

8 Temperate eucalypt woodlands

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SUMMARY

Temperate eucalypt woodlands are significant environments in Australia because they support large numbers of threatened species, are nationally listed as endangered ecosystems and are prominent in Indigenous and European culture. However, these vegetation communities have been extensively cleared and intensively grazed, particularly in south-eastern Australia. Small remaining areas of temperate eucalypt woodland are often very heavily degraded. Temperate eucalypt woodlands have been the focus of considerable ecological research and management, although there are relatively few long-term studies in these ecosystems. Temperate eucalypt woodlands are the target ecosystem for two Long Term Ecological Research Network plot networks and a Supersite within the Terrestrial Ecosystem Research Network. They are also part of two environmental transect projects within TERN (Box 8.2). Long-term data gathered in the three plot networks has led to critical new insights about the ecology, conservation and management of temperate eucalypt woodlands. Examples of new discoveries (Box 8.1) from these plot networks include: (1) increased levels of tree cover in many woodland-dominated landscapes through active re-planting programs; (2) increased detection rates of many

species of native bird species over the past decade, including a number previously thought to be declining; (3) positive responses of birds and reptiles to management interventions such as planting, natural regeneration and grazing control; and (4) barriers or time lags in restoring woodland plant diversity on retired agricultural land. These (and other) key findings could not have been identified without long-term ecological research. They are particularly important for guiding major conservation and resource management investments like restoration and grazing control programs in temperate eucalypt woodlands, which can exceed billions of dollars in value.

INTRODUCTION

The focus of this chapter is on temperate eucalypt woodlands (Fig 8.2) and what networks of long-term plots have revealed about environmental change and the temporal changes in biodiversity within them. Temperate eucalypt woodland landscapes are iconic ecosystems that have featured frequently in Australian Indigenous and European history. They were a source of inspiration for great artists such as Tom Roberts, Arthur Streeton and Hans Heysen (Fig. 8.1). Indeed, for Australia's largely urban population, temperate

Box 8.1: Key discoveries

Several major discoveries in temperate eucalypt woodlands could not have been made without long-term ecological research. Four of these are:

- Detection rates of some species of temperate woodland birds in southern New South Wales have increased over the past decade, including several which were previously considered to be declining.
- Both re-planted temperate woodlands and natural regrowth temperate woodland are important habitats for birds and reptiles, including a range of species of conservation concern. Such areas support a significantly different (but also complementary) assemblage of birds from old-growth woodland.
- Interventions such as grazing control lead to improvements in vegetation condition and these changes can, in turn, have positive impacts on temperate woodland birds.
- Temporal changes in plant species composition in revegetated temperate woodland areas can be on a different trajectory to that of 'natural' vegetation.

woodlands have become the quintessential image of the Australian bush (Lindenmayer *et al.* 2005).

Despite the historical and ecological importance of temperate woodlands in Australia, these ecosystems are also some of the most extensively cleared, heavily modified and highly degraded vegetation types in Australia. This is, in part, because of the suitability of these areas for cropping and/or grazing by domestic livestock. For instance, less than 3% of the original cover of woodland dominated by White Box (*Eucalyptus albens*) and Yellow Box (*E. melliodora*) remains (Gibbons and Boak 2002). Most remaining patches are degraded and the few that do still have a high-quality native understorey or ground-layer are typically smaller than 4 ha (Prober and Thiele 1995). More than one-third of the threatened ecological communities listed under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* are temperate woodlands (Department of Sustainability, Environment, Water, Population and Communities 2012c).



Figure 8.1: Reproductions of paintings by: (A) Arthur Streeton, Australia 1867–1943. *Land of the Golden Fleece* 1926. Oil on canvas 50.7 × 75.5 cm. National Gallery of Australia, Canberra, The Oscar Paul Collection, Gift of Henriette von Dallwitz and of Richard Paul in honour of his father 1965; (B) Frederick McCubbin, Australia 1855–1917. *Lost* 1886. Oil on canvas, 115.8 × 73.7 cm. National Gallery of Victoria, Melbourne, Felton Bequest, 1940.



Figure 8.2: Temperate eucalypt woodland at Nanangroe near Gundagai (photo by Esther Beaton).

Many of the species in these communities are Threatened or Endangered (Lindenmayer *et al.* 2010a).

Box 8.2: Links between TERN and the core studies in temperate eucalypt woodlands

One of the core datasets featured here is derived from the Nanangroe Plantation Study, near Jugiong and Tumut in south-eastern New South Wales. The Nanangroe Plantation Study is part of the Tumut Fragmentation Experiment (Lindenmayer 2009) and from the mid-2000s it was part of the Australian-Long Term Ecological Research Network (A-LTER) (see Box 1.4). In 2012, the Nanangroe Plantation Study became part of the Long Term Ecological Research Network (LTERN) within the Terrestrial Ecosystem Research Network (TERN). A second plot network in LTERN on the Cumberland Plains in western Sydney also focuses on temperate eucalypt woodlands. In addition, the newly established supersite in the Great Western Woodlands of south-western Australia is located in temperate eucalypt woodland (see Box 8.10). Finally, plots dominated by temperate eucalypt woodland occur in two environmental transect projects associated with TERN – the TREND transect in South Australia (see Box 7.5) and the SWATT transect in Western Australia (see Box 8.15).

In this chapter we first define temperate eucalypt woodlands and where they occur. Second, we briefly summarise some of the key threatening processes in temperate eucalypt woodlands. Third, we outline how communities, land managers, governments and scientists have come together to try to ameliorate some of these threatening processes. The fourth and major part of this chapter is a set of examples of documented changes in woodland biodiversity and environments based on data from three core studies that are long-term plot networks. Finally, we present a summary of tasks that need to be undertaken to tackle threats and improve the prognosis of the environmental integrity of temperate eucalypt woodland ecosystems.

A DEFINITION OF TEMPERATE WOODLAND

A general definition of temperate eucalypt woodland is provided in Yates and Hobbs (2000, p. 2):

ecosystems that contain widely spaced trees with their crowns not touching ... Australian woodlands may have a patchy understorey of low trees and shrubs (shrubby woodlands) or a more continuous ground layer of grasses, herbs and graminoids (grassy woodlands)

In temperate eucalypt woodlands it is not only the spacing of trees (which often gives them a park-like

appearance) that is important, but also the attributes of the tree crowns that help to broadly define woodlands. The crowns of trees are often characterised by a measure called ‘projected foliage cover’, or the proportion of the ground covered by the vertical projection of the vegetation. The projected foliage cover of woodlands is typically between 10% and 30% (except in dense regenerating stands comprised of many small saplings). That is, in woodlands, the crowns of the trees generally shade less than 30% of the ground (Yates and Hobbs 2000). In addition, the widely spaced trees in temperate eucalypt woodlands are typically 10–30 m tall.

Temperate eucalypt woodlands can generally be thought of as the interface between taller, wetter forested areas on the coast and the drier, hotter grasslands and shrublands of the interior. We recognise that there is a range of other kinds of temperate eucalypt woodlands, such as those in coastal as well as in subalpine areas (Yates *et al.* 2000), but we have elected

to exclude them as case studies in this chapter, in part because of the paucity of long-term ecological studies from these areas. Similarly, we have decided to exclude extensive Coolabah (*E. coolabah* and *E. microtheca*) and Black Box (*E. largiflorens*) woodlands from the floodplains of rangeland Australia, again because there have been few long-term ecological studies in this major vegetation type. Due to the case studies examined, the focus of the discussion in this chapter is on grassy woodland communities from south-eastern Australia rather than shrubby woodland systems that are more commonly found in drier and more nutrient-poor parts of the landscape.

The distribution of temperate eucalypt woodlands

The temperate woodlands that are the focus of this chapter run primarily along and to the west of the Great Dividing Range from southern Queensland, through New South Wales and the Australian Capital

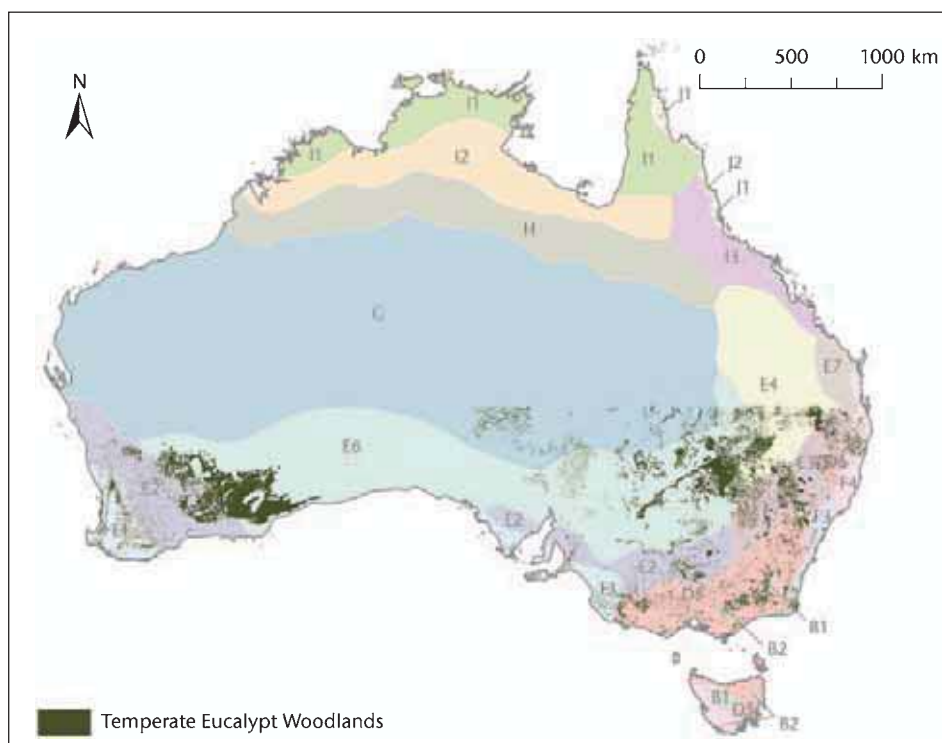


Figure 8.3: The spatial distribution of temperate eucalypt woodlands (as subset of MVG 5) relative to agro-climatic zones developed by (Hutchinson *et al.* 2005). (Note only extant woodlands are mapped and alpine woodlands are not shown). See Table 8.2 for more information on the agro-climatic zones.

