

EUCALYPTS, WILDLIFE AND NATURE CONSERVATION: FROM INDIVIDUAL TREES TO LANDSCAPE PATTERNS

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ABSTRACT: Eucalypts — gums, stringybarks, box, ironbarks and mallees — are key elements of ecosystems occupied by much of Australia's distinctive and unique wildlife. Individual eucalypts provide an array of food resources (e.g. foliage, seeds, nectar, sap) for animals, while shelter, refuge and breeding sites for many species are associated with the physical structures of eucalypts (e.g. dense foliage, bark crevices, hollows) and fallen material (logs, leaf litter). Stands of eucalypts make up patches of habitat that sustain populations and communities of animals. The size and shape of a patch, its tree-species composition and age structure, and the context of the patch (isolation, topographic position) influence the species that occur and the structure of animal communities. At a landscape scale, the extent and spatial pattern of eucalypt forests and woodlands and the types of land uses and disturbance regimes they experience (e.g. logging, grazing, fire) shape the distribution and conservation status of animal species across extensive areas. Eucalypts form a distinctive part of the natural and cultural heritage of Australia, yet too often they are taken for granted. The value that Australians place on the protection, management and restoration of eucalypts, from individual trees to ecosystems, will have a critical role in determining the future of Australian wildlife.

Keywords: forest, woodland, patches, landscape pattern, land use, Australia, nature conservation

INTRODUCTION

Eucalypts — including gums, stringybarks, box, ironbarks, peppermints and mallees — are key structural components of the habitats occupied by Australia's distinctive and unique wildlife. From semi-arid mallee shrubland to tall wet forests, eucalypts are the dominant canopy species in most ecosystems throughout Australia, and the eucalypt growth form (e.g. height, spacing of trees, canopy cover) typically determines the form of the vegetation present. Further, as 'foundation' species (*sensu* Ellison et al. 2005) in many ecosystems, eucalypts strongly influence the micro-environment and ecological processes that determine the habitat for many other plant species, and for vertebrate and invertebrate animal species.

The underlying theme of this contribution is the extraordinary breadth of ways in which eucalypts contribute to the habitat resources of animal species in Australia. The relationship between eucalypts and the Australian biota is an immense topic: syntheses, such as those by Keast et al. (1985), Lunney (1991), Williams & Woinarski (1997) and Gibbons & Lindenmayer (2002) provide a starting point. Here, I present a simple overview through the lens of landscape ecology. I consider the relationship between eucalypts and animals at different spatial scales from 1) individual eucalypt plants, to 2) patches or stands of eucalypts, to 3) broad patterns created by eucalypt forests and woodlands at the landscape scale. A temporal

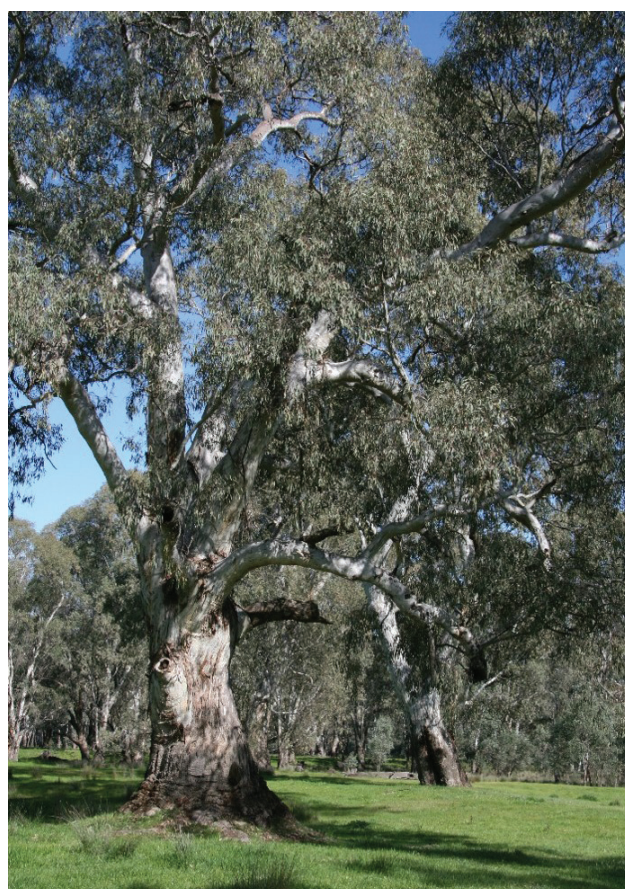


Figure 1: Eucalypt trees, such as this large old River Red Gum *Eucalyptus camaldulensis*, provide a wide array of resources (food, shelter, refuge, breeding sites) for animals. Photo: A. Bennett.

perspective is also important. The interactions between eucalypts and wildlife change through time, ranging from seasonal cycles in flowering and nectar production (e.g. Law et al. 2000), to long-term changes over decades and centuries in growth form and physical structures (e.g. Vesk et al. 2008). The examples used here relate mainly to eucalypt forests and woodlands of south-eastern Australia and to vertebrate animals, and I draw heavily on my own experience and research undertaken with students and colleagues over the last 35 years.

