Research for Ecologically Sustainable Forest Management in Victorian eucalypt forests

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ABSTRACT

This paper describes some of the research needed to help forest managers achieve Ecologically Sustainable Forest Management. As a case study, it also presents an overview of some of the research conducted to meet those needs in the state of Victoria, and identifies priorities for further research, monitoring and adaptive management. Vertebrate wildlife (mainly birds and mammals) has been a major focus of this review. The main strategic research questions concern the successional effects of logging, the relative merits and costs of integration or segregation and the appropriate scale for spatial integration. Retrospective research is a valuable tool to address some of the key questions, but longitudinal studies (i.e. over time), are also needed. Successional studies have identified hollow-dependent wildlife species and species that feed from open ground among trees as those that are most sensitive to logging. Thinning and control burning may have potential value as tools to modify regrowth forest structure to benefit the latter group, but this new concept needs field-testing. A general focus on hollow-dependent species may have diverted attention from the needs of other groups. A logical scheme is presented for evaluating costs and benefits of spatial integration or segregation in particular cases. The shape of the response curve is crucial in making these evaluations, but this aspect has received little attention. Segregation often has benefits both for wildlife conservation and wood production, but there are exceptions and socio-economic reasons for developing more integrated systems. Retaining patches of habitat on selected coupes combines some of the benefits of both approaches, and has been introduced on a trial basis in mixed eucalypt forests and ash forests, with associated monitoring. Effects of spatial scale and pattern have been studied in ash forests but more work of this sort is needed in mixed eucalypt forests and box-ironbark forests. Large owls have been used as umbrella species to select areas for special protection based on extensive field surveys, modelling and field-testing. Further monitoring and detailed research is needed to evaluate and refine the effectiveness of this strategy. This approach forms part of a suite of forest planning processes, which increasingly involve community participation. Associated research is needed to help inform debate and decisions in an adaptive management framework.

Key words: ESFM, forest management strategies, spatial integration, spatial segregation, forest wildlife, spatial scale

Introduction

Purpose, scope and structure of this paper

The main purpose of this review is to summarise some of the fauna research conducted by or for the Victorian Government to help achieve Ecologically Sustainable Forest Management (ESFM) in its public forests, and identify implications for policy, management and research. The Victorian Government has conducted research programs since the 1970s to help establish policies and practices that facilitate ESFM. This paper provides an overview of some of this work, relating to vertebrate fauna and their conservation in forests where timber production is one of several key objectives. The work has involved biologists from the Department of Sustainability & Environment (DSE) and its component research institutes (Arthur Rylah Institute for Environmental Research and the Forest Science Centre), and collaborative work involving universities and government departments in Victoria, New South Wales, Queensland, Tasmania and the Australian Capital Territory (ACT). Regional staff from DSE and Parks Victoria (PV) played important supporting roles in this research. Selective reference is also made to relevant work from other states and independent researchers (e.g. Ward 2000; Taylor *et al.* 2002a,b; Gibbons *et al.* 2002), although a comprehensive review is beyond the scope of this paper.

The body of this paper is arranged in four sections. The first establishes a framework for posing strategic management questions and selecting research approaches to address them, including a logical approach for selecting strategies to integrate or segregate competing requirements at various spatial levels. This framework has potential application to any forests of the world where competing values need to be accommodated. A subsequent section gives a historical overview of selected Victorian research on forest wildlife,

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showing how approaches have developed over recent decades. A third section examines how research has contributed to forest management, picking up on some of the strategic themes developed earlier. A final section draws some key conclusions, relating both to forest management and further research.

The paper focuses mainly on birds and mammals other than bats, in forest types where timber production is of economic importance. The emphasis on mammals and birds is largely a response to public expectations and practical logistics. Invertebrates form the bulk of the biodiversity, in terms of numbers of species (New 2000). They have been studied locally in Victorian forests, for example in relation to logging and wildfire (Neumann 1991) and control burning (e.g. Neumann and Tolhurst 1991; Collett 1998, 2003), and in other states (e.g. York 1999, 2000), but we are far from being able to provide a coherent picture. Broader studies of plant and invertebrate species, reptiles and frogs would help ensure a more holistic approach to forest management.

Ecologically Sustainable Forest Management (ESFM)

Forests can support high densities of diverse species of vertebrate animals because of their biological productivity, structural and floristic complexity and the stature of the dominant tree strata. Hence they are important reservoirs of biodiversity. In Australia, the nature and spatial extent of forest cover has varied greatly over geological time (Lamb and Smyth 2003), and eucalypt forests currently dominate much of the forest landscape in non-arid temperate parts of the country (Beadle 1981).

The complexity of forests can be viewed at various spatial and temporal scales, and many aspects of spatial arrangement have been studied to help inform forest management decisions, following early development of the concept of landscape ecology (Forman and Godron 1986; Franklin and Forman 1987). Ecologically sustainable forest management (ESFM) must be based on an understanding of this complexity and its spatial and temporal variation under proposed or alternative regimes. Throughout the world, there has been increasing public demand for ESFM to produce ecological services as well as economic products such as wood and water. Public demand has led to development of a range of international and national agreements and policies (e.g. see reviews by Ferguson 1996; Wescott 2003).

ESFM has been defined in different ways by different authors, and there is no single agreed definition. Ferguson (1996) observed that this reflects the complex and varied nature of policy issues relating to publicly owned resources, and discussed the need to provide inter-generational equity over time-scales relevant to forest management. Spatial scale is a particular source of complexity (Weaver 1995). It may be quite practical to conserve a set of species over time in 10,000 ha of forest, but much more demanding or impossible to do that on 20 or 100 ha (Loyn and Turner 2002). In the smaller unit, some of the species would be expected to be always absent, and others would come and go in response to stochastic events. Similar issues arise in relation to scale of socio-economic detail. It may be desirable and practical to provide a continuous supply of profitable jobs or business opportunities from a given area of forest over time (with the same spatial issues as above). But if the nature of those opportunities is defined too narrowly (e.g. tree-felling jobs in the hardwood sawlog industry, or specific bee-sites for honey production), a greater degree of difficulty and potential intervention will be needed to sustain the supply. Community needs and expectations will surely change over time, so it makes sense to define objectives broadly.

For the purposes of this review, a suitable definition is that forests are managed sustainably when broad community goals can be met indefinitely at suitable levels, over an appropriate area of forest. It has been argued that 1000-10000 ha is an appropriate scale in south-eastern Australia (Loyn and McAlpine 2001; Kavanagh *et al.* 2003). The ecological component of ESFM involves conserving all known species (higher plants and vertebrate wildlife) over the same spatial scale as above, with common species remaining common and rare species maintaining their presence and expected population viability. This approach could potentially be extended to lower plants and invertebrate fauna, but species-level data on them are generally inadequate and expensive to collect. A practical approach for these species is to maintain a sustained supply of microhabitats for them over the forest landscape as above, with special reference to those that may be best represented in mature forest (Taylor and Doran 2001). This ensures that the forest maintains its capacity to respond to a range of ecological events, and provide a range of ecological services.

Geographical context for case study: Australia and its state of Victoria

Australia is a dry continent with forests confined mainly to the tropical and temperate coastal fringe. The area of forest has been greatly reduced in the two centuries of European settlement, especially in temperate regions on the plains, valleys and foothills suitable for agriculture (Lamb and Smyth 2003). Nevertheless, extensive areas of continuous forest remain in eastern Australia, principally along the Great Dividing Range and in similar rugged terrain inhospitable for modern human settlement. Most of this forest is in public ownership, and the multi-faceted science of landscape ecology provides essential tools for managing these forests to meet multiple needs.

Victoria is a small state (22.7 million ha) that straddles the Great Dividing Range in south-eastern Australia. About a third of the land area (7.5 million ha) consists of native vegetation under public ownership, and most of this is classed as native forest or woodland. Much of the forest occurs as a contiguous band along the Great Dividing Range. About half of these forests (3.7 million ha) are reserved in National and State Parks, as a consequence of land allocation decisions determined through processes involving public participation. These included the work of the state Land Conservation Council (LCC) from the 1970s, and a recent Regional Forest Agreement

(RFA) process involving State and Commonwealth (national) governments in the 1990s (Wescott 2003). Timber production is generally excluded from Parks but continues to be managed in part of the land area within State Forests. Forest planning processes (including the RFA) adopt a further zoning system within State Forests, with many areas becoming reserved as Special Protection Zones (SPZs) to conserve threatened forest wildlife species (Commonwealth of Australia 1997). ESFM is an expectation for the entire forest estate, including State Forests, as recognised in Australia's national forest policy (Commonwealth of Australia 1992).

Management questions and research approaches

Any attempt to achieve ESFM must consider a range of strategic and tactical questions. The main strategic questions concern the level of wood production to be allowed, the extent of forest to be retained or logged, and the degree to which conservation and production can be integrated on a given parcel of land. All these questions are complex, requiring socio-economic analysis and public debate as well as biological research. Answers to them will inevitably evolve through debate in the public arena. The debate must be informed through targeted research, but it is naïve to expect definitive answers from research data alone. Research in Victoria and elsewhere has helped focus attention on the fauna species and their habitats that do not regenerate quickly within planned rotation times for commercial forestry (e.g. Loyn 1985a; Franklin and Forman 1987).

Hollow-bearing trees have become the classic example of a habitat element that develops slowly (Ambrose 1982; Mackowski 1984; Gibbons and Lindenmayer 1996, 1997, 2002). Other sensitive habitat elements include vegetatively resprouting plants and epiphytes (Hickey 1994; Ough and Murphy 1996; Williams *et al.* 1999), mistletoe (Loyn 1980, 2001; Turner 1991; Reid *et al.* 1994) and logs on the forest floor (Lunney *et al.* 1991; Brown and Nelson 1993; Lindenmayer *et al.* 1999a; Mac Nally *et al.* 2001). Mistletoe plays a valuable role as a source of nectar and fruit for many bird species, and is used for food and shelter by a range of wildlife species (Turner 1991; Reid 1991; Watson 2001, 2002). Various structural features of old forest take decades to develop (Loyn 1985a; Scotts 1991; Lindenmayer *et al.* 2000), including open spaces below a canopy of old trees (Loyn 2001) and mosaics of shrubs and open ground in mixed eucalypt forests (Williams *et al.* 1999).