Table 8.1: Classification and relative coverage of temperate eucalypt woodlands

Classification	Relative coverage
Terrestrial Ecoregions of Australia (Department of Sustainability, Environment, Water, Population and Communities 2012b)	Temperate broadleaf and mixed forest
Interim Biogeographic Regionalisation for Australia, version 7.0 (Department of Sustainability, Environment, Water, Population and Communities 2012a)	Australian Alps, Avon Wheatbelt, Brigalow Belt South, Ben Lomond, Broken Hill Complex, Channel Country, Coolgardie, Cobar Peneplain, Darling Riverine Plains, Esperance Plains, Eyre Yorke Block, Flinders Lofty Block, Furneaux, Gawler, Geraldton Sandplains, Great Victoria Desert, Jarrah Forest, Kanmantoo, King, Mallee, Murray–Darling Depression, Mulga Lands, Murchison, Nandewar, Naracoorte Coastal Plain, New England Tablelands, NSW North Coast, NSW South Western Slopes, Nullarbor, Riverina, South East Coastal Plain, South East Corner, South Eastern Highlands, South Eastern Queensland, Simpson Strzelecki Dunefields, Stony Plains, Southern Volcanic Plain, Swan Coastal Plain, Sydney Basin, Tasmanian Central Highlands, Tasmanian Northern Midlands, Tasmanian Northern Slopes, Tasmanian South East, Tasmanian Southern Ranges, Tasmanian West, Victorian Midlands, Warren, Yalgoo
National Vegetation Inventory System (NVIS) (Department of the Environment and Water Resources 2007)	A subset of ‘eucalyptus woodlands’ (MVG5) – south of 27.5°S.
Natural Resource Management regions	Australian Capital Territory, Adelaide and Mount Lofty Ranges, Avon, Border Rivers Maranoa–Balonne, Border Rivers–Gwydir, Central West, Condamine, Corangamite, Desert Channels, East Gippsland, Eyre Peninsula, Glenelg Hopkins, Goulburn Broken, Hawkesbury–Nepean, Hunter–Central Rivers, Kangaroo Island, Lachlan, Lower Murray–Darling, Mallee, Murray, Murrumbidgee, Namoi, North, North Central, North East, North West, Northern Agricultural, Northern Rivers, Northern and Yorke, Perth, Port Phillip and Western Port, Rangelands, South, South Australian Arid Lands, South Australian Murray–Darling Basin, South Coast, South East, South East Queensland, South West, South West Queensland, Southern Rivers, Sydney Metro, West Gippsland, Western, Wimmera

Territory, into Victoria, Tasmania and the south-east of South Australia and south-western Western Australia (Fig. 8.3). More localised occurrences are found in rain-shadow valleys scattered around Australia’s coast from south-eastern Queensland to Victoria.

Temperate woodlands encompass many ecological communities, habitats and species of national and global significance. Land-use intensification and ongoing transformation to support agricultural and other developments has resulted in the loss of ~75% of these woodlands across the continent, with impacts on many ecological communities and their fauna and flora. Today 10 of the 46 ecological communities listed

as threatened under the Commonwealth’s *Environment Protection and Biodiversity Conservation Act (EPBC Act) 1999* are found in temperate eucalypt woodlands. In addition, ~38% of listed threatened species have been recorded in association with these woodlands, most being plants (Zammit *et al.* 2010).

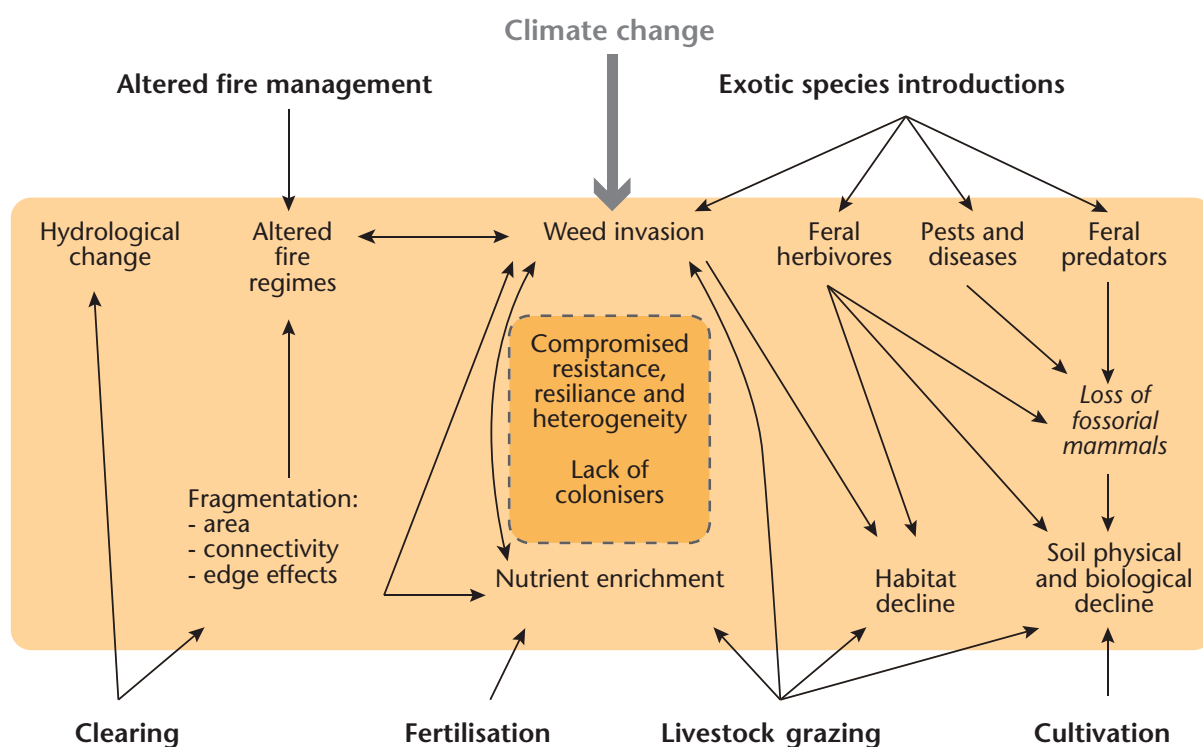
Congruence with other landscape and vegetation classifications

Temperate eucalypt woodlands are mapped in the National Vegetation Information System (NVIS) (Department of the Environment and Water Resources 2007) as part of the major vegetation group ‘eucalyptus

Table 8.2: The five main agro-climatic zones (after Hutchinson *et al.* 2005) that coincide with the temperate eucalypt woodlands, their approximate locations and common land uses

See Fig. 8.3 for a spatial representation of the agro-climatic zones. See Chapter 3 for a definition of the agro-climatic zones.

Code	Agro-climate	Location and land use
D5	Cool, wet climates with moisture availability high in winter–spring, moderate in summer, most plant growth in spring	Tasmanian lowlands, southern Victoria, southern and northern Tablelands of NSW. Forestry, cropping, horticulture, improved and native pastures
E1	Warm seasonally wet/dry climate. Classic ‘Mediterranean’ rainfall seasonality with peaks of growth in winter and spring and moderate growth in winter	South-west WA and southern SA. Forestry, horticulture, winter cropping, improved pastures
E2	Warm seasonally wet/dry climate. ‘Mediterranean’ rainfall seasonality, but with drier cooler winters and less growth than E1	Inland of E1 in south-west WA, southern SA, north-west Victoria and southern NSW. Horticulture, winter cropping, improved pastures
E3	Warm seasonally wet/dry climate. Most plant growth in summer, although summers are moisture limiting. Temperature limits growth in winter	Western slopes of NSW and part of the North Western Plains. Winter cereals and summer crops, grazing
E6	Semi-arid climate that is too dry to support field crops. Soil moisture tends to be greatest in winter	Southern edge of the arid interior in WA, SA, NSW and Queensland. Rangeland

**Figure 8.4:** The predominant human-derived drivers of decline in the extent and condition of temperate eucalypt woodlands (redrawn from Prober and Smith 2009).

woodlands' (MVG5). This major vegetation group also includes tropical and subtropical eucalypt woodlands, so we delineate temperate eucalypt woodlands as MVG5 south of ~27.5°S (c. Toowoomba, Queensland and Kalbarri, Western Australia; Fig. 8.3). Temperate eucalypt woodlands are described by various classifications in Australia (Table 8.1) and span several climatic zones, particularly D5, E1, E2 and E3, (Table 8.2) with some occurrence in adjoining drier (E6) and wetter zones (F3 and F4) (Hutchinson *et al.* 2005).

ECOSYSTEM DRIVERS AND THREATS IN TEMPERATE WOODLANDS

A wide range of natural and human-derived factors significantly influence the condition and extent of temperate eucalypt woodlands. Over the past 200 years, human disturbance regimes have directly and indirectly had profound effects on these ecosystems. We describe a range of the key drivers in the remainder of this section and present a brief description of them individually, but recognise that they often interact, as shown in Fig. 8.4.

Natural driving processes

The natural structure and biodiversity of temperate eucalypt woodlands is primarily driven by the moderate climate and relatively deep, fine-textured soils. These support the characteristic overstorey of widely spaced eucalypts and often promote a grassy ground-layer rich in native forbs (Prober and Thiele 2005). The large-crowned trees sustain many hollow-, canopy- and bark-dependent fauna such as parrots, cockatoos, possums, gliders and many invertebrates. In many temperate eucalypt woodlands, the open ground-layer provides foraging habitat for seed-eating species such as the Diamond Firetail (*Stagonopleura guttata*) and open-ground insect-eaters such as the Red-capped Robin (*Petroica goodenovii*) (Robinson and Traill 1996; Lunt and Bennett 2000). Woodland trees also drive small-scale heterogeneity, acting as wicks for water infiltration and soil drying (Eldridge and Freudenberger 2005), creating a range of different microclimates, concentrating nutrients beneath their canopies, and influencing the composition of grasses and forbs in the ground layer (Prober *et al.* 2002b).

Natural disturbances caused by fire, ground-dwelling mammals and marsupial grazing also shape the composition of plants and animals in temperate eucalypt woodlands. Before they became near-extinct after European settlement, it is likely that a suite of ground-dwelling mammals (e.g. the Tasmanian Bettong (*Bettongia gaimardi*)) contributed to soil nutrient cycling and natural plant regeneration through their diggings in the soil (Martin 2003). Fire and marsupial grazing influence the recruitment of woodland trees, shrubs and herbaceous species, and fire can determine the balance of C3 versus C4 grasses (see Box 8.3) (Bezkorowajnyj *et al.* 1993; Prober and Thiele 1995; Platt 1999; Amy and Robertson 2001; Rice *et al.* 2004). In temperate eucalypt woodlands on wetter, more fertile areas, the grassy ground layer can become thick and dense, and regular fires can help to maintain more open spaces for native forbs. However, resilience to frequent fire is lower in drier or less fertile woodlands (Amy and Robertson 2001).

Threatening processes

There are several major ecological threats in temperate eucalypt woodlands. These derive mostly from human-mediated activities, particularly vegetation clearing, livestock grazing, exotic species introductions, disruption of natural fire regimes, firewood harvesting, bush rock removal and soil fertilisation. These activities threaten biodiversity in temperate eucalypt woodlands both directly and indirectly

Box 8.3: Different kinds of grasses

Perennial grasses can be classified as either C3 or C4 plants. These terms refer to the different pathways that plants use to capture carbon dioxide during photosynthesis. All species have the more primitive C3 pathway, but the additional C4 pathway evolved in some species. The first product of carbon fixation in C3 plants involves a 3-carbon molecule, while C4 plants initially produce a 4-carbon molecule that then enters the C3 cycle. Grain-producing crop plants typically have the C4 pathway and are therefore of considerable economic importance in rural economies.

through the ecological changes they cause. Many of these threatening processes also interact and have conjoint or cumulative effects on vegetation condition, the prevalence of invasive species and native biota (Fig. 8.4) (Hobbs and Yates 2000; Prober and Smith 2009). We elaborate on some of the major threats and their consequences in the remainder of this section.