INDIVIDUAL EUCALYPTS

Eucalypts occur in many forms, from towering Mountain Ash *E. regnans* trees over 90 m tall to low shrubby species such as the mallee eucalypts (e.g. Narrow-leaved Red Mallee *E. leptophylla*). Individual eucalypt plants (termed ‘trees’ for convenience) provide a wide array of resources that provide food, shelter, refuge and breeding sites for animals (Figure 1). The type and availability of these resources vary between individual eucalypt trees and between species and, importantly, vary through time in relation to the seasonal cycles and age of the tree. A useful distinction can be made between resources provided by the eucalypt itself, and those resources provided by other organisms that live in, on, or in association with the eucalypt tree.

Provision of resources by eucalypts

Food

Many parts of a tree provide food for animals, including the foliage, seeds, sap and other exudates, woody material, and nectar and pollen from eucalypt flowers.

Eucalypt foliage is a food resource for a vast array of invertebrates (Landsberg & Cork 1997; Majer et al. 1997) but for relatively few vertebrate animals (Woinarski et al. 1997), notably arboreal mammals (possums, gliders, Koala *Phascolarctos cinereus*) and some terrestrial browsers (e.g. Black Wallaby *Wallabia bicolor*) that consume the foliage of seedlings and saplings. Several arboreal mammals feed mostly on eucalypts (e.g. Koala, Greater Glider *Petauroides volans*) (Figure 2), whereas others take foliage from a broader array of plant species (e.g. Common Brushtail Possum *Trichosurus vulpecula*). These herbivores generally favour younger rather than older eucalypt foliage. They may forage disproportionately among co-existing eucalypt tree species (Landsberg & Cork 1997) and also among individual trees of the same species (Lawler et al. 1998). Such selection apparently represents a trade-off between nutritional quality and the influence of plant secondary metabolites in the foliage. For example, in a given location koalas will select among the



Figure 2: The Koala *Phascolarctos cinereus* is a specialist feeder on eucalypt foliage. Individuals select among the tree species at a site, and also favour particular trees based on their size and the foliage characteristics. Photo: A. Bennett.

available tree species and then within species, based on tree size and the foliage characteristics of individual trees (Hindell & Lee 1987; Moore & Foley 2005).

Relatively few vertebrate animals consume eucalypt seeds (Woinarski et al. 1997), probably because of the limited energetic return gained by extracting small seeds from within a hard woody capsule. Some large parrots and cockatoos, such as the Crimson Rosella *Platycercus elegans*, Gang Gang *Callocephalon fimbriatum* and Forest Red-tailed Black Cockatoo *Calyptrorhynchus banksii naso*, use their powerful bills to extract seeds, while other bird species (e.g. pigeons, doves) and mammals can glean shed seeds from the forest floor. The Forest Red-tailed Black Cockatoo is a specialist seed-eater in eucalypt forests of south-west Western Australia, with the seeds of Marri *Corymbia calophylla* being the main food source. These cockatoos discriminate among individual Marri trees, selectively foraging from trees that have fruits with a high seed yield (Cooper et al. 2003).

Exudates from eucalypts include sap and manna, the latter occurring at sites of insect damage where sugary sap crystallises (Holland et al. 2007). The Yellow-bellied Glider *Petaurus australis* is one of few species that feeds on sap. It excises V-shaped notches in the trunks of eucalypt trees from which it then licks the phloem sap (Goldingay 1991). This species selects among eucalypt species, favouring smooth gum-barked eucalypts as ‘sap-site’ or ‘feed’ trees rather than those with fibrous bark. Particular trees are used heavily while nearby trees of the same species are not touched (Kavanagh 1987), potentially relating to variation in the volume of sap flow (Goldingay 1991).

Nectar from flowering eucalypts is a source of carbohydrates (i.e. energy) for a wide array of species, notably many birds, possums and gliders, and bats (Woinarski et al. 1997). These species vary in their

dependence on nectar. Specialised nectar feeders (e.g. lorikeets, friarbirds, some honeyeaters) typically display morphological (e.g. bill shape) and behavioural (e.g. mobility) adaptations to nectar-feeding. Many other species are facultative nectarivores, taking nectar when it is available but for much of the year feeding on other foods. For example, near Euroa, Victoria, the Squirrel Glider *Petaurus norfolcensis* forages at flowering Grey Box *E. microcarpa* in late summer and autumn when this species flowers, but for the remainder of the year the main dietary items are plant and insect exudates (Holland et al. 2007).

Flowering and nectar production vary markedly between eucalypt species, including the seasonal timing of flowering, the morphology and density of flowers, the volume of nectar per flower and the sugar concentration of the nectar (House 1997; Law et al. 2000; Wilson 2002; Keatley & Hudson 2007). Differences in flowering patterns also occur between individuals of the same species in the same location. Larger (older) trees, on average, flower more frequently, more intensely and for a longer period than small trees (Wilson & Bennett 1999; Wilson 2002). Not surprisingly, specialist nectar feeders such as the Swift Parrot *Lathamus discolor* (Kennedy & Tzaros 2005), as well as facultative nectar feeders such as marsupial gliders, favour larger trees when foraging for nectar (Kavanagh 1987; Holland et al. 2007). The synchronous mass flowering of eucalypts can trigger regional shifts in the composition of bird communities (Mac Nally & McGoldrick 1997). For example, heavy flowering of winter-flowering eucalypts in northern Victoria (Red Ironbark *E. tricarpa*, Yellow Gum *E. leucoxylon*) results in mass migration of nectarivores, both *within* the region (e.g. Red Wattlebird *Anthochaera carunculata*, Musk Lorikeet *Glossopsitta concinna*, Fuscous Honeyeater *Lichenostomus fuscus*) and *into* the region from southern Victoria (e.g. Yellow-faced Honeyeater *Lichenostomus chrysops*, White-naped Honeyeater *Melithreptus lunatus*) (Figure 3). Likewise, a

year with poor or no flowering results in the exit of tens of thousands of birds from large forest blocks.