Three primary strategies have been identified for conserving such elements of old forest in commercially managed forests: stand retention; retention of selected trees on logging coupes, or greatly increased rotation lengths (Loyn 1985a). These ideas have been adapted and modified by subsequent authors (e.g. Gibbons and Lindenmayer 1997; Lamb *et al.* 1998), and offer a framework for developing new prescriptions for conserving fauna species that depend on elements of old forest. The retention strategies involve provision for regrowing and replacing old trees or stands over very long rotations, with regrowing as the first step at a rate to balance natural attrition. Of the three primary strategies, it is generally considered impractical to rely on increased rotation lengths because by the time stands have developed the special features of old forest (e.g. a dominance of old senescent trees) they have lost much of their commercial value as a source of timber. Stand retention has become the strategy of choice in Victoria, but more effort is now being given to a range of integrated tree retention strategies.

Research over the last two decades has helped quantify the effects of various forest management practices (e.g. clearfelling and variable retention rates), and pointed to ways in which conservation and production can be integrated through variable retention rates on coupes. Options for the latter include understorey islands (Ough and Murphy 1996) and variable rates of retaining old trees on coupes or in reserves (e.g. Shaw 1983; Smith 1985; Loyn 1985a; Lunney 1987; Burgess *et al.* 1997; Lindenmayer and Recher 1998; Gibbons and Lindenmayer 1996, 1997, 2002; Lamb *et al.* 1998). Several models have been proposed for variable retention systems that may more closely mimic natural disturbance (e.g. Shaw 1983; Smith 1991; Burgess *et al.* 1997; State Forest Flora and Fauna Habitat Management Working Group 2002). Some of them have been implemented on a trial basis in Wombat State Forest (Macak *et al.* 2004), and more recently in montane ash forest in the Central Highlands. Further research is needed on all these aspects to tailor prescriptions for particular forest types, geographic regions or target fauna species.

Improved information is needed on the distribution and habitat requirements of fauna species known to be sensitive to logging, and threatened fauna species. Often this has been used to pursue a strategy of partly segregating habitat used by these species from areas available for logging. This has been the case with Leadbeater's Possum *Gymnobelideus leadbeateri* (Macfarlane and Seebeck 1991; Macfarlane *et al.* 1998), Long-footed Potoroo *Potorous longipes* (Saxon *et al.* 1994) and large forest owls (Webster *et al.* 1999; Loyn *et al.* 2001, 2002a; McIntyre and Henry 2002). Further work is needed on these and other species to examine options for more integrated management. The needs of rare forest species remain poorly known, although research projects are under way for some of them as discussed below under Focal Species.

Integrate or segregate?

In most forest controversies, a key question concerns the costs and benefits of integrating conservation and production on the same parcel of land, or segregating them on different parcels of land. In practice, the simplest (and in many cases most effective) way of integrating wood production and conservation objectives at the landscape scale is to segregate them at finer spatial scales (Loyn 1985a; Lamb *et al.* 1998).

A logical approach for deciding between strategies to segregate or integrate at the scale of logging coupes is shown schematically in Figure 1. When the response curves of competing values are both concave (implying that partial logging severely reduces one value, and partial retention severely reduces the other), spatial segregation provides the better outcome for both values. When the response curves of competing values are both convex (implying that partial logging and partial retention have little detrimental effect on the respective values), spatial integration is desirable. When the response curves are straight, similar outcomes can be expected from either approach. When one curve is convex and the other is concave, value judgements have to be made in deciding whether to segregate or integrate. Smith (1991) used similar curves to argue for a management system that more closely mimics natural disturbance regimes. More attention needs to be given to the potential utility of this approach in providing a unit-free approach to assessing merits of integrating or segregating competing values.

The strategic importance of this type of decision has often been overlooked or underrated by forest managers and policy makers. In Victoria, segregation of objectives in different areas of forest (zoning) has been the approach of choice, but more opportunities for integration may exist than have been recognised (Loyn 2001; Gibbons *et al.* 2002). Some forest species (notably Leadbeater's Possum) use combinations of resources from regrowth forest with old trees for shelter (Smith and Lindenmayer 1988, 1992), and reach their greatest abundance in regrowth forest with scattered retained old trees. The practical demands of regenerating ash forests have made it more realistic to conserve this species mainly by segregation (in a system of zoned reserves, Macfarlane and Seebeck 1991; Macfarlane *et al.* 1998), but efforts continue to be made to develop ways of providing suitable habitat among regrowth on logged coupes. A coupe in this context is defined as an area harvested in one cut, and is set as no more than 40 ha by the Code of Forest Practices (Government of Victoria 1996), with an average coupe size in recent years of ~20 ha.

In mixed eucalypt forests there are fewer practical constraints on retaining habitat within coupes, because successful regeneration does not demand such intense fire or a complete opening of the canopy, and retained trees are more able to survive the regeneration burns that may be used. Hence a greater range of useful opportunities may exist for integrating conservation and production at the coupe scale. Natural regeneration processes in mixed-species forests typically involve greater survival of trees from previous generations than is usual in ash forests (Ashton 1976; Attiwill 1994; Lamb and Smyth 2003).

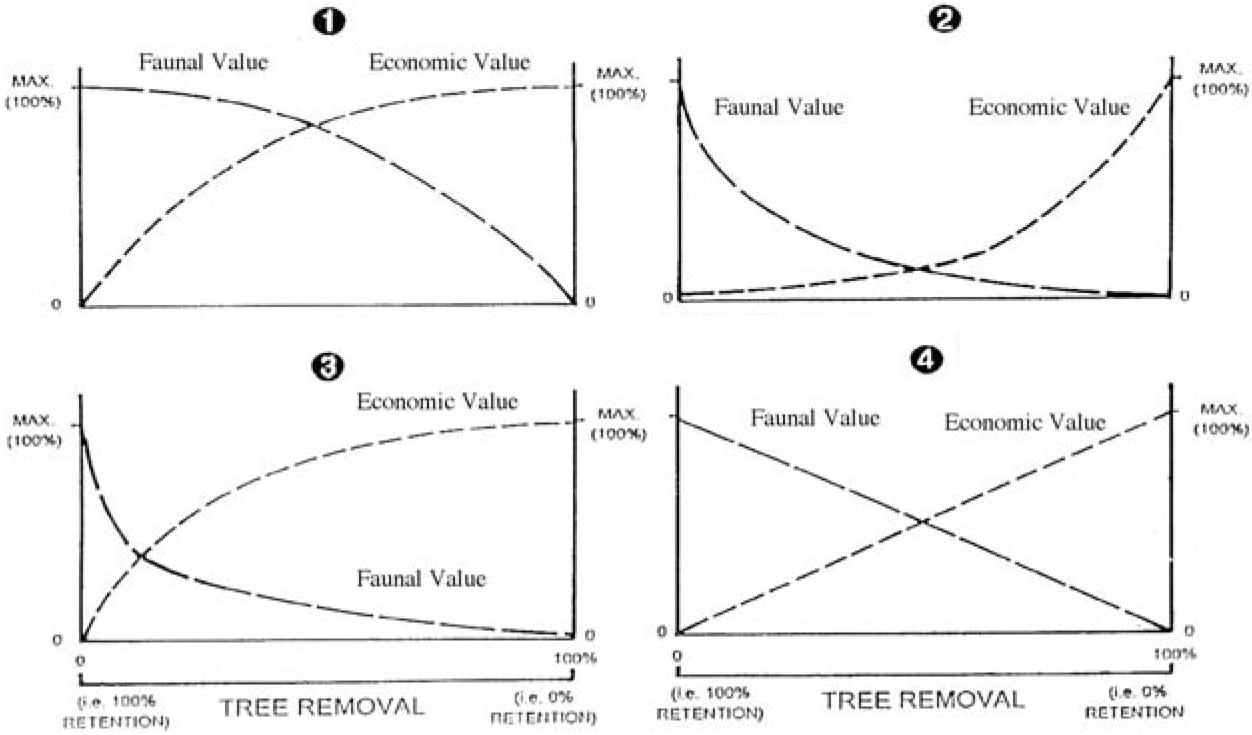

Figure 1. Stylised graphs showing hypothetical responses of faunal values (A) and economic values (B) to varying levels of tree retention on coupes. The values are integrated over an entire planned rotation between harvesting events. For example, Value A could represent the mean abundance of one or more selected animal (or plant) species over the planned rotation. Value B represents the economic return (appropriately discounted) measured over the same period. If both curves are predicted to be convex (graph 1), it is preferable to integrate conservation and production objectives on the same parcels of land. If both curves are concave (graph 2), it is preferable to segregate objectives at some spatial scale. If one is convex and the other concave (graph 3), value judgements have to be made in deciding whether to integrate or segregate in any particular situation. If the curves show little or no departure from linearity (graph 4), decisions about integration or segregation are not important, and from the fauna conservation viewpoint the main need may be to retain the right types of trees. Examples of inferred convex curves (Leadbeater's Possum), concave curves (Sooty Owl and Yellow-bellied Glider) and linear curves (Yellow-tailed Black-Cockatoo) are discussed in the text, albeit from imperfect knowledge.