Vegetation clearing

A primary threatening process in temperate eucalypt woodlands is land clearing. Because the broad spatial distribution of temperate woodlands coincides strongly with the nation's major wheat–sheep belts, much of the original vegetation cover has been cleared (Hobbs and Yates 2000). For example, only ~10% of temperate eucalypt woodlands with a grassy understorey remain uncleared in south-eastern Australia (Prober *et al.* 2012a). In the wheatbelt of Western Australia, ~90% of the vegetation – much of it temperate eucalypt woodland – has been cleared (Gibson *et al.* 2004).

A major exception to the widespread clearing of temperate eucalypt woodland is the extensive area to the east of the Western Australian wheatbelt in south-western Australia. This 16 million ha area, known as the 'Great Western Woodlands', is globally significant for its relatively intact eucalypt woodlands that occur in mosaic with mallee and shrublands (Judd *et al.* 2008; Recher *et al.* 2010; Prober *et al.* 2012b)(Fig. 8.5). These woodlands typically have a shrub or chenopod understorey with a range of annual forbs appearing in spring.



Figure 8.5: Extensive and relatively intact areas of temperate eucalypt woodland in the Great Western Woodland of Western Australia, looking southwards from the Helena and Aurora Range, which is ~100 km north of Southern (photo by Suzanne Prober).

Clearing directly affects native biota by removing habitat, and impacts indirectly by changing the connectivity and hydrology of temperate eucalypt woodland landscapes (Fig. 8.6). Local and regional extinctions can continue to occur long after the original clearing events. This is because some remaining remnants are too small to support viable populations, individuals may not be able to move easily between remnants to find food or mates and they may be exposed to unfavourable conditions such as fertiliser drift from adjoining paddocks. The widespread removal of trees has also affected the water table, causing lower parts of many woodland landscapes to become salinised (Stirzaker *et al.* 2002), with resulting death of woodland and other vegetation (Cramer and Hobbs 2002).

One key aspect of land clearing is the loss of scattered paddock trees. These trees are widely targeted for clearing as part of agricultural development by those farmers intent on optimising short-term production (Maron and Fitzsimons 2007). Scattered paddock trees (Fig. 8.7) are a key component of native vegetation cover in landscapes once dominated by temperate woodland (Gibbons and Boak 2002). As well as supporting long-term farm production through soil conservation and reducing livestock stress, scattered paddock trees have many ecological roles (Manning *et al.* 2006a). These include:

- contributing to the variety of vegetation cover on farms. This, in turn, is a highly significant factor influencing bird species richness (Cunningham *et al.* 2008)



Figure 8.6: Clearing of temperate eucalypt woodland near Jugiong in southern New South Wales (photo by David Lindenmayer).



Figure 8.7: A scattered paddock tree landscape near Ladysmith in southern New South Wales (photo by David Lindenmayer).

- increasing the suitability of adjacent woodland remnants for declining woodland birds (e.g. the Brown Treecreeper (*Climacteris picumnus*), Jacky Winter (*Microeca fascians*) and Black-chinned Honeyeater (*Melithreptus gularis*) (Montague-Drake *et al.* 2009)
- providing habitat for a very high diversity of woodland invertebrates (Barton *et al.* 2009)
- acting as stepping stones for the movement of birds through agricultural landscapes (Fischer and Lindenmayer 2002a,b)
- maintaining a flow of plant genes between trees in remnants of temperate eucalypt woodland (Ottewell *et al.* 2009; Breed *et al.* 2011)
- providing habitat for a range of species of reptiles such as the Marbled Gecko (*Christinus marmoratus*) and Carnaby's Wall Skink (*Cryptoblepharus carnabyi*) (Lindenmayer *et al.* 2001)
- providing key nesting trees for threatened species such as the Superb Parrot (*Polytelis swainsonii*) and Squirrel Glider (*Petaurus norfolcensis*) (Manning *et al.* 2006b)
- providing places around which young trees can regenerate naturally (Gibbons *et al.* 2008; Fischer *et al.* 2009)
- providing sites around which to establish plantings (Lindenmayer *et al.* 2010c)
- increasing the suitability of adjacent plantings for the White-browed Woodswallow (*Artamus superciliosus*) and the White-plumed Honeyeater (*Lichenostomus pencillatus*) (Lindenmayer *et al.* 2010c).

Tree decline (or dieback)

Since the mid to late 1960s, the premature decline and death of trees in rural landscapes has increased markedly (Reid and Landsberg 2000). This phenomenon is known in Australia as rural tree decline or die-back (Fig. 8.8). It has been reported from all Australian states and territories and affects a wide range of forest and woodland types (Rice *et al.* 2004) and is particularly pronounced in some areas. For example, Platt (1999) reported that ~28% of the trees in a 3300-ha area of pastoral land in north-eastern Victoria died in a 22-year period between 1971 and 1993. If this trend continued, then almost all remaining trees in the area would be dead in ~80 years. Tree decline is also becoming increasingly common in south-eastern Queensland (McIntyre *et al.* 2002) and in south-western Australia (Saunders *et al.* 2003; Martin and Possingham 2005).



Figure 8.8: Dieback-affected tree in farmland near Nangus, southern New South Wales (photo by David Lindenmayer).

Tree decline in stands of temperate woodland has been found to erode the quality of habitats for a wide range of species including the Squirrel Glider (Crane *et al.* 2010) and some bird species of conservation concern in woodlands such as the Eastern Yellow Robin (*Eopsaltria australis*), Black-chinned Honeyeater and Dusky Woodswallow (*Artamus cyanopterus*) (Montague-Drake *et al.* 2009).

There is no single cause of tree decline, but some of the factors thought to contribute to it include (after Landsberg and Wylie 1991; Reid and Landsberg 2000):

- defoliation by native invertebrates such as stick insects, scarabid beetles and lerps and introduced insects
- salinity
- application of nutrients to improve pastures, which can lead to changes in soil fertility and to changes in insect grazing pressure
- soil acidification
- drought and fire
- deterioration of the structure of the soil
- damage caused by livestock and farm machinery
- increased numbers of parasitic mistletoes
- decreased abundance of wildlife such as the Sugar Glider (*Petaurus breviceps*), which can consume large quantities of tree-defoliating insects, and the Echidna (*Tachyglossus aculeatus*), which eats insect larvae
- increased abundance of aggressive native birds such as the Noisy Miner (*Manorina melanoccephala*) which displace other species, reducing predation pressure on defoliating insects (Clarke and Grey 2010)
- increased browsing of trees by mammals such as the Common Brushtail Possum (*Trichosurus vulpecula*) (Kirkpatrick 2010).

Finally, long-standing problems have arisen from the limited regeneration of trees in temperate woodland environments – a result of high-intensity set stocking grazing (Fischer *et al.* 2009; Weinberg *et al.* 2011). Limited regeneration can, in turn, have significant impacts on woodland persistence and biodiversity more generally (Fischer *et al.* 2010a). Fischer *et al.* (2010b) showed that within 50–100 years in agricultural south-eastern Australia, tens of millions of large

old trees will be lost and not replaced through recruitment. This will leave an estimated 42.5% (± 0.68) of more than 1 million ha of grazing land supporting <0.5 large old trees per ha compared with benchmark densities of ~30–40 per hectare (Gibbons *et al.* 2010). The iconic Australian farming landscape with its scattered mature eucalypt trees is therefore likely to change dramatically in the coming decades. This, in turn, could have negative impacts on livestock such as through a lack of shade trees and windbreaks (Cleugh 2003).

Firewood harvesting

A key factor underpinning vegetation clearing in temperate eucalypt woodlands is firewood harvesting (Fig. 8.9). Firewood harvesting has taken place in temperate eucalypt woodlands for many decades, much of it is largely unregulated and cannot in any way be considered ecologically sustainable. As of 2000, more than 4.5 million tonnes of firewood was cut annually for domestic consumption (Driscoll *et al.* 2000; Wall 2000). The firewood industry is based primarily on cutting dead standing and fallen trees, particularly on private land and on roadside reserves. The trees are not replaced, so firewood harvesting can be seen as a form of land clearing (Driscoll *et al.* 2000). These trees and their surrounding vegetation have significant value for many elements of biodiversity, including rare and threatened species (Manning *et al.* 2006a; Fischer *et al.* 2010a). Moreover, much of the timber comes from temperate woodlands that have already been subject to widespread clearing and are subject to other threatening processes, such as overgrazing, rural dieback and salinity. More than 50 species of vertebrates, including 21 species of birds, are at risk from firewood harvesting (Driscoll *et al.* 2000).

Overgrazing by domestic livestock

Overgrazing by domestic livestock in remaining uncleared areas of temperate woodland remains a key problem (Lunt *et al.* 2007). There are many impacts from domestic livestock grazing in temperate eucalypt woodlands (Maron and Lill 2005; Martin and Possingham 2005; Lindenmayer *et al.* 2010a) and it is beyond the scope of this chapter to discuss them in detail. As grazing pressure increases, native plant



Figure 8.9: Firewood harvesting in a stand of temperate eucalypt woodland near Gundagai in southern New South Wales (photo by Esther Beaton).

diversity is reduced and exotic plant species cover increases (Yates *et al.* 2000). There also tends to be limited natural regeneration of native plants (including overstorey trees) in areas of temperate eucalypt woodland subject to intensive grazing by domestic livestock (Spooner *et al.* 2002; Fischer *et al.* 2009; Weinberg *et al.* 2011). Compromised habitat structure and weed invasion has, in turn, led to the decline of small passerine birds (Arnold and Weeldenburg 1998; Lindenmayer *et al.* 2012c) and arthropods such as primitive spiders and ants, although there may be increases in opportunistic species (Abensperg-Traun *et al.* 2000). Furthermore, grazing by domestic livestock can cause soil compaction (Bezkorowajnyj *et al.* 1993), add nutrients to the soil and damage remnant native trees (e.g. by rubbing) (McIntyre *et al.* 2002). Livestock often concentrate in more productive parts of paddocks and affect areas such as watercourses (and associated riparian vegetation) (Amy and Robertson 2001).

Fertilisation and nutrient enrichment

Although otherwise fertile, native topsoils of temperate eucalypt woodlands are typically low in available nitrogen and phosphorus (Morgan 1998; Prober *et al.*

2002a). Fertiliser drift from adjacent crops and pastures, livestock grazing and other disturbances have led to increased soil nutrients in most remnants of temperate eucalypt woodlands in agricultural landscapes (Yates and Hobbs 1997; Prober *et al.* 2002a; Standish *et al.* 2008). This has contributed to the widespread degradation of herbaceous ground-layers, promoting exotic invasions, reducing native plant diversity and compromising fauna habitat (Prober *et al.* 2002a; Dorrough and Scroggie 2008; Prober and Wiehl 2012). Fig. 8.10 shows an example of a heavily degraded landscape.