Shelter, refuge and breeding sites

The physical structures of eucalypt trees (e.g. dense foliage, bark crevices, hollows and cavities) together with fallen limbs (logs) and foliage (leaf litter) on the ground provide shelter, refuge or breeding sites for a large proportion of the vertebrate fauna of forests and woodlands. Birds construct nests in many structures (Recher 1991), including among dense foliage, suspended from foliage (e.g. Mistletoebird *Dicaeum hirundinaceum*), on limbs (e.g. Common Bronzewing *Phaps chalcoptera*), in the forks of trees (Rose Robin *Petroica rosea*), under bark (Buff-rumped Thornbill *Acanthiza reguloides*), among leaf litter on the ground (Bush Stone-Curlew *Burhinus grallarius*), and in hollows in trunk or limbs (e.g. Striated Pardalote *Pardalotus striatus*, Crimson Rosella *Platycercus elegans*). In doing so, they may variously use leaves, twigs, sticks and branches, and fibrous bark from trees as material to construct or line their nests.

Hollows and crevices in eucalypts are used as refuge or breeding sites by more than 300 species of vertebrates in Australia (~15% of the vertebrate fauna) (Gibbons & Lindenmayer 2002), including many rare and threatened species. Importantly, many of these species are obligate hollow-users that depend on the availability of suitable hollows for their persistence. The development of suitable hollows in trees takes many decades, with the number and variety of hollows increasing with tree size and age (Bennett et al. 1994; Gibbons & Lindenmayer 2001; Haslem et al. 2012).

When the use of tree hollows is examined in detail, such as for arboreal mammals (Lindenmayer et al. 1991; van der Ree et al. 2006), bats (Lumsden et al. 2002a,b) or cockatoos (Saunders et al. 1982), a striking feature is the fine level of selection shown by animal species — for particular types of trees, types of hollows and dimensions of

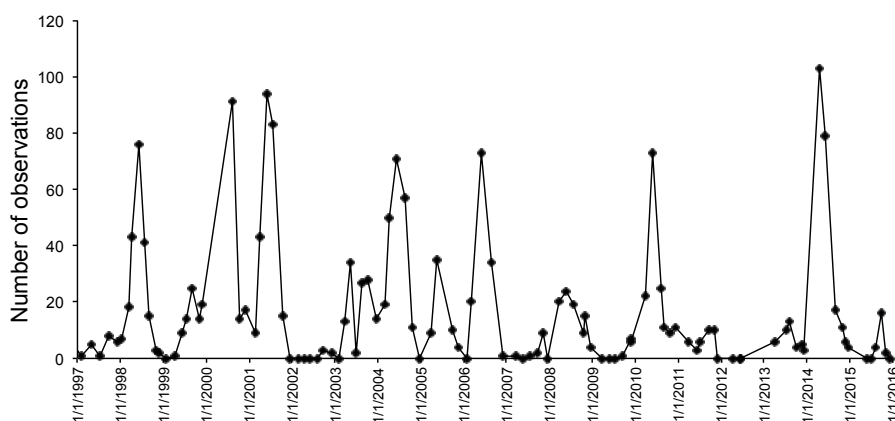


Figure 3: Variation in the number of Red Wattlebirds recorded from twelve 2-ha transects in the Rushworth Forest block from 1997–2015. Peaks correspond with winter months (June – August) in years when Red Ironbark trees were flowering heavily (data – A. Bennett).

suitable hollows. The Lesser Long-eared Bat *Nyctophilus geoffroyi*, for example, although one of the most common and widespread insectivorous bats in southern Australia, shows a high level of discrimination for roost sites and breeding sites in eucalypt trees (Lumsden et al. 2002a,b). Males and females differed in their selection of roost sites. Males roosted in crevices in trees, in fallen and decayed timber and in artificial structures, mostly at lower heights (mean 3.3 m above ground), and mainly under bark or in cracks in timber (Lumsden et al. 2002a). In contrast, roosts of females were located at greater heights (mean 8.7 m), and all within trees. Both sexes roosted primarily in dead timber and used cavities for which the narrowest entrance dimension was 2.5 cm. For breeding sites, females showed even greater specialisation: maternity roosts were predominantly in large dead trees, approximately twice the diameter of trees in which females roosted in the non-breeding season (Lumsden et al. 2002a). No maternity roosts were found under bark despite half the roosts used by non-breeding females being located in these situations (Lumsden et al. 2002a).

Resources from organisms living in association with eucalypt trees

In addition to the resources provided directly by individual eucalypt trees, other resources used by vertebrate animals are associated with organisms that live in, or on, the tree. Several examples illustrate this point.

