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Faunal response to revegetation in agricultural areas of Australia: A review

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***Nicola Munro**, **David Lindenmayer** and **Joern Fischer** are from the Fenner School of Environment and Society (Hancock Building (43), Biology Place, Australian National University, Canberra, ACT 0200, Australia; Tel. +61 2 61251495, Email: nicola.munro@anu.edu.au or nmunro@cres.anu.edu.au). The research was undertaken in response to a need for collated and reviewed information on how fauna respond to revegetation and how we can best revegetate to maximize use by fauna.*

Summary We reviewed the literature on fauna in revegetation in Australian agricultural areas. Of 27 studies, 22 examined birds, with few studies focusing on other faunal groups (four to six studies for each remaining group) and nine examined multiple groups. Existing evidence suggests that revegetation provides habitat for many species of bird and some arboreal marsupials. Species richness of birds was greater in revegetated areas that were large, wide, structurally complex, old and near remnant vegetation. Bats, small terrestrial mammals, reptiles and amphibians did not appear to benefit significantly from revegetation in the short term. Evidence to date suggests that revegetation is not a good replacement of remnant vegetation for many species. Key information gaps exist in the faunal response to (i) revegetation as it ages; (ii) different structural complexities of revegetation; (iii) revegetation that is composed of indigenous *vs.* non-indigenous plant species; and (iv) revegetation that is in riparian *vs.* non-riparian locations. In addition, little is known on the value of revegetation for declining or threatened fauna, or of the composition of fauna in revegetation. There is a need to better understand the balance between quantity of revegetation in the landscape, and the quality or complexity of revegetation at the patch scale. Based on current evidence, we recommend revegetation be conducted in patches that are large, wide and structurally complex to maximize the benefits to fauna.

Key words: *habitat, plantation, restoration, revegetation, structural complexity.*

Introduction

Throughout Australia, land clearing for agriculture has caused land degradation such as salinity and erosion (Bird *et al.* 1992; MDBC 1999), and the loss of native biota (Saunders 1989; Ford *et al.* 2001). The re-establishment of vegetation has been suggested as a potential solution to these problems (Hobbs 1993; Hobbs & Saunders 1993; Barrett 1997). Revegetation may have several ecological benefits, for example by lowering water tables (Stirzaker *et al.* 2002) and providing some habitat elements for wildlife (Kimber *et al.* 1999; Ryan 1999).

The faunal response to revegetation in Australian agricultural areas has been reviewed by Ryan (1999) and Kimber *et al.* (1999). Both reports concluded (from the small number of studies then available) that revegetated sites provided habitat for a range of bird species (the only taxa studied) although the majority of these were generalist or edge species, and birds with specialized needs were not provided for by revegetation. Substantially, more research has been conducted since the earlier reviews providing the impetus for this paper.

We review the use by fauna of revegetation in Australian agricultural landscapes and the effectiveness of different revegetation strategies. We define 'revegetation' as an area where native plants have been actively introduced, but we do not stipulate by what method those plants were established. Our definition of 'revegetation' includes all plantings of woody vegetation (excluding grasslands) in an area where woody vegetation previously occurred, and where the planted vegetation is native to Australia (but not necessarily locally indigenous). This includes both single species and multispecies plantings (Fig. 1). We exclude plantations of exotic species (e.g. *Pinus radiata*), plantations dominated by tree crops (e.g. orchards) and industrial-scale plantations, to focus the review on small-scale farm and community plantings. We define two types of revegetation based on structural complexity (Fig. 1): 'simple tree plantings' include windbreaks, community plantings, woodlots and other farm plantings that are structurally simple; and 'ecological restoration plantings' which aim to re-create the vegetation communities present before land clearing and are usually structurally and floristically diverse. 'Structural complexity' is defined as the number of different attributes present and the relative abundance of these attributes (McElhinny *et al.* 2005). We explain how authors have measured structural complexity where possible and appropriate.

We summarize the responses of different taxa to revegetation, and discuss the faunal response to different attributes of revegetation, such as size and shape. We conclude by outlining priorities for future research and revegetation management.

Methods

We reviewed all known scientific literature on the faunal response to revegetation in Australian agricultural areas (29 articles describing 27 studies; Table 1). Literature was found by searches through databases and citation lists and interviews with experts. Anecdotal descriptions were not included. More than half the articles were published in peer-reviewed journals (18 of 29 articles). Five articles were theses, resulting in one journal publication. Where multiple publications were produced from the same