Exotic species

Invasion by exotic predators, herbivores and weeds is another key threatening process in temperate woodlands. Exotic plants can comprise a significant proportion of the plant species diversity in temperate eucalypt woodlands in many landscapes (Yates *et al.* 2000; Smallbone *et al.* 2007). Exotic plant species can prevent native plant establishment (Prober and Lunt 2009), alter soil nutrient cycling (Prober and Lunt 2009) and change the suitability of habitats for animal taxa (Lindenmayer *et al.* 2012c). Habitats dominated by exotic plant species (including revegetation comprising



Figure 8.10: Heavily degraded temperate eucalypt woodland in South Australia (photo by David Lindenmayer).

of mostly exotic species), are often dominated by exotic animal species (e.g. House Sparrow *Passer domesticus* and Common Starling *Sturnus vulgaris*) (Munro and Lindenmayer 2011).

Exotic predators such as the Red Fox (*Vulpes vulpes*; Fig. 8.11) and the feral cat (*Felis catus*) have contributed to the near extinction of many native marsupials that were once common in temperate eucalypt woodlands, such as the Numbat (*Myrmecobius fasciatus*) and bettongs (*Bettongia* spp.) (Maron and Lill 2005). The loss of these native fauna is likely to have resulted in the loss of important ecosystem engineering roles such as digging, which increased percolation of water into the soil (Eldridge and Rath 2002; Maron and Lill 2005; Smallbone *et al.* 2007). Exotic herbivores such as the European Rabbit (*Oryctolagus cuniculus*) also limit native plant recruitment, promote weed invasion and soil erosion and may compete with native fauna.

Over-abundance of native species

Some species of native animals can become over-abundant in temperate woodlands and this can lead to a decline of other native taxa as well as a decline in the condition of the vegetation. For example, work by Barton *et al.* (2011) has highlighted the changes in beetle assemblages that occur in temperate woodlands subject to high-intensity grazing pressure from large numbers of the Eastern Grey Kangaroo (*Macropus*

giganteus). Similarly, the arboreal browsing impacts of the Common Brushtail Possum (*Trichosurus vulpecula*) have been found to have significant negative impacts on the canopy cover, leaf area and overall vegetation condition of temperate woodlands in Tasmania (Kirkpatrick 2010).

Another example is the hyper-aggressive native honeyeater, the Noisy Miner (Fig. 8.12) – a species that can attain very high levels of abundance in some areas of woodland, especially those on high productivity sites (Montague-Drake *et al.* 2011). Large numbers of the Noisy Miner can significantly depress the abundance and diversity of other species of native birds,



Figure 8.11: The Red Fox, an exotic predator that is known to have major negative impacts on native fauna (photo by Graeme Chapman).



Figure 8.12: The Noisy Miner – a hyper-aggressive native bird that can suppress the abundance of several species of other (smaller) native birds (photo by Graeme Chapman).

especially small-bodied species (Grey *et al.* 1998; Howes and Maron 2009).

Other threatening processes in temperate eucalypt woodlands

The preceding sections have focused on some of the major threatening processes in temperate eucalypt woodlands. There are others that we have not examined but which also have significant impacts, including disruption of natural fire regimes (Hobbs 2002; Lunt *et al.* 2012) and practices commonly associated with agriculture, such as chemical spraying, ploughing, the removal of bush rock and woody debris and a range of other management activities (Lindenmayer *et al.* 2010a).

Finally, the increasing threat of climate change can no longer be overlooked. For south-eastern Australia, spatial modelling suggests that, by 2070 under medium- to high-emissions scenarios, 25–60% of areas currently modelled as suitable for temperate eucalypt woodland may change to environments more suited to chenopod shrublands and other vegetation types (Prober *et al.* 2012a). Furthermore, climatic modelling demonstrates a drastic reduction in resilience of these woodlands to climate change when past clearing and fragmentation are accounted for (Prober *et al.* 2012a). In the Great Western Woodlands region of Western Australia, intact landscapes offer greater resilience to climate change. Nevertheless,

bioclimatic models predict 50–100% loss of current woodland environments by 2070 under medium and high severity climate change scenarios, respectively (Prober *et al.* 2012b).

CONSERVATION APPROACHES IN TEMPERATE EUCALYPT WOODLANDS

The high levels of clearing and degradation in temperate eucalypt woodlands impinge strongly on options for their conservation. Only 2.2% of the temperate eucalypt woodlands in south-eastern Australia are conserved within the national reserve system (Prober *et al.* 2012a). Woodlands in the agricultural region of Western Australia have fared a little better, with a significant suite of remnants having been gazetted in the wheatbelt over the past 50 years. About 9% of the 13.1 million ha wheatbelt region is in state government reserves, but this is likely to be skewed towards non-woodland vegetation and the median size of the 612 nature reserves is relatively small (114 ha) (Gibson *et al.* 2004).

Apart from the Great Western Woodlands region, few large, diverse areas of temperate eucalypt woodland remain available to substantially improve reservation status. However, there has been a steady evolution of alternative conservation approaches in the past 20 years, focused on appropriate management and legal protection of representative suites of smaller remnants of varying condition and land tenure. In addition, a multitude of revegetation and other initiatives aim to increase habitat areas, support critical ecosystem processes and limit the abundance and spread of exotic species in woodland landscapes (Lambert *et al.* 2000; Prober *et al.* 2001; Prober and Thiele 2005).

From an implementation perspective, a range of policy instruments and support programs have been developed to facilitate on-the-ground outcomes including: legislated regulations (e.g. threatened species legislation); legal protection through property rights (e.g. covenanting and targeted reservation programs); education; and incentives programs (e.g. the Environmental Stewardship Program which has targeted several ecological communities including box gum grassy woodlands and peppermint box woodlands; see

Zammit *et al.* 2010; Lindenmayer *et al.* 2012d) and coordinating networks (e.g. Conservation Management Networks such as the Grassy Box Woodlands Network in New South Wales, see <http://www.gbwcmmn.net.au>; see also Lambert *et al.* 2000; Prober *et al.* 2001).

With increasing resources and effort committed towards ecological management, restoration and revegetation of temperate eucalypt woodlands, it is critical that we understand the benefits and limitations of these approaches (Munro and Lindenmayer 2011). Much of the current knowledge about temperate eucalypt woodlands has been gleaned from less-than-ideal *post hoc* surveys. Long-term plot networks and other long-term studies offer an important opportunity to characterise and learn from long-term trends at site, landscape and regional scales.

OVERVIEW OF CORE STUDIES SHOWCASED

Much of the remainder of this chapter focuses on data from three long-term plot networks – all located in southern New South Wales (Table 8.3). Two of these – the Nanangroe Plantation Plot Network and the Woodland Restoration Plot Network on the Cumberland Plain – are presently part of the Long Term Ecological Research Network (LTERN) within the Terrestrial Ecosystem Research Network (TERN). Other research is also described briefly throughout the remainder of the chapter in feature boxes (see Boxes 8.5, 8.6, 8.8, 8.10, 8.11, and 8.15). However, we are acutely aware that there are also other long-term studies in temperate eucalypt woodlands that are underway including those in New South Wales (Reid and Cunningham 2008), the Australian Capital Territory (e.g. Greening Australia 2001; Bounds *et al.* 2010; Taws *et al.* 2012) and South Australia (The Nature Conservation Society of South Australia 2012). These investigations are producing important ecological findings of management and conservation relevance. Results from some of these long-term studies feature in boxes that are scattered throughout the remainder of this chapter.

Nanangroe Plantation Plot Network

The first study is on the South West Slopes of New South Wales and is quantifying the changes in

temperate woodland remnants when the surrounding landscape is dominated by stands of exotic Radiata Pine (*Pinus radiata*) (Lindenmayer *et al.* 2008). This is now known as the Nanangroe Plantation Plot Network. The key research question is: what are the effects of a changing matrix surrounding patches of temperate eucalypt woodland on the biota inhabiting those patches? In this case, the key driver of change in the matrix is the establishment and subsequent maturation of Radiata Pine stands in areas surrounding the patches of temperate eucalypt woodland (Lindenmayer *et al.* 2001).

The Nanangroe Plantation Plot Network is a longitudinal investigation taking place north of Gundagai (Fig. 8.13). The study comprises of 58 remnants surrounded by pine stands and a set of 58 matched woodland ‘control’ sites on farmland where the surrounding areas are semi-cleared grazing paddocks (Fig. 8.14; see also Box 8.4 for an explanation of the measurement units). The experimental design is underpinned by a randomised and replicated patch selection procedure in which patches in four different size classes and five woodland vegetation types were identified for study (Lindenmayer *et al.* 2001). Repeated sampling of the vegetation cover and selected vertebrate groups on all sites from 1998 to 2012 has created a high-quality time series dataset. Moreover, because the Nanangroe Plantation Plot Network has been designed so that it is a direct study of change, this means that each patch has become its own ‘control’. This will allow a detailed profile of longitudinal change to be constructed for each patch over time and, in turn, for that profile to be linked with changes in the conditions of the surrounding plantation matrix as well as temporal changes within a given patch (Lindenmayer *et al.* 2001).

The temperate woodlands in the Nanangroe Plantation Plot Network span a range of dominant tree species including Yellow Box (*Eucalyptus melliodora*), Red Box (*E. polyanthemos*), White Box (*E. albens*), Blakely’s Red Gum (*E. blakelyi*), Apple Box (*E. bridgesiana*) and Long-leaf Box (*E. goniocalyx*). In addition, there are patches dominated by Red Stringybark (*E. macrorhyncha*) and Broad-leaved Peppermint (*E. dives*).

Prior to the Nanangroe Plantation Plot Network, little was known about how natural communities

Table 8.3: Summary details of the three core studies featured in this chapter

Plot network/ study name	Major vegetation group	NRM	Data custodian	Data type (fauna/flora/ vegetation structure)	Spatial extent	No. of plots	Plot size	Start year	Current status	Temporal re-visit
Nanangroe Plantation Plot Network	A subset 'eucalyptus woodlands' (MVG5)	Murrumbidgee	David Lindenmayer (ANU)	Fauna/flora/ vegetation structure	21 300 ha	131	2 ha	1997	Ongoing	Annually
South West Slopes Restoration Study	A subset 'eucalyptus woodlands' (MVG5)	Murray and Murrumbidgee	David Lindenmayer (ANU)	Fauna/flora/ vegetation structure	490 000 ha	199	2 ha	2000	Ongoing	Annually
Woodland Restoration Plot Network (Cumberland Plain)	A subset 'eucalyptus woodlands' (MVG5)	Hawkesbury- Nepean and Sydney Metro	David Keith (OEH and UNSW)	Fauna/flora/ vegetation structure	2700 ha	114 ¹	0.1 ha (32 x 32 m)	1992	Ongoing	Every 4 years

¹ = Unique combinations of site and time (new random selection of sites at each survey time).