Invertebrates — food for other animals

Many vertebrates that forage in eucalypts or among the fallen debris of eucalypts (e.g. logs, leaf litter) feed on insects and other arthropods that live in association with eucalypt trees (Figure 4). A vast array of invertebrates live among foliage, such as leaf chewers (e.g. beetles, weevils, phasmids, sawflies and caterpillars), leaf miners (e.g. caterpillars) and sap suckers (Hemipterans including psyllids, leafhoppers, scale insects, coreid bugs). Other invertebrates are wood borers (e.g. termites, long-horned beetles, some moth larvae) or gall formers (wasps, scale insects, psyllids) (Landsberg & Cork 1997). A diverse arthropod fauna is also associated with bark on the trunks and major limbs of trees (Majer et al. 2003). These invertebrates provide a large and varied prey base for vertebrates, such as many species of forest and woodland birds (e.g. whistlers, thornbills, robins, flycatchers, fairywrens). In turn, these insectivorous bird species show complex patterns of resource partitioning that allow them to co-exist in the same forest or woodland habitat (Recher et al. 1985; Ford et al. 1986; Mac Nally 1994; Antos & Bennett 2005). They partition the invertebrate prey base by foraging on different substrates (e.g. in the air, canopy,



Figure 4: The Brush-tailed Phascogale *Phascogale tapoatafa* (top) and Yellow-footed Antechinus *Antechinus flavipes* (bottom) forage for invertebrates associated with the trunks, limbs, bark and fallen debris of eucalypt trees. Both species also use tree hollows for refuge and breeding and show strong selection for large old trees for this purpose. Photos: Russell Jones.

tall shrubs, trunks, litter), at different heights, and by using different foraging actions and behaviours (e.g. hawking, gleaning, pouncing, probing).

Mistletoes

Mistletoes are hemi-parasitic plants that depend on a host plant for water and mineral nutrients, but can manufacture their own carbohydrates by photosynthesis. Eucalypt trees are a primary host for many species of mistletoe (e.g. Reid 1986; Watson 2011). This relationship between tree and mistletoe provides multiple benefits for many species of vertebrates and invertebrates, such that mistletoes have been termed a 'keystone' species of forests and woodlands (Watson 2001). For example, mistletoe plants are used as nest sites by 217 species of birds in Australia, the potential benefits being a strong structural substrate for the nest, greater concealment (and possibly reduced predation) and a more benign microenvironment (Cooney et al. 2006). Mistletoe nectar and fleshy fruits provide food for many species, although only a few species are effective

dispersers of mistletoe seeds; in south-eastern Australia, these include the Mistletoebird *Dicaeum hirundinaceum*, Painted Honeyeater *Grantiella picta* and Spiny-cheeked Honeyeater *Acanthagenys rufogularis*.

Hypogeal fungi

Many species of fungi occur on, within, or in association with eucalypts (May & Simpson 1997). A notable group of fungi are those known as ‘hypogeal fungi’ for which the sporocarp (or fruiting body), occurs underground. These fungal species have an ectomycorrhizal association with the root systems of eucalypt trees, such that the fungal mycelia surround and extend the fine roots of the eucalypt (May & Simpson 1997). This assists the tree with the uptake of water and nutrients (especially phosphorus and nitrogen), and in return the fungus obtains carbohydrates from the eucalypt. These hypogeal fungi are consumed as food by a wide range of ‘mycophagous’ mammal species (Claridge & May 1994). Potoroos and bettongs (Family Potoroidae) are specialist mycophagists for whom fungi is an important and nutritious year-round food source (Bennett & Baxter 1989; Johnson 1994). A wide range of fungal species is consumed. In one locality in western Victoria, the Long-nosed Potoroo *Potorous tridactylus* foraged on at least 60 species of fungi (Bennett & Baxter 1989). Potoroos detect and dig up the fungal fruiting bodies, feed on them (but do not digest the spores), and disperse the spores in their faeces as they move through their home range. In this way, they act as an important vector for fungal dispersal. The outcome is a three-way symbiotic relationship between the eucalypt tree, the fungal species and the mycophagous mammal species, in which each party benefits.

STANDS OR PATCHES OF EUCALYPTS

Eucalypt trees typically occur in stands, either of a single species or more commonly of two to four co-occurring species. While individual trees provide specific resources that animals use to meet daily requirements, stands or patches of eucalypts occupy a larger area that can provide a home range for individual animals, sustain local populations of species, or support distinctive communities of animal species. The ecological value to animals of different eucalypt stands can be related to the composition of the eucalypt species present, and the density and size-class structure of trees (e.g. Antos & Bennett 2005). In areas of extensive native vegetation, variation between stands typically is associated with environmental features (e.g. soil types, topographic position, aspect) and the legacy of disturbance processes (e.g. logging, fire) experienced at the site (e.g. Loyn 1985; Kelly et al. 2011; Lindenmayer et al. 2013). In heavily modified environments such as extensive farmland, towns and cities, or where plantations of exotic

tree species have been established, stands of indigenous eucalypts commonly occur as fragmented and isolated patches of remnant forest or woodland. In such situations, the biogeographic properties of patches such as their size, shape and isolation, also have an important influence on their value for native fauna (Loyn 1987; Lindenmayer et al. 2002; Brown et al. 2008; Holland & Bennett 2010).