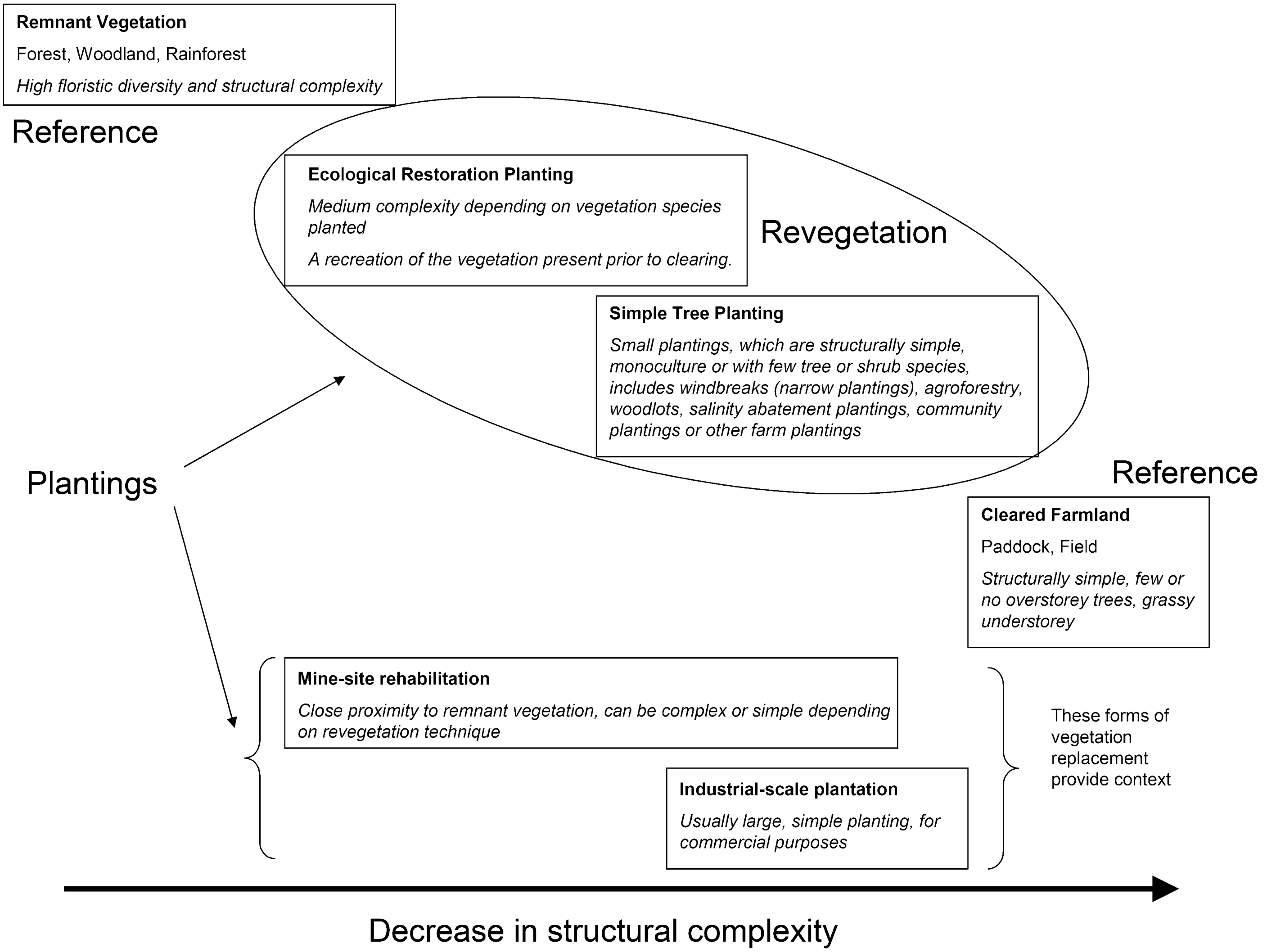

Figure 1. Overview of the terms used in the paper, on a scale of structural complexity. 'Revegetation' includes ecological restoration plantings and simple tree plantings. These forms of revegetation are compared to reference areas of remnant vegetation and cleared farmland. Industrial-scale plantations, mine-site rehabilitation and regrowth vegetation are not of primary concern in this review. Collectively, all forms of active vegetation establishment are called 'plantings'. Note that remnant vegetation sites in this review are timbered woodland, forest and rainforest.

study (e.g. a journal publication from a thesis), we used the journal article. Four articles were reports. The remaining two articles were one booklet and one book chapter.

Different studies explored different combinations of site types. Site types examined in this review were remnant (woody) vegetation, ecological restoration planting (high plant species diversity), simple tree planting (low plant species diversity), and cleared farmland. Many studies compared plantings to reference sites such as remnants (22 studies) or cleared farmland (15 studies; Table 1). More studies examined simple tree plantings than ecological restoration plantings (19/27 *vs.* 11/27), although six compared these two revegetation types.

Most studies examined birds as a response variable (22 studies). There were four to six studies for each of the following groups: arboreal marsupials, small terrestrial mammals, bats, reptiles, amphibians, invertebrates (Table 2). Nine studies examined multiple taxa. Most studies were conducted in woodland (17 studies), and in areas with a temperate climate (22 studies). Three studies were conducted in tropical or subtropical rainforest (Table 1).

Information on site attributes was not always available in the reviewed articles. Frequently missing was information on the age, size, isolation and complexity of the revegetation. Missing information has hampered this review. Several studies had limited replication: four studies had <10 sites and only 11 studies had >50 sites (Table 1).

Results

Birds

Typically, revegetation did not support the bird richness or composition characteristic of remnant vegetation (Crome *et al.* 1994; Leary 1995; Green & Catterall 1998; Klomp & Grabham 2002; Hobbs *et al.* 2003; Kinross 2004; Kavanagh *et al.* 2005; Loyn *et al.* 2007).

Table 1. Studies of faunal response to revegetation in agricultural landscapes

A tick indicates the vegetation types researched in each study/article

Authors	No. of sites	Taxa	Paddock	Plantation	Regrowth	Ecological planting	Remnant	Vegetation type	Climatic zone	Comments
Woinarski 1979	2	Birds		✓			✓	Forest	Temperate	Unreplicated, observational
Biddiscombe 1985	3	Birds		✓				Woodland	Temperate	A longitudinal study for 7 years, descriptive
Crome *et al*. 1994	64	Birds, arboreal marsupials, terrestrial mammals		✓	✓		✓	Rainforest	Tropical	Sites were on a single farm, poorly replicated
Leary 1995	15	Birds	✓	✓			✓	Woodland	Temperate	Honours thesis
Green & Catterall 1998	40	Birds, arboreal marsupials, reptiles, amphibians, invertebrates	✓		✓		✓	Forest	Subtropical	Site types were clustered
Harris 1999	25	Birds		✓	✓	✓	✓	Woodland	Temperate	Honours thesis
Kinross 2000	84	Birds	✓	✓			✓	Woodland	Temperate	PhD thesis
Fisher 2001	6	Birds			✓			Woodland	Temperate	Descriptive
Taws *et al*. 2001	132	Birds	✓			✓	✓	Woodland	Temperate	
Bonham *et al*. 2002	92	Invertebrates		✓			✓	Forest	Temperate	Both pine and Eucalypt plantations
Borsboom *et al*. 2002	18	Birds, terrestrial mammals, bats, reptiles, amphibians	✓	✓	✓			Forest	Subtropical	
Grabham *et al*. 2002	5	Birds		✓				Woodland	Temperate	
Klomp & Grabham 2002	12	Birds	✓	✓			✓	Woodland	Temperate	Only 3 replicates in study
Arnold 2003	27	Birds		✓			✓	Woodland	Temperate	
Hobbs *et al*. 2003	28	Birds, small and large terrestrial mammals, bats, reptiles, amphibians	✓	✓			✓	Forest	Temperate	
Rossi 2003	54	Birds, terrestrial mammals	✓	✓			✓	Forest	Temperate	Master's thesis, both pine and eucalypt plantations
Schnell *et al*. 2003	15	Invertebrates (ants)	✓	✓			✓	Woodland	Temperate	The 'remnant' vegetation is old regrowth
Martin *et al*. 2004	12	Birds	✓	✓		✓	✓	Woodland	Temperate	Sites were not spatially independent
Bond 2004	20	Birds				✓	✓	Woodland	Temperate	Honours thesis
Catterall *et al*. 2004	104	Birds, reptiles, invertebrates	✓	✓	✓	✓	✓	Rainforest	Tropical and subtropical	
Kinross 2004	84	Birds	+	+			✓	Woodland	Temperate	Paper resulting from thesis
Merritt & Wallis 2004	10	Birds, amphibians				✓		Woodland	Temperate	
Cunningham *et al*. 2005	27	Invertebrates	✓	✓			✓	Forest	Temperate	
Kanowski *et al*. 2005				✓		✓	✓			Review restricted to rainforests, with some additional data
Kavanagh *et al*. 2005	120	Birds, arboreal marsupials, bats, reptiles, amphibians	✓	✓		✓	✓	Woodland	Temperate	
Kanowski *et al*. 2006	104	Reptiles	✓	✓	✓	✓	✓	Rainforest	Tropical and subtropical	
Law & Chidel 2006	120	Bats	✓			✓	✓	Woodland	Temperate	
Cunningham *et al*. 2007	184	Arboreal marsupials, reptiles			✓	✓	✓	Woodland	Temperate	
Loyn *et al*. 2007	105	Birds	✓	✓			✓	Forest	Temperate	
Total articles = 29			16	21	8	11	23			
Total studies = 27			15	19	8	11	22			