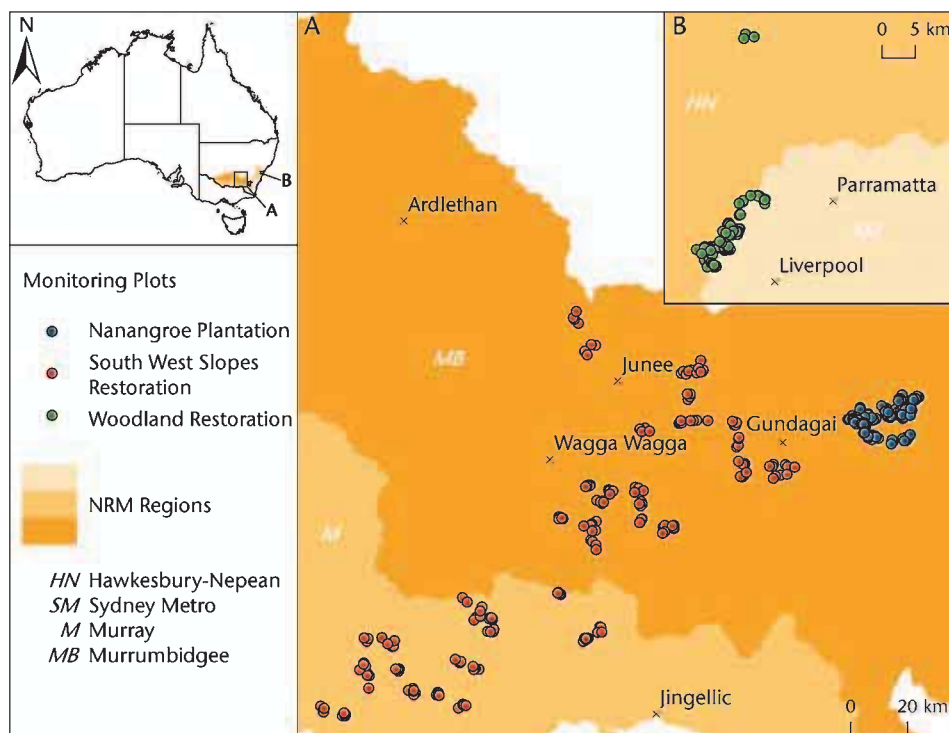


Figure 8.13: The location of the three core studies (the Nanangroe Plantation Plot Network, South West Slopes Restoration Study and Woodland Restoration Plot Network) in temperate eucalypt woodlands. The Nanangroe Plantation Plot Network and Woodland Restoration Plot Network are presently part of the Terrestrial Ecosystem Research Network.

respond to the design and establishment of plantations of exotic trees. The Network has been instructive in guiding the design and establishment of plantations of exotic trees to ensure that plantation landscapes also maintain some other ecological values such as providing habitat for elements of the biota (Lindenmayer 2009). Understanding the impacts of large-scale landscape change on biodiversity is critical because of the considerable expansion of the plantation estate in the past few decades. This has arisen through a transition away from logging native forest logging and, more recently, the likelihood that carbon sequestration through plantation development will become a key part of efforts to tackle rapid climate change (Lindenmayer *et al.* 2012a).

The South West Slopes Restoration Study

The second temperate woodland study is also from the South West Slopes of New South Wales (Fig. 8.13; see also Box 8.4 for an explanation of the

measurement units). This work commenced in 2000 and is examining long-term changes in populations of birds, reptiles and mammals within 184 sites located within remnant temperate woodlands and in replanted woodlands. Surveying most groups of animals is completed annually and the results are important for determining the effectiveness of management interventions such as establishing plantings – a key area of major investment of public funds in Australian agricultural regions (Hajkowicz 2009).

The work in the South West Slopes Restoration Study is underpinned by a nested hierarchical design comprising four sites on a given farm, two farms within a given landscape and 23 landscapes (Cunningham *et al.* 2008). The key question is: are there combined effects of plantings and remnant native vegetation on native biota at the site, farm and landscape levels? The complementary and cumulative effect of different kinds of vegetation on animal occurrence has rarely been examined, especially at the

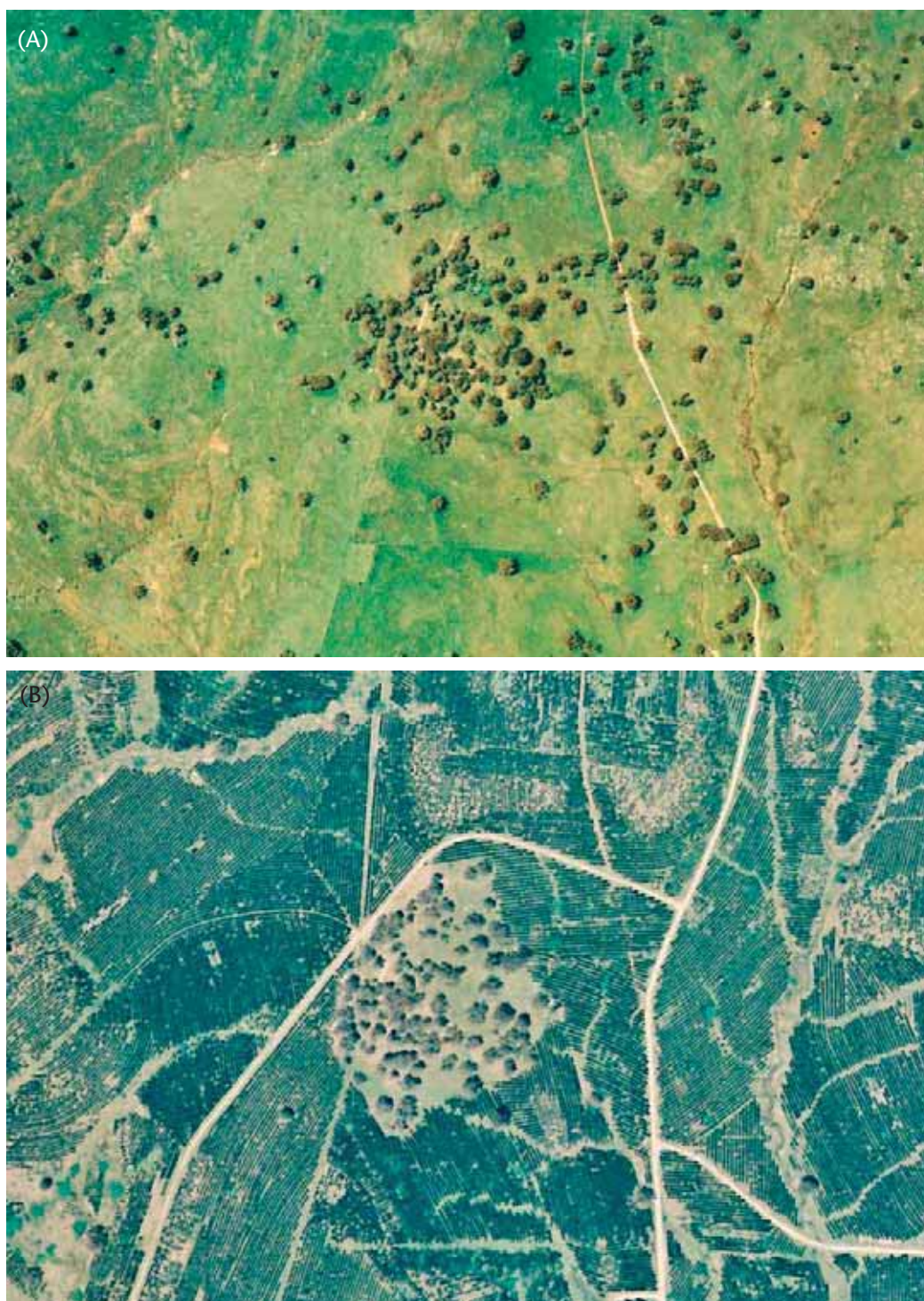


Figure 8.14: Aerial photos of a temperate eucalypt woodland patch before and after the surrounding landscape has been planted with stands of Radiata Pine at Nanangroe: (A) the patch before plantation commenced; (B) the patch in 2004 after plantation establishment (photos by State Forests of New South Wales).

Box 8.4: Defining the measurement units in the Nanangroe Plantation Plot Network and the South West Slopes Restoration Study

Both the Nanangroe Plantation Plot Network and the South West Slopes Restoration Study are comprised of 2 ha sites within which sample plots have been established at the 0 m, 100 m and 200 m points along a permanent 200 m long transect. The plots are marked with a star picket and geo-referenced. In addition, artificial substrates to facilitate surveys of reptiles are located at each plot – roof tiles, sheets of corrugated iron and timber sleepers (Fig. 8.15).



Figure 8.15: A plot within a site in an area of temperate eucalypt woodland in southern New South Wales (photo by Damian Michael).

level of individual farms. Nevertheless, to better guide the large investments made in on-farm environmental management, it is critical to determine those farms where restoration is most efficient.

Site selection for the South West Slopes Restoration Study was based on two cross-classifying factors: (1) the amount of planting in a landscape; and (2) the amount of remnant native vegetation in a landscape. Two classes of remnant vegetation cover were recognised and these corresponded to >15% and <9% cover, respectively. Percentage cover for planting intensity classes were >1%, 0.5–0.9% and 0.2%. There are four landscapes in each of the six remnant × planting cover classes except for the class corresponding to high levels of remnant vegetation and high levels of

planting (i.e. >15% native vegetation cover and >1% plantings cover) where only three landscapes were available. Two farms were then selected within each of the 23 landscapes – one with plantings and one without plantings. Generally, for the 23 farms with plantings, two sites were established in plantings and two in woodland remnants. On the 23 farms without plantings, all four sites were located in patches of remnant eucalypt woodland. The different kinds of vegetation (see e.g. Fig. 8.16) on the sites were: plantings, remnant old growth woodland, seedling regrowth woodland (that established from seeds in the soil or released by overstorey trees) and coppice regrowth woodland that recovered following disturbance through burning, thinning or partial clearing



Figure 8.16: Different kinds of temperate eucalypt woodland vegetation in the South West Slopes Restoration study: (A) old growth; (B) seedling regrowth; (C) planting; (D) coppice regrowth (photos A and C by Mason Crane, B and D by Esther Beaton).

(Lindenmayer *et al.* 2012b). The dominant tree species in the South West Slopes Restoration Study include Yellow Box, Red Box, White Box, Blakely's Red Gum and Red Stringybark (Lindenmayer *et al.* 2012b).