If the decision is taken to segregate, further questions arise about the appropriate spatial scale to choose. Strategically, we must decide whether we want the forests of the future to be a fine-grained or coarse-grained mosaic of regrowth and mature forest, or a mixture of the two. A fine-grained mosaic would contain small reserves and small coupes, with lots of edge. A coarser-grained mosaic would contain large patches of each, and less edge. A strategic mixture of the two could contain large patches of mature forest but small patches of regrowth, or *vice versa*. Research on effects of edges and patch size can help inform such decisions. At a more detailed tactical level, decisions need to be made about land use priorities for specific parcels of land. Which areas need to be reserved or managed for conservation purposes, and which areas are best for extractive use such as wood production as the main priority? Answers to such questions can help inform the key strategic decisions about the amount of forest that needs to be assigned to each use, and assess the level of trade-off that may need to be involved under alternative management strategies.

An important input to this process is knowledge about the distribution and abundance of key wildlife species that are believed to be sensitive to forest management including wood production (McIlroy 1978; Loyn 1985a; Hunter 1990). Species differ in their habitat requirements and potential exposure to logging, as well as their sensitivity to logging (Kavanagh *et al.* 2003). Gullies provide a classic example, and all states have prescriptions for retaining gully vegetation to protect watercourses. Gullies often support high densities of fauna species, and some species favour gullies whereas others avoid them (Recher *et al.* 1980; Loyn *et al.* 1980; Loyn 1985b,c; Smith 1985; Soderquist and Mac Nally 2000; Mac Nally *et al.* 2000). Those that favour gullies may be less exposed to logging as a consequence, whereas the reverse applies to species that avoid gullies (Recher 1991; Kavanagh *et al.* 2003). Similar issues apply to slopes too steep for commercial logging, or where the Code of Forest Practices prohibits logging (Government of Victoria 1996). Unfortunately, steep slopes tend to be less attractive than flatter country, at least to some fauna species including arboreal marsupials (Lindenmayer *et al.* 1999) and various owls (Loyn *et al.* in press). The best habitats for some species coincide with those most desired for timber production, whereas little conflict is involved for species where the reverse applies.

Research approaches to studies of succession, scale and pattern

Studies of forest succession are vital for understanding forest dynamics under natural or managed disturbance regimes, and in identifying species or groups of species that may be sensitive to particular types of disturbance. Before-after studies can be useful in understanding short-term effects but rarely continue long enough to provide useful insights about effects over relevant time-scales for forest management (decades or centuries). One before-after study in Victoria has been monitored intermittently for 25 years (Loyn *et al.* 1983, 1999; Williams *et al.* 1999). When studies are initiated, we never can afford to wait for decades or centuries for useful answers. Hence additional approaches are needed, with selected before-after studies to provide confirmation or contradiction over time.

Retrospective studies provide a powerful approach to studying succession over long periods of time, as many successional stages can be examined simultaneously. These studies are sometimes termed “space for time” studies. Extensive replication is needed to cater for natural variation between sites. Care is needed in site selection to ensure that sites representing each successional class are selected from a set of sites with common intrinsic characters such as landform or geology. This process is complicated by the fact that disturbance is rarely a random event, but concentrates on particular areas such as north-facing slopes (severe wildfire) or forest on gentle slopes with good road access (logging). Hence random site selection is unlikely to provide comparable samples unless appropriate decisions are made about initial stratification.

The retrospective approach is also a powerful way of tackling questions about scale and pattern, especially if done in conjunction with experimental work. For example, it may be useful to know the short-term effect of a new design for coupes or reserves, but the more important information relates to the effect of a particular forest landscape structure on fauna over time. If forest landscapes can be found with those structural features, studies of wildlife in relation to those structures may yield the required information. The retrospective approach has been used extensively in Victoria to examine succession and various aspects of scale and pattern in ash forests (e.g. Loyn 1985b, 1998; Macfarlane 1988; Lindenmayer *et al.* 1990a, 1999b; Milledge *et al.* 1991; Brown and Nelson 1993; Nelson *et al.* 1996; Incoll *et al.* 2001). In mixed eucalypt forests, retrospective studies have focused on basic questions about succession after logging (e.g. Loyn *et al.* 1980; Loyn 1993; Alexander *et al.* 2002), with less emphasis on further questions about scale and pattern. Retrospective approaches have also been used effectively in New South Wales (Kavanagh and Stanton 2003 a, b) and Queensland (Goodall *et al.* 2003).

A third approach is to deduce successional trends and effects of scale or pattern on the basis of habitat requirements and knowledge of how those habitats may change over time (ecological processes). Modelling is a useful tool in advancing and formalising this process, but it needs a rigorous reference process to ensure that predictions accord with real-world observations or data. These approaches have been used in a range of studies in Victoria, including many of those mentioned above. General accounts of habitats used by forest wildlife in Victoria are given by Menkhorst (1995) for mammals and Loyn (1985c, 2002) and Emison *et al.* (1987) for birds.

Forest wildlife research in Victoria: a historical overview

Distributional surveys: Atlas of Victorian Wildlife

In the 1970s and early 1980s the Departmental emphasis was on general fauna surveys to document the distribution of wildlife species in the state, and provide data to help the LCC in its charter for allocating public land to different uses (e.g. Emison *et al.* 1984; Lumsden *et al.* 1991). In 1977 a non-government organisation, the Royal Australasian

Ornithologists Union (now Birds Australia), undertook a major initiative to map the current distribution of birds across Australia on a grid system, effectively harnessing the energies of thousands of amateur bird observers over a five-year period (Blakers *et al.* 1984). No other continent has attempted the task of producing a comparable snapshot of animal distribution at this scale. The effort has recently been repeated with strategic modifications (Barrett *et al.* 2003), providing a second benchmark for assessing changes over time. In Victoria, the combination of the first Atlas and the LCC surveys laid the foundation for an invaluable database of fauna distribution, the Atlas of Victorian Wildlife. This is continually updated with new records (including those from Birds Australia), and contains 2.7 million records of 1200 vertebrate species. Publications have been produced using the data on birds (Emison *et al.* 1987) and mammals (Menkhorst 1995). The database is used routinely as a source of geographical fauna data in planning decisions.

Most Australian states have comparable databases of wildlife distribution but these represent snapshots in time of extremely imperfect knowledge, mainly arising from opportunistic surveys. Some states have implemented programs of prelogging surveys to improve this knowledge with a focus on areas likely to be logged (Earl and Lunt 1989; Meek 2004; Shields 2004), but these suffer from several limitations. If attention is focused too narrowly on proposed logging coupes, the sampling regime is biased towards a conclusion that the target species occur preferentially in areas suitable for timber production. Many of the species of greatest concern are hard to find without heavy investment of resources in targeted surveys. Prelogging surveys rarely provide comprehensive information on these species, and the issue of imperfect knowledge remains.

A recent program of Regional Forest Agreements (RFAs) aimed to overcome these limitations by encouraging broadscale surveys on a tenure-blind basis, with unbiased effort in State Forest, Parks and reserves. Modelling was then used to predict distributions of selected wildlife species beyond the sites that were actually surveyed, as described under Umbrella Species below. Results of these studies are being applied in various ways to inform public land use decisions at a regional or local level.

Focal species studies (threatened species)

Along with the general surveys discussed above, many projects focused on particular species or groups of species. These have included pest species, game species and threatened species, and a full review is beyond the scope of this paper. Many of the species selected for study inhabit localised habitats or rural environments where their habitat has been highly modified, or where their pest status is of direct economic concern to landholders. Bennett *et al.* (1995) provided a summary of threatened species programs on private land. Wilson (1991) reviewed research and conservation of threatened forest species, most of which occur primarily on public land.

Studies of selected forest species have been influential in shaping forest management over broad areas. These include Leadbeater's Possums in ash forests (Smith and Lindenmayer 1988, 1992; Macfarlane and Seebeck 1991; Macfarlane *et al.* 1998), Long-footed Potoroos in mixed-species forests of eastern Victoria (Saxon *et al.* 1994), and large forest owls across all forests (Webster *et al.* 1999; Loyn *et al.* 2001, 2002a; McIntyre and Henry 2002). Research on threatened fish (Jackson and Williams 1980) and Spotted Tree-frogs *Litoria spenceri* (Gillespie and Hollis 1996; Gillespie 2001) has helped focus attention on the need to protect water quality in forest streams. That research has also highlighted the adverse impact of introduced fish such as Brown Trout *Salmo trutta*, and the need to maintain selected streams free from introduced fish.

It is now generally recognised that effective conservation demands a holistic approach, and single-species studies are most useful when the species selected act as umbrella species for broader elements of the ecosystem (Caughley and Sinclair 1994; Forsman 2002). This applies to the forest owls mentioned above and discussed further under Umbrella Species below. So the fashion has changed to favour broader ecosystem studies. Many of the forest studies described below endeavoured to take this approach from an early stage.

Focal species studies (pest species)

Red Foxes *Vulpes vulpes* and other introduced mammals have had a serious impact on fauna of mainland Australia, especially on medium-sized mammals such as bandicoots and potoroos (e.g. Burbidge and McKenzie 1989; Friend *et al.* 2001; Kinnear *et al.* 2002). Some states have implemented ambitious programs to control foxes, with the Western Shield program in WA being a prime example (Bailey 1996). A similar approach (Southern Ark) has been initiated for eastern Victoria (anon 2002). In Victoria, an initiative has been undertaken by DSE and Parks Victoria to refine methods of fox control and assess their efficacy in helping to conserve selected threatened species, using an adaptive management framework (Robley and Wright 2002).

More work is needed on the roles of other introduced carnivores (e.g. Feral Cat *Felis catus*) and also herbivores, such as deer. Native herbivores can become locally over-abundant when natural controls are removed, and damage vegetation in those situations (McIlroy 1978). Eastern Grey Kangaroos *Macropus giganteus*, Swamp Wallabies *Wallabia bicolor* and Koalas *Phascolarctos cinereus* are the main examples in Victoria (Menkhorst 1995).