Table 2. The number of studies found on particular faunal groups
The groupings used in this graph are those referred to throughout the review. Several studies researched more than one faunal group (see Table 1)

Faunal group	Number of studies
Birds	22
Arboreal marsupials	4
Terrestrial marsupials	4
Bats	4
Reptiles	6
Amphibians	5
Invertebrates	4

Conversely, compared with open farmland, revegetation typically supported more bird species (Leary 1995; Green & Catterall 1998; Klomp & Grabham 2002; Hobbs *et al.* 2003; Catterall *et al.* 2004; Loyn *et al.* 2007), more woodland/forest dependent species (Loyn *et al.* 2007) and more declining species (Leary 1995; Kinross 2004).

Nichols and Nichols (2003) suggested that birds recolonizing rehabilitated mine sites respond to the development of vegetation structure and diversity. A correlation between bird species richness and remnant vegetation complexity has been demonstrated in Australian ecosystems (Gilmore 1985; Hobbs *et al.* 2003; Rossi 2003). Revegetation does not approximate the floristic and structural diversity of remnants in the first few decades after establishment (Kanowski *et al.* 2003). Several studies observed that bird species richness was higher in complex revegetation than in simple revegetation (Harris 1999; Barrett 2000; Arnold 2003; Hobbs *et al.* 2003; Rossi 2003; Kavanagh *et al.* 2005). However, most of these studies did not measure complexity directly. Rossi (2003), the only author to do so, defined complexity as the number of stratas present (out of 17).

Recent revegetation guides suggest that planting local plant species should benefit local fauna (Bennett *et al.* 2000). This has been implicitly tested in only one study: the diversity of woodland birds was greater if local native plants were established, and conversely, exotic birds were more diverse if exotic trees were planted (Barrett 2000).

Bird abundance and species richness are relatively simple measures. Of perhaps more importance to restoration is the bird community composition in revegetation. Several studies found that the bird composition in revegetation as young as 5 years after mining resembled that in the surrounding forest, depending on the development of the vegetation, particularly the understorey (Nichols & Watkins 1984; Armstrong & Nichols 2000). Borsboom *et al.* (2002) found that largely undisturbed 40-year-old simple eucalypt plantings approached the plant species richness and abundance of selectively logged old-growth forest, and also approached the bird species richness and composition of the reference forest. This latter project, however, was unable to separate the effects of plantation age and structural complexity (because complexity increased with age). Catterall *et al.* (2004) separated these effects and compared ecological restoration plantings (high structural complexity) with simple tree plantings (low complexity) of the same age and found that bird composition in ecological restoration plantings was closer to that in remnant forest than in simple tree plantings.

Structural complexity of revegetation, as measured by the cover or abundance of a number of vegetation attributes, increases with age (Kanowski *et al.* 2003; Martin *et al.* 2004). Possibly because of this increased complexity as well as increased time for recolonization, bird species richness also tends to increase with revegetation age (Biddiscombe 1985; Taws *et al.* 2001; Borsboom *et al.* 2002; Martin *et al.* 2004). Common bird species can recolonize revegetation within 2 to 3 years (Biddiscombe *et al.* 1981; Taws *et al.* 2001; Martin *et al.* 2004), and many declining and uncommon birds after 8 years (Taws *et al.* 2001). However, some bird species, such as bark foragers, had not recolonized revegetation in northern New South Wales after 50 years (Martin *et al.* 2004). Woinarski (1979) noted that guilds such as granivores, nectarivores, frugivores and bark gleaners were absent or uncommon in 25-year-old simple tree plantings.

Many revegetation guides recommend maintaining remnant features such as old trees, logs and rocks (Barrett 2000; Bennett *et al.* 2000; Salt *et al.* 2004). Few studies have examined the bird responses to remnant features, although some have found increased bird diversity in plantings with retained large trees (Kavanagh & Turner 1994; Taylor *et al.* 1997; Barrett 2000; Grabham *et al.* 2002).

Only two studies investigated the response of birds to planting area, with differing results. Borsboom *et al.* (2002) found no correlation between bird species richness and simple tree planting area. Kavanagh *et al.* (2005) found that bird species richness and abundance had a strong positive response to patch size. These studies differed in their ranges of patch sizes and complexity, with the former being small simple eucalypt plantings (1.5 to 10.5 ha), and the latter including large ecological restoration plantings (<5 to >1000 ha).

