	√					
Campephagidae	Ground Cuckoo-shrike	*Coracina maxima*	√	√						VU	L			
	Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	√	√	√	√	√	√	√					
	White-bellied Cuckoo-shrike	*Coracina papuensis*	√	√	√	√	√	√	√					
	Cicadabird	*Coracina tenuirostris*		√		√	√	√	√					
	White-winged Triller	*Lalage sueurii*	√	√	√	√	√	√	√					
Pachycephalidae	Grey Shrike-thrush	*Colluricincla harmonica*	√	√	√	√	√	√	√					
	Crested Shrike-tit	*Falcunculus frontatus*	√	√	√	√	√	√	√					
	Crested Bellbird	*Oreoica gutturalis*		√	√	√	√			NT	L			
	Gilbert's Whistler	*Pachycephala inornata*	√	√	√	√	√							
	Olive Whistler	*Pachycephala olivacea*	√	√	√	√	√	√	√					
	Golden Whistler	*Pachycephala pectoralis*	√	√	√	√	√	√	√					
	Rufous Whistler	*Pachycephala rufiventris*	√	√	√	√	√	√	√					
Oriolidae	Olive-backed Oriole	*Oriolus sagittatus*	√	√	√	√	√	√	√					
	Australasian Figbird	*Sphecotheres viridis*							√					
Artamidae	Black-faced Woodswallow	*Artamus cinereus*	√	√	√	√	√					N	N	L
	Dusky Woodswallow	*Artamus cyanopterus*	√	√	√	√	√	√	√			N	N	L
	White-breasted Woodswallow	*Artamus leucorynchus*	√	√	√		√	√				N	N	L
	Masked Woodswallow	*Artamus personatus*	√	√	√	√	√		√			N	N	L
	White-browed Woodswallow	*Artamus superciliosus*	√	√	√	√	√	√	√			N	N	L
	Pied Butcherbird	*Cracticus nigrogularis*	√	√	√	√	√	√						
	Australian Magpie	*Cracticus tibicen*	√	√	√	√	√	√	√					
	Grey Butcherbird	*Cracticus torquatus*	√	√	√	√	√	√	√					
	Pied Currawong	*Strepera graculina*	√	√	√	√	√	√	√					
	Grey Currawong	*Strepera versicolor*	√	√	√	√	√	√	√					
Rhipiduridae	Grey Fantail	*Rhipidura albiscarpa*	√	√	√	√	√	√	√					
	Willie Wagtail	*Rhipidura leucophrys*	√	√	√	√	√	√	√					
	Rufous Fantail	*Rhipidura rufifrons*	√	√	√	√	√	√	√					
Corvidae	Australian Raven	*Corvus coronoides*	√	√	√	√	√	√	√					
	Little Raven	*Corvus mellori*	√	√	√	√	√	√	√					
	Forest Raven	*Corvus tasmanicus*				√								
Monarchidae	Magpie-lark	*Grallina cyanoleuca*	√	√	√	√	√	√	√					
	Black-faced Monarch	*Monarcha melanopsis*			√	√	√	√	√					
	Satin Flycatcher	*Myiagra cyanoleuca*	√	√	√	√	√	√	√					
	Restless Flycatcher	*Myiagra inquieta*	√	√	√	√	√	√	√					
	Leaden Flycatcher	*Myiagra rubecula*	√	√	√	√	√	√	√					
Corcoracidae	White-winged Chough	*Corcorax melanorhamphos*	√	√	√	√	√	√	√					
	Apostlebird	*Struthidea cinerea*	√	√							L			
Petroicidae	Southern Scrub-robin	*Drymodes brunneopygia*			√									

	Eastern Yellow Robin	*Eopsaltria australis*		√	√	√	√	√	√				F		