The ongoing work in the South West Slopes Restoration Study has been valuable for a range of key reasons. For example, it has: (1) highlighted how plantings might be best done to maximise their value for biodiversity (Cunningham *et al.* 2007; Lindenmayer 2009; Lindenmayer *et al.* 2010c); (2) demonstrated how plantings and areas of remnant native vegetation interact at different spatial scales to influence birds and reptiles (Cunningham *et al.* 2008); and (3) shown how birds respond to different growth types of native vegetation (Lindenmayer *et al.* 2012b). The ecological value of the datasets continues to increase over time and new findings are important for informing

decisions about where and how to make investments to better conserve on-farm biodiversity (Lindenmayer *et al.* 2011).

The Woodland Restoration Study (Cumberland Plain)

The third temperate woodland study is located on the Cumberland Plain in western Sydney (Fig. 8.13). The primary goal is to assess the pace and direction of long-term changes in planted woodlands to determine progress towards the development of native woodland ecosystems. Related goals include the identification and resolution of restoration barriers and the development of methods for evaluating restoration success. The plantings were established sequentially over a decade from 1992 to 2002 in improved exotic pastures, formerly managed for livestock grazing until they were acquired as part of a green belt within the rapidly

developing urban landscape of western Sydney. Approximately 1000 ha of abandoned pastures were planted with 28 local native species of trees and shrubs (Davies and Christie 2001). The plantings are interspersed with patches of untreated pastures and remnant woodland in a state of regrowth after selective removal of timber. Monitoring commenced in 2002 (Wilkins *et al.* 2003) and has been repeated at ~5-year

intervals. In each monitoring cycle, a random sample of plots was stratified across replicated plantings of different ages, as well as untreated pasture (controls) and remnant woodland (reference sites), allowing a spatio-temporal analysis of the trajectory of planted woodlands from pasture to native woodland. As of 2012, 114 plots sampling unique combinations of site and time have been surveyed for vegetation structural

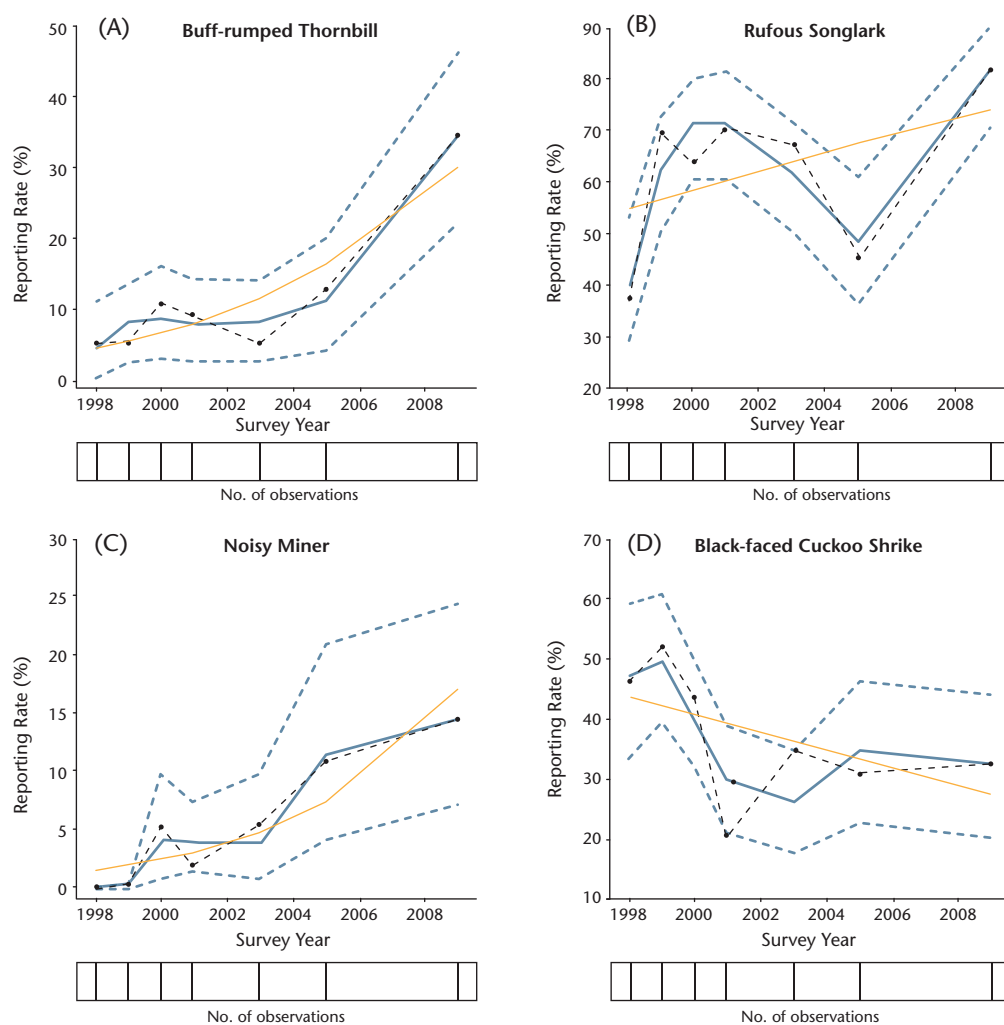


Figure 8.17: Long-term changes in the reporting rates of selected species of birds aggregated across 60 temperate eucalypt woodland patches surrounded by grazed paddocks in the Nanangroe Plantation Plot Network in southern New South Wales (redrawn from Lindenmayer and Cunningham 2011). Presented in the plots are observed reporting rate, fitted model with the 5th and 95th percentiles and a linear fit. A sub-graph or rug plot (at the bottom of each graph) shows the relative sample size for each year, which relates to the precision of the estimates at each sample session. (A) Buff-rumped Thornbill; (B) Rufous Songlark; (C) Noisy Miner; (D) Black-faced Cuckoo Shrike; (E) Sulphur-crested Cockatoo; (F) Brown Treecreeper; (G) Jacky Winter; (H) Rufous Whistler; (I) White-winged Triller; (J) Black-chinned Honeyeater.

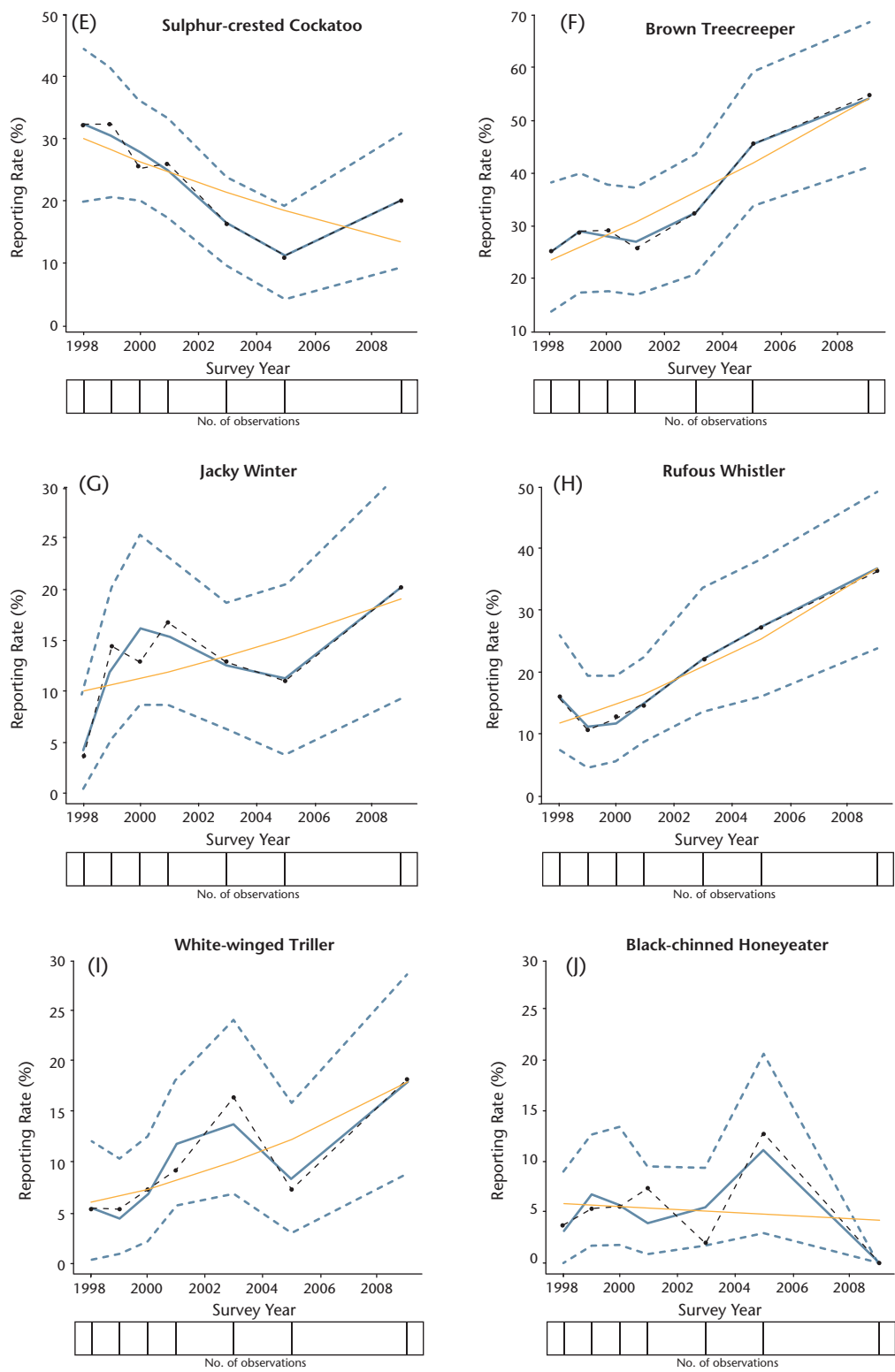


Figure 8.17: (Continued)



Figure 8.18: Selected bird species of conservation concern recorded in the Nanangroe Plantation study and which exhibited an increase in reporting rate between 1998 and 2009: (A) Brown Treecreeper; (B) Jacky Winter; (C) Rufous Whistler (*Pachycephala rufiventris*); (D) White-winged Triller (*Lalage sueurii*) (photos by Julian Robinson).

attributes and vascular flora, and a subsample of sites has been sampled for invertebrate fauna.

The study is producing important insights into: (1) the pace and direction of change in plant community composition with time since planting (Wilkins *et al.* 2003); (2) whether tree planting fosters the entry of other plant species into the restored ecosystem (Nichols *et al.* 2010); (3) the pace and direction of change in invertebrate communities with time since planting (Lomov *et al.* 2006, 2009); (4) the development of ecological functions in the planted woodlands over time; and (5) the identification of restoration barriers (Nichols *et al.* 2010). The results are important for determining the effectiveness of investments in

woodland restoration through plantings on retired agricultural lands. These investments represent a major expenditure of public funds in Australian agricultural regions (Hajkowicz 2009) and are used increasingly to offset losses of biodiversity in development projects (Maron *et al.* 2012).

TRENDS IN ENVIRONMENTAL CHANGE AND BIODIVERSITY BASED ON LONG-TERM PLOT DATA

In the following section we present a series of data analyses from the three core long-term studies featured in this chapter.

