THE FENNER SCHOOL OF
ENVIRONMENT & SOCIETY

THE AUSTRALIAN NATIONAL UNIVERSITY

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

DAVID B. LINDENMAYER

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State Government Victoria

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PREFACE

This report was commissioned by the Victorian Government through the Department of Primary Industries (DPI) in mid-2006. The aim of the report was to describe the impacts of timber harvesting activities on biodiversity in native forests. It was to focus on these impacts at a landscape level and describe opportunities for improving biodiversity and other outcomes through alternative approaches to timber harvesting. The report focuses on the highly-productive, wet ash-type eucalypt forests of the Central Highlands of Victoria.

The alternative silvicultural system described in this report is referred to as the Variable Retention Harvest System (VRHS) and involves the retention of strategic elements of the forest from one rotation to the next. The VRHS aims to maintain ecological functionality at a landscape level and is based on insights into ecologically appropriate harvesting methods being developed and adopted in the Pacific-Northwest of North America.

The latter sections of the report present early findings from a major research project called "The Cutting Experiment" which applies VRHS in the Mountain Ash forests of the Central Highlands of Victoria. The Cutting Experiment has received generous support from the Victorian Department of Sustainability and Environment (DSE), Forest and Wood Products Research and Development Corporation, the federal Department of Agriculture Fisheries and Forestry, Parks Victoria and the Earthwatch Institute.

I would like to acknowledge Ross Garsden (DPI), Peter Fagg (DSE) and Michael Ryan (VicForests) for their constructive comments and feedback throughout the development of this report. I would also like to acknowledge the tireless efforts of my field staff, Mason Crane, Chris MacGregor, Lachie McBurney, Damian Michael and Rebecca Montague-Drake, and the many Earthwatch volunteers without which this project would not be possible. Finally, I would like to thank Rachel Muntz who helped admirably in preparing the final manuscript.

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Professor David Lindenmayer
July 2007

EXECUTIVE SUMMARY

Ecologically sustainable forest management (ESFM) is, in part, predicated on the assumption that harvesting activities undertaken within the forest will not lead to species decline or loss or the impairment of key ecological processes. Timber harvesting and subsequent regeneration of forests must therefore be conducted in ways that do not diminish opportunities for forest-dependent species to persist within forest landscapes.

Victoria's forests, including the Mountain Ash forests of the Central Highlands of Victoria, are managed for a variety of purposes including timber production, catchment protection and biodiversity conservation. Mountain Ash forests are significant for a range of species including endangered ones like Leadbeater's Possum that occur virtually nowhere else. Mountain Ash forests also support important populations of many other species of mammals as well as populations of a range of bird, reptile, frog and plant taxa.

Although a relatively small percentage of the overall Mountain Ash forest estate is subjected to timber harvesting each year, the community perception is that these activities may be incompatible with biodiversity conservation. However, improvements in silviculture and an adaptive management approach have the potential to deliver positive outcomes for both timber production and biodiversity conservation. If such improvements in timber harvesting activities are embraced in the Mountain Ash forests of the Central Highlands of Victoria, they offer the potential to become one of very few examples of demonstrated ecologically sustainable forest management in Australia and indeed around the world.

Forms of silviculture that are currently widely applied in Mountain Ash forests, such as clearfelling, are proven methods of timber harvesting and are relatively straightforward and efficient to apply. However, extensive clearfelling without adequate retention of structural elements can have significant negative effects on other values demanded from multiple-use forests, such as biodiversity conservation. In particular, they can substantially alter levels and spatial patterns of stand structural complexity on which many elements of forest biota depend. Alternative forms of logging such as the Variable Retention Harvest System (VRHS) that retain key structural elements of native forests can, in turn, promote the conservation of structure-dependent biota in wood production forests.

The Variable Retention Harvest System (VRHS) is an emerging silvicultural system designed to better maintain and perpetuate stand structural complexity. The overarching goal of the VRHS is to develop structurally more complex managed forests that meet explicitly defined management objectives.

Implicit in the VRHS is acceptance of the idea that some of the productive capacity and economic value of a stand will be devoted to the maintenance of biodiversity (and other values like the maintenance of ecosystem processes) rather than maximizing the regeneration and growth of commercial tree species. This is entirely consistent with the underpinning philosophy of a modern application of ecologically sustainable forest management.

VRHS has its origins in North America and the approach typically includes:

- A level of retention of structural features necessary for the practice to be socially credible and ecologically effective.
- The retention of particular stand structural attributes (e.g. dominant living trees and large dead trees with hollows).
- A reasonable spatial distribution of retained structures (i.e. retention cannot be concentrated only along drainage lines or along the edges of a harvest unit). And,
- The retention of structures for at least one rotation (i.e. structures that are retained only temporarily, such as a shelterwood overstorey, do not meet the goal of structural retention).

Beyond this general consensus, VRHS encompasses a broad continuum of silvicultural prescriptions. It is flexible in terms of levels of stand retention and the array of structural conditions that can be created (e.g. even-aged, multi-aged, or all-aged). This flexibility provides an opportunity for adapting and applying the best approach for each stand throughout a forest estate.

The VRHS is now widely applied in western and eastern North America, South America and many parts of Northern Europe. There also are examples of VRHS in native forests in south-eastern Australia (Tasmania and Victoria).

A major VRHS experiment has commenced in the Mountain Ash forests of the Central Highlands of Victoria. It has been established through a partnership between The Australian National University, Department of Sustainability and Environment, and VicForests. The three key imperatives for the application of VRHS to Mountain Ash forests are:

- The need to reduce the negative impacts of traditional clearfelling on stand structural complexity,
- The realisation of opportunities for harvesting operations to create and then potentially maintain habitat for particular high profile species such as Leadbeater's Possum (if appropriate stand conditions are allowed to develop). And,
- The desirability of fostering greater congruence between natural disturbance regimes and human (logging) disturbance practices to promote biodiversity conservation.

The VRHS experiment was established in late 2003 and is examining the response of vertebrates and plants to alternative silvicultural systems. There has been extensive research and development and subsequent change in commercial management practices in the Mountain Ash forests of the Central Highlands of Victoria over the past 50 years, with the Silvicultural Systems Project (set up in the late 1980s) being one example of a large study. The VRHS experiment is different in that it has been established as a true adaptive management-by-experiment-and-monitoring project. That is, the VRHS experiment is based on a formal experimental design targeting a significant policy and scientific issue and which aims to generate the kinds of new information to be fed back to managers and, subsequently, improve on-ground management practices. The VRHS experiment offers considerable potential for improved integration of production and conservation goals and as such, presents a model for silvicultural practices elsewhere in Victoria, Australia and overseas

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INTRODUCTION

Forestry and forest management has been among the most socially divisive resource management issues in Australia for over the past three decades (Routley and Routley, 1975; Dargarvel, 1995; Lindenmayer and Franklin, 2003; Lunney, 2004). There have been two major areas of conflict:

- Land allocation (i.e. setting aside forest reserves versus maintaining forest in production areas). And,
- The impacts of some kinds of forestry practices such as clearfelling on other values (e.g. biodiversity conservation and the maintenance of water catchment values). Indeed, efforts to maintain a wide range of values in production forests are pivotal to the concept of Ecologically Sustainable Forest Management (ESFM) (Commonwealth of Australia, 1992) which can be broadly defined as (after Lindenmayer and Recher, 1999):

  ".....perpetuating ecosystem integrity while continuing to provide wood and non-wood values; where ecosystem integrity means the maintenance of forest structure, species composition, and the rate of ecological processes and functions within the bounds of normal disturbance regimes".

Ecologically Sustainable Forest Management has rightly become a key component of major state and federal agreements on native forest utilization and management in Australia such as the Regional Forest Agreements (e.g. Department of Natural Resources & Environment and Commonwealth of Australia, 1999).

Given widespread concerns about native forest management and potential impacts of even-aged silvicultural systems like clearfelling, not only in Australia but elsewhere around the world (e.g. Yaffee, 1994; Hunter, 1999; Haila and Dyke, 2006), new approaches are being developed to the way forests are harvested. This report discusses a range of issues associated with timber harvesting in the Mountain Ash forests of the Central Highlands of Victoria. First, a brief description of these forests is provided to give background to their biodiversity conservation values and the current timber harvesting activities that takes place within them. Second, problems associated with the impacts of current even-aged clearfelling practices in Mountain Ash forests are discussed. Ways to mitigate these impacts via the application of what is termed the Variable Retention Harvesting System (VRHS) (Franklin *et al.*, 1997) are outlined. The VHRS is defined and discussed in terms of how it differs from other kinds of harvesting systems. Applications of the VHRS in various parts of the world are very briefly outlined to provide some context to proposed changes in silvicultural practices in the Central Highlands of Victoria. A recent application of the Variable Retention Harvesting System in the Mountain Ash (*Eucalyptus regnans*) forests of the Central Highlands of Victoria is then described. The scientific basis for its application is presented and then advantages, disadvantages and some of the recent experiences of the new cutting method are outlined.

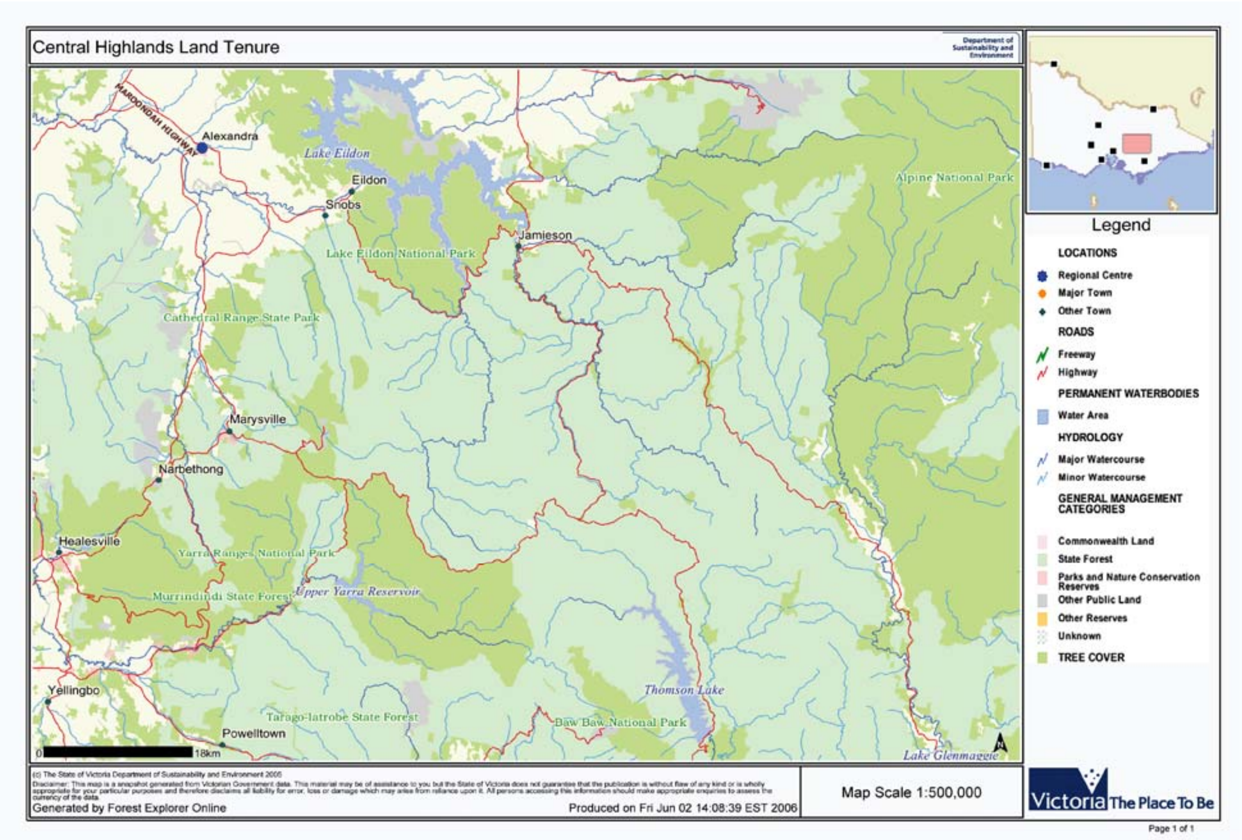
A BRIEF DESCRIPTION OF VICTORIA'S MOUNTAIN ASH FORESTS

Background – the Mountain Ash forests of the Central Highlands of Victoria

The Central Highlands of Victoria is a region covering about one degree of latitude and longitude (37°20' - 37°55' S latitude and 145°30' - 146°20' E longitude) near Melbourne in southern Australia (Figure 1). The region is characterized by a humid environment (Dick, 1975) with some parts of the region experiencing an average annual precipitation exceeding 2000 mm. The range in mean annual temperature is ~7-13.5°C (Lindenmayer et al., 1996).