Stands within extensive eucalypt forest or shrubland

Variation between eucalypt stands that occur along streams (riparian vegetation) and those on adjacent forest slopes is a common example of differentiation associated with environmental features. Such topographic differences in the composition of canopy tree species are also reflected in differences in the structure of faunal communities (Loyn et al. 1980; Mac Nally et al. 2000; Palmer & Bennett 2006). For example, Palmer & Bennett (2006) compared forest bird communities between 30 pairs of sites, in riparian eucalypt forest and on adjacent slopes, within continuous forests in southern Victoria. The eucalypt composition and structure differed markedly — riparian sites were characterised by species such as Manna Gum *E. viminalis* and had a taller canopy and greater amount of woody debris than sites on adjacent forest slopes. Bird assemblages at riparian sites had more species (~45% greater) and greater total abundance (more than twice) than were recorded at sites on adjacent slopes (Palmer & Bennett 2006). The composition of bird assemblages also differed significantly, due to a suite of distinctive species in each topographic position; for example, Pink Robin *Petroica rodinogaster* and Rufous Fantail *Rhipidurus rufifrons* in riparian sites and Scarlet Robin *Petroica boodang* and Rufous Whistler *Pachycephala rufiventris* on slopes. These differences in bird communities can be attributed to differences in the types of food and structural resources and their abundance and reliability. Streamside vegetation is moister, had greater vertical structural complexity and more reliable year-round provision of resources than forests on adjacent slopes.

Disturbance processes, such as fire, also result in differences in eucalypt stands. The regeneration strategy after fire of the eucalypts present (e.g. survive and recover by epicormic growth, or re-grow from seed or rootstock) will determine the magnitude and duration of the succession process. In semi-arid, ‘mallee’ eucalypt shrubland, in which fire is stand replacing, the structure of the vegetation shows gradual change for over a century or more following fire (Haslem et al. 2011, 2012). Mallee eucalypts resprout from a basal lignotuber after fire and increase in height and cover over subsequent decades. They reach maximum cover ~30–40 years post-fire and maximum height ~50–60 years post-fire, while average stem density peaks in the

first 20 years then declines for up to 100 years post-fire (Haslem et al. 2011). Similar changes occur over decades with leaf litter, low vegetation cover and understorey cover (e.g. *Triodia*). Consequently, stands of different post-fire age offer habitat of different quality for species of reptiles (Nimmo et al. 2012), birds (Watson et al. 2012) and small mammals (Kelly et al. 2011).

Some species (e.g. Chestnut-rumped Thornbill *Acanthiza uropygialis*) are more likely to occur in younger post-fire stands in mallee vegetation, whereas others (e.g. Yellow-plumed Honeyeater *Lichenostomus ornatus*) reach their greatest frequency of occurrence at ~40–50 years post-fire (Watson et al. 2012). The availability of tree hollows for hollow-using species in mallee ecosystems (e.g. insectivorous bats, parrots and pardalotes) is also strongly influenced by post-fire changes. In stands less than ~40 years post-fire, few hollows occur in live trees: those hollows available are primarily in dead stems killed during the previous fire (Haslem et al. 2012). A rare species of bat, the South-eastern Long-eared Bat (*Nyctophilus corbeni*), for example, selected roosts in hollows in dead mallee stems, which were located in stands with abundant hollows and known to have remained unburnt for at least 70 years (and possibly a century or more) (Lumsden et al. 2008).

Remnant patches of eucalypts in modified landscapes

In heavily modified landscapes (e.g. cleared farmland, urban areas, exotic plantations) remnant patches of eucalypts have a key role in maintaining wildlife populations in otherwise largely unsuitable environments. Species differ in their ability to persist in such remnant stands of eucalypts, with these differences associated with factors such as the size of the remnant patch, its isolation from similar habitat, the type and quality of the vegetation, impacts from surrounding land-uses, and interactions with other species (Bennett 2006; Lindenmayer & Fischer 2006).

The size (area) of a remnant patch is an important influence both for individual species and for communities of animal species. The larger the patch, the larger the number of individuals of a particular species that are likely to occur. This is important because small isolated populations in patches are vulnerable to a number of stochastic (or chance) processes: random variation in demographic parameters (e.g. sex ratio, birth rate), loss of genetic diversity (e.g. inbreeding, genetic drift), fluctuation in environmental conditions (e.g. food availability, predators), and natural catastrophes (e.g. flood, fire). For example, a comparison of the population ecology of the Bush Rat *Rattus fuscipes* in small (<2.5 ha) and larger

(>45 ha) forest patches in western Victoria (Holland & Bennett 2010) found that populations in larger patches had a higher density, received more potential immigrants, and had more predictable reproductive patterns than those in small patches. Patch size is also a highly significant influence on the number of species that occur in remnant eucalypt stands. Species richness increases with patch size in a logarithmic manner (Figure 5), a pattern demonstrated for a wide range of taxa (Kitchener & How 1982; Bennett 1987; Loyn 1987; Prober & Thiele 1995).

The isolation of remnant eucalypt patches from other nearby habitat influences the ability of species to move to or from a patch, whether for short-term visits to forage, or to recolonise the patch if a local population has been lost. The level of isolation of a particular patch depends on the mobility of the organisms concerned and their capacity to cross gaps. For a small tree-dwelling lizard such as the Reticulated Velvet Gecko *Oedura reticulata* in the Western Australian wheatbelt, cropland surrounding a eucalypt patch creates a high level of isolation (Sarre et al. 1995), but a large mammal such as the Euro *Macropus robustus* may cross such gaps easily (Arnold et al. 1993). In Victoria, squirrel gliders living in remnant Grey Box woodland along roadsides made forays into small clumps of trees in adjacent paddocks; 95% of records in paddock trees were within 75 m of the roadside, corresponding with the maximum distance that this species can glide in a single movement between trees (van der Ree et al. 2003).