	Hooded Robin	*Melanodryas cucullata*	√	√	√	√	√	√	√		NT	L	F		
	Jacky Winter	*Microeca fascinans*	√	√	√	√	√	√	√				F		
	Scarlet Robin	*Petroica boodang*	√	√	√	√	√	√	√				F		
	Red-capped Robin	*Petroica goodenovii*	√	√	√	√	√	√	√				F		
	Flame Robin	*Petroica phoenicea*	√	√	√	√	√	√	√						
	Pink Robin	*Petroica rodinogaster*	√	√	√	√	√	√	√				F		
	Rose Robin	*Petroica rosea*		√	√	√	√	√	√						
Alaudidae	Horsfield's Bushlark	*Mirafra javanica*	√	√	√	√	√	√	√						
Cisticolidae	Golden-headed Cisticola	*Cisticola exilis*	√	√	√	√	√	√	√						
Acrocephalidae	Australian Reed Warbler	*Acrocephalus australis*	√	√	√	√	√	√	√						
Megaluridae	Brown Songlark	*Cincloramphus cruralis*	√	√	√	√	√	√	√						
	Rufous Songlark	*Cincloramphus mathewsi*	√	√	√	√	√	√	√						
	Little Grassbird	*Megalurus gramineus*	√	√	√	√	√	√	√						
Timaliidae	Silvereye	*Zosterops lateralis*	√	√	√	√	√	√	√						
Hirundinidae	White-backed Swallow	*Cheramoeca leucosterna*	√	√	√	√	√								
	Fairy Martin	*Hirundo ariel*	√	√	√	√	√	√	√						
	Welcome Swallow	*Hirundo neoxena*	√	√	√	√	√	√	√					N	L
	Tree Martin	*Hirundo nigricans*	√	√	√	√	√	√	√					N	H
Turnidae	Bassian Thrush	*Zoothera lunulata*	√	√	√	√	√	√	√						
Nectariniidae	Mistletoebird	*Dicaeum hirundinaceum*	√	√	√	√	√	√	√						
Estrildidae	Red-browed Finch	*Neochmia temporalis*	√	√	√	√	√	√	√						
	Beautiful firetail	*Stagonopleura bella*					√	√	√						
	Diamond Firetail	*Stagonopleura guttata*	√	√	√	√	√	√	√		VU	L			
	Double-barred Finch	*Taeniopygia bichenovii*		√			√	√							
	Zebra Finch	*Taeniopygia guttata*	√	√	√	√	√		√						
Motacillidae	Australasian Pipit	*Anthus novaeseelandiae*	√	√	√	√	√	√	√						
REPTILES															
Cheluidae	Common Long-necked Turtle	*Chelodina longicollis*	√	√	√	√	√	√	√				S		
	Murray River Turtle	*Emydura macquarii*	√	√	√	√	√		√		DD	L			
	Broad-shelled Turtle	*Macrochelodina expansa*	√	√	√		√		√		EN	L			
Agamidae	Tree Dragon	*Amphibolurus muricatus*		√	√	√	√	√	√				BFNS	S	HL
	Eastern Water Dragon	*Physignathus lesueurii*							√				BS	S	HL
	Gippsland Water Dragon	*Physignathus lesueurii howittii*						√	√				BS	S	HL
	Bearded Dragon	*Pogona barbata*	√	√	√	√	√		√		DD		BFS		
	Mountain Dragon	*Rankinia diemensis*				√		√	√				BS		
Gekkonidae	Marbled Gecko	*Christinus marmoratus*	√	√	√	√	√	√	√				FNS	FS	L
	Southern Spiny-tailed Gecko	*Diplodactylus intermedius*		√			√						NS	FS	L
	Tessellated Gecko	*Diplodactylus tessellatus*	√	√	√								NS		