Old growth stands of Mountain Ash can include mature and old trees with heights approaching 100 m, making these trees the tallest flowering plants in the world (Ashton, 1976). Following germination, young Mountain Ash trees exhibit rapid rates of growth and may reach 50 m height within 35 years (Ashton, 1975). As Mountain Ash forests mature, the crowns of dominant eucalypts become larger, more open and increasingly separated from those of surrounding trees (Ashton, 1975). There is also a reduction in the number of stems per unit area (Dahl, 1940). The seedlings of Mountain Ash trees are considered to be shade intolerant (Cunningham, 1960) and therefore rarely survive under the extensive crowns of mature trees. As the forest ages, most species of *Acacia* trees in the understorey eventually die (Adams and Attiwill, 1984). The decline in the number of *Acacia* spp. stems is pronounced (Adams and Attiwill, 1984).

Figure 1. The general location of the Central Highlands of Victoria



Mountain Ash trees are self-thinning (Ashton, 1981) and self-pruning (Cunningham, 1960), leaving large relatively well spaced trees with few branches on the lower trunk in mature and old growth stands that are dominated by a single age cohort of trees (Ashton, 1975). Small, suppressed pole and sapling trees, which add greatly to the density of the vegetation in regrowth forests, die as the forests mature (Opie *et al.*, 1984).

Current biodiversity values of Victoria's Mountain Ash forests

Mountain Ash forests are significant areas for biodiversity conservation. Some of the species inhabiting Mountain Ash forests in the Central Highlands of Victoria are endangered such as Leadbeater's Possum (*Gymnobelidues leadbeateri*) (Lindenmayer, 1996, 2000) and others are vulnerable, like the Sooty Owl (*Tyto tenebricosa*) (Milledge *et al.* 1991) and Tree Geebung (*Persoonia arborea*) (Mueck, 1990). Together with forests that support Alpine Ash (*Eucalyptus delegatensis*) and Shining Gum (*Eucalyptus nitens*), Mountain Ash forests support virtually the entire known distribution of the endangered Leadbeater's Possum (*Gymnobelidues leadbeateri*) (Lindenmayer, 2000). Two populations of the species are known from high elevation Snow Gum (*Eucalyptus pauciflora*) woodlands at Lake Mountain and lowland Swamp Gum (*Eucalyptus *ovata*) forests at Yellingbo, but the highest densities and primary populations of Leadbeater's Possum occur in the Mountain Ash forests of the Central Highlands of Victoria. Other species of arboreal marsupials in Mountain Ash forests have much broader distributions than Leadbeater's Possum and inhabit a broad range of vegetation types throughout Victoria as well as other parts of Australia. These include (among others) the Sugar Glider (*Petaurus breviceps*), Yellow-bellied Glider (*Petaurus australis*), Greater Glider (*Petauroides volans*) and Mountain Brushtail Possum (*Trichosurus cunninghamii*). Nevertheless, the large intact areas of old growth Mountain Ash forest such as those located within the closed water catchments of the Yarra Ranges National Park are important habitats for these species, particularly the Yellow-bellied Glider which is rare or absent from wood production Mountain Ash forests where extensive old growth stands are rare (Lindenmayer *et al*., 1999a).

Mountain Ash forests support over 30 mammal taxa (Macfarlane, 1988; Lumsden *et al.,* 1991). Several species of small mammals (Lumsden *et al*., 1991) such as the Bush Rat (*Rattus fuscipes*), Agile Antechinus (*Antechinus agilis*) and Dusky Antechinus (*Antechinus swainsonii*) reach densities higher there than almost all other terrestrial environments in Australia (Cunningham *et al*., 2005). Mountain Ash forests also support many species of bats (Lumsden *et al*., 1991, Brown *et al*., 1997).

Mountain Ash forests provide habitat for more than 100 species of birds (Loyn, 1985; 1998) and several hundred plant species (Ashton, 1986; Mueck, 1990). The diversity of reptiles in Mountain Ash forests is relatively limited, in part, because of the cool moist climatic conditions which characterise these areas (Brown and Nelson, 1993). Nevertheless, there are significant populations of several species including Spencer's Skink (*Pseudemoia spenceri*).

The invertebrate fauna of Mountain Ash forests has received relatively limited study, but appears to be diverse and includes a wide range of species from many groups (e.g. Neumann, 1991; 1992).

Given both the diversity of the biota *per se* which occurs in the Mountain Ash forests of the Central Highlands of Victoria and the conservation significance of several key species (e.g. Leadbeater's Possum), issues of the intersection of forest biodiversity conservation and wood production are quite rightly fundamental parts of appropriate forest management in the Central Highlands of Victoria (Lindenmayer and Franklin, 2002, 2003; Loyn, 2004).

CURRENT TIMBER HARVESTING PRACTICES IN VICTORIA'S MOUNTAIN ASH FORESTS

Timber and economic values

There is approximately 121 000 ha of Mountain Ash forest in the Central Highlands of Victoria and the vast majority is in public ownership (Land Conservation Council, 1994). Approximately 20-25% of the area of montane ash forest occurs within the Yarra Ranges National Park and is exempt from logging, including post-fire salvage logging (Land Conservation Council, 1994; Lindenmayer and Ough, 2006). The remaining ~75-80% of the resource is in places broadly designated for wood production. Of this, it has been estimated that ~35% is actually available for timber harvesting; some areas are unharvestable because they are in streamside zones, are on steep and rocky terrain, or occur in special protection zones for biodiversity protection (Commonwealth of Australia and Department of Natural Resources and Environment, 1997). For example, Figures 2a, 2b and 2c show forest planning maps with timber harvesting exclusions for three blocks in the Central Highlands of Victoria.

Mountain Ash forests are important for wood and paper production and a large forest industry has developed around them (Government of Victoria, 1986; Gooday *et al.*, 1997). They support major timber and pulpwood industries (Commonwealth of Australia and Department of Natural Resources and Environment, 1997). The Central Highlands region is estimated to produce 132,400m^3 net of Mountain Ash sawlogs per annum (information provided by VicForests and Department of Primary Industries, unpublished data, June 2006). These logs make a significant contribution to the operation of fifteen mills, and the towns in which they are located, by directly employing approximately 600 people in sawmills alone. It is estimated that the Mountain Ash forests of the Central Highlands region employs up to 1000 people in harvesting, haulage, sawmilling, secondary processing and pulp and paper manufacture. The Victorian Government receives approximately $11 million in revenue per annum from the sale of Central Highlands Mountain Ash sawlogs and approximately $4 million from the sale of residual logs. After processing and value-adding, the net value of the Central Highlands Mountain Ash resource makes an estimated contribution of ~$485 million to the Victorian economy (information provided by VicForests and Department of Primary Industries, unpublished data, August 2006).

Figure 2a. Forest planning maps with timber harvesting exclusions for the Ada Forest Block in the Central Highlands of Victoria.

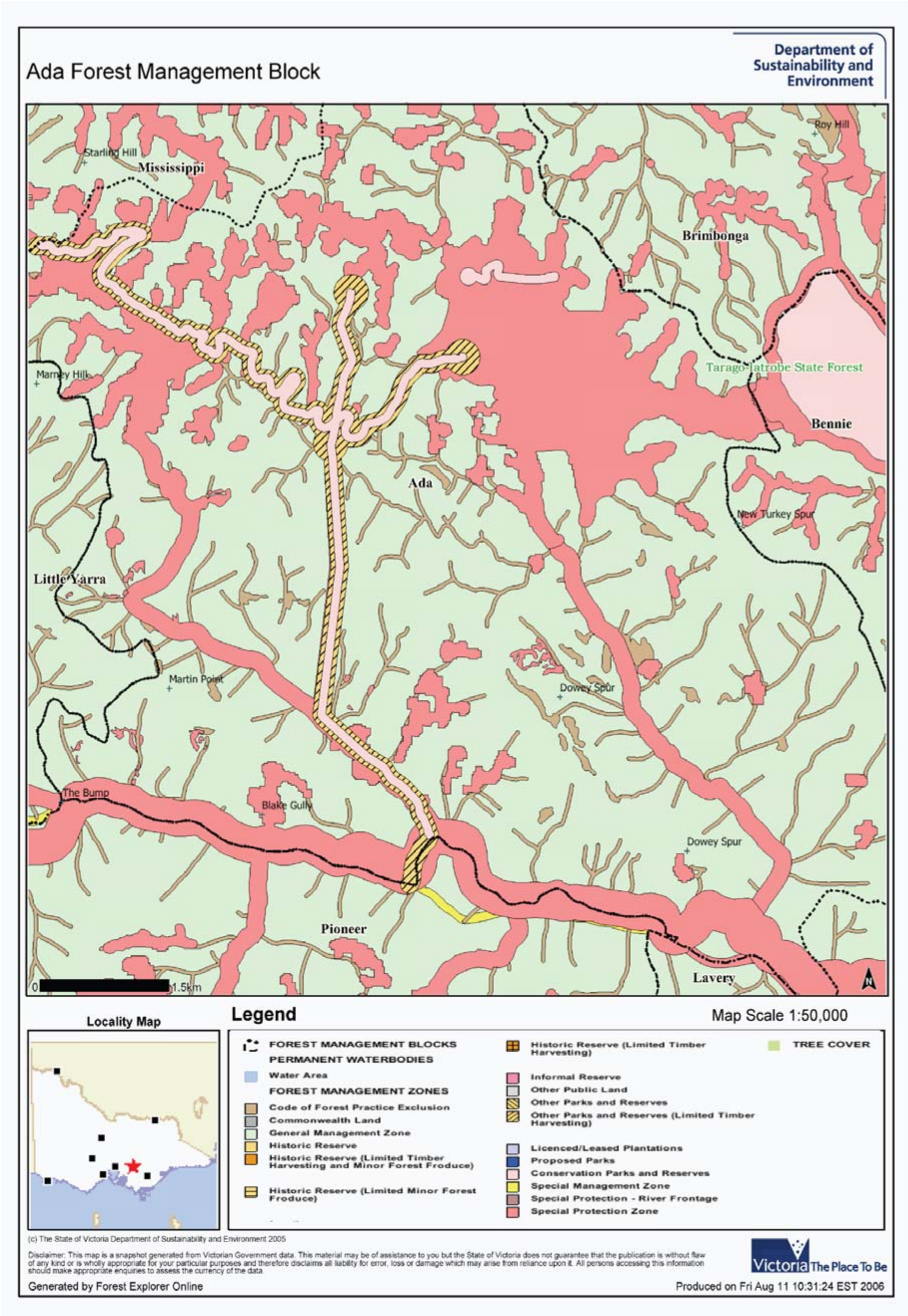


Figure 2b. Forest planning maps with timber harvesting exclusions for the Steavenson Forest Block in the Central Highlands of Victoria.