Introduced birds are common in suburban habitats and fragmented forests (Loyn 1987), but form only low proportions of the forest bird fauna in extensive forests (<3% of individuals, Loyn 1985c), where they are not a major issue. Introduced fish have a major adverse influence in waterways over much of the state (Jackson and Williams 1980; Koehn and O'Connor 1990; Gillespie 2001; Koehn 2001). Domestic and feral European Honeybees *Apis mellifera* compete with native fauna (birds, mammals and insects) for nectar and hollows (Paton 2000). A valuable honey industry is based on mobile hives of domestic bees, especially in the drier parts of the state (box-ironbark forests and mallee). Management of domestic and feral bees deserves further attention and associated research. Most of these pest issues apply across all land tenures and further discussion is beyond the scope of this paper. However, more work is needed on interactions between control of foxes (and other pest species) and forest habitat management (Friend *et al.* 2001).

Research on forest management issues

In the 1970s, the former Forests Commission of Victoria recognised the need for targeted research on forest management issues. It established small research groups examining flora and fauna in pine plantations in north-east Victoria (Suckling *et al.* 1976) and intensively managed native forest in Gippsland (Loyn *et al.* 1980). The latter studies led the way in use of retrospective research on forest processes with replicated study sites (stratified by landform, *pace* Wilson 1991), although low levels of replication were achieved in the early studies (Wilson 1991). The research groups were combined at the Mountain Forest Research Station (MFRS) in Sherbrooke, and conducted an increasing range of studies in various parts of the state, including forests of Mountain Ash *Eucalyptus regnans* and River Red Gum *E. camaldulensis*, and mixed-species forests in the foothills. They examined a range of issues including effects of fire management, floodwater management, forest fragmentation and wood production.

The research group at MFRS was incorporated within the Arthur Rylah Institute for Environmental Research (ARI) in the mid 1980s. At the same time, the Victorian Government developed a Timber Industry Strategy (Ferguson 1986), which involved a program of strategic research on forest management issues. Biodiversity aspects of this research were conducted by ARI staff with support from the Forests Service through its Forest Science Centre (formerly the Centre for Forest Tree Technology), with a primary focus on forests that were important for commercial wood production. Major research initiatives included the Silvicultural Systems Project (SSP) and the Value Added Utilisation Systems Project (VAUS), later combined as VSP (Squire *et al.* 1991; Wilson 1991). These were set up as ambitious multi-disciplinary research projects, and scaled back with financial constraints in the early 1990s. However, some useful fauna research projects were initiated and maintained, and are described further in sections below on Scale, Pattern and Succession. The Timber Industry Strategy also led to substantial changes in forest management planning, and a reduction in estimated sustainable yields of timber. These estimates have been reduced again in recent years.

Various external institutions (universities and the Museum of Victoria) were involved as collaborators in all these projects. Most of the universities were Victorian (Table 1), but a prolific line of research, focused mainly on arboreal marsupials in montane ash forests, grew at the Australian National University from early associations at MFRS and ARI (e.g. Lindenmayer *et al.* 1990a, 1991a, 1993a,b, 1994, 1999b, 2000). Some key staff moved between ARI and universities or other states in the 1990s, and projects were continued with varying degrees of collaboration. Other collaborative arrangements were fostered specifically, or grew from staff recruitments and co-supervision of postgraduate projects.

In addition, ARI staff and external collaborators conducted a major study of the fauna of box-ironbark forests (a less commercially important forest type) in the 1990s (Bennett 1993; Silveira *et al.* 1997; Brown 2001). This followed a similar study in the extensively cleared landscape of the Victorian Riverina or Northern Plains (Bennett *et al.* 1994, 1998; Lumsden *et al.* 1995, 2002). The two studies involved fruitful collaborations with research staff from Deakin, Monash and La Trobe Universities and the Museum of Victoria (Mac Nally and Bennett 1997; Grey *et al.* 1997, 1998; Wilson and Bennett 1999; Mac Nally *et al.* 2000; Mac Nally and Brown 2001).

Most of these studies took a multi-species or ecosystem approach, generally attempting to examine all forest species in each taxonomic group. Some of the main studies are summarised in Table 1. All studies considered diurnal birds and arboreal mammals, and most also considered small mammals. More limited work has been done on reptiles (e.g. Brown and Nelson 1993). Frogs and bats have been the subject of research focused on the needs of threatened frog species (Gillespie and Hollis 1996; Gillespie 2001) and the ecology of bats in forest and rural environments (Brown *et al.* 1997; Lumsden *et al.* 2002). However, more information is needed on these groups in relation to forest succession and management.

Regional Forest Agreement studies

The next major initiative came when the national government attempted to defuse some of the highly contentious forest management issues. Forest management is generally delegated to state governments under the Australian constitution, but the national government retained powers to issue or deny export licences for products such as woodchips. A program was established whereby national and state governments would reach agreement about aspects of forest management in a number of specified regions (Wescott 2003). Five such regions were defined in Victoria (East Gippsland, Central Gippsland, Central Highlands, North East and West). Biodiversity conservation was a key element in these agreements, as was the need to establish a Comprehensive and Representative reserve system (CAR). Special efforts were made to map old-growth forest as part of this process, and include it substantially in the upgraded reserve system. A goal was also set to include at least 15% of the pre-European area of each Ecological Vegetation Class (EVC) in reserves (Commonwealth of Australia 1997).

The need was identified to conduct general fauna surveys across all tenures of forest land, to generate data from which the comprehensiveness of any proposed reserve system could be assessed. As surveys provide sample data only (at discrete points of time and space), the need was also identified to model the data to provide pictures of the broader spatial and temporal distributions of target biota.

Hence a series of fauna surveys was initiated across the RFA regions of Victoria, covering all terrestrial vertebrate

Table 1. Summary of selected strategic forest wildlife studies conducted in Victoria, 1975-2002, by the Department of Sustainability & Environment (or its constituent agencies, including regional staff, the Arthur Rylah Institute for Environmental Research and the Forest Science Centre) and external collaborators. This table focuses mainly on forests where commercial logging occurs, and excludes substantial bodies of work in other environments such as heathland, mallee, riverine forests, and heavily fragmented rural environments.

Study	Forest type and region	Fauna	Sites	Collaborators	Selected references
Succession after logging					
Retrospective, 0-25 years	Mixed eucalypts, Cent Gippsland	Mammals, birds	12 main 50 other		Loyn (1980); Loyn *et al.* (1980)
Retrospective, 0-30 years	Mixed eucalypts, E.Gippsland	Mammals, birds, reptiles	63		Loyn (1993); Alexander *et al.* (2002)
Retrospective, 0-15 years	Montane ash, Central Highlands	Mammals, birds, reptiles	100		Loyn (1985b); Macfarlane (1988); Brown and Nelson (1993)
Before/after, 0-22 years	Mixed eucalypts, E.Gippsland	Mammals, birds	12		Williams *et al.* (1999); Loyn *et al.* (1999)
Before/after, 0+ years	Mixed eucalypts, E.Gippsland	Mammals, birds	15		Unpublished reports (VAUS experimental)
Succession after fire					
Opportunistic before/after, wildfire 0-3 years	Mixed eucalypts, E.Gippsland	Birds	13 main 17 other		Loyn (1997)
Retrospective, wildfire 0-55 years	Montane ash, Central Highlands	Mammals, birds	16	Deakin Uni	van der Ree and Loyn (2002)
Retrospective, fuel reduction 0-20 years	Mixed eucalypts, NE Victoria	Small mammals	8	CSU	Brown (1997)
Planned before/after, fuel reduction, 0-20 years	Mixed eucalypts, Central Highlands (Wombat Forest)	Mammals, birds	25	Ballarat & Melbourne Unis	Humphries (1994); Tolhurst *et al.* (1992); Loyn *et al.* (1992 and in prep.); Collett (1998)
Scale and pattern					
Fragmented patches in farmland	Mixed eucalypts, Cent Gippsland	Mammals, birds	56	Monash & Deakin Unis	Suckling (1984); Loyn (1985d, 1987)
Patches of old forest in regrowth	Montane ash, Central Highlands	Mammals, birds	57	Melbourne Uni	Loyn (1998); Incoll *et al.* (2001)
Retrospective, shape and size of coupe	Montane ash, Central Highlands	Birds	20		Unpublished reports
Edges, successional stages	Montane ash, Central Highlands	Mammals, birds	150	Melbourne & Deakin Unis	Loyn (1994 and in prep.); Nelson *et al.* (1996)
Linear retained systems	Montane ash, Central Highlands	Mammals	50	ANU	Lindenmayer (1992); Lindenmayer *et al.* (1993a, 1994)
Variable retention rates	Montane ash, Central Highlands		100		Unpublished reports
Variable retention rates	Mixed eucalypts, SW Vic and Wombat Forest		100	Melbourne & Ballarat Unis	Maries (2001); unpublished reports
Indicator species, threatened species, modelling and surveys					
Population Viability Analyses	Ash forests	Arboreal marsupials		ANU	Lindenmayer *et al.* (1993b); Possingham *et al.* (1994)
Population Viability Analyses	Forests generally	Powerful Owl		Melbourne Uni	McCarthy *et al.* (1999)

Study	Forest type and region	Fauna	Sites	Collaborators	Selected references
Montreal indicator 1.2c	Review			CSIRO, other State govts	Taylor and Doran (2001); Loyn and McAlpine (2001); Kavanagh *et al.* (2003)
Surveys for Land Conservation Council, etc.	All forests		100s	MV, various	Emison *et al.* (1987); Menkhorst (1995)
Use of eucalypt plantations by wildlife	Gippsland, NE Victoria, etc.		80+	Melbourne & Monash Unis	Holmes (2001); Rossi (2003); further work in progress
Research on arboreal marsupials & other fauna	Montane ash, Central Highlands		800+	ANU	Smith and Lindenmayer (1988, 1992); numerous papers by Lindenmayer *et al.*
Research on threatened frog species (Baw Baw Frog *Philoria frosti*, Spotted Tree Frog *Litoria spenceri*)	Ash forests; streams		many	EA, Melbourne Uni	Gillespie and Hollis (1996); Gillespie (2001)
Box-ironbark fauna studies	Box-ironbark		80 main +others	Deakin, Monash & La Trobe Unis; MV	Bennett (1993); Silveira *et al.* (1997); Brown (2001)
Regional Forest Agreement surveys; owl & arboreal mammal modelling	All forests		2000	EA, MV, RMIT	Newell *et al.* (2000); Loyn *et al.* (2001, 2002a)

EA=Environment Australia; ANU=Australian National University; CSU=Charles Sturt Uni; MV=Museum of Victoria; RMIT=RMIT University (formerly Royal Melbourne Institute of Technology).

fauna groups (Commonwealth of Australia 1997; Newell *et al.* 2000). Invertebrates were also studied using pitfall traps. Seasonal counts were made of diurnal birds (spring and winter), and targeted research was conducted on roosting requirements of forest bats, as this group was seen as potentially sensitive to forest harvesting and their needs were poorly known. Large forest owls and arboreal mammals were surveyed ahead of other groups because large forest owls were seen as potential umbrella species, which could be used to design a system of reserves (Special Protection Zones) that would also be useful to a range of other species. This work is discussed further under Umbrella Species below. Funds were provided from national and state governments.