	Wood Gecko	*Diplodactylus vittatus*	√	√	√	√	√	√					NS		
	Thick-tailed Gecko	*Nephrurus milii*		√	√	√							NS		
Pygopodidae	Pink-tailed Worm-lizard	*Aprasia parapulchella*			√					VU	EN	L	S		
	Aprasia	*Aprasia* sp.		√	√								S		
	Southern Legless Lizard	*Delma australis*	√										S		
	Striped Legless Lizard	*Delma impar*		√	√	√				VU	EN	L	S		
	Olive Legless Lizard	*Delma inornata*	√	√	√	√		√					SN		
	Burton's Snake-lizard	*Lialis burtonis*	√	√		√							S		
	Common Scaly-foot	*Pygopus lepidopodus*		√	√				√				S		
	Hooded Scaly-foot	*Pygopus schraderi*		√							CR	L			
Scincidae	Eastern Three-lined Skink	*Bassiana duperreyi*			√	√	√	√	√				BFNS		
	Red-throated Skink	*Bassiana platynotum*					√	√					BFNS		
	Bassiana	*Bassiana* sp.		√			√	√	√				BFNS		
	Southern Rainbow Skink	*Carlia tetradactyla*		√	√	√	√	√	√				BFNS		

	Carnaby's Wall Skink	*Cryptoblepharus carnabyi*	√	√	√		√					BFNS	FS	L
	Eastern Striped Skink	*Ctenotus orientalis*		√	√				√			BFS		
	Large Striped Skink	*Ctenotus robustus*	√	√	√	√	√	√	√			BFS	S	L
	Copper-tailed Skink	*Ctenotus taeniolatus*		√		√	√	√	√			BFS		
	Swamp Skink	*Egernia coventryi*				√			√	VU	L	BF		
	Cunningham's Skink	*Egernia cunninghami*		√	√	√	√	√	√			BF	S	HL
	Black Rock Skink	*Egernia saxatilis intermedia*		√	√	√	√	√	√			BFNS	S	HL
	Tree Skink	*Egernia striolata*	√	√	√		√	√				BFNS	S	HL
	White's Skink	*Egernia whitii* (group)		√	√	√	√	√	√			BFS		
	White's Skink (plain back morph)	*Egernia whitii (plain back morph)*						√				BFS		
	White's Skink (spotted back morph)	*Egernia whitii (spotted back morph)*					√	√	√			BFS		
	Yellow-bellied Water Skink	*Eulamprus heatwolei*	√	√		√	√	√	√			BFNS		
	Alpine Water Skink	*Eulamprus kosciuskoi*						√		CR	L	BFS		
	Southern Water Skink	*Eulamprus tympanum tympanum*				√	√	√	√			BFNS		
	Unidentified Water Skink	*Eulamprus* sp.	√	√	√	√	√	√	√			BFNS		
	Three-toed Skink	*Hemiergis decresiensis*		√	√	√	√	√	√			FNS		
	Delicate Skink	*Lampropholis delicata*				√		√	√			BFNS		
	Garden Skink	*Lampropholis guichenoti*	√	√	√	√	√	√	√			BFNS		
	Bougainville's Skink	*Lerista bougainvillii*	√	√	√	√	√	√	√			FNS		
	Spotted Burrowing Skink	*Lerista punctatovittata*	√									FS		
	Grey's Skink	*Menetia greyii*	√	√	√	√	√					BFNS		
	Samphire Skink	*Morethia adelaidensis*		√						EN	L	BFNS		
	Boulenger's Skink	*Morethia boulengeri*	√	√	√	√	√	√				BFNS		
	McCoy's Skink	*Nannoscincus maccoyi*		√		√	√	√	√			FNS		