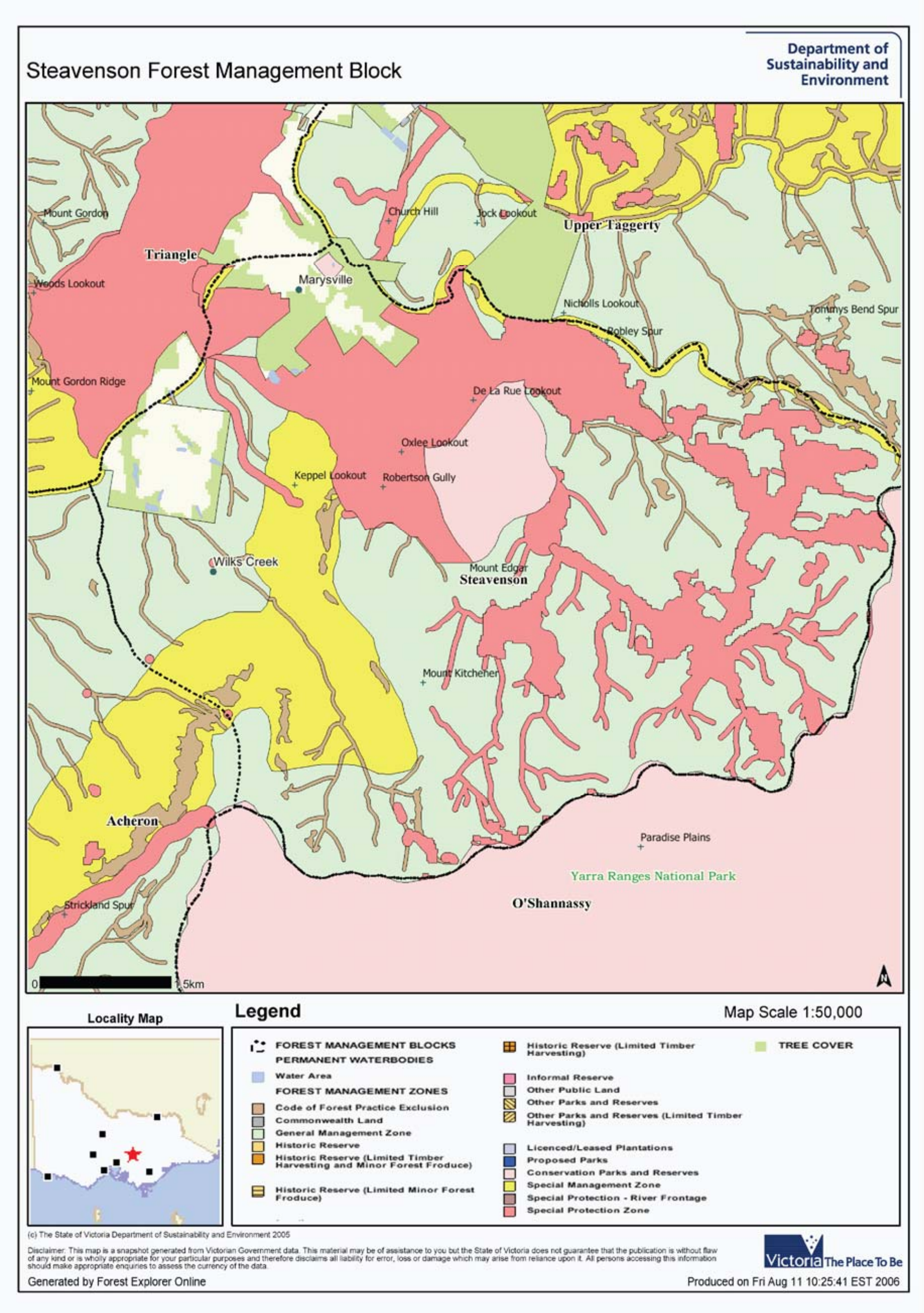
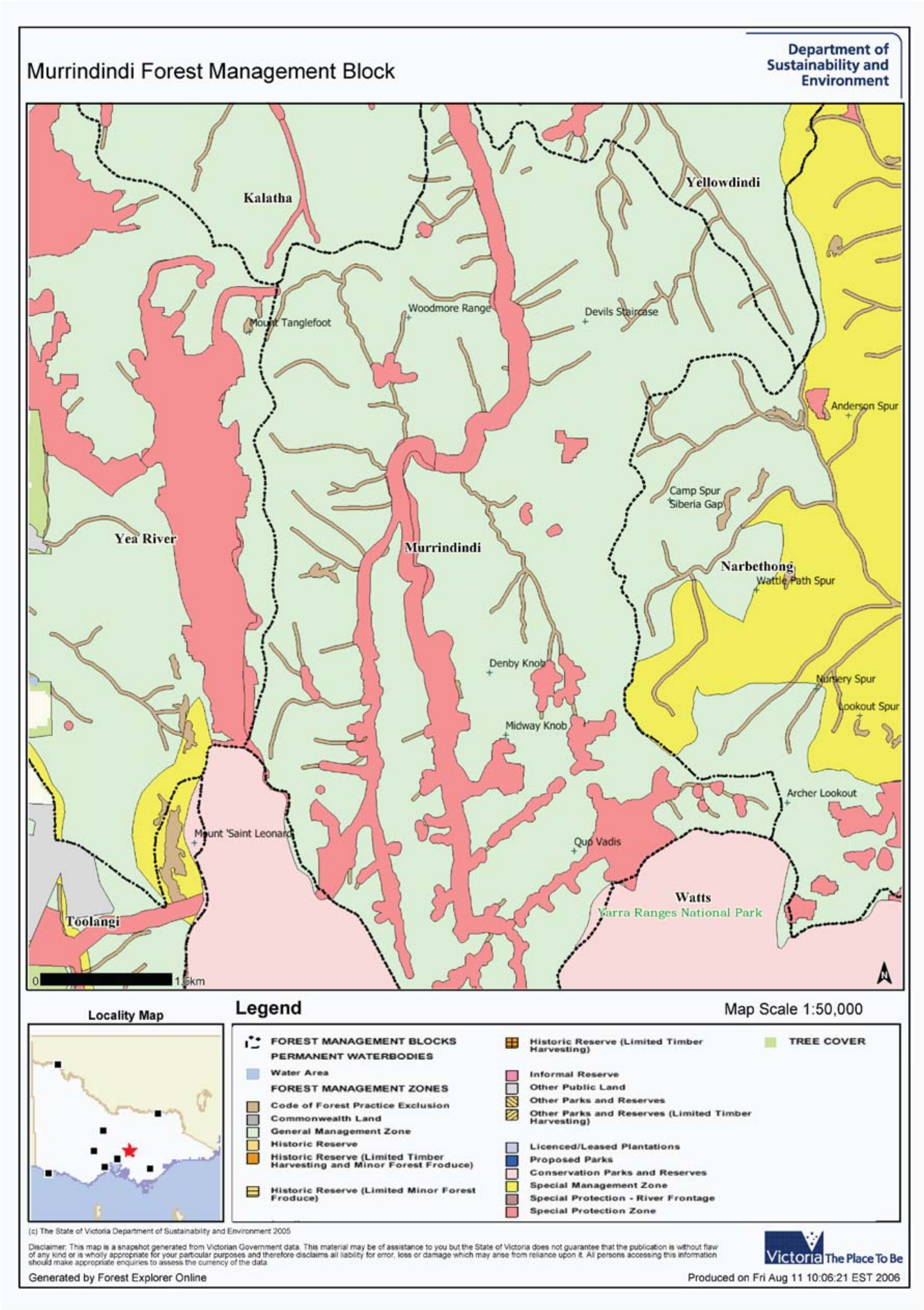


Figure 2c. Forest planning maps with timber harvesting exclusions for the Murrindindi Forest Block in the Central Highlands of Victoria.



The way forests are cut within the Central Highlands of Victoria has major implications not only for biodiversity (Lindenmayer, 1996), but also for water production as there are strong positive correlations between stand age and water yield (see O'Shaughnessy and Jayasuriya, 1991). These considerations are beyond the scope of this report and are not discussed further.

Disturbance regimes in Mountain Ash forests

There are two major forms of disturbance in Mountain Ash forest – natural disturbance (primarily wildfire) and human disturbance (logging). The two are often not "independent" because some fire-damaged stands may be subject to salvage logging (Noble, 1977; Lindenmayer and Ough, 2006). Other kinds of natural disturbance in Mountain Ash forests include windthrow and mechanical damage resulting from snow storms (particularly in the understorey) as well as insect attack.

Natural disturbance regimes

Wildfire is the main form of natural disturbance in Mountain Ash forests (Ashton, 1981; Attiwill, 1994). Many major fires have occurred in the past 400 years with the largest and most extensive in 1939 (Gill, 1981). Stands dating from the extensive 1939 conflagration dominate the Central Highlands of Victoria and comprise more than 70% of the ash-type eucalypt forest in the region.

The intensity of wildfires is highly variable (Mackey *et al*., 2002) and major conflagrations can be stand-replacing events in which virtually all dominant overstorey ash-type trees are killed. Large areas of predominately even-aged Mountain Ash forest presently characterize the landscape in the Central Highlands of Victoria (Commonwealth of Australia and Department of Natural Resources and Environment, 1997). Young seedlings germinate from seed released from the crowns of burnt mature ash eucalypts to produce a new even-aged regrowth stand (Ashton, 1976). These processes make it possible to readily determine the age of the dominant overstorey in a stand. For example, using forest mapping in closed water catchments and production forests that was derived from a range of sources, Lindenmayer *et al*. (2000a) identified ten different fire-derived age classes of Mountain Ash forest; those dating from mid 1700's, 1824, 1851, 1895, 1905, 1908, 1926, 1932, 1939, 1948, 1983

Although high-intensity fires in Mountain Ash forests can largely be overstorey-replacing events, they nevertheless leave many kinds of biological legacies (Ough, 2001; Lindenmayer and Franklin, 2002). For example, a wide range of plant species survive and resprout vegetatively after wildfires

(Ough, 2001; Lindenmayer and Ough, 2006). Similarly, large diameter fire-damaged living and dead standing trees occur in many stands of young regrowth montane ash forest (Lindenmayer *et al.*, 1991a, 1997). Such trees often contain hollows that provide den and nest sites for many species of arboreal marsupials (Lindenmayer *et al.*, 1991b) as well as birds and bats (Loyn, 1985; Gibbons and Lindenmayer, 2002).

Wildfires in Mountain Ash forests not only produce important standing biological legacies, but they also significantly influence conditions on the forest floor. Trees that are killed and collapse onto the forest floor in burned stands become key habitat components for a range of vertebrates. Large decaying logs in montane ash forests are also important substrates for the germination of rainforest plants (Howard, 1973), tree ferns (Ashton, 2000) and the development of dense and luxuriant mats of bryophytes (Ashton, 1986, 2000).

High-intensity overstorey-replacing fires represent one disturbance pathway in Mountain Ash forests. Lower intensity fires also occur and these lead to only partial stand replacement because some trees survive (Smith and Woodgate, 1985; Lindenmayer and Franklin, 1997). Regeneration of young trees in these forests creates multi-aged stands comprised of ash-type eucalypt trees of two (and sometimes more) distinct age cohorts (Lindenmayer *et al.*, 1999a). The understorey is also multi-aged in these forests, with plants regenerating from seed after each fire event and others surviving many fires.

Human disturbance regimes – clearfell logging

Logging is the predominant form of human disturbance in Mountain Ash forest and the most widely applied harvesting method is clearfelling. Virtually all standing trees are removed over 15-40 ha in a single operation (Squire *et al.*, 1991; Lutze *et al.*, 1999). The Code of Forest Practice allows for up to three adjacent 40 ha coupes (Department of Natural Resources and Environment, 1996) although rarely this occurs. The average size of coupes in Central Highlands of Victoria in the 1990s was 16 ha because of topographic constraints on where logging could take place. Nevertheless, some areas have been subjected to extensive harvesting over the past 30-50 years (e.g. the Toolangi Forest District and the Toorongo Plateaux) and they contain limited areas of old growth and/or unlogged ash forest.

Logging is followed by a high-intensity prescription fire to burn logging debris (e.g., bark, tree crowns, and branches), creating a nutrient-rich ash seedbed to promote the regeneration of a new stand of eucalypts. The rotation time between clearfelling operations is nominally 80 years

(Government of Victoria, 1986), although the Timber Industry Strategy permits logging below the nominal rotation age to regulate age classes and provide for smooth timber flows (Department of Natural Resources and Environment, 2002). This also means that some areas might be harvested at rotation intervals longer than the nominal 80 year rotation.

The effects of conventional clearfelling operations on biodiversity have been the subject of an array of detailed studies in Mountain Ash forests over the past 23 years (e.g. Lindenmayer, 2000; Ough, 2001; Lindenmayer and Franklin, 2002; Loyn, 2004). Some of the impacts of traditional clearfelling include (see also Tables 1 and 2):

- Hollow-bearing trees are significantly reduced in abundance (Lindenmayer *et al.*, 1991a). These trees are nesting and denning sites for arboreal marsupials including Leadbeater's Possum.
- Plant species composition and the trajectory of understorey development is significantly altered by clearfelling (Ough, 2001; Ough and Murphy, 1996, 2004; but see Harris, 2004). Thickets of long-lived fire-resistant understorey plants are severely depleted or lost (Mueck *et al.*, 1996).
- Landscape composition is altered and the limited remaining areas of old-growth forest (now reserved from logging) are scattered among extensive stands of young forest that have regenerated after logging and fire. These changes have negative effects on some wide-ranging vertebrates such as the Yellow-bellied Glider and the Sooty Owl (Milledge *et al.*, 1991; Lindenmayer *et al.*, 1999b; Incoll *et al.*, 2000)

The impacts of clearfelling are discussed in more detail in the section below on the justification of the VRHS in Mountain Ash forests.

Table 1. Differences in the effect of clearfelling and natural wildfires on stand structure in Mountain Ash forest

Attribute	Forest response after natural wildfires	Forest response after clearfelling
Forest floor architecture	Large diameter logs often occur	Average number, size and volume of logs reduced
Spacing of hollow trees in the forest	Clustered	Regular or random
Standing life of hollow trees	Up to, or more than, 50 years	Trees removed during logging or destroyed by regeneration fire
Range of forms of living trees and snags	Often two or more morphological forms present	Trees removed during logging
Survival of hollow trees	Variable – it depends on stand age and fire intensity	Stems removed or severely burnt
Age class structure stands	Multi-aged stands may occur	Even-aged stands
Plant species composition reduced	Variable, depending on fire intensity	Tree ferns, fire resistant understorey thickets and rainforest trees depleted

Table 2. Landscape-level differences in patches between clearfell logging and wildfire

Form of disturbance Attribute	Wildfire	Clearfell logging
Patch no.	Variable but can be small depending on spatial contagion	Deterministic and set by prescription for number of harvest units
Patch size	Highly variable, but can be very large	Deterministic and set by prescription for cutover size
Patch location	Variable – depending on climate, terrain and other factors	Set by prescription and accessibility
Patch pattern	Often displays contagion	Usually dispersed
Patch boundary	Often diffuse	Sharp

THE NEED FOR MULTI-SCALED STRATEGIES FOR BIODIVERSITY CONSERVATION IN WOOD PRODUCTION FORESTS

Biodiversity conservation is a critical element of ecologically sustainable forest management. Most programs to sustain forest biodiversity have focused on the creation of protected areas. Reserves are a critical part of any credible strategy for conserving forest biodiversity (Norton, 1999), but reserves alone are insufficient to adequately conserve forest biodiversity (Sugal, 1997; Lindenmayer and Franklin, 2002). Off-reserve conservation strategies are essential and they need to be implemented at a range of spatial scales for a range of key reasons. Indeed, this is entirely congruent with legislation and policy directives (e.g. the Victorian Flora and Fauna Guarantee Act 1988) which specify that species should be conserved throughout their known natural ranges – i.e. both in large ecological reserves and off-reserve areas (see also Commonwealth of Australia, 1992).