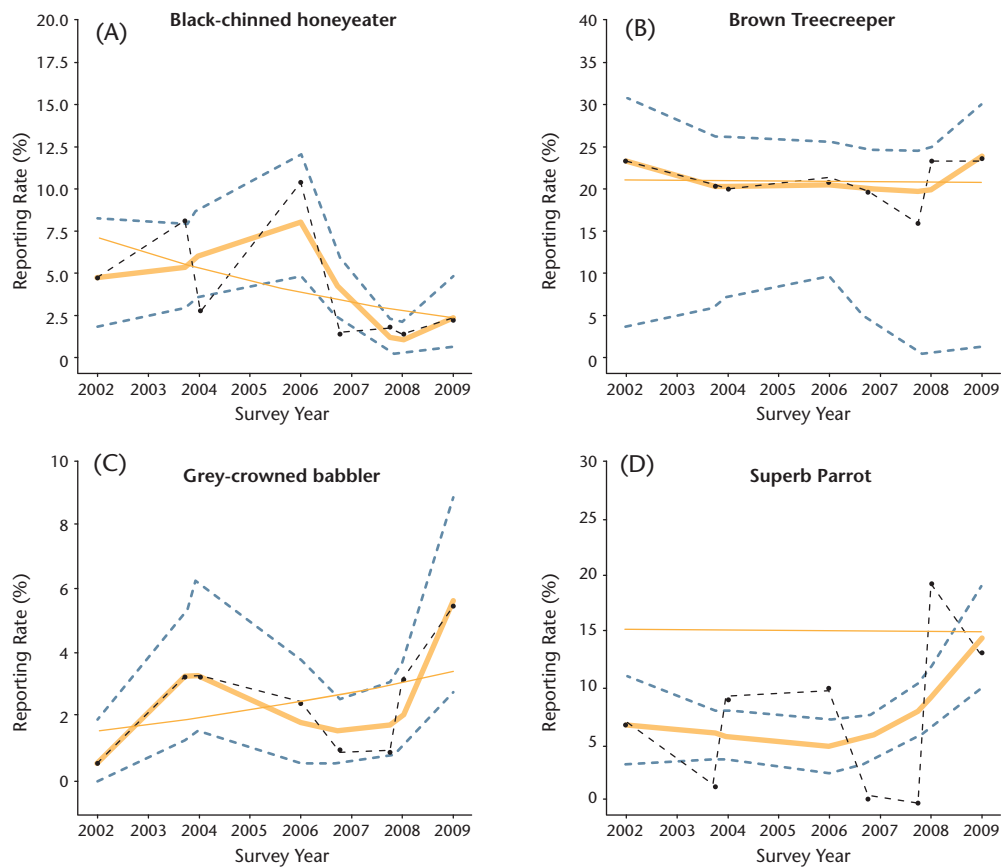


Figure 8.19: Long-term changes in the reporting rates of selected species of birds aggregated across temperate woodland patches in the South West Slopes Restoration study in southern New South Wales: (A) Black-chinned Honeyeater; (B) Brown Treecreeper; (C) Grey-crowned Babbler; (D) Superb Parrot. Graphical components as per Fig. 8.17.

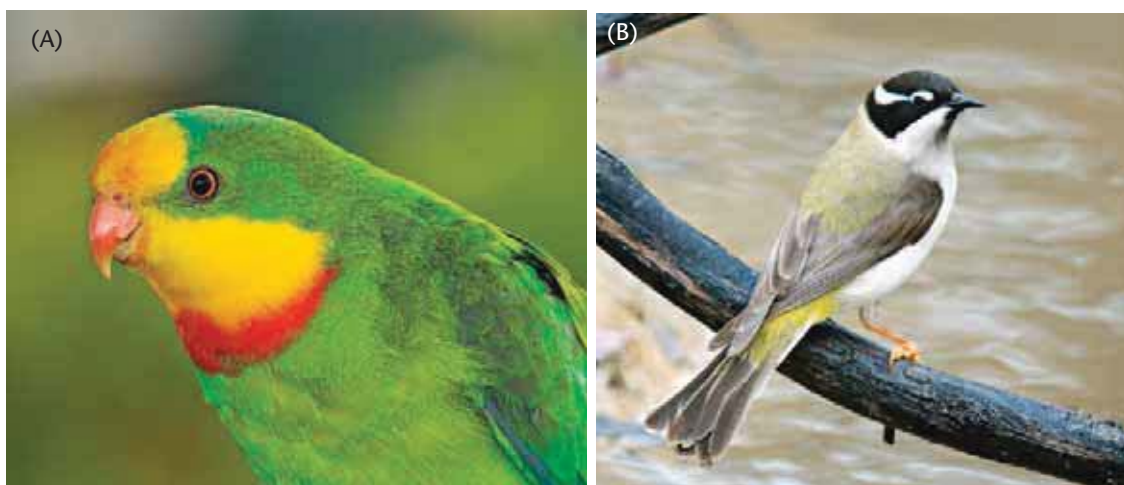


Figure 8.20: (A) Superb Parrot; and (B) Black-chinned Honeyeater (photo A by Julian Robinson, B by Graeme Chapman).

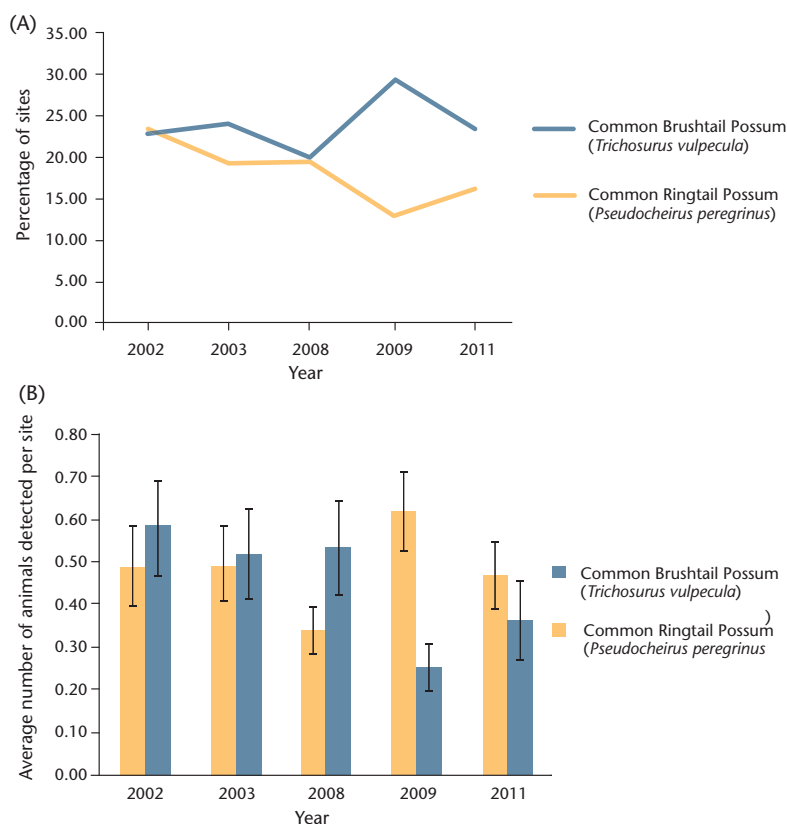


Figure 8.21: Longitudinal changes in arboreal marsupials on long-term sites within temperate eucalypt woodlands of the South West Slopes Restoration Study: (A) percentage of sites (of a total of 184) where the Common Ringtail Possum (Fig. 8.22) and the Common Brushtail Possum (Fig. 8.22) were detected; (B) average number of animals detected per site and associated 95% confidence interval.

Longitudinal changes in temperate woodland birds

Here we use datasets from both the Nanangroe Plantation Plot Network and from the South West Slopes Restoration study to highlight long-term trend patterns for birds (see Fig. 8.17). Data presentations for birds are important because of widespread concern about the declines of many species (Ford 2011) and the risk that many species will be lost within 50–100 years (Recher 1999).

Data from the Nanangroe Plantation Plot Network shows considerable inter-year fluctuations in mean reporting rate of many species (reporting rate is calculated from the proportion of sites where occupancy was detected from multiple surveys *sensu* Cunningham and Olsen 2009). Nevertheless, many taxa exhibit

a general trend for increasing reporting rate over time, when considering only those landscapes that were not planted with stands of Radiata Pine. These include species of conservation concern in woodlands (Fig. 8.18, p. xxx) such as the Brown Treecreeper (*Climacteris erythrops*), Jacky Winter (*Microeca fascinans leucophaea*), Rufous Whistler (*Pachycephala rufiventris*) and White-winged Triller (*Lalage seuri*). Conversely, some species of birds exhibited a decreasing trend in reporting rate, including the introduced/exotic Common Starling (*Sturnus vulgaris*) and House Sparrow (*Passer domesticus*), and two native taxa the Black-faced Cuckoo-Shrike (*Coracina novaehollandiae*) and Sulphur-crested Cockatoo (*Cacatua galerita*).

Bird data from the long-term plot network on the South West Slopes Restoration Study were aggregated



Figure 8.22: (A) Common Ringtail Possum; and (B) the Common Brushtail Possum (photo A by Esther Beaton, B by Mason Crane).

to create a measure of reporting rate similar to that used for data from the Nanangroe Plantation Plot Network. This data shows that, similar to the

Box 8.5: Temporal changes in populations of the Brush-tailed Phascogale based on long-term monitoring

The Brush-tailed Phascogale (*Phascogale tapoatafa*) is a small carnivorous marsupial that is primarily arboreal and is dependent on tree hollows for nesting (Fig. 8.23). A monitoring program to quantify changes in populations of the species has been underway at 17 sites in north-eastern Victoria since 2000 (Holland *et al.* 2012). The work highlighted a substantial temporal decline in the abundance of the species between 2000 and 2010. These changes were attributed to declining rainfall during the monitoring period. Changes in rainfall were suggested to alter the abundance of prey species (Holland *et al.* 2012). It will be interesting to maintain the monitoring program in wet years to determine if there has been a corresponding increase in the abundance of the Brush-tailed Phascogale.



Figure 8.23: The Brush-tailed Phascogale (photo by Frank Woerle/AUSCAPE).

Nanangroe Plantation Plot Network, some species exhibited strong temporal increases in reporting rate whereas the opposite (decreasing) trend was apparent for others (Fig. 8.19). For example, two species of conservation concern – the Superb Parrot and the Black-chinned Honeyeater (Fig. 8.20) – showed markedly different temporal trends. Other species of conservation concern such as the Brown Treecreeper exhibited no significant temporal change in reporting rate between 2000 and 2009.