Several studies identified width of revegetation as being positively correlated with bird species richness (Taws *et al.* 2001; Merritt & Wallis 2004; Kavanagh *et al.* 2005) or richness of forest/woodland birds (Kinross 2000). The composition of birds in wider revegetation patches was no different to that in narrow revegetation patches (comparing <15 m with >19 m sites), although some small insectivorous species preferred wider sites to narrow (Kinross 2004).

Landscape-level attributes of revegetation have been little studied. Hobbs *et al.* (2003) found that adjacency to remnant vegetation increased the abundance of some birds in simple tree plantings, but overall differences between isolated plantings and those adjacent to remnant vegetation were relatively small. Kavanagh *et al.* (2005) compared birds in revegetation in two landscapes differing in vegetation cover – variegated and cleared – and found no difference in the total numbers of bird species in each landscape. Cunningham *et al.* (in press) demonstrated that bird richness was greater where the total area of both remnants and revegetation was greater. Also, the effect of plantings was greater on farms with little remnant vegetation, than on farms with more remnant vegetation (Cunningham *et al.* in press).

Arboreal marsupials

Studies of arboreal marsupials have shown that some members of this group can recolonize revegetated areas if hollows (a key resource) are present or provided (e.g. nestboxes) (Suckling & Goldstraw 1989; Irvine & Bender 1997; Smith & Agnew 2002; Kavanagh *et al.* 2005). Although revegetation can sometimes provide habitat for arboreal marsupials, this group is typically more abundant in remnant vegetation (Green & Catterall 1998; Kavanagh *et al.* 2005). Cleared farmland provides almost no habitat for arboreal marsupials (Green & Catterall 1998; Kavanagh *et al.* 2005).

Older revegetation sites contain more arboreal marsupials than young sites (Kavanagh *et al.* 2005). The older areas of revegetation in that study were 20–25 years old, and so were unlikely to provide nesting hollows (Gibbons & Lindenmayer 2002) – hence it is unclear why these older sites contained more arboreal marsupials. Kavanagh *et al.* (2005) also found that arboreal marsupials were more abundant in relatively large revegetation sites (>5 ha), but did not respond to planting width (where a narrow site was <50 m wide).

A study by Cunningham *et al.* (2007) found that farms and landscapes with many revegetation plantings supported a lower abundance of arboreal marsupials. This was attributed to those farms supporting less remnant vegetation than farms and landscapes with few plantings.

Small native terrestrial mammals

Two of four studies examining small native terrestrial mammals had sufficient data to indicate the value of revegetation as habitat. In one study, two species were observed, and both occurred only in remnant vegetation and not in simple tree plantings (Hobbs 2003; Hobbs *et al.* 2003). In the other, one species was ubiquitous, and three were more abundant in remnant vegetation than simple tree plantings (Rossi 2003). Habitat complexity of plantings (as measured by the number of stratas including ground cover elements) explained most variability in native mammal richness (Rossi 2003).

Bats

Three studies provided results of bats in revegetation. Hobbs *et al.* (2003), Kavanagh *et al.* (2005) and Law and Chidel (2006) found greater bat foraging activity in remnant vegetation than in revegetation, and Hobbs *et al.* (2003) found greater species richness in remnant vegetation, whereas Kavanagh *et al.* (2005) did not. There also were mixed responses when bat activity in cleared farmland was compared to that in revegetation. Kavanagh *et al.* (2005) and Law and Chidel (2006) found no differences between revegetation of any size and cleared farmland, whereas Hobbs *et al.* (2003) found more bat activity in cleared farmland compared to an isolated simple tree planting, but less compared to a planting near a remnant. Law and Chidel (2006) found more bat activity in older revegetation than in younger revegetation, but Kavanagh *et al.* (2005) and Hobbs *et al.* (2003) did not.

Bats appeared to be insensitive to revegetation size and width as well as to the amount of vegetation cover in the landscape (Kavanagh *et al.* 2005; Law & Chidel 2006). Bat species richness and activity was negatively correlated with shrub cover, possibly because many bats experience 'structural clutter' which reduces foraging ability (Kavanagh *et al.* 2005).

Reptiles

Five of six studies examining reptiles had sufficient data to indicate responses to revegetation. Typically, remnant vegetation contained more reptile species and higher abundances than revegetation, and revegetation supported more species than cleared farmland (Borsboom *et al.* 2002; Hobbs *et al.* 2003; Kavanagh *et al.* 2005; Kanowski *et al.* 2006). Kanowski *et al.* (2006) found mixed responses depending on the species of reptile, and whether they were rainforest dependent, or habitat generalists. In the south-west slopes of New South Wales, reptile abundance and species-richness were not affected by revegetation age, width or size (Kavanagh *et al.* 2005). Reptiles in general (Kavanagh *et al.* 2005; Cunningham *et al.* 2007) and in one study, rainforest-specialized reptiles (Kanowski *et al.* 2006), appeared to be associated with complex microhabitats. Cunningham *et al.* (2007) found that reptiles were less abundant on farms with many revegetation plantings than on farms with little revegetation. Reptiles were, however, correlated with the amount of remnant vegetation cover on a farm (Cunningham *et al.* 2007).

Amphibians

Amphibians exhibited a mixed response to revegetation. Kavanagh *et al.* (2005) found that frogs were present in ponds with water regardless of vegetation type (remnant, revegetation or cleared farmland); Hobbs *et al.* (2003) found more frogs in remnants than in revegetation and cleared farmland, and no difference between the latter two. Frogs in western Victoria did not respond to planting width (Merritt & Wallis 2004).