Multi-scaled approaches at scales from a few square meters to thousands of hectares; (from individual trees to a large ecological reserves) are important for a range of other reasons:

- *Different species have different spatial and other requirements.* Suitable habitat may vary from extensive intact stands for area-sensitive organisms like some wide-ranging carnivores (e.g. large forest owls; Milledge *et al.*, 1991) to the moisture and decay conditions provided by individual logs for invertebrates (Meggs, 1997). For example, empirical studies suggest that while the provision of wildlife corridors and retained trees on logged sites will make a major contribution to the conservation of populations of the Mountain Brushtail Possum in Mountain Ash forests (Lindenmayer *et al.* 1994b), areas containing large continuous stands dominated by old growth trees will be essential for the conservation of the Yellow-bellied Glider in this same forest type (Lindenmayer *et al.*, 1999a)
- *Individual taxa respond to factors at multiple spatial scales.* The distribution and abundance of a given individual species is influenced by factors at multiple scales (Forman, 1964; Schneider, 1994). Work on Leadbeater's Possum highlights this and has demonstrated the importance of factors ranging from regional environmental conditions to the attributes of individuals nest trees (reviewed in Lindenmayer, 2000).
- *Different processes at different spatial scales are inter-dependent*. What happens at the stand level cannot be divorced from what takes place at the landscape-level and vice-

versa. A stand of old-growth surrounded by other old-growth stands may support different species assemblages than an old-growth stand embedded within an extensive region of continuous clearfelling (Loyn, 1998; Incoll *et al.*, 1999). Similarly, a landscape is comprised of an array of stands and the structural composition of these stands can influence species occurrence at the landscape level. A lack of suitable habitat within many different stands may combine to preclude a species from entire landscapes (Lindenmayer *et al.*, 1999a).

A multi-faceted approach to management has another advantage. If any one strategy is found to be ineffective (e.g. the establishment of wildlife corridors), others (like tree retention on logged areas) will be in place that might better protect sensitive elements of forest biodiversity. This is a form of 'risk-spreading' in forest management (Lindenmayer and Franklin, 1997); it reduces over-reliance on one strategy which may subsequently be found to be of limited value in meeting specific conservation objectives. Risk-spreading is particularly appropriate for biodiversity conservation because it is often extremely difficult to accurately forecast the response of species to landscape modification (see Mac Nally *et al.,* 2000). Another advantage of multiple management strategies is that a given approach may generate positive benefits for another strategy implemented at a different spatial scale. For example, increased levels of stand retention on logged sites can reduce rates of windthrow and vegetation loss in adjacent wildlife corridors, riparian areas, and small reserves within wood production areas (Lindenmayer and Franklin, 2002).

Lindenmayer *et al.* (2006) have argued that multi-scaled strategies for biodiversity conservation need to be targeted at achieving the maintenance of habitat for the full range of biota via four key guiding principles. These principles to meet this objective are:

- Maintenance of connectivity across a landscape.
- Maintenance of landscape heterogeneity.
- Maintenance of structural complexity and plant species diversity within managed stands.
- Maintenance of the integrity of aquatic ecosystems including hydrological and geomorphological processes.

There are strategies for environmental management and biodiversity conservation at multiple spatial scales within the Mountain Ash forests of the Central Highlands of Victoria. There is a substantial protected area in the Yarra Ranges National Park where logging and post-fire salvage harvesting is excluded. Within wood production areas, there is a network of wildfire corridors and riparian buffers together with unlogged stands on steep and rocky terrain. Management zoning for Leadbeater's Possum is another mid-spatial-scale conservation strategy that has been implemented within forests broadly designated for wood production. The zoning partitions wood production forests into three types of areas: **Zone 1**: where the conservation of Leadbeater's Possum is a priority; **Zone 2**: where wood production is a priority; and **Zone 3**: where joint land use is a priority (Macfarlane *et al.*, 1998). Finally, at the stand level logging operations are governed by a Code of Forest Practices (Department of Natural Resources and Environment, 1996) that encompasses a wide range of environmental considerations including the retention of trees on logged sites.

However, while these current multi-scaled approaches are useful, there are problems at the stand level because:

- Retained trees often are destroyed or badly damaged by high-intensity slash fires, and trees that do remain standing often have poor survival rates (Lindenmayer *et al.*, 1990a; 1997a).
- Tree retention strategies, even if increased by 100% over those presently recommended, will still leave significantly fewer cavity trees in logged areas than occurred in unmanaged stands (Ball *et al.*, 1999).
- Numbers of retained trees may be insufficient to meet the habitat requirements of Leadbeater's Possum as well as wide range of other cavity-dependent taxa (Gibbons and Lindenmayer, 1997, 2002).

Hence, current clearfelling operations significantly reduce levels of stand structural complexity and new ways need to be employed to address this problem and ensure the maintenance of habitat across a range of spatial scales as proposed under the multi-scaled approach to biodiversity conservation recommended by Lindenmayer and Franklin (2002) and Lindenmayer *et al.* (2006).

MOTIVATIONS FOR ALTERNATIVE SILVICULTURAL SYSTEMS – THE MAINTENANCE OF STAND STRUCTURAL COMPLEXITY

Clearfelling may lead to marked medium to long-term changes in stand structure and plant species composition (Halpern and Spies, 1995; Lindenmayer and Franklin, 1997; Bunnell *et al.*, 2003) which can negatively impact not only on taxa dependent on particular structural attributes but also on presently abundant generalist species (Niemela *et al.*, 1993; Lindenmayer and Franklin, 1997). For example, it can impair the suitability of foraging habitat for vertebrates, such as birds and bats (Brown *et al.*, 1997; Woinarski *et al.*, 1997). Therefore, a key motivation for the application of silvicultural systems alternative to widely applied ones like clearfelling is the maintenance of stand structural complexity (Franklin *et al.*, 1997) and, in turn, the maintenance of opportunities for a wide range of species and ecological processes associated with structurally complex forests (Lindenmayer *et al.*, 2006).

Stand structural complexity includes a wide variety of features such as:

- Trees from multiple age cohorts within a stand.
- Large living trees and their abundance and distribution within a stand.
- Large dead trees and their abundance and distribution within the stand.
- Large diameter logs on the forest floor.
- Vertical heterogeneity created by multiple or continuous canopy layers.
- Thickets of understorey vegetation.

Structural complexity embodies not only particular types of stand attributes, but also the way they are spatially arranged within stands. For example, the juxtaposition of overstorey and understorey trees from multiple age cohorts within a stand contributes to vertical heterogeneity in forests (Franklin and van Pelt, 2004). Structural complexity *per se* is a common feature of all natural temperate forests throughout the world (e.g. Franklin *et al.*, 1981; Noel *et al.*, 1998), and high levels of spatial heterogeneity are characteristic of essentially all old-growth forests (Franklin *et al.*, 2002; Franklin and van Pelt, 2004), although each type differs in specific details.

Active stand management to maintain structural complexity

The potentially negative effects of logging on key ecological processes and biodiversity may be partly mitigated by the retention of structural elements at the time of harvesting (Hansen *et al.,* 1991; Franklin *et al.,* 1997; Hazell and Gustafsson, 1999). Maintenance of stand structural complexity can be valuable in four ways:

- Lifeboating
- Structural enrichment
- Connectivity
- Habitat heterogeneity.

Maintenance of stand complexity may allow organisms to persist in logged areas from which they would otherwise be eliminated – a 'lifeboating' function (Franklin *et al.*, 1997). Some species may remain in logged areas if some of the original key structures are retained or microclimatic conditions are maintained within tolerance levels. Examples include:

- Species which display long-term site affinity (Van Horne, 1983) like parrots (Webster, 1988; Manning *et al.*, 2004) and some types of arboreal marsupials (Tyndale-Biscoe and Smith, 1969; Kavanagh, 2000). And,
- Plants that persist on large trees such as epiphytes including lichens and mosses (Hazell and Gustaffson, 1999; Coxson and Stevenson, 2005).

Very long-term persistence or continuity of particular structural features through many successive generations on the same site may allow insects and threatened species of fungi to persist within logged Norwegian forests (Svendrup-Thygeson and Lindenmayer, 2003). Such ecological 'continuity' is regarded as a measure of forest sustainability by forest managers in that country. Retaining freshly cut logs within harvested forests facilitates the persistence of diverse groups of fungi that might otherwise be lost from production landscapes (Niemelä *et al.*, 1995). Living and dead trees left in these environments are also used by a wide range of invertebrates (Schowalter *et al.*, 2005; Pihaja *et al.*, 2006) including saproxylic beetles (Niemelä *et al.*, 1993, 1995; Kaila *et al.*, 1997).

Maintenance of stand structural complexity may allow logged and regenerated stands to more quickly return to suitable habitat for species that have been displaced – a 'structural enrichment' function (Franklin *et al.*, 1997). This can limit the time logged areas remain unsuitable habitat (Lindenmayer and Franklin, 1997). Several studies have shown that retained trees can promote the recolonisation of logged and regenerated forests by birds (e.g., Recher *et al.*, 1980; Kavanagh and Turner, 1994; Hansen *et al.*, 1995).

Maintenance of stand structural complexity may enhance dispersal of some animals through a cutover area – a 'connectivity' function (Franklin *et al.*, 1997). For example, retention of logs provides travel routes for rodents and other small mammals (Braithwaite, 1979) and allows them to disperse into, and through, disturbed areas (Maser *et al.*, 1977). This has been termed 'softening the matrix' (Franklin, 1993). It may be particularly useful for taxa that employ random dispersal strategies and do not use wildlife corridors (Murphy and Noon, 1992; Lindenmayer and Franklin, 2002).

Maintenance of structural complexity may be essential to provide the within-stand variation in habitat conditions required by some taxa – a 'habitat heterogeneity' function. Structural complexity (e.g. trees of multiple ages or multiple layers of understorey and overstorey vegetation) can provide optimum habitat for a range of forest taxa, including some habitat specialists (Franklin, 1993b). It also may provide more niches within a stand with corresponding benefits for species richness (Lindenmayer *et al.*, 1991a; Niemela *et al.*, 1996). For example, it can provide for the spatial juxtaposition of early successional (regrowth) and older growth vegetation needed by particular species (e.g. Leadbeater's Possum).

THE VARIABLE RETENTION HARVEST SYSTEM (VRHS)

The Variable Harvest Retention System is an emerging silvicultural system designed to better maintain and perpetuate stand structural complexity (Franklin *et al.*, 1997). The overarching goal of the VRHS is to develop structurally complex managed forests that meet explicitly defined management objectives. Each prescription is expected to be a unique solution to such key questions as the type, density and spatial arrangement of retained structures. The following sections define the VRHS and outline cases where is has been applied overseas and in Australia.

A definition of the Variable Retention Harvest System

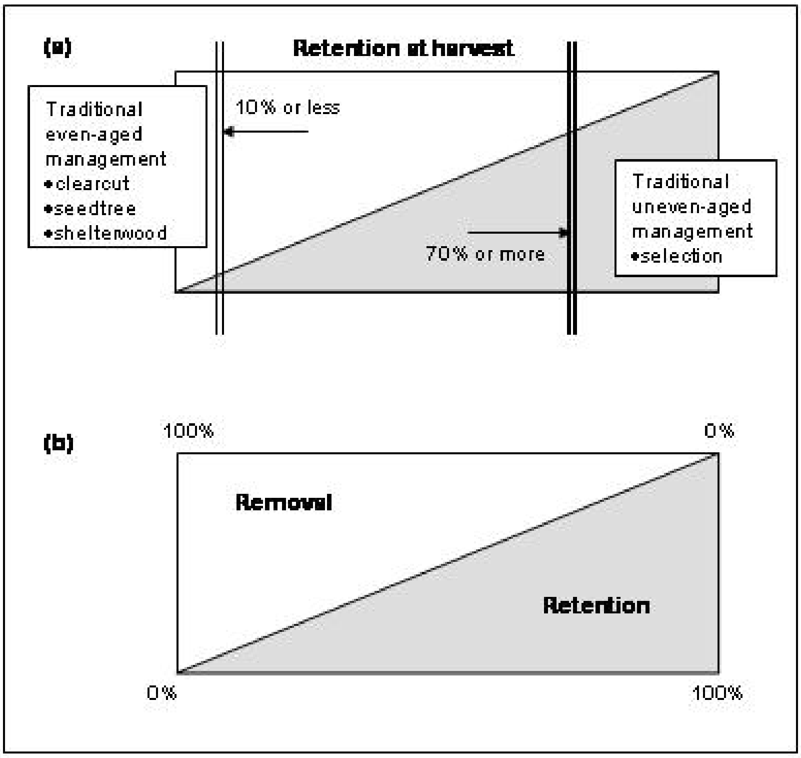
The Variable Retention Harvest System (VRHS) is a systematized approach to structural retention that is defined as:

> *"an approach to harvesting based on the retention of structural elements from the harvested stand (e.g. living trees, dead trees, logs, etc.) for integration into the new stand to achieve various ecological objectives"*
> (The Society of American Foresters: Helms, 1998).