Technical innovations

Various technical innovations were made during the course of the work described above. For example, Suckling (1978) introduced the use of hair-tubes for sampling small mammals, building on the pioneering work of Brunner and Coman (1974) who developed microscopic methods for identifying mammalian hair from scats and other sources. The hair-tubing technique has been further refined by Scotts and Craig (1988) and others, and is now a standard survey procedure with well-known strengths and limitations (Kavanagh and Stanton 1998; Lobert *et al.* 2001; Mills *et al.* 2002), along with other methods for identifying mammal tracks and signs (Triggs 1996). Ultrasonic bat detection has been adopted as a standard tool in wildlife research (Lumsden and Bennett 1995; Brown *et al.* 1997). Staff of Ballarat University and ARI have recently made great advances in automating the process of identifying bat calls by species (Lumsden *et al.* 2002). A simple area-search method for assessing relative abundance of forest birds (Loyn 1986) has become a popular standard method nationally (Hewish and Loyn 1989; Barrett *et al.* 2003). The stag-watching method of surveying hollow-dependent marsupials proved highly effective in ash forests (Seebeck *et al.* 1983; Smith and Lindenmayer 1988, 1992; Lindenmayer *et al.* 1989). The call playback method of surveying owls has been developed as a routine tool in New South Wales and Victoria (Kavanagh and Peake 1993; McNabb 1990; Loyn *et al.* 2001, 2002a) and other states.

Arguably the most important technical advances have been those done in collaboration with colleagues from a broad range of disciplines and institutions. Colleagues at DSE have introduced some important new ideas in vegetation description and classification, including the concept of Ecological Vegetation Class (EVC) (Woodgate *et al.* 1994) and more recently Habitat Hectares as an index of vegetation condition (Parkes *et al.* 2003). Enormous advances in computer technology have enabled staff to use a greatly increased range of statistical and geospatial tools.

Collaborations with management

Various forums have been formed to facilitate communication between research and forest management in particular types of forest in Victoria, including a system of Research & Development Action Groups. Generally they have focused more on wood production and regeneration aspects than on biodiversity. Recently the Mountain Ash Research & Development Action Group, MARDAG, has been replaced with a new Tall Forests Working Group, involving an increased degree of community participation. A more holistic and strategic forum may be useful to examine a range of forest management issues on a state or regional basis, with active collaboration from forest managers, policy makers, ecologists and the community. This may be especially valuable in the new era where local communities are becoming increasingly involved with forest management through a range of participatory models.

Interstate collaboration

Many of the forest management issues are common to all states, and it makes sense to collaborate on research. For example, the national Forests and Wood Products Research & Development Corporation recently funded a project to examine the potential use of fauna abundance as an indicator of ESFM (indicator 1.2c under the Montreal Process). A team with representatives from six eastern states or territories, led by New South Wales, undertook the project. They concluded that it made more sense to monitor groups of fauna species than single species, and explored some of the issues and limitations involved in the indicator species approach (Kavanagh *et al.* 2003). Colleagues from CSIRO, working in south-eastern New South Wales, obtained promising results in use of air-borne videography to monitor habitat for fauna, with a special focus on terrestrial mammals such as bandicoots (Catling and Coops 1999; Catling *et al.* 2001).

A mechanism for liaison between researchers in different states lies with the system of Research Working Groups (RWGs), established under the umbrella of a national Research Priorities Coordinating Committee at the Bureau of Rural Sciences. Each RWG has representatives from all states and the national government, along with selected experts in the relevant fields. RWG4 covers native forest management, including silviculture and biodiversity conservation. It meets annually and contributes to national processes such as developing research priorities.

Progress and the future

The first edition of this book included a review of forest fauna conservation in Victoria (Wilson 1991). She applauded some of the state policy initiatives in the 1980s, notably the Timber Industry Strategy (Ferguson 1986), the State Conservation Strategy (Government of Victoria 1987) and the *Flora & Fauna Guarantee Act* 1988. These have been followed by the state Biodiversity Strategy (Government of Victoria 1997) and the national *Environment Protection & Biodiversity Conservation Act* 1999 in the 1990s. Regional Forest Agreements have been completed for all five Victorian RFA regions. However, Wilson feared that financial constraints and deficiencies in knowledge would limit progress. Wilson described forest wildlife research as being in its infancy, with few published papers in refereed journals, and called for more information especially on threatened or sensitive species; essential habitat variables, and effects of forestry practices on species distributions, abundance and habitat use. In particular, she stressed the need for good predictive habitat models, and testing hypotheses about retained habitat systems.

Some of these deficiencies have been addressed in subsequent years, to varying extents, but much more remains to be done. Most but not all threatened forest vertebrates now have action statements under the *Flora & Fauna Guarantee Act* 1988, and relevant actions are addressed through Forest Management Plans. Publication rates have improved, but need to improve further as several important studies remain unpublished. Despite the predicted fund restrictions, productive collaborative arrangements continued for forest biodiversity research. These arrangements are currently under review. Extensive fauna surveys were conducted under the RFA process, and predictive habitat models were developed for certain forest owls and arboreal mammals as discussed below. A decade ago we knew little about the broad-scale distribution of these species in forests and parks. Now we have good sets of data and predictive models for them, which have been used to define and protect substantial areas of forest for these species and the ecosystems upon which they depend (Loyn *et al.* 2001, 2002a; McIntyre and Henry 2002).

But distributions and habitat requirements of other species remain poorly known, including the rarer owls and small cryptic mammals such as the Smoky Mouse *Pseudomys fumeus* (Menkhorst 1995). Work is in progress on Barking Owls *Ninox connivens* (Taylor *et al.* 2002a, b) and preliminary studies of Masked Owls *Tyto novaehollandiae* (McNabb *et al.* 2003). However, much more is needed to develop a holistic approach to forest management to benefit such species. Little information is available on the effects of forest management on bats, reptiles, frogs or invertebrates in Victoria.

Woodland birds have declined in eastern Australia (Robinson and Traill 1996; Ford *et al.* 2001), and are sometimes neglected in forest research because their main habitats lie in the rural landscape. Nevertheless, some of these species make substantial use of public forests (Bennett and Ford 1997; Silveira *et al.* 1997; Loyn *et al.* 2002b), and further work is needed to help forest managers contribute to their conservation.

Various projects have tested hypotheses about the relative merits of different habitat retention systems in montane ash forests (Lindenmayer 1992; Lindenmayer *et al.* 1993a, 1994; Loyn 1998; Incoll *et al.* 2001) and fragmented forests in rural landscapes (Suckling 1984; Loyn 1987; Bennett *et al.* 1998; Mac Nally and Brown 2001). However, much more work is needed in this area, and especially in mixed-species eucalypt forests where these issues have received little attention. Mixed-species eucalypt forests comprise the majority of the forest estate, and there may be wide scope to vary the management systems to include scattered retained trees or larger patches of retained habitat among regrowth. Hopefully this will be addressed in new research projects, in association with proposals for adaptive management of new systems for habitat retention (State Forest Flora and Fauna Habitat Management Working Group 2002; Macak *et al.* 2004).

Selected contributions of wildlife research to Victorian forest management

This section examines how wildlife research discussed above has helped shape changes in forest management. Some of the contributions have been conceptual in nature, while others have involved direct differences in management of particular parcels of land. Forest managers now think deeply on more levels than they did in the 1970s, and recognise the need to manage public forests sensitively with respect to multiple values. This change in attitude has been largely a response to public demand and organisational change, including amalgamation of Victorian departments of Forests and Conservation in the 1980s. But it has also been informed by research, and research has provided a framework and sets of tools and options for dealing with the issues.

Succession

Successional studies have shown that two groups of vertebrates are particularly sensitive to intensive logging, with abundance generally depressed for many years within planned rotation times of 80 years. Species that need hollows for shelter and nesting formone group, as useful hollows rarely form within this time scale (Mackowski 1984; Gibbons and Lindenmayer 2002). Some hollow-dependent species may benefit from dense regrowth after logging, as long as suitable hollow trees remain available to them, with Leadbeater's Possum being a notable example (Smith and Lindenmayer 1988, 1992; Lindenmayer *et al*. 1991a). Other species, such as Yellow-bellied Gliders *Petaurus australis,* are more dependent on mature forest, perhaps because they can move more easily through open stands of tall eucalypts than through dense regrowth to access their patchy food resources (Loyn *et al.*1980, Henry and Craig 1984, Incoll *et al.* 2001). Large owls, such as the Sooty Owl *Tyto tenebricosa*, appear to have similar requirements for forest with an open structure below canopy level (Milledge *et al.*1991; Kavanagh 1997, 2002; Loyn *et al.* 2001, 2002a).