Invertebrates

Four studies on invertebrates found more taxa in remnant vegetation than in simple tree plantings (Green & Catterall 1998; Bonham *et al.* 2002; Schnell *et al.* 2003; Cunningham *et al.* 2005). However, the studies found different responses of invertebrates to revegetation compared with cleared farmland. One found more ant species in 6-year-old simple tree plantings than on cleared farmland (Schnell *et al.* 2003), whereas another study found no difference (Green & Catterall 1998). The latter study, plus another (Catterall *et al.* 2004) found highly variable responses by different invertebrate orders. Catterall *et al.* (2004) found that Orthoptera (grasshoppers) were much more abundant in cleared farmland than revegetation or remnants; Coleoptera (beetles) and Formicidae (ants) were reasonably abundant in all vegetation types (cleared farmland, revegetation, remnants); Amphipoda (litter hoppers) were abundant only in vegetation of high floristic diversity (remnant forest, regenerating forest and floristically rich ecological restoration plantings), with very low numbers in cleared farmland and monoculture revegetation. Cunningham *et al.* (2005) found the species richness of Coleoptera (beetles), Lepidoptera (moths) and Hymenoptera (ants, bees and wasps) did not differ between simple tree plantings, remnant vegetation and cleared farmland, but the community composition differed between site types for Coleoptera and Lepidoptera. They also found no differences in community composition of these insect groups between edge and interior habitats, or between isolated plantings and those adjacent to remnant vegetation. Bonham *et al.* (2002) found no difference in the number of native species of invertebrate with age of revegetation.

Majer and Nichols (1998) found that the composition of ants in an ecological restoration planting of a mined site approached that in a remnant forest sooner than that in a simple tree planting. Ant richness increased in both revegetation plots over a 14-year period, and the composition approached that of remnant forests in both revegetation types (Majer & Nichols 1998).

Revegetation attributes affecting fauna use

Patch size

In fragmented landscapes, patch size of remnants tends to have a positive effect on birds (Loyn 1987; Lindenmayer *et al.* 2002; Seddon *et al.* 2003), arboreal marsupials (Pahl *et al.* 1988) and reptiles (MacNally & Brown 2001). The effect of patch size has been poorly researched in revegetation studies. Larger revegetation patches may benefit some faunal groups such as birds and bats (see sections above), whereas the effect of patch size on other faunal groups is largely unknown.

Width of revegetation

Bird species richness is generally higher in relatively wide plantings (see above), whereas frogs, bats, arboreal marsupials and reptiles appear to show no consistent response to revegetation width.

Age of revegetation

Birds and arboreal marsupials appear to increase in richness and abundance with increased revegetation age, but bats, reptiles and invertebrates do not. We found no studies with data on the response of small terrestrial mammals and amphibians to revegetation age. Most revegetation plantings examined in this review were young (mostly <30 years). Some key resources such as large logs, dead trees, tree hollows, or ground cover complexity may take longer than this to develop (McElhinny *et al.* 2006), whereas others may be independent of revegetation age (e.g. water availability, rocks).

Faunal composition also may change in revegetation over time. Young revegetated mine sites in south-west Western Australia contained competitive colonizing species or generalist species of mammal, bird and ant; then as the vegetation matured, a new suite of species took advantage of the changes in structure at the site (Majer & Nichols 1998; Nichols & Nichols 2003). In Queensland, bird guilds in simple tree plantings became more like those in selectively logged forest over time (Borsboom *et al.* 2002).

Structural complexity and floristic diversity

Structurally complex revegetation typically supports more fauna species and a different faunal composition than structurally simpler revegetation. Some attributes of complexity are particularly important to some faunal groups. For example, amphibians and reptiles respond predominantly to complexity in the ground layer, and small terrestrial mammals respond to complexity in the mid- and understorey layer (McElhinny *et al.* 2006). Similarly, the presence of old trees in a eucalypt plantation can significantly increase bird diversity and abundance (Grabham *et al.* 2002).

Vegetation that is floristically diverse may contain more fauna species than monocultures, even if vegetation structure is similar (Barrett 2000; Kanowski *et al.* 2005). Plantings established for ecological restoration generally exhibit greater floristic and structural diversity than simple tree plantings, and typically support higher faunal diversity (Catterall *et al.* 2004; Kanowski *et al.* 2005; Kavanagh *et al.* 2005).

Adjacency to remnant vegetation

Adjacency to remnant vegetation can increase the use of revegetation by birds (Hobbs 2003; Hobbs *et al.* 2003). Less mobile species such as mammals are less likely to inhabit planted vegetation than highly mobile animals such as birds (Hobbs 2003; Hobbs *et al.* 2003). White *et al.* (2004) found that plantings close to remnants had higher numbers of rainforest plants dispersed by birds, small mammals and wind, than distant sites, indicating that adjacency may benefit plants as well as animals.

Vegetation cover in the landscape

The amount of overstorey vegetation cover in the landscape has been identified as a key variable determining the presence of birds at revegetated sites (Barrett 2000; Kavanagh *et al.* 2005). Birds, arboreal marsupials and reptiles are also more likely to inhabit revegetation when remnant cover is high (Kavanagh *et al.* 2005; Cunningham *et al.* 2007, in press).

Comparisons with mine site rehabilitation

Revegetated mine sites provide an interesting parallel to revegetated areas in agricultural landscapes. However, the contextual position of revegetated mine sites, which are usually surrounded by remnant vegetation, is very different to revegetation in agricultural areas where issues of isolation and vegetation cover occur. Revegetated mine sites can therefore provide important information on the faunal use in the absence of isolation, landscape cover or gap-crossing issues.

Revegetated mine sites show successional trends in bird species, beginning with generalist taxa (Nichols & Nichols 2003). Recolonization of revegetated mine sites appears to be rapid: birds may recolonize within 6 years (Nichols & Watkins 1984); reptile species richness may resemble that of low quality remnant vegetation after 4 to 6 years (Nichols & Bamford 1985); many invertebrates orders had similar species richness to surrounding unmined forest within 7 years (Nichols *et al.* 1989); native small mammals recolonized sand-mined forests within 8 years (Fox & Fox 1984); and many birds were breeding in revegetated sites within 10 years (Curry & Nichols 1986). Birds that did not breed in the revegetated sites had requirements for features not yet available in the sites, such as tree hollows (Curry & Nichols 1986). The presence of lizards in rehabilitated sand-mining sites was predominantly explained by vegetation complexity (Twigg & Fox 1991). Bauxite mine sites in Western Australia have seen an evolving rehabilitation method (Collins *et al.* 1985; Armstrong & Nichols 2000). Older rehabilitation sites contained very little understorey vegetation, whereas more recent sites contained an understorey plant species richness and diversity comparable to unmined forests (Collins *et al.* 1985). The older sites contained very low bird species richness and densities, whereas the recent sites with understorey support bird species richness and densities similar to those in unmined forest (Nichols & Watkins 1984; Collins *et al*. 1985; Armstrong & Nichols 2000). Bird species composition was similar in the recently rehabilitated areas to that of forests (Collins *et al*. 1985). Similarly, ant species richness and composition was positively associated with plant species richness and diversity and age of the planting (Majer *et al*. 1984; Majer & Nichols 1998). These studies have emphasized the benefits of developing an understorey in the plantings (where an understorey originally occurred) (Armstrong & Nichols 2000).