Implicit in the VRHS is acceptance of the idea that some of the productive capacity and economic value of a stand will be devoted to the maintenance of biodiversity (and other values like the maintenance of ecosystem processes) rather than maximizing the regeneration and growth of commercial tree species (Franklin *et al.*, 1997). The consensus among forest ecologists is that the VRHS concept must provide:

- A minimum level of retention necessary for the practice to be socially credible and ecologically effective.
- The retention of sufficient large structures (e.g. dominant living trees and large dead trees with hollows).
- The reasonable spatial distribution of retained structures (i.e. retention cannot be concentrated only along drainage lines or the edges of a harvest unit). And,
- The retention of structures for at least one rotation – i.e. structures that are retained only temporarily, such as a shelterwood overstorey do not meet the goal of structural retention.

Figure 3. The variable retention harvest concept (modified from Franklin *et al.,* 1997).



Beyond this broad consensus, VRHS encompasses a broad continuum of silvicultural prescriptions (see Figure 3). It is flexible in terms of levels of stand retention and the array of structural conditions that can be created (e.g. even-aged, multi-aged, or all-aged) (Figure 3).

The spatial pattern of structural retention in VRHS

The spatial arrangement of structures within stands is as important to structural complexity as the diversity and density of individual structures (Franklin *et al.*, 1997, 2002). Two contrasting spatial patterns for retention are:

- **Dispersed retention** in which structures are dispersed uniformly over a harvested area. And,
- **Aggregated retention** in which structures are concentrated in aggregates or small forest patches (sometimes called "islands") within a harvested area.

Both the dispersed and aggregated patterns of structural retention have particular advantages and disadvantages. These depend upon such variables as the objectives of structural retention, the biology of taxa targeted for management, potential loss of retained structures (such as to windthrow), and operational constraints, such as worker safety and logging costs (Table 3). There are many variants on the dispersed and aggregated approaches, including combinations of both approaches.

Dispersed retention

A dispersed pattern of structural retention in a harvest unit may be desirable or necessary to achieve specific conservation goals (Table 3). An example is the provision for well-distributed populations of trees with hollows and logs. Some vertebrates require dispersed cavity trees, such as arboreal marsupials (Lindenmayer *et al.*, 1990b) and large parrots (Rowley and Chapman, 1991; Nelson and Morris, 1994; Krebs, 1998). This is necessary to accommodate the social behaviour of these territorial species. Dispersed retention is also superior in achieving modified environmental conditions (e.g. temperature, relative humidity, and insolation) throughout a harvested area, which can be important to the survival of some organisms (e.g., Naughton *et al.*, 2000).

Aggregated retention

Aggregated retention involves the retention of small, intact areas of forest in harvest units. The appropriate size of aggregates depends upon many variables including forest and conservation management objectives, the silvicultural system being applied in the harvest unit, and the forest type. Some variability in aggregate size is probably also appropriate. Aggregates currently being retained in clearcut harvest units in north-western North America typically vary in size from 0.4 to 1.5 ha (Franklin *et al.*, 1997). Aggregates of 0.2 ha in size have been used in shelterwood-harvested *Nothofagus* forests in Tierra del Fuego, South America.

Aggregates are intended to be **a part of** and **not apart from** the harvested stand in which they are located. The objective of aggregated retention is **not** to create large forest islands that provide true forest-interior conditions – this is the role of intermediate and large ecological reserves. Aggregates provide small distributed refugia within harvest units that function as lifeboats for biodiversity and structurally enrich the managed stand throughout the rotation. In some forest ecosystems they may mimic the remnant (unburned) patches left by wildfire (British Columbia Ministry of Forests, 1995; Delong and Kessler, 2000; Lindenmayer and Noss, 2006).

Table 3. Contrasting effects of dispersed and aggregated structural retention (from Franklin *et al.*, 1997).

	Pattern of Retention	
Objective on Harvest Unit	**Dispersed**	**Aggregated**
Microclimate modification	Less, but generalized over harvest area	More, but on localized portions of harvest area
Influence on geohydrological processes	Same as above	Same as above
Maintenance of root strength	Same as above	Same as above
Retain diversity of tree sizes, species, and conditions	Low probability	High probability
Retain large-diameter trees	More emphasis	Less emphasis
Retain multiple vegetation (including tree) canopy layers	Low probability	High probability
Retain snags	Difficult, especially for soft snags	Readily accomplished, even for soft snags
Retain areas of undisturbed forest floor and intact understorey community	Limited possibilities	Yes, can be as extensive as aggregates
Retain structurally intact forest habitat patches	Not possible	Possible
Distributed source of coarse woody debris (snags and logs)	Yes	No
Distributed source of arboreal energy to maintain below-ground processes and organisms	Yes	No
Carrying capacity for territorial snag- and/or log-dwelling species	More	Less
Windthrow hazard for residual trees	Average wind firmness greater (strong dominants), but trees are isolated	Average wind firmness less, but trees have mutual support
Management flexibility in treating young stands	Less	More
Harvest (e.g., logging) costs	Greater increase over clearcutting	Less increase over clearcutting
Safety issue	More	Less
Impacts on growth of regenerated stand	More, generalized over harvest area	Less, impacts are localized

Aggregated retention offers a number of environmental and practical advantages over dispersed retention (Franklin *et al.,* 1997) (Table 3). Assuming that aggregates are fully protected from logging, slash disposal, and site preparation operations, aggregated retention is designed to retain:

- A wide range of structures, including different sizes and conditions of living and dead trees and logs (Gibbons and Lindenmayer, 1997, 2002).
- Multiple or continuous canopy layers (Franklin *et al*., 1997).
- Undisturbed understorey and forest floor conditions (Ough and Murphy, 1998). And,
- Small areas where environmental conditions come close to those of an intact forest, even though they are not true forest-interior conditions (Halpern and Raphael, 1999).

Aggregated retention can allow the goals of understorey and overstorey vegetation retention to be achieved simultaneously, as in the 'understorey island' strategy developed for Victorian ash forests by Ough and Murphy (1998).

With regard to management and operational considerations and compared with dispersed retention, aggregated retention typically:

- Provides safe working conditions (by creating no-work zones) but still allows hazardous structures, such as dead hollow-bearing trees to be retained (Hope and McComb, 1994; Hickey *et al.,* 1999). Some authors view aggregated retention as one of the few ways to protect dead trees with hollows without increasing risks to timber workers, such as 'Wildlife Tree Patches' in British Columbia (Fenger, 1996). In these cases, aggregates may need to be of sufficient size to overcome worker safety issues; i.e. collapsing dead or highly decayed trees can not reach workers operating in the harvest zone outside retained patches.
- Allows for efficient logging operations (Beese *et al*., 2005). And,
- Limits the area in which tree growth and reproduction may be suppressed by retained overstorey trees (Incoll, 1979; van der Meer *et al*., 1999).

Aggregated retention is an efficient strategy for lifeboating many elements of biodiversity within a logged area. Stand islands (aggregates) provide more niches and, consequently, more species are likely to persist using aggregated than dispersed structural retention (Berg *et al.,* 1994). Some animals depend upon the adjacency of overstorey and understorey structures, such as using overstorey trees for nesting and understorey plants for foraging (Lindenmayer *et al.*, 1991a)..

Loss of retained living trees and dead trees to windthrow and exposure may be less with aggregated than dispersed retention under some circumstances. Aggregated retention of 'wildlife habitat clumps' was adopted in harvested forests in Tasmania because of concerns about windthrow (Duhig *et al.,* 2000). Other approaches to minimizing windthrow include laying out aggregates with streamlined shapes, locating them in topographically sheltered parts of harvest units, and the incorporation of sound (decay-free) dominant trees (Gibbons and Lindenmayer, 1996; Franklin *et al.,* 1997).

In prescribing the location, size, and shape of aggregates and the structures to be retained, many factors have to be considered including:

- Local site conditions.
- Stand conditions, including such questions as to whether aggregates are to be a representative cross-section of the stand being harvested.
- Biology of the taxa targeted for management.
- Patterns created by natural disturbance regimes and spatial variation in quantities of biological legacies across landscapes and their abundance and distribution within the stand.
- Types and intensities of other matrix-based management strategies (e.g. riparian buffers and mid-spatial-scale protected areas).
- Management objectives.

The degree to which the aggregates are representative of the stand (point 2 above) – is an important issue. Structural features, such as large dead trees with hollows or large logs can be used as the focal or 'anchor points' for aggregates. Biasing aggregate locations toward parts of a harvest unit that are non-forested (e.g. wetlands) or of low productivity and occupied primarily by unmerchantable trees is **not** appropriate if the goal is to lifeboat forest biodiversity and structurally enrich the managed stand. In some forest types it may be inappropriate to locate, for example, retained aggregates only in riparian zones because mid-slope and up-slope tree species are not represented and the generally shallower root systems of trees in gullies may make them more susceptible to windthrow. In other cases, it may be appropriate to locate aggregates around biotically-rich non-forested features, including streams, rock outcrops or wetlands, particularly if the aggregates also incorporate the structural complexity of the surrounding stand. In the Queen Charlotte Islands of British Columbia, culturally modified trees such as those used in the construction of canoes by indigenous people are often used as anchor points in aggregated retention (Lindenmayer and Franklin, 2002).

The biology of target taxa can be particularly important. Haesler and Taylor (1993) believed that limiting retained trees to riparian buffers might exacerbate patterns of territorial behaviour among Tasmanian forest birds and thereby reduce occupancy rates of trees with hollows. Increased stand complexity through structural retention may not affect all species equally (Newton, 1994). In the case of cavity-dependent vertebrates, Gibbons and Lindenmayer (2002) speculated that the retention of trees with hollows in Australian forests might benefit larger more aggressive generalist taxa than smaller species with more specialized nest and den requirements.

As with all forest management strategies, there is no specific set of prescriptions that can be applied generically and uncritically to all stands. There is an infinite variety of forest, environmental, and social conditions and the most effective structural retention design will be based on considerations of the natural history and management experiences of the particular location, as well as common sense. Moreover, extensive stand retention may not be necessary (nor feasible) on every hectare of production forest; it may not even be possible in some locations for reasons such as worker safety.

Applying retention uniformly on all harvest units may homogenize landscapes just as with widespread clearfelling. Dispersed retention will be most appropriate for some species and ecological processes and aggregated retention (or a combination of both) for others. Hence, spatial variation in structural retention is appropriate and is a technique for risk-spreading. That is, variability in stand conditions increases the chance that suitable habitat will occur for most species in at least part of a landscape.

OVERSEAS ORIGINS AND APPLICATIONS OF THE VRHS CONCEPT

VRHS first emerged as a concept in the recommendations of the Scientific Panel for Sustainable Forestry Practices in Clayoquot Sound (1995) on the west coast of Vancouver Island, British Columbia. The Scientific Panel recommended that the government:

> *"Replace conventional silvicultural [clearfell] systems in Clayoquot Sound with a 'variable retention silvicultural system'. The purpose of this system is to preserve, in managed stands, far more of the characteristics of natural forests. The variable retention harvest system provides for the permanent retention after harvest of various forest structures or habitat elements, such as large [living] decadent trees, snags[large dead trees], logs, and downed wood from the original stand that provide habitat for forest biota."*

The Scientific Panel for Clayoquot Sound recommended the retention of at least 15% of the forest. This retention was to occur primarily as 0.1 to 1 ha aggregates representative of the forest conditions within and well dispersed throughout the cutting units. Furthermore, aggregates were to be spatially distributed so that all parts of the harvest unit were within two tree heights of an aggregate or stand edge.

Subsequently, the MacMillan-Bloedel Corporation (the largest wood products company in Canada at that time) announced that it was phasing out clearfelling and adopting the VRHS as its primary silvicultural system (Beese and Bryant, 1999; Dunsworth and Beese, 2000). Because government cutting permits could be issued only for officially recognized silvicultural systems, a legal definition of VRHS in British Columbia was adopted:

> *"Retention system means a silvicultural system that is designed to: (a) retain individual trees to maintain the structural diversity over the area of the cut block for at least one rotation, and (b) leave more than half of the total area of the cut block within one tree height from the base of a tree or group of trees, whether or not the group of tree or group of trees is within the cut block."*

The BC Coastal Forest Project of Weyerhaeuser Corporation (the successor to MacMillan-Bloedel) continued to refine the application of structural retention (Mitchell and Beese, 2002; Bunnell *et al.*, 2003; Beese *et al.*, 2005) as has the Cascadia Company which recently took over the land holdings formerly managed by the Weyerhaeuser Corporation (W. Beese, personal communication [June, 2006]). A large number of diverse projects are associated with the project, ranging from the application of VRHS and the maintenance of soil function (Grayston *et al.*, 2006) to the response of vertebrates (Wind and Dunsworth, 2006) and regeneration effectiveness and harvest damage to retained patches (D'Angou, 2006). On-ground prescriptions in the VRHS project have been specifically designed to balance ecological and economic objectives (Weyerhaeuser, 2000; Swift, 2006) and the forest managers involved with the project are among the foremost practitioners of the VRHS in North America (Bunnell and Dunsworth, 2003). It is notable that the VRHS system is now applied in 50-60% of the Coastal Forest Region of British Columbia (Swift, 2006) and has been adopted by most of the major timber companies (L. Kremsater, personal communication).