	Coventry's Skink	*Niveoscincus coventryi*		√	√	√		√	√			BFNS		
	Metallic Skink	*Niveoscincus metallicus*						√	√			BFNS		
	Glossy Grass Skink	*Pseudechis rawlinsoni*				√		√	√	NT		BFS		
	Southern Grass Skink	*Pseudemoia entrecasteauxii*				√		√	√			BFNS		
	Tussock Skink	*Pseudemoia pagenstecheri*				√		√	√			BFS		
	Tussock Skink/Alpine Bog Skink	*Pseudemoia pagenstecheri/cryodroma*				√			√			BFS		
	Spencer's Skink	*Pseudemoia spenceri*				√	√	√				BFNS	BFS	L
	Unidentified Grass Skink	*Pseudemoia* sp.			√	√	√	√	√			BF		
	Weasel Skink	*Saproscincus mustelinus*						√	√			FNS		
	Blotched Blue-tongued Lizard	*Tiliqua nigrolutea*		√	√	√		√	√			S		
	Stumpy-tailed Lizard	*Tiliqua rugosa*	√	√	√	√	√		√			S		
	Common Blue-tongued Lizard	*Tiliqua scincoides*		√	√	√	√	√	√			S		
Varanidae	Sand Goanna	*Varanus gouldii*	√	√	√	√	√					BFNS	BFNS	HL
	Lace Goanna	*Varanus varius*	√	√	√	√	√	√	√	VU		BFS		
Boidae	Carpet Python	*Morelia spilota metcalfei*	√	√			√			EN	L	BFNS	BFNS	HL
Typhlopidae	Peters's Blind Snake	*Ramphotyphlops bituberculatus*	√	√	√		√					S		
	Gray's Blind Snake	*Ramphotyphlops nigrescens*		√	√	√	√	√	√			S		
	Woodland Blind Snake	*Ramphotyphlops proximus*	√	√	√	√	√	√		NT		S		
Elapidae	Highland Copperhead	*Austrelaps ramsayi*							√			BNS		
	Lowland Copperhead	*Austrelaps superbus*				√		√	√			BNS		
	White-lipped Snake	*Drysdalia coronoides*				√	√	√	√			NS		
	Tiger Snake	*Notechis scutatus*	√	√	√	√	√	√	√			BNS	FS	HL
	Red-bellied Black Snake	*Pseudechis porphyriacus*	√	√	√	√	√	√	√			NS		
	Eastern Brown Snake	*Pseudonaja textilis*	√	√	√	√	√	√	√			BNS		
	Eastern Small-eyed Snake	*Rhinoplocephalus nigrescens*		√	√	√	√	√	√			NS		
	Coral Snake	*Simoselaps australis*	√									NS		
	Dwyer's Snake	*Suta dwyeri*		√	√	√	√	√				NS		
	Little Whip Snake	*Suta flagellum*		√	√	√		√	√			NS		
	Mitchell's Short-tailed Snake	*Suta nigriceps*		√	√		√					NS		

	Curl Snake	*Suta suta*	√	√			√						NS		
	Bandy Bandy	*Vermicella annulata*	√	√	√	√	√				NT	L	NS		
FROGS															
Hylidae	Booroolong Tree Frog	*Litoria booroolongensis*					√				CR	L	S		
	Blue Mountains Tree Frog	*Litoria citropa*							√				S		
	Southern Brown Tree Frog	*Litoria ewingii*		√	√	√	√	√	√				S		
	Southern Brown Tree Frog Group	*Litoria ewingii* (group)				√	√	√	√				S		
	Southern/Plains Brown Tree Frog	*Litoria ewingii/paraewingii*		√		√	√	√	√				S		
	Lesueur's Frog	*Litoria lesueuri*		√		√	√	√	√				S		
	Large Brown Tree Frog	*Litoria littlejohni*							√	VU	NT	L	S		