Landscape-scale role of revegetation

Lindenmayer *et al*. (2002) suggested that remnant vegetation fragments of all sizes and shapes have significant conservation value, both as habitat and as stepping stones through the landscape (Fischer & Lindenmayer 2002). This notion may extend to revegetation, despite the lower faunal use compared to remnants. Revegetation may also help buffer adjacent remnants from climatic extremes and other degrading processes, and may stabilize key ecological processes in agricultural landscapes (e.g. by reducing water tables) (Hobbs 1993; Bennett *et al*. 2000; Kanowski *et al*. 2005). At a landscape scale, there may be negative consequences for fauna if remnant vegetation is replaced with revegetation (Cunningham *et al*. 2007), and positive consequences if revegetation is situated on already cleared farmland.

Progress to date

Much new research has been completed since previous reviews on revegetation in agricultural landscapes in Australia (Kimber *et al*. 1999; Ryan 1999) (Table 1). However, many knowledge gaps remain. Much research has focused on the value of revegetation for birds, but there is a paucity of information on other faunal groups and on threatened and declining taxa. Most research has focused on simple measures of species richness and abundance but faunal composition would provide valuable information on the benefits of revegetation to fauna.

Establishment of ecological restoration plantings is a relatively new practice. It is logical to study both ecological restoration plantings (as an example of the best revegetation currently conducted) and simple tree plantings (as the most common form of revegetation). Differences between these forms of revegetation can provide insights into the conservation capacity of revegetation under both a best-case scenario and the current scenario of mostly simple tree plantings.

The value of revegetation to fauna is rarely put into a landscape context. This context is important because patch-scale research provides information on the local faunal richness (alpha diversity), but it is the landscape faunal richness (beta diversity) that is often of greatest conservation concern (Tscharntke *et al*. 2005).

Most studies have not examined underlying processes involved in faunal use of revegetation. We found only one study which explored this issue – use of revegetation by birds for breeding (Bond 2004). To date, no research has been conducted on processes such as competition or predation in revegetation.

The faunal response to revegetation studied to date is mostly short-term because revegetation has become common only in recent decades. As revegetation ages, and incorporates more features such as logs and leaf litter, its value to wildlife may increase. Ongoing studies will be required to assess the long-term benefits of revegetation.

Recommendations

Many research projects are written as reports or unpublished theses that are not widely available. To maximize accessibility of findings to other researchers, we advocate publication in peer-reviewed journals. There is also a need for scientists to more clearly explain site attributes of revegetation – in particular age, size, isolation, and structural complexity and floristic diversity. Much of this basic information was unavailable in the reviewed articles. Clear and consistent information can provide future opportunities for systematic reviews or meta-analyses.

We suggest further research should target the following areas:

- long-term trends and successional changes in revegetation including the development of key structural features and their effect on fauna;
- comparisons of different types of revegetation including analyses of potential trade-offs between quantity and quality of revegetation at the landscape scale;
- the value of planting indigenous plant species for fauna;
- the faunal composition changes in revegetation over time and with different site attributes;
- the response by terrestrial mammals to revegetation;
- the resource needs of reptiles, amphibians and bats which could be provided by revegetation;
- the conservation value of revegetation for declining or threatened fauna;
- the value to wildlife of revegetation in riparian compared to non-riparian areas; and;
- the interaction of remnant vegetation and revegetation.

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References

Armstrong K. N. and Nichols O. G. (2000) Long-term trends in avifaunal recolonisation of rehabilitated bauxite mines in the Jarrah forest of south-western Australia. *Forest Ecology and Management* **126**, 213–225.

Arnold G. W. (2003) Bird species richness and abundance in wandoo woodland and in tree plantations on farmland at Baker's Hill, Western Australia. *Emu* **103**, 259–269.

Barrett G. (1997) Birds on farms: Repairing the rural landscape. *Wingspan* **7**, 10–13.

Barrett G. J. (2000) Birds on farms: Ecological management for agricultural sustainability. *Wingspan* **10** (Suppl.), I–XV.

Bennett A. F., Kimber S. and Ryan P. (2000) *Revegetation and Wildlife: A Guide to Enhancing Revegetated Habitats for Wildlife Conservation in Rural Environments*. Bushcare – National Projects Research and Development Program, Canberra, ACT.

Biddiscombe E. F. (1985) Bird populations of farm plantations in the Hotham River Valley, W.A. *Western Australian Naturalist* **16**, 32–39.

Biddiscombe E. F., Rogers A. L., Greenwood E. A. N. and DeBoer E. S. (1981) Establishment and early growth of species in farm plantations near salt seeps. *Australian Journal of Ecology* **6**, 383–389.

Bird P. R., Bicknell D., Bulman P. A. *et al*. (1992) The role of shelter in Australia for protecting soils, plants and livestock. *Agroforestry Systems* **20**, 59–86.

Bond S. (2004) *Do woodland birds breed in revegetated sites?* Honours, School of Resources, Environment and Society, Australian National University, Canberra, ACT.

Bonham K. J., Mesibov R. and Bashford R. (2002) Diversity and abundance of some ground-dwelling invertebrates in plantation vs. native forests in Tasmania. *Australia Forest Ecology and Management* **158**, 237–247.

Borsboom A. C., Wang J., Lees N., Mathieson M. and Hogan L. (2002) *Measurement and Integration of Fauna Biodiversity Values in Queensland Agroforestry Systems*. Rural Industries Research and Development Corporation, Canberra, ACT.

Catterall C. P., Kanowski J., Wardell-Johnson G. W. *et al*. (2004) Quantifying the biodiversity values of reforestation: Perspectives, design issues and outcomes in Austalian rainforest landscapes. In: *Conservation of Australia's Forest Fauna* (ed. D. Lunney), pp. 359–393. Royal Zoological Society of New South Wales, Mosman, NSW.