Table 4. International examples of the application of VRHS.

Location	Citations
Coastal Forests, British Columbia, Canada	Dunsworth and Beese (2000); Bunnell et al. (2003), Outerbridge and Trofymow (2004), Swift (2006)
Interior and boreal forests of Canada	Hollstedt and Vyse (1997), Sullivan and Sullivan (2001), Coxson and Stevenson (2005), Deans et al. (2005)
Washington and Oregon, U.S.A	Halpern and Raphael (1999), Lazaruk *et al.* (2005), Nelson and Halpern (2005), Schowalter *et al.* (2005)
California, USA	Franklin and Fites-Kaufmann (1996)
Maine, north-eastern USA	Roe and Ruesink (2000), Seymour *et al.* (2002)
South-eastern USA	Engstrom *et al.* (1996), Mitchell *et al.* (2000)
Patagonia, Argentina	Rebertus *et al.* (1997)
Sweden, Finland	Fries *et al.* (1997), Korpilahti and Kuuluvainen (2002), Hautala *et al.* (2004)

Other jurisdictions in Canada have adopted the VRHS. It is being used in some areas of inland forest in British Columbia (e.g. the Sicamous Creek trial near Kamloops in interior British Columbia [Hollstedt and Vyse, 1997]), although extensive areas of inland boreal and mid-boreal forest affected by beetle infestations are subject to traditional clearfelling (Government of British Columbia, 2006). Structural retention is mandated for essentially all regeneration harvest units on federal lands within the range of the Northern Spotted Owl (*Strix occidentalis caurina*) in the northwestern USA (USDA Forest Service and USDI Bureau of Land Management, 1994; Lindenmayer and Franklin, 2002). The DEMO (Demonstration of Ecosystem Management Options) project in the Douglas-fir forests in western Oregon and Washington, U.S.A. is a major experimental test of alternative retention approaches (Halpern *et al.*, 1999).

Australian applications of the VRHS concept

The silvicultural systems trial at the Warra Long Term Ecological Research (LTER) site in the southern Australian State of Tasmania is a useful example of a study to develop new silvicultural systems that better integrate wood production with biodiversity conservation and other environmental values (Hickey *et al.*, 1999). Clearfelling is the traditional harvesting system in the wet forests of southern Tasmania. There have been concerns about the negative environmental impacts of clearfelling including detrimental effects on biodiversity. The organization responsible for harvesting on public land (Forestry Tasmania) instigated a major cutting trial to explore methods to manage the wet eucalypt forests of southern Tasmania. The range of treatments tested (and their potential benefits) is outlined in Table 5. Some entirely new methods of harvesting are showing promise, such as the 30% aggregated retention or 'fairway' system with snig tracks two tree-widths wide with trees retained between the 'fairways' (J. Hickey, personal communication).

The Warra silvicultural systems trial is an excellent example of a proactive approach to integrate multiple uses in matrix forests through testing new harvesting methods that are not constrained by traditional silvicultural paradigms. Notably, VRHS is being progressively implemented in tall old growth (wet) eucalypt forests in Tasmania following the Tasmanian Community Forest Agreement in 2005. The objective is to apply non-clearfell harvesting methods to more than 80% of old growth logging coupes by 2010 (J. Hickey, personal communication). Notably, old growth Mountain Ash forest is not logged in the Central Highlands of Victoria and the aim of VRHS (see below) there is to apply it in 1939 regrowth stands where timber harvesting operations are conducted.

Table 5. Range of treatments tested in the Warra Silvicultural Trial in Tasmania (modified from Hickey and Neyland, 2000).

Treatment	Potential Benefits
Clearcut, burn and sow (traditional harvest system)	Economically and operationally efficient, results in effective regeneration
Clearcut, burn and sow with understorey islands	Increased biodiversity values
Cable harvested 300m x 80 m strips and low intensity burn	Natural seedfall, low soil damage, protection of rainforest
Cable harvested in 300 x 240 m patch and low intensity burn	Natural seedfall, low soil damage, protection of rainforest
Dispersed retention (10% basal area retention, and low intensity burn)	Natural seedfall, more trees with hollows, supply of large logs
Aggregated retention (30% basal area retention, 'fairways' one log width either side of a snig track, aggregate strips of 0.5-1.0 ha in size)	Natural seedfall, more trees with hollows, increased worker safety
Single tree/small group retention (permanent snig tracks, repeat cutting every 20 years, site scarification	Natural seedfall, enhanced biodiversity values, protection of rainforest

Various kinds of VRHS have been applied outside of Tasmania. For example, Kavanagh (2000) described an innovative study examining the response of arboreal marsupials to variable intensity harvesting in the wet forests of south-western New South Wales. Similarly, VRHS studies have been commenced by staff of the Victorian Department of Sustainability and Environment in the wet eucalypt forests of East Gippsland. A major experimental study is well underway in the Mountain Ash forests of the Central Highlands of Victoria. A description of this project is the key topic of the following sections.

VRHS IN VICTORIAN MOUNTAIN ASH FORESTS

Mountain Ash forests have been a focus of extensive research in the past three decades for a number of inter-related reasons, including concerns over the conservation of Leadbeater's Possum (Warneke, 1962; Rawlinson and Brown, 1980; Macfarlane *et al*., 1998) and other elements of biodiversity, as well as controversy stemming from the impacts of clearfelling on environmental values such as nature conservation (Squire, 1993; Campbell, 1997).

In response to these key issues, the Silvicultural Systems Project (SSP) was established in Victoria in the 1980's. A wide range of projects associated with improved silvicultural practices and reduced impacts on the environment were completed, including numerous investigations in Mountain Ash forests (reviewed by Campbell, 1997). The broad objectives of the Silvicultural Systems Project were:

> *"… to identify and develop silvicultural systems with clear potential as alternatives to the clearfelling (clearcutting) system and model those systems against clearfelling in terms of the long-term balance between socio-economic and environmental considerations" (Squire, 1990).*

A range of types of forest logging treatments were investigated in the Silvicultural Systems Project including: **1.** Clearfelling, **2.** Shelterwood; **3.** Small gap selection; **4.** Large gap selection; **5.** Seed tree; and **6.** Strip-felling. In addition, various methods of seedbed preparation were examined. Squire *et al.* (1987) and Squire (1990) give details of these various treatments.

Although the Silvicultural Systems Project was laudable in exploring alternatives to clearfelling, the study was limited by its use of a restricted set of traditional silvicultural methods (Lindenmayer, 1992). Each treatment resulted in the removal of all stems in a given area on a 50–80 year rotation. For example, one of the shelterwood treatments removed retained trees only three years after the regeneration felling (Saveneh and Dignan, 1998). Given removal of all stems, coupled with the requirement for nest sites in large old cavity trees by virtually all species of arboreal marsupials (including Leadbeater's Possum), all silvicultural practices tested have detrimental long-term 'on-site' impacts (Lindenmayer, 1992). It has been established that adequate regeneration can be obtained by the use of cutting regimes other than clearfelling (Campbell, 1997), and high intensity slash fires (Squire, 1993). However, such alternative methods have not been widely embraced in Mountain Ash forests and more than 95% of harvested sites are still logged using clearfelling and high-intensity slash-burning methods (Lutze *et al.*, 1999).

These issues have created an imperative to consider the VRHS as one of the silvicultural practices that could be applied in Victoria's Mountain Ash forests (Lindenmayer and Franklin, 2003). Four key lines of reasoning can be used to justify consideration of the use of the VRHS in the Mountain Ash forests of the Central Highlands of Victoria. They are:

- The effects of current traditional forms of clearfelling on stand structure and key elements of the biota and the need to find ways to mitigate such impacts (Smith and Lindenmayer, 1992).
- The habitat requirements of key elements of the biota in Mountain Ash forests (e.g. Leadbeater's Possum and other species of arboreal marsupials) and opportunities for altered silvicultural systems to enhance habitat suitability for these species (Lindenmayer and Franklin, 2003).
- The reduction of multi-aged Mountain Ash stands by more than two-thirds (based on empirical data and analysis) across the Central Highlands of Victoria (McCarthy and Lindenmayer, 1998; Lindenmayer and McCarthy, 2002). Multi-aged stands are significant ones for arboreal marsupials and birds and provide key habitats for species such as Leadbeater's Possum (Mackey et al., 2002; Lindenmayer et al., unpublished data).
- The importance of maintaining some congruence between natural disturbance (e.g. wildfire) and human disturbance regimes (e.g. logging) and opportunities for VRHS to do this better than continued widespread use of clearfelling or a widespread catastrophic bushfire (Lindenmayer and McCarthy, 2002; Mackey *et al.*, 2002).

These motivating reasons for the application of VRHS are outlined in detail in the following sections. These motivating factors have guided the establishment of a new VRHS experiment in the Mountain Ash forests of the Central Highlands of Victoria. Preliminary experiences and findings from this important experiment are discussed. This is followed by a more general discussion of issues associated with VRHS in Victorian forests.

Justification for VRHS – mitigating the impacts of traditional clearfell logging on stand structural complexity and biodiversity

Many studies in the Mountain Ash forests of the Central Highlands of Victoria over the past 23 years have focussed on several themes associated with the impacts of clearfelling on stand structure and key elements of forest-dependent biota. These impacts can be summarized as effects on:

- Overstorey hollow tree diversity and abundance.
- The prevalence of multi-aged stands.
- Understorey trees and other plants. And,
- Ground cover and coarse woody debris.

These impacts include:

- Overstorey trees with hollows are significantly reduced in abundance by clearfelling (Lindenmayer *et al.*, 1991b) and can be < 5% of levels in unlogged stands. Areas of forest can be rendered unsuitable for cavity-dependent animals and the recurrent application of clearfelling on a 50-80 year rotation can mean these areas are unlikely to become suitable for the entire suite of cavity-dependent fauna including Leadbeater's Possum. Large trees with hollows are nesting and denning sites for arboreal marsupials. In addition, the range of types of trees with hollows in stands (i.e. those with different external morphological characteristics) is substantially reduced in forests subject to clearfelling. This can deplete the diversity of arboreal marsupials as each species requires trees with hollows for nesting and denning that are in different stages of decay and senescence (Lindenmayer, 1997). Large living trees that survive the effects of fire and form a second age cohort within multi-aged forests not only provide nest sites for vertebrates, they also provide large numbers of flowers (Ashton, 1975) which can be a critical food resource for pollen and nectar-feeding vertebrates.
- Clearfelling operations in Mountain Ash forests produce areas with a uniform, even-aged stand structure with the young regenerating trees belonging to a single cohort (Squire *et al.*, 1991). This contrasts with a more complex multi-aged stand structure produced by wildfires in some parts of Mountain Ash landscapes (McCarthy and Lindenmayer, 1998; Lindenmayer *et al.*, 1999b). Multi-aged Mountain Ash stands are particularly important for biodiversity conservation. They support the highest densities of native mammals (Macfarlane, 1988). In addition, microchiropteran bats spend more time foraging in multi-aged stands where there is considerable variation in vertical vegetation structure (Brown *et al.*, 1997). The highest diversity of species of arboreal marsupials is found in multi-aged Mountain Ash forests (Lindenmayer *et al.*, 1991a). This is possibly because different species of arboreal marsupials have requirements for hollow-bearing trees with markedly different external morphological features (e.g. diameter and stage of

senescence) (Lindenmayer *et al.*, 1991b) and multi-aged stands may be more likely to support a range of tree types.