	Leaf Green Tree Frog	*Litoria nudidigita*						√	√				S		
	Plains Brown Tree Frog	*Litoria paraewingi*	√	√	√	√	√	√	√				S		
	Peron's Tree Frog	*Litoria peronii*	√	√	√	√	√	√	√				FS	S	L
	Growling Grass Frog	*Litoria raniformis*	√	√	√	√	√	√	√	VU	EN	L	BS		
	Spotted Tree Frog	*Litoria spenceri*						√	√	EN	CR	L	S		
	Verreaux's Tree Frog	*Litoria verreauxii*				√		√	√				S		
	Alpine Tree Frog	*Litoria verreauxii alpina*						√	√	VU	CR	L	S		
	Whistling Tree Frog	*Litoria verreauxii verrreauxii*				√		√	√				S		
Myobatrachidae	Plains Froglet	*Crinia parinsignifera*	√	√	√	√	√	√	√				S		
	Common Froglet	*Crinia signifera*	√	√	√	√	√	√	√				S		
	Sloane's Froglet	*Crinia sloanei*	√	√	√		√						S		
	Victorian Smooth Froglet	*Geocrinia victoriana*			√	√		√	√				S		
	Giant Burrowing Frog	*Heleioporus australiacus*							√	VU	VU	L	S		
	Southern Bullfrog	*Limnodynastes dumerilii*	√	√	√	√	√	√	√				S		
	Southern Bullfrog (northern form)	*Limnodynastes dumerilii dumerilii*		√		√	√	√	√				S		
	Southern Bullfrog (south-eastern form)	*Limnodynastes dumerilii insularis*				√		√	√				S		
	Barking Marsh Frog	*Limnodynastes fletcheri*	√	√	√		√						S		
	Giant Bullfrog	*Limnodynastes interioris*	√	√			√				CR	L	S		
	Striped Marsh Frog	*Limnodynastes peronii*			√	√	√	√	√				S		
	Spotted Marsh Frog	*Limnodynastes tasmaniensis*	√	√	√	√	√	√	√				S		
	Spotted Marsh Frog (northern call race)	*Limnodynastes tasmaniensis* NCR	√	√	√	√	√						S		
	Spotted Marsh Frog (southern call race)	*Limnodynastes tasmaniensis* SCR				√							S		
	Mallee Spadefoot Toad	*Neobatrachus pictus*			√	√							S		
	Common Spadefoot Toad	*Neobatrachus sudelli*	√	√	√	√	√	√	√				S		
	Haswell's Froglet	*Paracrinia haswelli*							√				S		
	Baw Baw Frog	*Philoria frosti*							√	EN	CR	L	S		
	Brown Toadlet	*Pseudophryne bibronii*	√	√	√	√	√	√	√		EN	L	S		
	Dendy's Toadlet	*Pseudophryne dendyi*					√	√	√		DD		S		
	Southern Toadlet	*Pseudophryne semimarmorata*			√	√			√				S		
	Smooth Toadlet	*Uperoleia laevigata*		√	√		√	√			DD		S		
	Rugose Toadlet	*Uperoleia rugosa*		√			√				VU	L	S		

Appendix 2

All vascular plant species (from forests and woodlands), in three bioregions subject to firewood harvesting, that have a rare and threatened status.

EPBC (Australian Threatened) status: E Endangered; V Vulnerable. FFG status: f = listed. Victorian (Rare or Threatened) status: e endangered; v vulnerable; r rare; k poorly known but suspected to be r, v or e.