Collins B. G., Wykes B. J. and Nichols O. G. (1985) Re-colonization of restored Bauxite minelands by birds in Southwestern Australian forests. In: *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation, Management* (eds A. Keast, H. F. Recher, H. A. Ford and D. A. Saunders), pp. 341–354. Surrey Beatty & Sons, Chipping Norton, NSW.

Crome F., Isaacs J. and Moore L. (1994) The utility to birds and mammals of remnant riparian vegetation and associated windbreaks in the tropical Queensland uplands. *Pacific Conservation Biology* **1**, 328–343.

Cunningham S. A., Floyd R. B. and Weir T. A. (2005) Do Eucalyptus plantation host an insect community similar to remnant Eucalyptus forest? *Austral Ecology* **30**, 103–117.

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

Cunningham R. B., Lindenmayer D. B., Crane M. *et al*. (in press) What factors influence bird biota on farms? Putting Restored Vegetation Into Context. *Conservation Biology*.

Curry P. J. and Nichols O. G. (1986) Early regrowth in rehabilitated bauxite minesites as breeding habitat for birds in the Jarrah forest of south-western Australia. *Australian Forestry* **49**, 112–114.

Fisher A. (2001) Avifauna changes along a *Eucalyptus* regeneration gradient. *EMU* **101**, 25–31.

Fischer J. and Lindenmayer D. B. (2002) The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 2. Paddock trees as stepping stones. *Biodiversity and Conservation* **11**, 833–849.

Ford H. A., Barrett G. W., Saunders D. A. and Recher H. F. (2001) Why have birds in the woodlands of Southern Australia declined? *Biological Conservation* **97**, 71–88.

Fox B. J. and Fox M. D. (1984) Small-mammal recolonization of open-forest following sand mining. *Australian Journal of Ecology* **9**, 241–252.

Gibbons P. and Lindenmayer D. B. (2002) *Tree Hollows and Wildlife Conservation in Australia*. CSIRO Publishing, Collingwood, Vic.

Gilmore A. M. (1985) The influence of vegetation structure on the density of insectivorous birds. In: *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation, Management* (eds A. Keast, H. F. Recher, H. A. Ford and D. A. Saunders), pp. 21–31. Surrey Beatty & Sons, Chipping Norton, NSW.

Grabham C., Klomp N. and Robinson W. (2002) *The Influence of Remnant Trees Retained within Native Hardwood Plantations on the Diversity and Abundance of Birds, 2000–2001*. Ettamogah Research Consultants, Wangaratta, Vic.

Green R. J. and Catterall C. P. (1998) The effects of forest clearing and regeneration on the fauna of Wivenhoe Park, south-east Queensland. *Wildlife Research* **25**, 677–690.

Harris W. (1999) *Revegetation: Its biodiversity conservation effectiveness*. Honours Thesis, Department of Environmental Biology, University of Adelaide, Adelaide, SA.

Hobbs R. J. (1993) Can revegetation assist in the conservation of biodiversity in agricultural areas? *Pacific Conservation Biology* **1**, 29–38.

Hobbs R. (2003) Ecological management and restoration: Assessment, setting goals and measuring success. *Ecological Management & Restoration* **4** (Suppl.), S2–S3.

Hobbs R. and Saunders D. A. (1993) *Reintegrating Fragmented Landscapes: Towards Sustainable Production and Nature Conservation*. Springer-Verlag, New York.

Hobbs R., Catling P. C., Wombey J. C., Clayton M., Atkins L. and Reid A. (2003) Faunal use of bluegum (*Eucalyptus globulus*) plantations in southwestern Australia. *Agroforestry Systems* **58**, 195–212.

Irvine R. and Bender R. (1997) Introduction of the Sugar Glider *Petaurus breviceps* into re-established forest of the Organ Pipes National Park, Victoria. *Victorian Naturalist* **114**, 230–239.

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

Kanowski J., Catterall C. P. and Wardell-Johnson G. W. (2005) Consequences of broadscale timber plantations for biodiversity in cleared rainforest landscapes of tropical and subtropical Australia. *Forest Ecology and Management* **208**, 359–372.

Kanowski J. J., Reis T. M., Catterall C. P. and Piper S. D. (2006) Factors affecting the use of reforested sites by reptiles in cleared rainforest landscapes in tropical and subtropical Australia. *Restoration Ecology* **14**, 67–76.

Kavanagh R. P. and Turner R. J. (1994) Birds in eucalypt plantations: The likely role of retained habitat trees. *Australian Birds* **28**, 32–40.

Kavanagh R. P., Law B. S., Lemckert F. *et al*. (2005) *Biodiversity in Eucalypt Plantings Established to Reduce Salinity*. Rural Industries Research and Development Corporation, Joint Venture Agroforestry Program, Canberra, ACT.

Kimber S. L., Bennett A. F. and Ryan P. (1999) *Revegetation and Wildlife: What Do We Know About Revegetation and Wildlife Conservation in Australia?* A report to Environment Australia, School of Ecology and Environment, Deakin University, Warrnambool, Vic.

Kinross C. (2000) *The ecology of avian communities of farm windbreaks*. PhD, Environmental Studies Unit, Faculty of Science and Agriculture, Charles Sturt University, Bathurst, NSW.

Kinross C. (2004) Avian use of farm habitats, including windbreaks, on the New South Wales Tablelands. *Pacific Conservation Biology* **10**, 180–192.

Klomp N. and Grabham C. (2002) *A Comparison of the Avifaunal Diversity on Native Hardwood Plantations and Pasturelands in North-east Victoria, 1999–2001*. Charles Sturt University, Johnstone Centre, Albury, NSW.

Law B. S. and Chidel M. (2006) Eucalypt plantings on farms: Use by insectivorous bats in south-eastern Australia. *Biological Conservation* **133**, 236–249.

Leary D. E. (1995) *An ecological assessment of the monarto revegetation program*. Honours Thesis, Department of Environmental Biology, University of Adelaide, Adelaide, SA.