- Clearfelling can markedly alter the understorey vegetation of logged and unlogged Mountain Ash forests (Ough, 2001; Ough and Murphy, 2004; but see Harris, 2004). Weed and sedge species are more common on clearfelled sites and populations of resprouting shrubs, tree ferns, and many species of ground-ferns are depleted (Ough, 2001). Indeed, mechanical disturbance from logging machinery, together with the effects of prescribed high-intensity slash fires following harvesting, reduces the abundance of tree ferns (*Dicksonia antarctica* and *Cyathea australis*) to approximately 5% of that in unlogged stands (Ough and Murphy, 1996; Lindenmayer and Ough, 2006). Loss of tree ferns substantially reduces the availability of nursery sites for other plants (Ough and Ross 1992) such as epiphytic plant species (Ough and Murphy, 1996, 2004) and eliminates the sheltered moist microhabitats that support fungal and other food resources for forest animals (Lindenmayer *et al.* 1994b). Thickets of long-lived fire-resistant understorey plants can be significantly depleted or lost as a result of clearfelling (Mueck *et al.,* 1996; Ough and Murphy, 1998). Intact thickets of understorey vegetation are important foraging sites for some species of forest-dependent vertebrates such as the Mountain Brushtail Possum (Lindenmayer *et al.*, 1994a). Stands of understorey rainforest plants such Myrtle Beech (*Nothofagus cunninghamii*) may be negatively influenced by clearfelling operations. The occurrence of the species is significantly reduced in young clearfelled stands relative to burnt old growth ones (Lindenmayer *et al.,* 2000d). The species may be slow to re-establish on intensively clearfelled sites. Myrtle Beech understorey stands provide important breeding habitat for the Pink Robin (Loyn, 1985).

- Young logged stands support significantly lower volumes of large logs than older uncut stands. The diameter of logs is also significantly smaller in clearfelled forests (Lindenmayer et al., 1999c). Many regrowth stands of montane forest recovering after the 1939 wildfires are characterised by high volumes of large diameter logs often exceeding 1000 m^3 per ha (Lindenmayer *et al.*, 1999c). The size and accumulated volume of these logs is greater than the size and volume of the standing living trees, reflecting the existence of a major cohort of biological legacies on the floor of these post-fire regrowth stands. Changes in conditions on the forest floor of logged forests may influence the suitability of substrates for reptiles (Brown and Nelson, 1993), small mammals

(Lindenmayer *et al*., 2002; Cunningham *et al*., 2005); the germination of rainforest plants (Howard, 1973), and the development of mats of moss cover (Ashton, 1986), although further work is required to examine such effects (reviewed by Lindenmayer *et al*., 2002).

The impacts of clearfelling can extend beyond effects at the stand level. Such operations may alter landscape composition with remaining areas of old-growth forest (now exempt from logging) becoming isolated among extensive stands of young forest recovering after harvesting. These changes have negative effects on some wide-ranging vertebrates such as the Sooty Owl and Yellow-bellied Glider which are strongly associated with large areas of old growth forest (Milledge *et al.*, 1991; Lindenmayer *et al.*, 1999a; Incoll *et al*., 2000). Old growth forests are also important habitat refugia for the Mountain Brushtail Possum and the Greater Glider. Populations of these species in late-successional stands that are fragmented by widespread clearcutting may not be viable in the medium to long-term (Possingham *et al.*, 1994; Lindenmayer and Lacy, 1995a; 1995b; McCarthy and Lindenmayer, 1999a).

Marked reductions in the structural complexity of stands of Mountain Ash forest associated with clearfelling operations have the potential to be countered (at least in part) by altered silvicultural systems (like VRHS) that result in greater levels of structural retention (Lindenmayer and McCarthy, 2002).

Justification for VRHS – the habitat requirements of key elements of biodiversity

Extensive studies over the past two decades have focused on elucidating the habitat requirements of a range of species in Mountain Ash forests. Strong, positive statistical relationships have been demonstrated between the presence and abundance of arboreal marsupials and the abundance of trees with hollows. For example, in the case of Leadbeater's Possum, field-validated regression models of night-time count data confirm that the species is typically found in patches of regrowth and old growth Mountain Ash forest characterized by both numerous large trees with hollows (used as nest sites) (Lindenmayer and Meggs, 1996) and a dense understorey of Wattle (*Acacia* spp.) trees, which are a foraging resource (Lindenmayer *et al.*, 1991a; 1994a). Colonies of Leadbeater's Possum are totally dependent on large trees with cavities that require 200–400 years to develop (Lindenmayer *et al.*, 1991c; 1993a) — a period 3-5 times the length of current clearfelling rotations. The response of other arboreal marsupials like the Mountain Brushtail Possum and the Greater Glider to the prevalence of tree hollows is similar to that described for Leadbeater's Possum.

Clearfelling operations result in a reduction of key nesting resources for arboreal marsupials (Lindenmayer *et al.*, 1991a). This typically results in changes in the abundance of these species on logged and regenerated sites. Quantification of the habitat requirements of arboreal marsupials, such as Leadbeater's Possum, has clarified the essential structural features that need to be retained and perpetuated as part of stand management strategies.

Field data suggests that populations of Leadbeater's Possum can occur on logged coupes where large old trees have been retained, particularly where clusters of trees have been retained. Therefore, retaining clusters of trees on-site offers an important opportunity to conserve Leadbeater's Possum and extract timber – **provided a modified cutting system is implemented.** Hence, the work over the past two decades has highlighted what modifications to silvicultural systems are needed to enhance biodiversity conservation in wood production areas.

There are requirements for habitat tree protection under the current Code of Forest Practice in Victorian Mountain Ash forests (Department of Natural Resources and Environment, 1996; reviewed by Wayne *et al.*, 2006). However, there is considerable evidence of difficulties in adequately protecting these trees from the regeneration burn used to promote regrowth in the recovering stand (Lindenmayer *et al.*, 1990a, 1997) and exposure and increased mortality following logging (Ball *et al.*, 1999). Aggregated retention may afford better protection to trees that need to be retained on logged sites as part of the Code of Forest Practice. Thus, VRHS may provides an important opportunity to maintain key structural habitat attributes for species such as Leadbeater's Possum, other arboreal marsupial taxa as well as a range of other reptiles and birds dependent on trees with hollows in Mountain Ash forests (reviewed by Gibbons and Lindenmayer, 2002).

Justification for VRHS – the use of natural disturbance regimes as a template for guiding silvicultural systems in Victorian ash-type eucalypt forests

Hunter (1994, 2006) hypothesized that the conservation of biodiversity in production landscapes requires management to be as consistent as possible with natural ecological processes. In this context, Attiwill (1994), Bunnell (1995) and other authors contend that logging will reduce negative effects on biodiversity if it is within the bounds of natural disturbance regimes. This requires strong congruence between natural disturbances and disturbances created by logging operations at a range of spatial scales including the stand level (Fries *et al.*, 1997) and the landscape level (Welsh and Healy, 1993).

Wildfire is the main form of natural disturbance in Mountain Ash forests (Ashton, 1981) and a previous section in this report outlined the spatial variability and variation in intensity of fires in the Central Highlands region. Major conflagrations can be complete stand-replacing events in which virtually all dominant overstorey ash-type trees are killed. Indeed, large areas of predominately even-aged Mountain Ash forest disturbed by the 1939 wildfires presently characterise the landscape in the Central Highlands of Victoria (Noble, 1977; Commonwealth of Australia and Department of Natural Resources and Environment, 1997).

Low intensity fires in Mountain Ash forests lead to only partial stand replacement because some trees survive (Smith and Woodgate, 1985). This creates multi-aged stands comprised of ash-type eucalypt trees of two (and sometimes more) distinct age cohorts (Lindenmayer et al., 1999b, McCarthy and Lindenmayer, 1998). McCarthy and Lindenmayer (1998) defined multi-aged stands as stands in which at least 15% of the stems belonged to a distinctly different age-class than the remainder of the trees. Approximately 7- 9% of montane ash (Mountain Ash, Alpine Ash and Shining Gum) forests in the Central Highlands of Victoria are presently multi-aged (Lindenmayer *et al.*, 1991a), although stand reconstruction studies indicate that this proportion was considerably higher 70 or more years ago – up to 30% (Lindenmayer and McCarthy, 2002). Extensive salvage harvesting operations following major fires in 1926, 1932, and 1939 (Noble, 1977) has converted many stands that would have been multi-aged to even-aged ones (Lindenmayer and Ough, 2006).

Landscape-level factors influence variation in fire-intensity in Mountain Ash forests. Integrated statistical and environmental modelling studies have shown that multi-aged stands are most likely to occur in parts of forest landscapes characterised by low levels of incident solar radiation (Lindenmayer *et al.*, 1999b; Mackey *et al.*, 2002). Thus, the prevalence of different types of structural conditions varies between stands in response to fire intensity which is, in turn, influenced by stand location in the landscape.

Clearfelling operations are the norm in those areas of Mountain Ash forests available for logging (Squire *et al.*, 1991; Campbell, 1997) and greater than 95% of coupes are cut using that silvicultural method (Lutze *et al.*, 1999). However, widespread application of clearfelling operations does not appear to be consistent with the variable effects of natural disturbance regimes. This suggests there is a need to change cutting and regeneration methods to more closely resemble natural disturbance regimes and promote structural complexity in stands of harvested forest to enhance their value for wildlife (Lindenmayer and McCarthy, 2002).

The VRHS offers an important opportunity to create greater congruence between human and natural disturbance regimes by creating more multi-aged stands in logged and regenerated areas and, in turn, promoting or creating the maintenance of key elements of stand structural complexity. However, extensive data and environmental modelling suggests that it would be inappropriate to fully replace one silvicultural system (clearfelling) with another (VRHS) on all coupes. Given variations across landscapes in fire intensity, stand structural complexity, and levels of multi-agedness, it appears appropriate to apply different harvesting methods in different areas. Areas where multi-aged stands are most likely to occur such as those characterized by low levels of incoming radiation and flat plateaux (Mackey et al., 2002) would be those where application of VRHS would be appropriate both ecologically and also from the perspective of timber worker safety.

MOVING FORWARD – THE APPLICATION OF ADDITIONAL SILVICULTURAL SYSTEMS IN VICTORIAN MOUNTAIN ASH FORESTS

A major VRHS experiment in Victorian Mountain Ash forests

Lindenmayer *et al*. (unpublished data) instigated a major experiment examining the effectiveness of the VRHS in the Mountain Ash forests of the Central Highlands of Victoria in 2003. The experiment has three broad aims:

- To promote the retention of key structural attributes on logged stands (particularly large trees and understorey vegetation).
- To grow these retained structures through several rotations so that they become old growth structures.
- To assess the logistical and operational feasibility of retaining islands of the original forest within otherwise clearfelled coupes.

The experiment also has some general objectives including the creation of more areas of multi-aged forest and to reduce the amount of time it takes for regenerating forest to become suitable habitat for species such as Leadbeater's Possum.

The VRHS experiment is taking place in the Toolangi, Marysville and Powelltown districts and is constrained to one age class of forest – 1939 regrowth Mountain Ash. This is because this age class is where the bulk of harvesting activity presently takes place. In addition, because different types of ash forest support different faunal compositions (Loyn, 1985; Lindenmayer *et al*., 1990), it is important to constrain the project to a single forest type to avoid treatment/forest type confounding.

The experiment involves the comparison of two different configurations of retained forest within otherwise clearfelled coupes, current practice, plus a natural control. The total area of retained vegetation sums to 1.5 ha per coupe. The two configurations are – 1 x 1.5 ha (ie. 1 consolidated retained patch) and 3 x 0.5 ha (ie. 3 scattered clusters). Thus, the 'treatments' in the experiment are:

- Existing clearfelling practice.
- 1 x 1.5 habitat island is retained.
- 3 x 0.5 ha habitat islands are retained.

- A “pseudo-coupe” or a location in 1939 regrowth forest in which no harvesting takes place.

There are six replicate blocks in the experiment. A block consists of a broadly homogenous area dominated by 1939 regrowth Mountain Ash forest where one of each of the four treatments is established. The six blocks x four treatments per block gives a total of 24 coupes in the experiment. Of these, there are 18 treatment coupes and 6 control “pseudo-coupes”. The aim has been to establish 2-3 complete blocks in each year over three years since the experiment commenced, although this has not always been achieved for a range of reasons.

Photo 1. Harvested coupes with three retention islands at South Spur near Marysville. (Photo by Wally Notman).

The establishment of habitat islands and surveys plots within treatment classes

Staff from The Australian National University, Department of Sustainability and Environment and VicForests, as well as logging contractors, have helped identify the best location/s on a coupe to set aside habitat islands. Habitat islands are marked out before logging begins. This is to ensure that harvesting contractors are well aware of their location before operations are commenced. The selection of islands in the experiment is based on:

- Safety considerations for timber workers and field staff.
- Habitat values for wildlife (e.g. places that currently support large trees with hollows)
- Locations where retained vegetation is best protected from regeneration fires.
- Ensuring that habitat islands are at least 50 m from coupe boundaries. The experiment has focused on coupes that are 15 ha or larger so that retained forest patches will be some distance from the neighbouring unharvested forest.

There are five wildlife survey points per coupe: (i) one within each of the three 0.5 ha islands or three within the single 1.5 ha island, (ii) one within a plot located in the clearfelled part of a coupe will allow within island versus coupe comparisons. A fifth plot is added to the margins of the coupe at all sites. This makes it possible to contrast the value of retention within coupes (= the islands) versus retention at the margins of coupes. As for the coupes with retention islands, there are 5 sample plots per coupe for the traditional clearfelling coupes and the pseudo-coupes. This ensures that sampling effort is the same for all treatments. Hence, in total there are 24 coupes x 5 plots per coupe = 120 permanent survey plots in the entire study.