DICOTYLEDONS	Common name	EPBC	FFG	Vic
Acacia aspera subsp. parviceps	Rough Wattle			r
Acacia ausfeldii	Ausfeld's Wattle			v
Acacia deanei	Deane's Wattle			r
Acacia deanei subsp. *deanei*	Deane's wattle		f	e
Acacia decora	Western Silver Wattle			v
Acacia doratoxylon	Currawang			r
Acacia euthycarpa subsp. *oblanceolata*	Wedderburn Wattle			v
Acacia flexifolia	Bent-leaf Wattle			r
Acacia omalophylla	Yarran Wattle		f	e
Acacia penninervis var. *penninervis*	Hickory Wattle			r
Acacia sporadica	Pale Hickory-wattle			v
Acacia verniciflua (southern variant)	Southern Varnish Wattle			k
Allocasuarina luehmannii	Buloke		f	
Alternanthera sp. 1 (Plains)	Plains Joyweed			k
Amaranthus macrocarpus var. *macrocarpus*	Dwarf Amaranth			v
Amyema linophylla subsp. *orientale*	Buloke Mistletoe			v
Asperula gemella	Twin-leaf Bedstraw			r
Atriplex lindleyi subsp. *lindleyi*	Flat-top Saltbush			k
Atriplex spinibractea	Spiny-fruit Saltbush			e
Boronia anemonifolia subsp. *aurifodina*	Goldfield Boronia			r
Boronia nana var. *pubescens*	Dwarf Boronia			r
Bossiaea cordigera	Wiry Bossiaea			r
Bossiaea riparia	River Leafless Bossiaea			r
Brachyscome chrysoglossa	Yellow-tongue Daisy		f	v
Brachyscome cuneifolia	Wedge-leaf Daisy			k
Brachyscome debilis s.s.	Weak Daisy			v
Brachyscome gracilis	Dookie Daisy		f	v
Brachyscome muelleroides	Mueller Daisy	V	f	e
Brachyscome readeri	Reader's Daisy			r
Calotis cuneifolia	Blue Burr-daisy			r
Calotis lappulacea	Yellow Burr-daisy			r
Cardamine moirensis	Riverina Bitter-cress			r
Cardamine papillata	Forest Bitter-cress			r
Cassinia diminuta	Dwarf Cassinia			r
Cassinia ozothamnoides	Cottony Cassinia			v
Cassinia scabrida	Rough Cassinia			r
Centipeda crateriformis subsp. *compacta*	Compact Sneezeweed			r

Centipeda nidiformis	Cotton Sneezeweed			r
Centipeda pleiocephala	Tall Sneezeweed			e
Centipeda thespidioides s.l.	Desert Sneezeweed			r
Chenopodium desertorum subsp. *virosum*	Frosted Goosefoot			k
Choretrum glomeratum	Common Sour-bush			r
Choretrum glomeratum var. *chrysanthum*	Golden Sour-bush			r
Convolvulus angustissimus subsp. *omnigracilis*	Slender Bindweed			k
Cullen tenax	Tough Scurf-pea		f	e
Cymbonotus lawsonianus	Bear's-ear			r
Desmodium varians	Slender Tick-trefoil			k
Discaria pubescens	Australian Anchor Plant		f	r
Dodonaea boroniifolia	Hairy Hop-bush			r
Dodonaea heteromorpha	Maple-fruited Hop-bush			x
Dodonaea procumbens	Trailing Hop-bush	V		v
Eremophila debilis	Winter Apple			e
Eremophila divaricata subsp. *divaricata*	Spreading Emu-bush			r
Eremophila gibbifolia	Coccid Emu-bush			r
Eremophila maculata var. *maculata*	Spotted Emu-bush			r
Eriochlamys sp. 1	Lesser Mantle			v
Eucalyptus aff. *aromaphloia* (Castlemaine)	Fryers Range Scentbark			e
Eucalyptus aff. *porosa* (Quambatook)	Quambatook Mallee-box			e
Eucalyptus aggregata	Black Gum		f	e
Eucalyptus alligatrix subsp. *limaensis*	Lima Stringybark	V	f	e
Eucalyptus froggattii	Kamarooka Mallee		f	r
Eucalyptus polybractea	Blue Mallee			r