The type and quality of the vegetation in a remnant eucalypt patch also influence its value for faunal species. Factors that influence habitat quality include the way in which it is managed, such as whether it is grazed by stock or has been felled for timber. Pressures may also occur from surrounding land-use, such as invasion by weed species or altered hydrology (Saunders et al. 1991). Many questions remain as to the optimum management of remnants for wildlife, but evidence points to the key role of protecting and retaining micro-habitat features that meet species' needs for foraging, shelter or refuge (Smith et al. 1996; Brown et al. 2008; Michael et al. 2014). For example, the ability of the Brush-tailed Phascogale to occur in a network of remnant roadside vegetation (van der Ree et al. 2001) was attributed in large part to the high density of large old trees along the roadsides, which provide high quality foraging and refuge (den) sites.

Interactions with predators, competitors or parasites can have a marked influence on the ability of species to persist in remnants of native vegetation. A notable example is the profound influence of the Noisy Miner *Manorina melanoccephala* on the occurrence of woodland birds in remnant vegetation. Colonies of Noisy Miners, a native species, aggressively exclude small insectivorous species

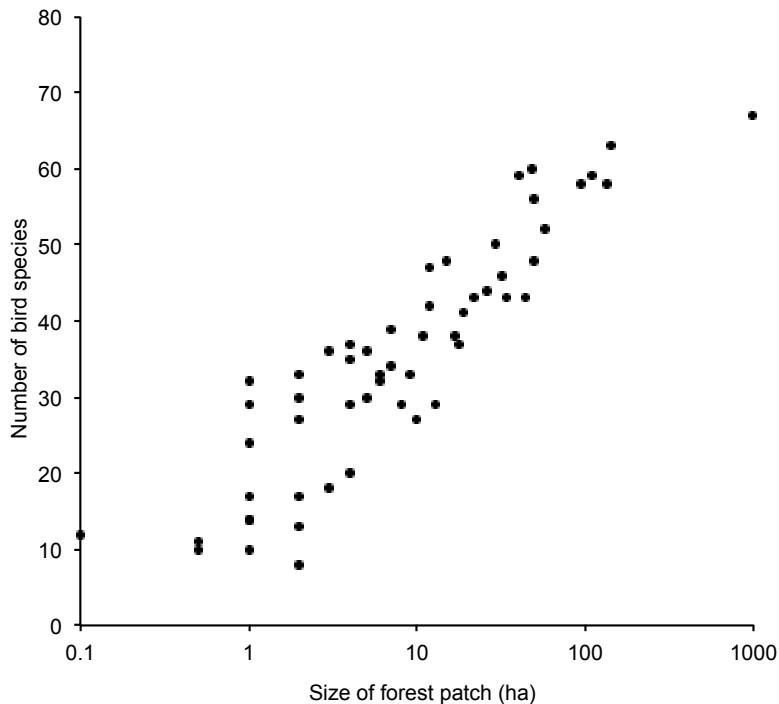


Figure 5: The species-area relationship for birds in forest patches of different size in Gippsland, Victoria (data from Loyn 1987). Note that the horizontal axis has a logarithmic scale.

(e.g. thornbills, pardalotes, whistlers, robins, fairywrens) from remnant patches in farmland, along roadsides and in urban environments, resulting in a depleted avifauna (Loyn 1987; Mac Nally et al. 2012; Maron et al. 2013). Experimental removal of Noisy Miners from small eucalypt patches resulted in an influx of other bird species (Grey et al. 1997, 1998). This single ‘despotic species’ has reduced the carrying capacity for other woodland birds, including threatened species, across millions of hectares of scattered and remnant patches of eucalypt forest and woodland in south-eastern Australia (Mac Nally et al. 2012; Thomson et al. 2015). Similar impacts have been reported for the Yellow-throated Miner *Manorina flavigula* (Mac Nally et al. 2014) and Bell Miner *Manorina melanophrys* (Loyn et al. 1983).

Planting, revegetation and natural regeneration of eucalypt patches in farmland is being actively pursued in many regions, both for productive purposes (e.g. shelterbelts on farms, tree plantations) and to enhance conservation in rural environments (e.g. restoring understorey vegetation, expanding habitats, creating corridors). Mobile species, such as many common bird species, clearly benefit from such restoration (Kinross 2004; Munro et al. 2007; Haslem & Bennett 2008), but other taxa such as reptiles may be slower to gain benefits (Michael et al. 2011, 2014, Jellinek et al. 2014). The value of such restored patches for animal species depends on a range of factors, including its context in relation to remnant eucalypt forest, the age and growth

stage of the vegetation, the availability of particular micro-habitat features (e.g. logs, rocks, shrub cover), and the capacity of species to recolonise (Munro et al. 2007; Vesik et al. 2008; Lindenmayer et al. 2010, Michael et al. 2011).

EUCALYPT FORESTS AND WOODLANDS — PATTERNS ACROSS THE LANDSCAPE

The overall spatial pattern of eucalypt forests and woodlands at the landscape scale has a strong influence on the conservation of faunal species (Radford et al. 2005; Cunningham et al. 2014). It is at these scales — landscapes rather than individual stands or patches — that planning for management and conservation is most effectively undertaken. For example, to manage forests for both timber production and nature conservation at a regional scale requires spatial planning to identify areas available for timber harvest and those not available due to topographic constraints, retention for water production, streamside buffer strips, special conservation values, location of road networks, and other land uses (e.g. CNR 1995). Effective planning for nature conservation at the landscape scale, whether for production forests, conservation reserves, rural environments or urban situations requires an understanding of the way in which the spatial pattern of forest and woodland habitats across the ‘whole landscape’ influence the distribution and abundance of species. Several reasons for planning at such a landscape-scale perspective can be recognised.