Target response groups

The response of four broad groups of vertebrates to the experiment is being quantified. These are birds, reptiles, terrestrial mammals and arboreal marsupials. Each of these groups is counted:

- Before harvesting commences.
- After harvesting is completed but before a regeneration burn is applied.
- After a regeneration burn is applied. And,
- Repeatedly after the regeneration of the cut stand. (The intention is to maintain this monitoring at yearly intervals in perpetuity).

This gives a before and after component to the experiment and so increases the power of the experiment to quantify 'treatment' effects.

In addition to intensive data gathering for vertebrates, the experiment is recording the structure, composition and condition of the vegetation at all 120 survey plots in the experiment. This enables not only the response of the vegetation to the experimental treatments to be quantified, but also allows relationships between vegetation cover and animal response to be examined.

Progress as at mid-2007

To date (mid-2007), 16 experimental coupes and 6 control sites have been established and surveyed for vertebrates within State forests situated in Marysville, Toolangi and Powelltown districts. All 24 coupes in the entire experiment will be established by the end of 2007. Detailed information on the early responses of vertebrates to the experiment will be published in the scientific literature in 2008.

Wildlife responses

Preliminary findings from the experiment to date suggest that the terrestrial small mammals Agile Antechinus (*Antechinus agilis*), Dusky Antechinus (*Antechinus swainsonii*) and Bush Rat *Rattus fuscipes*) can persist within the retained islands after the harvesting process although densities are lower than unharvested forest. Further work (which is currently taking place) will quantify animal response following post-harvesting regeneration burning. The composition and number of bird species changes substantially post harvest but a number of taxa continue to use the islands following logging of the surrounding forest. Reptiles respond poorly to the harvesting process and are generally not detected within the cutover area or within the retained islands post harvest.

The persistence of some species (e.g. small mammals) within the retention islands in the experiment was surprising. It is nevertheless an encouraging finding because such residual animals may well be important for promoting population recovery following disturbance (see Lindenmayer *et al.*, 2005). Alterations in the presence and abundance of other species in the islands following harvesting was expected. However, a key issue is that <u>the retained islands in the VRHS are not intended to retain viable populations of particular species</u>. Rather, the aim is to promote the future structural complexity of logged and regenerated forests (for example, 10-40 years following harvesting) and, in turn, improve the habitat quality of regrowth forests for otherwise logging-sensitive species such as Leadbeater's Possum. Indeed, current data on the habitat requirements of Leadbeater's Possum and some other species of vertebrates in Mountain Ash forests, suggests that the VRHS has the potential to actually create suitable habitat for them. Hence, as indicated by Smith *et al.* (1985) and Lindenmayer (1994), the conservation of Leadbeater's Possum is a rare example where altered silvicultural systems (i.e. logging methods not based on traditional clearfelling) could significantly benefit the species (see also Lindenmayer, 2000). However, there are some important caveats associated with this conclusion.

- First, although the experimental implementation of the VRHS in Mountain Ash forests is reasonably well advanced, effectiveness of such altered silvicultural systems for biodiversity conservation remains to be demonstrated. Considerable ongoing monitoring effort over a prolonged period (5-10+ years) will be required continually assess progress and feed key findings back to forest managers and policy makers. This will require a commitment to on-going monitoring over an extended (5-20+ year) period to provide meaningful information for forest and wildlife managers and policy makers. The greatest value of ongoing monitoring will be to progressively improve forestry operations through adaptive management.
- Second, there are clear logistical, worker safety, and habitat island protection issues associated with the application of the VRHS in Mountain Ash forests. For example, it is difficult to apply the system on steep terrain where there are considerable safety issues for timber workers and high risks of retained islands being badly damaged by regeneration burning. Thus, this report does not call for a complete substitution of clearfelling by VRHS on all harvested coupes. Rather, the VRHS will be applicable in places where it is safe and logistically feasible to do so and hence where the chances of retention of habitat island/s within coupes can be most successfully achieved. Coupes on flat terrain, on south-facing slopes and where there are low levels of incoming radiation are good candidate areas for the application of the VRHS. Importantly, such kinds of areas are also where multi-aged stands are most likely to develop (Lindenmayer *et al.*, 1999b; Mackey *et al.*, 2002). The ratio of coupes subject to clearfelling versus VRHS should be guided by data on natural disturbance regimes. This indicates that ~30% of coupes might be appropriate for the application of the VRHS.
- Third, given present uncertainty of the effectiveness of the VRHS in Mountain Ash forests, it is critical that there are large ecological reserves in place where logging disturbances

(of any kind) do not take place. Indeed, large ecological reserves are a core component of all credible conservation and resource management plans (Lindenmayer and Franklin, 2002; Lindenmayer and Burgman, 2005). In the case of the Mountain Ash forests of the Central Highlands of Victoria, reserves such as the Yarra Ranges National Park provide both:- **(1)** important benchmark landscapes against which (positive and negative) changes in biodiversity can be compared against wood production landscapes (see Lindenmayer *et al.*, 2002), and, **(2)** critical places exempt from many kinds of human disturbance that safeguard against unexpected or unanticipated errors in production forest management practices (if they were to arise).

Logistical issues

Experiments are one of the most powerful ways to generate understanding about ecological systems and, in turn, learn about how to best manage them. However, large-scale logging experiments are rare. They can be expensive and labour intensive. The long-term nature of forestry experiments makes them difficult to establish and subsequently maintain ongoing financial and logistical commitments. Indeed, many forestry experiments have subsequently been abandoned for these reasons. The VRHS experiment in the Victorian Mountain Ash forests has attempted to avoid some of these problems by overlaying the experimental design and implementation on existing logging plans and operations. This has been done deliberately in an attempt to limit the costs of establishment, conduct research that is relevant to management, and create a research program that is economically sustainable in the medium to long term.

Feedback on the VRHS experiment has been provided by regional staff from VicForests and the Department of Sustainability and Environment. Management of regeneration burns to limit damage to retained islands is a key issue. It is possible to protect islands, but it requires more staff and resources to do so effectively, particularly on coupes with 3 x 0.5 ha islands. The single 1.5 ha island on a coupe appears to be logistically more straight-forward for forest managers to work around than coupes with multiple smaller patches. Logging slash removal away from island boundaries is important for protection of the islands from regeneration burning. The strategic location of islands is also critical to their protection during burning. Islands on flatter areas would appear to be easier to protect from fire than those on steeper areas. This issue highlights the value of communication between logging contractors and forest management staff in best locating islands as part of the application of the VRHS in Mountain Ash forests.

The VRHS as an adaptive management experiment and a model experimental system

Adaptive management involves the integration of research, monitoring and management to improve the management of resource management prescriptions (Holling, 1978). Adaptive management is often discussed by researchers and resource managers, but **true** adaptive management studies are extremely rare in practice (Bunnell and Dunsworth, 2003). The VRHS experiment in the Mountain Ash forests has involved experimenting with logging practices, monitoring responses to modified practices, and close communication between researchers and forest managers on the positive and negative aspects of the experimental harvesting. This means that the experiment has many of the ingredients of a true adaptive management study (*sensu* Walters, 1986). This factor alone makes the VRHS experiment a model one that should not only be embraced in the long term, but also be far more widely embraced elsewhere in Victoria, Australia, and overseas. Indeed, Lindenmayer *et al.* (2000c) argue that a commitment to adaptive management should be a key requirement underpinning ecologically sustainable forest management.

Future re-entries into coupes where VRHS has been applied will be a continuing challenge. Specific treatments will depend on management objectives. Computer-visualizations may assist managers by providing images of likely future stand conditions under various management alternatives (Ball *et al.*, 1999). In addition, management of stand information (such as precise location and extent of retained areas) will be greatly aided by the advent of technologies such as Global Positioning Systems and Geographic Information Systems. However, empirical data from VRHS applications, monitoring and experiments are likely to provide the most useful information. This is why long-term experimental monitoring and adequate record keeping on applications of VRHS (such as why particular treatments were applied within a harvest unit and what additional operations were conducted) is so important. This information is essential to guide subsequent generations of forest managers and wildlife managers in evaluating the success of various prescriptions including responses of species to stand conditions.

POSSIBLE OTHER APPLICATIONS OF VRHS IN VICTORIAN FORESTS

VRHS has potential for application in a range of other forest types. These include Alpine Ash and Shining Gum stands where stand-replacing wildfires are not uncommon and clearfelling is currently the most widely applied method of harvesting. Indeed, studies using VRHS have commenced in wet, high elevation mixed species eucalypt forests in East Gippsland.

Applications of VRHS might be extended to forest types where recurrent selective harvesting and other forms of silviculture can lead to the same stand simplification problems that characterize clearfelled areas (Gibbons and Lindenmayer, 2002). For example, VRHS might be considered as an additional silvicultural system in a wide range of lower elevation forests in the Central Highlands of Victoria and in East Gippsland. Appropriate prescriptions for application of VRHS should be treated initially in an experimental way as has been done in the Central Highlands of Victoria. However, the specifics of applications should be directed by particular management objectives and other issues (e.g. the habitat requirements of particular species of management concern).

The VRHS concept also should not be limited to applications of harvest and regeneration silviculture. There are opportunities to apply the approach in stands targeted for thinning, such as 20-30 year regrowth Mountain Ash and Alpine Ash forests in the Central Highlands of Victoria. These kinds of forests can have significant habitat values for species such as Leadbeater's Possum. Appropriate thinning regimes have the potential to maintain or even improve habitat for this (and other) species, provided sufficient trees with hollows are retained. "Leave areas" or harvesting exemption zones around such trees within densely stocked stands targeted for thinning could have significant conservation benefits while enabling large quantities of thinned wood to be removed. Work done elsewhere such as the Pacific Northwest of the USA can help guide appropriate thinning regimes and simultaneously promote conservation values. Variable-density thinning in which thinning intensity and tree marking rules are varied within the stand of interest (Carey and Johnson, 1995; Carey and Curtis, 1996), is a useful approach to increasing heterogeneity in stand density, and canopy cover. Variable-density thinning is sometimes referred to as the 'skips-and-gaps' approach. In such a prescription, some portions of a stand are left lightly or completely unthinned ('skips') providing areas with high stem density, heavy shade, and freedom from disturbance while other parts of the stand are heavily harvested ('gaps') (Carey *et al.,* 1996). Intermediate levels of thinning are also applied in a typical variable density prescription. Tools, such as Global Positioning Systems can make spatially variable stand management relatively straightforward and cost-effective (G. Schreuder, personal communication).

Possible Future Directions

The VRHS has been applied widely around the world and is now used extensively in western and eastern North America as well as in Europe. It has considerable potential to better balance a range of values demanded from native forest management including the integration of biodiversity conservation and wood production. A VRHS experiment in the Victorian Mountain Ash forests is close to being fully implemented and key results will begin to emerge from that work in the coming 2-10 years.

Given the progress to date with the VRHS experiment in the Mountain Ash forests, the following two general recommendations are made:

1. A medium term (5-10 year) commitment be made to continue the existing VRHS experiment in the Toolangi, Marysville and Powelltown districts in the Central Highlands of Victoria. This will ensure that preliminary trends can be quantified in vertebrate responses to logging and retention island treatments.

2. Regular workshops need to be held with forest and wildlife managers, logging contractors, forest industry representatives, conservationists and the general public to discuss the potential advantages and disadvantages of the VRHS and other silvicultural systems. The existing set of VRHS coupes in the Mountain Ash forests in the Central Highlands of Victoria provide an ideal venue for such workshops.

If the VRHS is found to be suitable on an operational basis, then it should be more widely adopted in Victorian Mountain Ash forests with a medium term aim of it being applied in 30% of Mountain Ash logging coupes statewide. There also should be formal recognition of its application in key documents such as Codes of Forest Practice.

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APPENDIX 1: MODIFIED PROJECT BRIEF FROM VICTORIAN DEPARTMENT OF PRIMARY INDUSTRIES

Objective

To present the results of a literature review of the current understanding of biodiversity within Mountain Ash (*Eucalyptus regnans*) forests of the Central Highlands of Victoria.

The results of the review are to be interpreted at the landscape or catchment level.

The paper should provide comment on the biological legacy of extensive even-aged forests, particularly the forest regrowth from the 1939 Black Friday bushfires.

The discussion of the results should, where possible, provide the scientific justification for variable retention timber harvesting in even-aged forests in terms of its effect on forest structure and habitat potential over time and space.

Where possible, identify examples or situations (in the form of case studies) where active management (thinning and harvesting) is necessary to maintain or enhance habitat values. Similarly, identify examples or situations where active management may be detrimental to fauna at the landscape level.

The paper will be a brief document written in non-technical language suitable for public release. The target audience would be government agency staff, students and community groups. The output of the project is to be a document that can provide guidance for policy development and future research opportunities.

Scope

The project should be confined to studies conducted in Mountain Ash (*Eucalyptus regnans*) forests of the Central Highlands of Victoria. However, if relevant and appropriate research has been conducted outside this geographic zone then it may be included.

The review should be confined to current scientific literature from legitimate studies (peer reviewed publications and from current work-in-progress by recognised research bodies).

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