Lindenmayer D. B., Cunningham R. B., Donnelly C. F., Nix H. and Lindenmayer B. D. (2002) Effects of forest fragmentation on bird assemblages in a novel landscape context. *Ecological Monographs* **72**, 1–18.

Loyn R. H. (1987) Effect of patch area and habitat on bird abundances, species numbers and tree health in fragmented Victorian forests. In: *Nature Conservation: The Role of Remnants of Native Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J. M. Hopkins), pp. 65–77. Surrey Beatty & Sons, Chipping Norton, NSW.

Loyn R. H., McNabb E., Macak P. and Noble P. (2007) Eucalypt plantations as habitat for birds on previously cleared farmland in south-eastern Australia. *Biological Conservation* **137**, 533–548.

MacNally R. and Brown G. W. (2001) Reptiles and habitat fragmentation in the box-ironbark forests of central Victoria, Australia: Predictions, compositional change and faunal nestedness. *Oecologia* **128**, 116–125.

Majer J. C. and Nichols O. G. (1998) Long-term recolonization patterns of ants in Western Australian rehabilitated bauxite mines with reference to their use as indicators of restoration success. *Journal of Applied Ecology* **35**, 161–182.

Majer J. D., Day J. E., Kabay E. D. and Perriman W. S. (1984) Recolonization by ants in Bauxite mines rehabilitated by a number of different methods. *Journal of Applied Ecology* **21**, 355–375.

Martin W. K., Eyears-Chaddock M., Wilson B. R. and Lemon J. (2004) The value of habitat reconstruction to birds at Gunnedah, New South Wales. *Emu* **104**, 177–189.

McElhinny C., Gibbons P., Brack C. and Bauhus J. (2005) Forest and woodland stand structural complexity: Its definition and measurement. *Forest Ecology and Management* **218**, 1–24.

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

MDBC (1999) *The Salinity Audit of the Murray-Darling Basin: A 100 Year Perspective*. Murray-Darling Basin Commission, Canberra, ACT.

Merritt B. and Wallis R. (2004) Are wide revegetated riparian strips better for birds and frogs than narrow ones? *The Victorian Naturalist* **121**, 288–292.

Nichols O. G. and Bamford M. J. (1985) Reptile and frog utilisation of rehabilitated bauxite minesites and dieback-affected sites in Western Australia's Jarrah Eucalyptus marginata forest. *Biological Conservation* **34**, 227–249.

Nichols O. G. and Nichols F. M. (2003) Long-term trends in faunal recolonization after bauxite mining in the Jarrah Forest of southwestern Australia. *Restoration Ecology* **11**, 261–272.

Nichols O. G. and Watkins D. (1984) Bird utilisation of rehabilitated bauxite minesites in Western Australia. *Biological Conservation* **30**, 109–131.

Nichols O. G., Wykes B. J. and Majer J. D. (1989) The return of vertebrate fauna to bauxite mined areas in south-western Australia. In: *Animals in Primary Succession: The Role of Fauna in Reclaimed Lands* (ed. J. D. Majer), pp. 397–422. Cambridge University Press, Cambridge, UK.

Pahl L. I., Winter J. W. and Heinsohn G. (1988) Variation in responses of arboreal marsupials to fragmentation of tropical rainforest in north eastern Australia. *Biological Conservation* **46**, 71–82.

Rossi S. (2003) *Birds, mammals and their habitat in a variegated landscape in the western Strzelecki Ranges*. Masters Thesis, School of Applied Sciences, Faculty of Science, Monash University, Melbourne, Vic.

Ryan P. (1999) The use of revegetated areas by vertebrate fauna in Australia: A review. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J. Hobbs and C. J. Yates), pp. 318–335. Surrey Beatty & Sons, Chipping Norton, NSW.

Salt D., Lindenmayer D. B. and Hobbs R. (2004) *Trees and Biodiversity: A Guide for Australian Farm Forestry*. Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra, ACT.

Saunders D. A. (1989) Changes in the avifauna of a region, district and remnant as a result of fragmentation of native vegetation: The wheatbelt of western Australia. A case study. *Biological Conservation* **50**, 99–135.

Schnell M. R., Pik A. J. and Dangerfield J. M. (2003) Ant community succession within eucalypt plantations on used pasture and implications for taxonomic sufficiency in biomonitoring. *Austral Ecology* **28**, 553–565.

Seddon J. A., Briggs S. V. and Doyle S. J. (2003) Relationships between bird species and characteristics of woodland remnants in central New South Wales. *Pacific Conservation Biology* **9**, 95–119.

Smith G. C. and Agnew G. (2002) The value of 'bat boxes' for attracting hollow-dependent fauna to farm forestry plantations in southeast Queensland. *Ecological Management & Restoration* **3**, 37–46.

Stirzaker R., Vertessy R. and Sarre A. (2002) *Trees, Water and Salt: An Australian Guide to Using Trees for Healthy Catchments and Productive Farms*. Joint Venture Agroforestry Program, Rural Industries Research and Development Corporation, Canberra, ACT.

Suckling G. C. and Goldstraw P. (1989) Progress of the Sugar Glider, Petaurus breviceps, establishment at the Tower Hill State Game Reserve, Vic. *Victorian Naturalist* **106**, 179–183.

Taws N., Streatfield S. and Reid J. (2001) *Bringing Birds Back*. Greening Australia, Canberra, ACT.

Taylor R., Duckworth P., Johns T. and Warren B. (1997) Succession in bird assemblages over a 7-year period in regrowth dry sclerophyll forest in south-east Tasmania. *Emu* **97**, 220–230.

Tscharntke T., Klein A. M., Kruess A., Steffan-Dewenter I. and Thies C. (2005) Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters* **8**, 857–874.

Twigg L. E. and Fox B. J. (1991) Recolonisation of regenerating open forest by terrestrial lizards following sand mining. *Australian Journal of Ecology* **16**, 137–148.

White E., Tucker N., Meyers N. and Wilson J. (2004) Seed dispersal to revegetated isolated rainforest patches in North Queensland. *Forest Ecology and Management* **192**, 409–426.

Woinarski J. C. Z. (1979) Birds of a Eucalypt plantation and adjacent natural forest. *Australian Forestry* **42**, 243–247.