Eucalyptus pyrenea	Pyrenees Gum			r
Eucalyptus tricarpa subsp. *decora*	Bealiba Ironbark			v
Euphrasia collina subsp. *muelleri*	Purple Eyebright	E	f	e
Euphrasia collina subsp. *speciosa*	Purple Eyebright			x
Euphrasia scabra	Rough Eyebright		f	e
Geijera parviflora	Wilga		f	e
Glycine canescens	Silky Glycine		f	e
Glycine latrobeana	Clover Glycine	V	f	v
Goodenia benthamiana	Small-leaf Goodenia			r
Goodenia lunata	Stiff Goodenia			v
Goodenia macbarronii	Narrow Goodenia		f	v
Goodia medicaginea	Western Golden-tip			r
Grevillea dimorpha	Flame Grevillea			r
Grevillea dryophylla	Goldfields Grevillea			r
Grevillea floripendula	Ben Major Grevillea	V	f	v
Grevillea micrantha	Small-flower Grevillea			r
Grevillea obtecta	Fryerstown Grevillea			r
Grevillea polybractea	Crimson Grevillea			r
Grevillea repens	Creeping Grevillea			r
Haloragis glauca f. glauca	Bluish Raspwort			k
Hibbertia humifusa	Rising Star Guinea-			r
Hibbertia humifusa subsp. *erigens*	Euroa Guinea-flower	V	f	v

Hibbertia humifusa subsp. *humifusa*	Rising Star Guinea-			r
Hovea asperifolia subsp. *spinosissima*	Rough Hovea			r
Indigofera adesmiifolia	Tick Indigo			v
Lepidium pseudohyssopifolium	Native Peppercress			k
Lepidium pseudopapillosum	Erect Peppercress	V	f	e
Leptorhynchos elongatus	Lanky Buttons			e
Leucochrysum molle	Soft Sunray			v
Lotus australis var. *australis*	Austral Trefoil			k
Myoporum montanum	Waterbush			r
Olearia pannosa subsp. *cardiophylla*	Velvet Daisy-bush		f	v
Olearia tubuliflora	Rayless Daisy-bush			r
Philotheca difformis subsp. *difformis*	Small-leaf Wax-flower		f	e
Pomaderris paniculosa subsp. *paniculosa*	Inland Pomaderris			v
Prostanthera saxicola var. *bracteolata*	Slender Mint-bush			r
Pseudanthus ovalifolius	Oval-leaf Pseudanthus			r
Ptilotus erubescens	Hairy Tails		f	
Ptilotus sessilifolius var. *sessilifolius*	Crimson Tails			k
Pultenaea foliolosa	Small-leaf Bush-pea			r
Pultenaea graveolens	Scented Bush-pea		f	v
Pultenaea juniperina s.s.	Prickly Beauty			r
Pultenaea lapidosa	Stony Bush-pea		f	v
Pultenaea platyphylla	Flat-leaf Bush-pea			r
Pultenaea reflexifolia	Wombat Bush-pea			r
Pultenaea vrolandii	Cupped Bush-pea			r
Quinetia urvillei	Quinetia			r
Rumex stenoglottis	Tongue Dock			k
Santalum lanceolatum	Northern Sandalwood		f	e
Sida intricata	Twiggy Sida			v
Stylidium calcaratum var. *ecorne*	Foot Triggerplant			k
Swainsona adenophylla	Violet Swainson-pea		f	e
Swainsona behriana	Southern Swainson-pea			r
Swainsona galegifolia	Smooth Darling-pea		f	e
Swainsona recta	Mountain Swainson-pea	E	f	e
Swainsona sericea	Silky Swainson-pea		f	v
Swainsona swainsonioides	Downy Swainson-pea		f	e
Templetonia egena	Round Templetonia			v
Tetragonia eremaea s.s.	Desert Spinach			k
Teucrium albicaule	Scurfy Germander			k
Thesium australe	Austral Toad-flax	V	f	v
Vittadinia condyloides	Club-hair New Holland Daisy			r
Vittadinia cuneata var. *hirsuta*	Fuzzy New Holland			r
Vittadinia cuneata var. *morrisii*	Fuzzy New Holland			r