The needs of hollow-dependent species have been widely recognised, but a second group of sensitive species may be more surprising. This group contains birds and mammals that forage from dry open ground among trees. It includes some locally common species (e.g. Red-necked Wallaby *Macropus rufogriseus*, Superb Fairy-wren *Malurus cyaneus* and Scarlet Robin *Petroica multicolor*) as well as species that are generally regarded as uncommon (e.g. Spotted Quail-thrush *Cinclosoma punctatum* and Chestnut-rumped Heathwren *Hylacola pyrrhopygia*). Before-after studies in East Gippsland showed that many of these species disappeared from logged coupes 10-20 years after logging, despite an initial surge in abundance as open conditions prevailed in the early years. These species initially appeared to benefit from logging, but longer term monitoring showed that dense regrowth became unsuitable for them and the net effect over ~20 years was negative (Loyn *et al.* 1999). Similar results were found after wildfire (Loyn 1997). Retrospective studies provide weak evidence that some of these species increase again from ~25 years after logging, as regrowth thins out (Loyn 1993), but more data are needed from stands aged 30-80 years to assess the species' sensitivity to logging over a whole rotation. These results support the cautionary comment by Recher (1991), that species have complex requirements and hollow-dependent species are not the only ones in need of special management.

In contrast, the studies in East Gippsland showed that species that favour dense shrubs and the damp ground below were found to increase in abundance after logging in the time-scale of ~20 years. This group included many common species, as well as some less common species such as Southern Brown Bandicoot *Isoodon obesulus*, Superb Lyrebird *Menura novaehollandiae* and Large-billed Scrubwren *Sericornis magnirostris* (Loyn *et al*. 1999). Southern Brown Bandicoots are now listed as nationally Endangered (Environment Australia website). Recovery Plans are being prepared, and are likely to focus on predator control, habitat retention and availability of hypogeal fungi, an important food source for bandicoots and potoroos (Claridge *et al*. 1993). However, the paradoxical possibility exists that logging may be beneficial in some areas, by providing stands of dense regrowth with adequate food supplies and dense shrub cover that impedes the movement of introduced predators such as Red Foxes *Vulpes vulpes*. Further research is needed to determine whether these characteristics of older post-logging regrowth as bandicoot habitat can be emulated generally, or only on a limited local basis.

Successional studies are still needed from a greater range of forest types to ensure that we have really identified the important groups of sensitive species that may need special conservation measures in any given forest landscape. In some cases it may be possible to provide some of the favoured habitat features in regrowth through deliberate management (Loyn 2001). One option is to retain selected patches of trees on coupes, including some with existing hollows and others with potential to develop hollows in future. Hollows are discussed separately below.

Thinning can help create openings in the canopy and understorey and it deserves more attention as a management tool. Studies of short-term effects of thinning on wildlife (e.g. Kutt 1994, 1996) need to be extended to provide a more comprehensive picture of longer-term effects of this process. Thinning can also accelerate formation of hollows through physical damage to a proportion of retained trees during felling. Control burning may have potential as a tool for manipulating structure of regrowth forests. Effects of control burning have been studied in a long-term experiment in mixed eucalypt forests (Tolhurst *et al*. 1992; Collett 1998), and such studies need to be extended to a greater range of forest types.

Hollow management and artificial hollows

The best way to provide a sustainable supply of hollows is to provide a sustained supply of hollow-bearing trees, through appropriate strategies for retaining and regrowing stands of trees or selected trees on coupes (Loyn 1985a; Gibbons and Lindenmayer 2002). Variable retention systems are being developed to provide new and flexible approaches for achieving this objective. Recent studies have examined the dynamics and spatial distribution of natural hollows in box-ironbark forests (Soderquist 1999) and in mixed eucalypt forests of south-western Victoria (Nelson and Macak 2001; Macak 2003). Extensive studies have been conducted by ANU researchers in mixed eucalypt forests of eastern Victoria and south-eastern NSW (Gibbons and Lindenmayer 1996, 1997, 2002; Gibbons *et al.* 2002). Similar work has been conducted in temperate forests of Western Australia (Whitford 2002 ; Whitford and Williams 2002) and subtropical forests of south-eastern Queensland (Smith 1998; Wormington and Lamb 1999). In Victoria, hollows are routinely assessed as part of a wide-ranging State-wide Forest Resource Inventory (SFRI: R. Penny, pers. comm.). Further work is needed to develop models for predicting hollow availability in space and time for these forests.

A more controversial option is to address the expected shortage of hollows by supplying artificial nest-boxes (Menkhorst 1984; Wardell-Johnson 1986; Newton 1994). This could be especially valuable for Leadbeater's Possum, which would benefit from a more integrative strategy as discussed previously. Net hollow loss and a shortage of hollows for this species in ash forests seem inevitable over several decades (Lindenmayer *et al.* 1997). Nest-boxes or artefacts may be used readily by the species in ash forests (Macfarlane *et al.* 1988) and elsewhere (Smales 1994; Spring *et al.* 2001; Harley *et al.* in press). Arguments against this have been raised on the basis of installation and maintenance costs (Lindenmayer *et al.* 1991b; McKenney and Lindenmayer 1994) and low box occupancy rates in a recent study (Lindenmayer *et al.* 2003). Recent analyses of ecological and economic data suggests that their potential use as a short-term measure should be re-evaluated (Spring *et al.* 2001; Harley *et al.* in press, but see Lindenmayer *et al.* 2003). In some forests overseas, nest-boxes play an important role in maintaining populations of hollow-dependent fauna in heavily managed forests (e.g. for owls in Finland, Saurola 2002). In parts of south-western Victoria, nest-boxes have been used for management with re-introduced Sugar Gliders *Petaurus breviceps* (Suckling *et al.* 1983; Irvine and Bender 1997) and for an endangered subspecies of Red-tailed Black-Cockatoo *Calyptorhynchus banksii* (Emison 1996).

Philosophical issues fuel the debate on the value of nest-boxes, with a fear that nest-boxes may wrongly be seen as substitutes for old trees. Nest-boxes can be used to supply just one of the many resources available in old trees (hollows), but that does not mean that their potential use should be dismissed. Their use as a research tool is more widely accepted (e.g. Soderquist *et al.* 1996; Ward 2000; Dashper and Myers 2003), as long as potential confounding factors are considered appropriately (Koenig *et al.* 1992). Experiments using different spatial arrangements of nest-boxes in regrowth would provide a valuable model to help assess potential benefits of different densities of hollow-bearing trees, as a resource for hollow-dependent fauna.

Umbrella species

Large owls have been selected as umbrella species because they depend on elements of old forest (hollow-bearing trees) and their prey includes arboreal marsupials that also need hollow-bearing trees: owls cannot be conserved without also conserving their prey and appropriate habitat. (Webster *et al.* 1999; Loyn *et al.* 2001, 2002a; McIntyre and Henry 2002). As part of the Victorian RFA process, data on owls were modelled to produce maps of predicted distribution, and after successful field-testing they were used along with actual records to define areas, each of ~500 ha, where habitat would be protected for owls. The RFA process identified ~1000 areas, each of ~500 ha, that would be given special protection for large owls, about half of them in existing reserves and the remainder as Special Protection Zones (SPZ) in State Forest (Loyn *et al.* 2001, 2002a, and in press). Similar work on owls was conducted in other states (Kavanagh 1997; Kavanagh and Stanton 2002; Bell and Mooney 2002; Liddelow *et al.* 2002). Extensive surveys of many other species have been conducted in all states, with associated modelling especially in NSW (e.g. Ferrier 1991; Neave and Norton 1991; Lunney *et al.* 2000; Pearce and Ferrier 2001; Pearce *et al.* 2001).

Monitoring programs are being developed to assess the effectiveness of these measures in Victorian forests and refine them further. What is the frequency of occurrence, site fidelity and breeding success of target species in landscapes with many, few or no reserves or Special Protection Zones? A key question concerns the ways in which owls use mosaics of mature and regrowth habitat. Is it effective to conserve a 500 ha core of protected habitat for a pair of Powerful Owls *Ninox strenua* or Sooty Owls, even when they range more widely (Soderquist *et al.* 2002), or are additional measures needed? Work in NSW has shown that large owls need core areas of protected habitat, but make extensive use of mosaics of mature forest and regrowth (Kavanagh 1997; Kavanagh *et al.* 1995; Kavanagh and Stanton 2002). Detailed work is needed in selected parts of Victoria to determine whether similar principles apply. In North America, work on Northern Spotted Owls *Strix occidentalis* showed that many young birds died during dispersal, and a strategy of clustering reserves was needed to conserve viable populations (Thomas *et al.* 1990). Our population viability analysis did not identify a need for clustering (McCarthy *et al.* 1999), but recognised a general lack of data about dispersal and survival. Some of our owl SPZs are clustered and some are not. Information on persistence and breeding success in these situations would help determine any merits of moving to a system of preferring clustered or dispersed reserves. Genetic information could help determine natural and artificial barriers to gene flow in the forest landscape.

Parallel work on arboreal marsupials shows that these species tend to be somewhat more numerous in areas selected as SPZs for large owls than in the forest generally (Loyn *et al.* in press). This provides limited support for the concept that measures to benefit large owls will benefit a broader range of fauna species, and hence they have value as umbrella species. However, Taylor and Doran (2001) rightly observed that conservation of a few umbrella species cannot be expected to provide adequate protection for the full range of forest fauna species, especially when the diversity of invertebrates is considered. Not all species will fit under a single umbrella. Umbrellas may be useful (and large owls appear to be effective in this respect), but additional management measures are needed to conserve the full range of forest fauna.

Pattern: clumped or scattered old trees?