First, the total area required for the long-term conservation of many forest and woodland species is large. For top predators and wide-ranging species, such as forest owls, each individual requires a large home range (e.g. ~500–4300 ha for the Sooty Owl *Tyto tenebricosa* — Bilney et al. 2011) and so to maintain a local population (e.g. tens of individuals) requires extensive tracts of eucalypt forests at the landscape scale. In fragmented landscapes, long-term conservation of species depends on the availability of multiple patches of habitat which collectively are of sufficient area to support local populations that can persist in the form of a metapopulation.

Second, a landscape-scale perspective is necessary to understand and facilitate the movements of individuals and genes through the landscape. For some mobile species, there is a need to access different parts of the landscape to obtain resources required for food, shelter or breeding (Law & Dickman 1998; Manning et al. 2004). This may

involve regular movement on a daily basis (e.g., between foraging and shelter or breeding locations) (Lumsden et al. 2002b; Manning et al. 2004), or sequential use of different habitats to track resources that vary through time (Kavanagh 1984; Mac Nally & Horrocks 2000; Stojanovic et al. 2015). In north-western Victoria, for example, the Regent Parrot *Polytelis anthopeplus* nests in River Red Gum *E. camaldulensis* forests along the Murray River but forages in adjacent dry mallee shrublands. A suitable landscape for this species requires both vegetation types to be present, as well as a high level of connectivity (e.g. vegetated roadside strips) to assist daily movements of individual parrots between nesting and feeding locations (Watson et al. 2014).

For species that persist in the landscape in the form of a metapopulation, the capacity for movement of individuals and genes among local populations is paramount. For example, in the wheatbelt of Western Australia, the biology of the Blue-breasted Fairy-wren *Malurus pulcherrimus* was studied in a 32,000 ha landscape at Kellerberrin in which just 7% cover of native vegetation remained (Brooker &

Brooker 2002). Local populations of fairy-wrens persisted in fragments of eucalypt mallee-heath vegetation. Annual survival of adults was higher in the larger fragments, but annual reproductive success was greater in the smaller fragments (less nest parasitism). Overall, the survival of these local populations and the persistence of the species in the region was highly dependent on the capacity for birds to disperse among the set of occupied patches (Brooker & Brooker 2001, 2002). In Victoria, studies on the genetic structure of woodland bird populations in fragmented landscapes found that large-scale genetic connectivity was surprisingly high, but fine-scale population and genetic processes were disrupted at local scales in heavily modified landscapes (Harrisson et al. 2012, 2013).

A third reason for a landscape-scale approach for wildlife conservation relates to the need by some species for habitats at particular successional stages, such as after fire (Brown et al. 2009) or logging (Lindenmayer et al. 1990). The endangered Mallee Emu-wren *Stipiturus mallee*, for example, does not occur in mallee eucalypt vegetation until at least 17 years after fire (Brown et al.



Figure 6: Streamside vegetation is a particularly important component in the landscape. It supports a distinctive faunal community, provides connectivity through the landscape, and protects and enhances aquatic environments. Photo: A. Bennett.

2009). A single large wildfire could burn all suitable habitat in a local area or small reserve, thus entirely eliminating the resident population. Conservation management for this species must encompass a sufficiently large area such that a range of post-fire successional stages (including those at least 20–40 years post-fire) are present, thus allowing local populations to persist in the wider landscape and individuals to recolonise unoccupied areas as they become suitable over time (Brown et al. 2009).

How does the landscape pattern influence the conservation of native fauna?

In contrast to a large body of research investigating factors that determine the value of individual stands or patches for conservation (e.g. Lindenmayer & Fischer 2006), much less is known about the properties of landscapes that make them more or less beneficial for nature conservation. One way in which conservation biologists have addressed this question is by comparing ‘whole landscapes’ to determine which aspects of their structure make them valuable for particular species (e.g. Villard et al. 1999; Mortelliti et al.

2011) or assemblages of species (Atauri & de Lucio 2001; Cunningham et al. 2014).

A study in rural environments in northern Victoria used such a ‘whole of landscape’ approach to investigate the properties of landscapes that influence the distribution of woodland birds (Radford et al. 2005). Birds were surveyed in 24 landscapes, each 10 x 10 km (100 km²) in size, that varied in the cover of native eucalypt vegetation from ~60% down to <2% cover, the latter almost entirely farmland. Variation in the number of woodland species per landscape (from 12 to 53 species) was best explained by the total amount of wooded eucalypt vegetation in the landscape, with additional influence from the shape of wooded patches (more species with irregular shaped patches), the range in elevation within the landscape, and geographic location (more species in the east) (Radford et al. 2005). Individual species differed in how they responded to the landscape structure, but again the strongest influence overall was the total amount of wooded vegetation (e.g. for Crimson Rosella *Platycercus elegans*, Eastern Yellow Robin *Eopsaltria australis*) (Radford & Bennett 2007). For



Figure 7: Eucalypts form part of our natural and cultural heritage. Large old Grey Box *E. microcarpa* trees along this roadside in north-central Victoria date to before European settlement in Australia, and the vegetation is representative of the highly depleted Plains Grassy Woodland. The Tait-Hamilton Rd was the historic route between the gold diggings at Bendigo and Whroo in the 1850s. Photo: A. Bennett.

some species, measures of the configuration of wooded vegetation were a strong influence (e.g. Spotted Pardalote *Pardalotus punctatus*), and for others the composition of the landscape (e.g. Western Gerygone *Gerygone fusca*) or its geographic location (e.g. Scarlet Robin *Petroica boodang*, Sacred Kingfisher *Todiramphus sanctus*) (Radford & Bennett 2007).