Vittadinia pterochaeta	Winged New Holland Daisy			v
Westringia crassifolia	Whipstick Westringia	E	f	e
Zieria aspalathoides subsp. *aspalathoides*	Whorled Zieria		f	v

MONOCOTYLEDONS	**Common name**	**EPBC**	**FFG**	**Vic**
Acianthus collinus	Hooded Mosquito-orchid		f	v
Aristida calycina var. *calycina*	Dark Wire-grass			r
Austrodanthonia monticola	Small-flower Wallaby-			r
Austrodanthonia setacea var. *breviseta*	Short-bristle Wallaby-grass			r
Austrostipa breviglumis	Cane Spear-grass			r
Austrostipa tenuifolia	Long-awn Spear-grass			v
Austrostipa trichophylla	Spear-grass			r
Caladenia audasii	McIvor Spider-orchid	E	f	e
Caladenia clavescens	Midlands Spider-orchid			v
Caladenia cruciformis	Red-cross Spider-orchid		f	e
Caladenia fulva	Tawny Spider-orchid	E	f	e
Caladenia oenochila	Wine-lipped Spider-			v
Caladenia ornata	Ornate Pink-fingers	V		v
Caladenia reticulata s.s.	Veined Spider-orchid			v
Caladenia rosella	Little Pink Spider-orchid	E	f	e
Caladenia sp. aff. *fragrantissima* (Central Victoria)	Bendigo Spider-orchid		f	e
Caladenia toxochila	Bow-lip Spider-orchid		f	v
Caladenia versicolor	Candy Spider-orchid	V	f	e
Caladenia xanthochila	Yellow-lip Spider-orchid	E	f	e
Calochilus richiae	Bald-tip Beard-orchid	E	f	e
Corunastylis ciliata	Fringed Midge-orchid			k
Deyeuxia imbricata	Bent-grass			v
Dianella amoena	Matted Flax-lily	E		e
Dianella sp. aff. *longifolia* (Riverina)	Pale Flax-lily			v
Dianella tarda	Late-flower Flax-lily			v
Dipodium pardalinum	Spotted Hyacinth-orchid			r
Diuris behrii	Golden Cowslips			v
Diuris dendrobioides	Wedge Diuris		f	e
Diuris palustris	Swamp Diuris		f	v
Diuris punctata var. *punctata*	Purple Diuris		f	v
Diuris tricolor	Painted Diuris		f	e
Diuris X palachila	Broad-lip Diuris			r
Eragrostis alveiformis	Granite Love-grass			k
Hypoxis vaginata var. *brevistigmata*	Yellow Star			k
Juncus psammophilus	Sand Rush			r
Prasophyllum aff. *fitzgeraldii B*	Elfin Leek-orchid			e
Prasophyllum aff. *pyriforme* (Inglewood)	Trim Leek-orchid			e
Prasophyllum hygrophilum	Swamp Leek-orchid		f	e
Prasophyllum lindleyanum	Green Leek-orchid			v
Prasophyllum pyriforme s.s.	Silurian Leek-orchid			e
Prasophyllum sp. aff. *fitzgeraldii A*	Pink-lip Leek-orchid		f	e
Prasophyllum sp. aff. *validum A*	Woodland Leek-orchid			e
Prasophyllum subbisectum	Pomonal Leek-orchid	E	f	e
Pterostylis aciculiformis	Slender Ruddyhood			k

Pterostylis boormanii	Sikh's Whiskers			r
Pterostylis despectans	Lowly Greenhood	E	f	e
Pterostylis diminuta	Crowded Greenhood			k
Pterostylis hamata	Scaly Greenhood			r
Pterostylis maxima	Large Rustyhood			v
Pterostylis smaragdyna	Emerald-lip Greenhood			r
Pterostylis sp. aff. *plumosa* (Woodland)	Woodland Plume-orchid			r
Pterostylis woollsii	Long-tail Greenhood		f	e
Thelymitra epipactoides	Metallic Sun-orchid	E	f	e
Thelymitra mackibbinii	Brilliant Sun-orchid	V	f	e
Thelymitra X chasmogama	Globe-hood Sun-orchid			v
Thelymitra X macmillanii	Crimson Sun-orchid			v