Many studies have focused on the needs of hollow-dependent fauna (e.g. Lindenmayer *et al.* 1990a and subsequent papers; Gibbons *et al.* 2002), but few have examined the strategic spatial questions identified in this paper. Lindenmayer's data show that Leadbeater's Possums make greater use of old trees scattered among regrowth than they do of similar numbers of old trees grouped together as patches of mature forest. His published models for Leadbeater's possum occurrence include a curvilinear term for density of old trees, showing that possum densities continue to increase with density of old trees, but the rate of increase declines with increasing density of old trees (Lindenmayer *et al.* 1991a). His data show that many more Leadbeater's Possums were recorded per old tree when densities of old trees were low than when they were high (D.B. Lindenmayer, pers. comm.): the relationship with hollow-bearing trees is convex (Figure 1). Hence this species appears to be one that would benefit from a strategy of integrating conservation and wood production at the spatial scale of the coupe, if practical ways can be found to implement such a strategy in ash forests. Retention of patches of trees on selected coupes is the main option under current investigation.

Of the species studied to date, Leadbeater's Possum is the main example that would benefit greatly from a more integrated management strategy. In contrast, data from ash forests and mixed eucalypt forests suggest that Yellow-bellied Gliders and Sooty Owls are much more likely to be found in mature forest than regrowth with scattered old trees (Henry and Craig 1984; Milledge *et al.* 1991; Incoll *et al.* 2001). It seems that the response curves for these species are concave (Figure 1), and hence they would benefit from a strategy of segregating conservation and wood production. Yellow-tailed Black-Cockatoos *Calyptorhynchus funereus* breed in mature forest or in regrowth with scattered old trees, and do not show significant departures from linearity in their response to density of old trees (Nelson and Morris 1994). For Yellow-tailed Black-Cockatoos, it seems to make little difference whether retained old trees are scattered or clumped, and the main need is to ensure that adequate numbers of suitable trees are retained in the forest landscape.

Recent studies of diurnal birds in ash and mixed-species forests have also shown roughly linear relationships between densities of hollow-dependent birds and densities of old trees (R. Loyn, unpublished data), suggesting that the number of trees retained is more important than their distribution, within certain limits. In developing prescriptions for retaining and regrowing old trees, it is important to recognise the spatial heterogeneity that exists in the forest, at a multitude of spatial scales (Forman and Godron 1986; Hunter 1990; Franklin and Forman 1991; Hobbs *et al.* 1993; Bennett 1999). For some fauna species, the type of tree retained (species, age and growth form) may be more important than the number of trees or their distribution (Gibbons and Lindenmayer 1996, 2002; Lamb *et al.* 1998). It is futile to specify a desired distribution of trees to be retained, when trees of that type are uncommon and their actual distribution conforms to a different pattern.

Some of the birds and mammals that forage from open ground would benefit from retaining patches of forest rather than single trees, as patches also include some of the structural features (e.g. lack of dense understorey) that these species require. Open spaces between large trees may also be important for species such as Sooty Owl and Yellow-bellied Glider that need to move through the air between trees to hunt their prey or access patchy food resources (Kavanagh 1997; Incoll *et al.* 2001; Loyn *et al.* 2002a). Retaining patches of trees can also help to protect sensitive understorey plant species (Ough and Murphy 1996). Contrary arguments have been raised in favour of uniform distributions of old trees for arboreal marsupials (Smith and Lindenmayer 1992), and this may be the optimum solution when it is practical to maintain high levels of old trees throughout the forest landscape, as in retained systems of mature forest. However, it is not sensible to aim for uniformity if the uniform level of retention falls below any threshold density for a particular target species: clumping is the only practical option in such cases. The spatial arrangement of retained patches becomes a crucial issue in these cases, and the aim must be to ensure that they remain accessible to individual animals of the target species, so that populations do not lose viability through fragmentation.

From a wood production viewpoint, retained old trees suppress regrowth to varying extents in different forest types (Incoll 1979; Rotheram 1983; Bassett and White 2001), and this effect can be reduced (per tree retained) if retained trees are clumped rather than scattered. Clumping also reduces hazards to timber workers from falling branches. This all amounts to an argument for segregation rather than integration at the coupe scale (as recognised by Loyn 1985a), or an argument for clumping retained trees where possible if integration is to be attempted on particular coupes. There are increasing social and political pressures to avoid clear-felling on coupes, and retaining clumps of trees within coupes offers a possible solution with advantages both to conservation and production. Systems of retained clumps of trees have been implemented on a trial basis in the Wombat State Forest (Macak *et al.* 2004), and are proposed for more general introduction in the near future (State Forest Flora and Fauna Habitat Management Working Group 2002.). Monitoring programs are in place and further research is proposed.

Three main philosophies are apparent among the proponents of variable retention systems. One is to focus mainly on providing habitat patches in parts of the forest where coupes are remote from existing reserves (State Forest Flora and Fauna Habitat Management Working Group 2002), where the need for such systems may be greatest. Another is to provide them mainly close to reserves, effectively feathering the edges of such reserves (Shaw 1983). Proximity to reserves may increase their value to certain fauna species, and especially to those animals that cannot easily travel large distances through regrowth forests. A unifying philosophy may be to provide retained patches mainly in parts of the landscape where uneven-aged stands or fine-scale mosaics are likely to be a common feature of the natural environment (Burgess *et al.* 1997; Mackey *et al.* 2002).

Pattern: fine or broad scale mosaics?

Management of spatial pattern is often seen as a useful way of meeting conservation objectives with minimum effect on production, or *vice versa*. However, there is surprisingly little agreement on the fundamental strategic questions about conservation values of fine-scale or broad-scale mosaics of age-classes. Public perception favours small coupes, and coupe size is limited by the Code of Forest Practices in Victoria (Government of Victoria 1996) and similar legal or administrative instruments elsewhere. Usually the public view is based on a conceptual comparison of one small coupe with one large coupe, whereas it would be more appropriate to compare equal areas of small coupes and large coupes.

Similarly, public perception favours large reserves over small reserves, and this view is often backed by reference to the theory of island biogeography (MacArthur and Wilson 1963; Diamond 1975). Again, the view is based on conceptual comparison of one small reserve with one large reserve, whereas the equal-area comparison is more appropriate. This debate (Single Large or Several Small, or SLOSS) raged in the literature for several years, with the conclusion that there was no general answer to the question (Simberloff and Abele 1982). Hence, empirical research is needed for each situation where management choices are made between fine or coarse-grained mosaics of reserves or logged areas (Franklin and Forman 1987).

Patches

In Victoria, studies of forest patches in farmland have confirmed the general principle that large patches support more species of bird or mammal than small patches, and also showed that there was no simple answer to the SLOSS question in this case (Loyn 1985d, 1987). The practical value of the SLOSS debate has arguably been degraded by its focus on numbers of species rather than abundance of individuals by species or groups of species. In forest patches and farmland in the Latrobe Valley, a marked reduction in abundance (density) of forest birds was found in patches smaller than ~10 ha in size. The reduction was most apparent where such patches were heavily grazed by domestic stock (as they often were) and dominated by an aggressive native honeyeater, the Noisy Miner *Manorina melanocephala* (Loyn 1987). Similar results were found in box-ironbark forests of northern Victoria (Mac Nally *et al.* 2000). The active role of Noisy Miners was confirmed through removal experiments in north-east Victoria (Grey *et al.* 1997, 1998) and south-east Queensland (Catterall *et al.* 2002). Thus groups of small forest patches (<10ha) in farmland will support fewer individual forest birds than large patches of equivalent area, and hence will probably make a lesser contribution to conservation of those species in the rural landscape. But this should never be used to deny a role for small forest patches in conservation strategies, and in some rural landscapes small forest patches may be the only representations of certain forest types available for conservation purposes. Some species may actually favour small patches: for example, Suckling (1984) found that Sugar Gliders *Petaurus breviceps* were more common in roadside strips of trees than in extensive forest. The same is clearly true of a suite of "open-country birds" including Noisy Miners and Grey Butcherbirds *Cracticus torquatus* (Loyn 1987; Grey *et al.* 1997, 1998).

A different situation arises where patches of mature forest are surrounded by regrowth forest. Studies in such mosaics of montane ash forest have shown that some species are more likely to be found in large patches than small patches, including Sooty Owl, Yellow-bellied Glider and Greater Glider *Petauroides volans* (Milledge *et al.*1991; Incoll *et al.* 2001). However, the abundance (density) of forest birds was no less in small patches than large patches (Loyn 1998), suggesting that collections of small patches of mature forest can be as valuable as large patches of equivalent area for those species. The contrast with the rural landscape reflects the absence of domestic stock and Noisy Miners from the montane forest ecosystem (Loyn 2001). The current conservation strategy within the range of Leadbeaters Possum is to conserve all patches of mature forest (Macfarlane and Seebeck 1991) and this approach also appears to have merit for diurnal bird species in the forest landscape.

In both environments, it seems that there is merit in ensuring that small and large patches are conserved, with a preference for large patches where available, especially in the rural environment. Regrowth forest may be an adequate buffer for valuable old patches in extensive forest, but more attention may be needed to creating suitable buffers for patches of special value in farmland. New eucalypt plantations may have a potential role in buffering remnant vegetation, but research data are needed. Research projects have commenced in Victoria and other states to examine the value of eucalypt plantations as fauna habitat.

Edges

Montane ash forests also provide a relatively simple medium for studying effects of edges between age-classes, because individual age-classes are usually better defined than they are in multi-aged mixed species forests. Studies of edge effects need to examine effects on both sides of the edge, especially when positive effects are expected on one side and negative effects on the other. They also need to extend for several hundred metres on each side of the edge, so that comparisons can be made with areas where edge effects are expected to be minimal. Studies of this sort in montane ash forests have shown that, of the species examined, few showed clear positive or negative effects of transient edges between age classes (Nelson *et al.* 1996; Loyn 1994, 1998 and in prep.; Incoll *et al.* 2001; van der Ree and Loyn 2002).