Streamside (riparian) vegetation was identified as a particularly important part of the landscape (Figure 6). Such sites (typically dominated by River Red Gum) supported a rich and distinctive bird community (Bennett et al. 2014a). In addition, in landscapes with depleted native vegetation (e.g. <10% tree cover), streamside sites made a disproportionately large contribution to the overall number of species of woodland birds in the landscape. Thus, streamside vegetation is an important target for protection and restoration in rural landscapes, with numerous benefits in addition to those for woodland birds (such as water quality, aquatic environments, erosion prevention and aesthetics).

Surveys in these same landscapes (initially in 2002–2003) were undertaken again in 2006–2007 and 2011–2012; this period coinciding with the Millennium drought,

the most severe drought on record in south-eastern Australia (van Dijk et al. 2013). Sampling corresponded with early drought (2002), mid-drought (2006), and post-drought (2011), respectively. The Millennium drought had a severe effect on the bird community, with 62% of bird species declining from 2002–2003 to 2006–2007 (Bennett et al. 2014b). The breaking of the drought resulted in partial recovery, but overall 55% of species had a lower reporting rate post-drought than during the initial surveys (Bennett et al. 2014b). Land managers cannot prevent climatic extremes such as drought, but it is possible to manage patterns of native vegetation in the landscape. Consequently, an important finding was that changes in bird communities through this drought period differed between landscapes and were related to the landscape structure (Haslem et al. 2015; Nimmo et al. 2016). The stability of bird communities, measured as the *proportional* change in the number of species through time, was most strongly influenced by the total amount of streamside and floodplain vegetation in a landscape. Those landscapes with more riparian vegetation showed a greater resistance to change in bird species richness and greater stability through time (Nimmo et al. 2016).



Figure 8: Scattered trees in farmland face an uncertain future. Many trees in this rural landscape are dead or dying, and there is a lack of regeneration to replace them. Photo: A. Bennett.

EUCALYPTS AND THE FUTURE OF THE AUSTRALIAN FAUNA

Eucalypts are ubiquitous across Australian landscapes; from deserts to wet forests to alpine treelines, they are a typical and distinctive component of the landscape. The colours of foliage and bark, the smell of eucalyptus oil, the texture of bark and leaves, the weathered pattern of logs and dead trees, are part of the sensory experience of the Australian 'bush'. Eucalypts are a distinctive part of the Australian identity (Figure 7) and are ingrained in our cultural heritage in many ways — through art, poetry, music and design. So familiar are they, that often they are taken for granted. Yet, in many locations, the capacity of eucalypts to continue to provide the resources and structural habitat components required by animals is not assured. Disease, insect outbreaks, parasites and climatic extremes can threaten the health and survival of trees and stands of eucalypts. Other threats relate to land management practices.

At the scale of individual trees an important land management issue is the loss of large old trees in forests and farmland, particularly given their multiple ecological values and the timescale (a century or more) required to replace them (Manning et al. 2006). More generally, the ongoing cumulative loss of individual trees in farmland, urban and other developed areas will have long-term ecological implications. Rural landscapes with scattered, isolated trees are a notable challenge: often these are veteran trees, many in poor health, with a lack of regeneration to replace them (Figure 8). Under current land management, such areas will become denuded of trees over time with associated loss of amenity, services (e.g. shade for stock) and habitat values for fauna. The management of stands and patches of eucalypts will also have a marked influence on the future quality of the habitat for fauna. Disturbance regimes, such as logging, grazing, firewood removal, planned burns and recreational use, alter the size-class structure and regeneration of eucalypt trees, as well as the structure and composition of understorey vegetation. Likewise, restoration actions such as fencing to exclude stock, replanting understorey vegetation and managing disturbance regimes also influence such stands and can counter and reverse degrading processes.

At the landscape scale, the contribution of eucalypt ecosystems to future nature conservation is strongly influenced by their extent, representativeness and spatial pattern, and the changes through time arising from human land use (e.g. Radford et al. 2005; Cunningham et al. 2014). Critical components of landscape pattern include large, continuous tracts of native vegetation, wide streamside corridors, keystone structures such as scattered large trees, and vegetated strips and patches that enhance

connectivity for individual animals and gene flow. Actions that destroy, degrade or fragment these components have both a local effect and a wider cumulative effect across the landscape. Similarly, actions that protect, restore and recreate eucalypt ecosystems have a wider beneficial effect across the landscape (Munro et al. 2007; Bennett et al. 2014a). Practical actions by individuals, community groups and agencies can, and do, make a difference (e.g. Thomas 2009; Norton & Reid 2013).

Eucalypts, in their many forms, are the dominant structural component of the forests, woodlands and shrublands that make up habitats for much of the Australian fauna. Consequently, the value that Australians place on the protection, management and restoration of eucalypt ecosystems will have a profound influence on the future of Australian wildlife — whether in extensive forests, rural environments or peri-urban landscapes — over the next century and beyond.

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