The most convincing evidence for edge effects arose where habitat gradients crossed the edges concerned. For example, numbers of old hollow-bearing trees declined progressively from interiors of mature forest into adjacent 1939 regrowth (Nelson *et al.* 1996). This pattern is a consequence of the progressive impact of the severe 1939 fires as they waxed, waned, changed direction, flared or petered out locally in response to local and rapid changes in conditions on the day or night of the fire. The linear "edge" between mature forest and regrowth was to a large extent an artefact, and may have been exaggerated by post-fire salvage logging. The real gradient of old trees was reflected in the abundance of Greater Gliders (Nelson *et al.* 1996) and White-throated Treecreepers *Cormobates leucophaea* (Loyn 1994 and in prep.). Both species declined across edges in proportion to the abundance of old trees. These gradients could be used as arguments for emulating such patterns in managed forests but should not be used to argue for fine-grained or coarse-grained patterns of harvesting or retention, especially as the negative effects on one side of the "edge" are balanced by positive effects on the other.

A possible positive effect of permanent edges was observed in the course of the studies on birds, where several species were seen to make extensive use of such edges for feeding on food sources not available in extensive forests. Seeds of Compositae species that thrive along tracks constituted one such food source, and were found to be attractive as food to Crimson Rosellas *Platycercus elegans* in late summer (Loyn 1994 and in prep.). It is a common observation that herbivorous marsupials (Swamp Wallabies *Wallabia bicolor* and Common Wombats *Vombatus ursinus*) often feed preferentially along the grassy edges of permanent tracks. It is not known whether the existence of such edges helps increase populations of these species in the forest as a whole. Permanent edges can also have negative effects, especially when they involve roads with associated traffic hazards. Grassy verges also attract introduced mammals such as European Rabbits *Oryctolagus cuniculus*, and they in turn attract introduced predators including the Red Fox.

A special case of edge effects was examined in studies commissioned by ARI to examine effects of linear strips of retained vegetation in recently logged montane ash forest (Lindenmayer 1991; Lindenmayer *et al.* 1993a, 1994). This study found that Leadbeater's Possums were less likely to occur in such strips than in extensive forest with similar habitat features, suggesting a negative edge effect on that species in early successional stages. Different results might be expected when regrowth had developed further, in view of the needs of that species for mixed-age stands as discussed above. In contrast, other arboreal mammals such as Greater Glider and Mountain Brushtail Possum *Trichosurus cunninghamii* were as prevalent in retained linear strips as they were predicted to be from habitat models derived from data in continuous forest.

Coupes

Effects of coupe size and shape were examined in ash forests in the Central Highlands in the early 1990s, as part of an ambitious Silvicultural Systems Project (Squire 1990). The experimental studies focused mainly on regeneration and operational issues, as any important benefits of new systems to wildlife were not expected to accrue for many years. Hence associated wildlife studies were conducted with a more wide-ranging spatial focus, using the retrospective approach. Nevertheless, data were collected on diurnal birds on some of the experimental coupes (R.Loyn, upubl. data). More birds were found in long thin coupes than in equivalent areas on conventional coupes. The birds concerned were all common species, not considered sensitive to logging. It may be worth repeating the studies when regeneration has developed further. However, the generally neutral results from edge studies suggest few important medium-term benefits would be obtained through design changes in coupe shape and size.

No work was done on possible effects of increasing coupe size, as coupe size is currently limited to 40 ha under the Code of Forest Practices (Government of Victoria 1996). Further work on possible effects of large coupes would be needed if moves were made to relax these provisions. The 1939 and 1983 wildfires produced large areas of regrowth, many of which were then stripped of fire-damaged old trees by salvage logging. The opportunity was taken to study mammals in the regrowth 13 years after the 1983 fire, and results suggested that colonisation depended on habitat development not on distance from edge (van der Ree and Loyn 2002). For example, Leadbeater's Possums were found over 1 km into 1983 regrowth, but Greater Gliders were rarely found in 1983 regrowth as trees had not yet reached a suitable height.

Conclusions

Segregate or integrate?

The balance of data suggests that more species are favoured by a strategy to segregate (at some spatial scale) than to integrate. Nevertheless, one species that has been studied intensively (Leadbeater's Possum) would be favoured by closer integration of conservation and production at the coupe scale in ash forest. Other examples are likely to come to light with further research and operational experience. Practical impediments to integration (including safety issues and effects on wood production) are less in mixed eucalypt forests and box-ironbark forests than they are in ash forests. The natural structure of these mixed forests includes a high proportion of uneven-aged stands, in contrast to the even-aged stands that are a common though not universal feature of ash forests (Ashton 1976; Lindenmayer *et al*. 1990b; Attiwill 1994; Lamb and Smyth 2003). Public opinion is in favour of moves away from clear-felling. Complete withdrawal of timber production from native forests may be the ultimate goal of some people, but an effective strategy of conservation and production, integrated to some extent at the coupe level, would be more palatable to many than the current emphasis on segregation. Hence there are socio-political arguments for further development of such systems, even if the current biological data point more in the direction of segregation.

Retaining clumps of trees within coupes offers a possible solution with advantages both to conservation and production. Systems of retained clumps of trees have been implemented on a trial basis in the Wombat State Forest, and are proposed for more general introduction in the near future. Monitoring programs are in place and further research is proposed. A mix of strategies is likely to be needed to satisfy a range of competing demands in different parts of the forest.

Fine or coarse-scale mosaic?

Our studies of scale and pattern in ash forest have shown that some species (large gliders and the Sooty Owl) are likely to benefit from retaining large patches of mature forest, where such patches exist (Milledge *et al.* 1991; Incoll *et al.* 2001). In contrast, most diurnal birds showed little difference in density between small and large patches (Loyn 1998), and any patch of old forest has value in proportion to its area. Studies of edge effects suggest that the transient edges between different age-classes of ash forest have little positive or negative effect on distribution and abundance of bird and mammal species, except in response to habitat gradients. In this forest type, the habitat features of the forest are more important than the spatial arrangement of retained patches and logged coupes. Hence it is appropriate to design the mosaic of reserved and logged forest on the basis of what is available, and the habitats actually used by target species. This is the logic behind current processes to select and protect habitats used by featured species such as Leadbeater's Possum, Long-footed Potoroo *Potorous longipes* and large forest owls (Macfarlane and Seebeck 1991; Saxon *et al.* 1994; Webster *et al.* 1999; Loyn *et al.* 2001, 2002a; McIntyre and Henry 2002). The results also suggest that coupe size, shape and distribution are likely to have only minor effects on distribution and abundance of wildlife species, although more research is needed on effects of larger coupes.

Different conclusions were found in mosaics of remnant forest and farmland, where edges with grazed pasture had negative effects on forest birds in small remnant patches of forest (Loyn 1987; Mac Nally *et al.* 2000). Course-grained mosaics and large reserves appear to be preferable in rural environments, where this is an option. It should be stressed that small reserves are clearly far better than no reserves, and in many situations the only parcels of native vegetation are small. Even scattered trees have important value for some species, and especially for mobile animals such as birds (Fischer and Lindenmayer 2002) and bats (Law *et al.* 2000; Lumsden *et al.* 2002).

Different conclusions again may be reached when similar work on scale and pattern is conducted in mixed-species eucalypt forests and box-ironbark forests. These forests have been sadly neglected in terms of such research, despite their extent and amenability to varied forms of management. This leads to a key conclusion from this review: nobody should expect to find a universal panacea, or an optimum set of prescriptions that can be applied universally. Diversity is part of the essence of forests, and diversity in management is surely part of the key to fostering the diversity of attributes that we value.

The way forward: future research and management

Further studies are planned to examine the effectiveness of new prescriptions for retaining patches of forest on coupes, in selected situations, using an adaptive management framework (State Forest Flora and Fauna Habitat Management Working Group, 2002; Macak *et al.* 2004). Research in varied landscapes is needed to evaluate the relative merits of alternative approaches.

Retrospective research is needed on effects of scale and pattern (retained trees, edges, patches and coupe size, shape and distribution) in mixed eucalypt forests and box-ironbark forests. Possibilities for improving habitat values of regrowth need to be investigated. Thinning and control burning could potentially be used as tools for improving habitat as well as meeting traditional objectives. These needs and others have been identified in a recent document on national research priorities for native forest ecosystem management, produced by the Research Working Group 4 (anon 2003).

Monitoring and research programs are being developed (and some have been implemented) to test the effectiveness of management measures to conserve threatened species or umbrella species such as large owls, and to improve management of pest species. They are expected to involve a mix of monitoring, detailed ecological research in selected forest landscapes, and broad-scale genetic studies. An adaptive management framework (Walters 1997) will be used to feed information through to periodic reviews of forest management. Detailed research is expected to consider the movements of large owls in complex forest landscapes (including the rarer species), and the role of predator-prey interactions in shaping forest ecosystems. A broader program to monitor forest wildlife is also proposed: one of the lessons from Spotted Owl controversies in North America is that a holistic view should be taken (Forsman 2002), using umbrella species as guides but not the whole story. Community involvement is expected to be a feature of these monitoring schemes.

The most fundamental strategic questions will continue to be debated at the community and political levels. They concern the appropriate extent of logging, the relative merits and costs of integration or segregation of logging and fauna conservation measures and the appropriate scale for integration. It is essential that strategic research should continue to be done to inform the public debate and the political process. This research should address questions about successional effects of logging, and effects of scale and pattern of reserves and regrowth, especially in mixed-species eucalypt forests where these questions have largely been neglected. The strategic implications of research should not be lost in the detail of specific studies.

Communication between research, management and policy staff is a vital element in this process. Improved communication is the key ingredient for more innovative adaptive management and more effective targeted research, and hopefully will be achieved through a range of possible models in the near future.

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