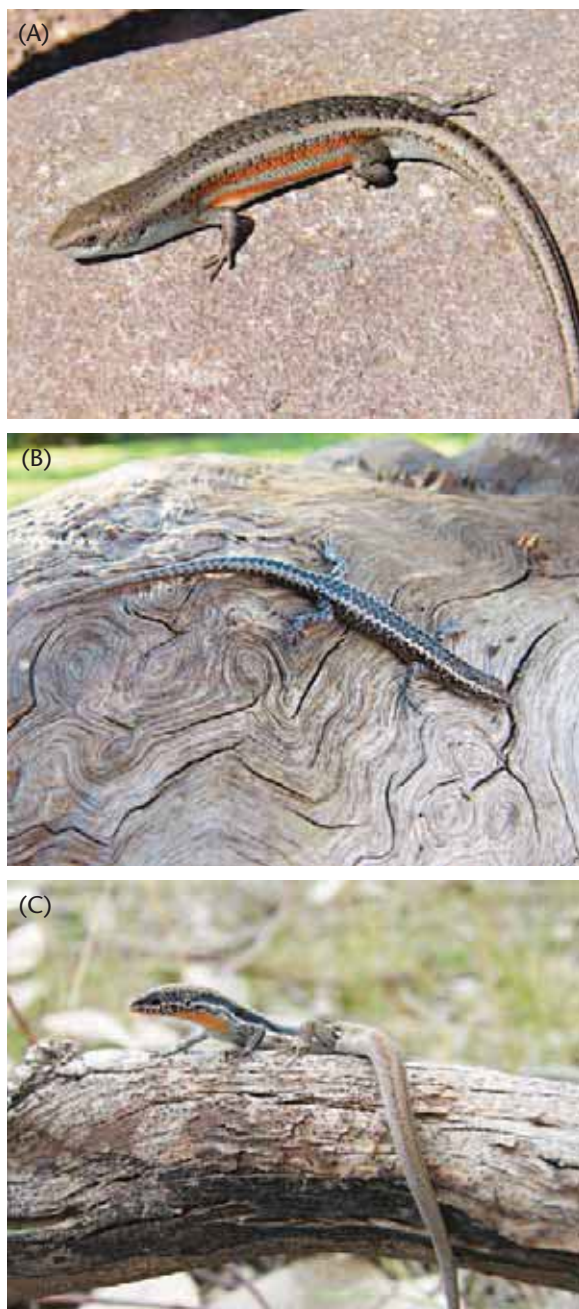


Figure 8.24: (A) Southern Rainbow Skink; (B) Ragged Snake-eyed Skink; (C) Boulenger's Skink (photos by Damian Michael).

Notably, some species (e.g. the Brown Treecreeper) exhibited strong increases in reporting rate in the Nanangroe Plantation Study (Fig. 8.17, p. xxx) but not for the South West Slopes Restoration study (Fig. 8.19,

p. xxx). Between-study differences reflect regional variation in temporal trajectories and suggest that there are spatial differences in the key drivers of population changes. However, it is not currently possible to determine which drivers are the most important ones underpinning such regional variations because the current time series is too short – indicating that ongoing data collection will be important.

Longitudinal changes in populations of arboreal marsupials in temperate woodlands

Repeated spotlighting surveys for the South West Slopes Restoration study have generated a high-quality long-term dataset on populations of arboreal marsupials. This dataset shows that the numbers of sites where the Common Brushtail Possum was recorded remained relatively unchanged between 2002 and 2011 (Fig. 8.21, p. xxx).

Longitudinal changes in populations of reptiles in temperate eucalypt woodlands

Surveys of reptiles in the South West Slopes Restoration study were based on time-constrained active searches and searches of artificial substrates (corrugated steel, roof tiles and wooden sleepers; Michael *et al.* 2012). The majority of species of reptiles were recorded too infrequently to produce convincing results. However, adequate data were available for several species including the Southern Rainbow Skink (*Carlia tetradactyla*), Boulenger's Skink (*Morethia boulengeri*) and the Ragged Snake-eyed Skink (*Cryptoblepharus pannosus*) (Fig. 8.24). This data shows an increasing trend between 2002 and 2011 in the proportion of sites where the Ragged Snake-eyed Skink and Boulenger's Skink were detected but a corresponding decline for the Southern Rainbow Skink (Fig. 8.25). Similarly, the number of animals detected per occupied site increased for the Ragged Snake-eyed Skink and Boulenger's Skink but declined for the Southern Rainbow Skink (Fig. 8.25). The reasons for these intriguing patterns remain unclear and they are not clearly linked with temporal changes in climatic conditions (e.g. rainfall) because the study period encompassed a prolonged drought in southern New South Wales.

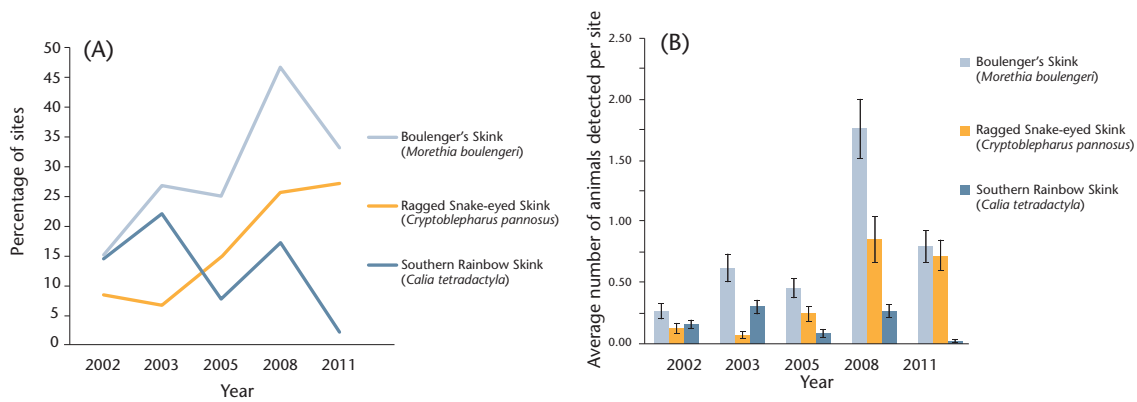


Figure 8.25: Longitudinal changes in reptiles on long-term sites within temperate eucalypt woodlands of the South West Slopes Restoration Study: (A) percentage of sites (of a total of 184) where the Southern Rainbow Skink, Boulenger's Skink and the Ragged Snake-eyed Skink were detected; (B) average number of animals detected per site and associated 95% confidence interval.

Time series changes in woody biomass cover

Much of the period of the South West Slopes Restoration study has been characterised by a prolonged drought. Despite this, there has been a noticeable increase in the cover of woody biomass on many farms and landscapes in the study region (Fig. 8.27). The reasons for this unexpected temporal change remain unclear although many landholders have undertaken active planting programs (see Box 8.7). In addition, the drought period led to significant destocking of domestic livestock and this may have allowed natural regeneration to occur in parts of farms (Lindenmayer *et al.* 2012b). However, at the same time, there are many remnants of old growth temperate woodland, which have been characterised by an almost complete lack of natural regeneration during the entire 10 years of vegetation surveying between 2000 and 2011 (Weinberg *et al.* 2010).

Trajectories of plants and invertebrate communities in restoration plantings

The long-term woodland restoration plot network among the fragmented temperate eucalypt woodlands on the Cumberland Plain in western Sydney provides some insights into the challenges of restoring woodland biota on land formerly used for agriculture. Ten years after planting, the restored patches had begun to develop structural attributes of woodland, with the tree canopy increasing in height and cover, and the cover of exotic perennial grasses declining in the

ground layer (Wilkins *et al.* 2003). However, at that stage of development, there was no evidence that new native plant species had entered the community or that species composition had converged with that of the reference woodlands or diverged from the untreated pastures when planted individuals were excluded from the comparison (Fig. 8.30). The reference sites contained a large number of native plant species that were not recorded in either the planted sites or the untreated pastures (Wilkins *et al.* 2003). Further sampling beneath the canopies of planted trees also failed to detect any facilitation effect of tree planting on the entry of missing floristic components of the woodland into the restored community (Nichols *et al.* 2010).

Surveys of ants, moths and butterflies showed a similar lack of progression towards a more diverse native assemblage (Lomov *et al.* 2006, 2009). A substantial proportion of the invertebrate species recorded in remnant woodlands were unrepresented in restored sites and untreated pasture and there was no evidence of convergence of the species assemblages recorded in the restored sites with those of adjacent remnant woodlands. Despite this, there was some evidence of ecological functionality in the restoration plantings, particularly in relation to the pollination of flowers on individuals of planted native species and the dispersal of seeds by ants (Lomov *et al.* 2009).

The results of the work to date suggest either that rates of transition towards more diverse native woodland assemblages are so slow that they cannot be

Box 8.6: The Monteagle and Woodstock fire experiments

The Monteagle and Woodstock fire experiments were established in 1993 in central NSW to facilitate optimal management of the few remnants of temperate grassy eucalypt woodland that still retain ground-layer and topsoil characteristics that are relatively unmodified (Fig. 8.26). The two experimental 'reference' sites were selected to represent two historical management extremes: Monteagle had few trees and had been burnt every ~4 years by the local bush fire brigade, while Woodstock had a mature eucalypt overstorey and had not been burnt since World War II (according to long-term local residents). The experiments focused on effects of different fire frequencies, applying 2-, 4- and 8-yearly burns, as well as undisturbed, mowing and marsupial exclusion treatments across 52 experimental plots each measuring 5 × 5 m. The experiments have provided many insights into woodland processes. Some conclusions we have drawn relevant to medium rainfall temperate eucalypt woodlands include:

- Fire regimes account for small but significant amounts (5–15%) of the variation in native plant diversity and cover, after accounting for high levels of inter-annual variation associated with rainfall.
- In fragmented landscapes that limit dispersal of woodland forbs, decadal scale response of native forb diversity and cover to fire is shaped by management history.
- Low-stature exotic annuals that are now ubiquitous in reference sites are promoted by autumn fires and can suppress native plants in high-rainfall years.
- Frequent low-intensity fire over a decadal timeframe does not significantly deplete soil carbon and nitrogen stores. However, it can reduce soil biological activity and moisture characteristics, potentially triggering further degradation (Prober *et al.* 2008).
- Frequent fire can reduce the resilience of dominant tussock grasses to drought, suggesting less fire may be appropriate in a drying climate (Prober *et al.* 2007).
- Increased resilience to the disturbance regime is promoted by the presence of a mix of C3 and C4 grasses (see Box 8.3).
- Frequent disturbance favours a high cover and richness of mosses, lichens and liverworts on the soil crust in mesic areas (O'Bryan *et al.* 2009).

Together these results suggest a 'status quo' strategy, i.e. maintenance of the historical management regime, as the most conservative approach to managing these valuable remnant temperate eucalypt woodlands. Notwithstanding, adjustments in management are likely to be needed in accordance with the changing climate and observed increases in tree densities. The work has also helped identify points of weakness and resilience that can guide management decisions. These experiments would not have been possible without the long-term engagement of the Monteagle and Woodstock Bush Fire Brigade volunteers.



Figure 8.26: Burning at the (A) Monteagle; and (B) Woodstock fire experiments (photos by Suzanne Prober).

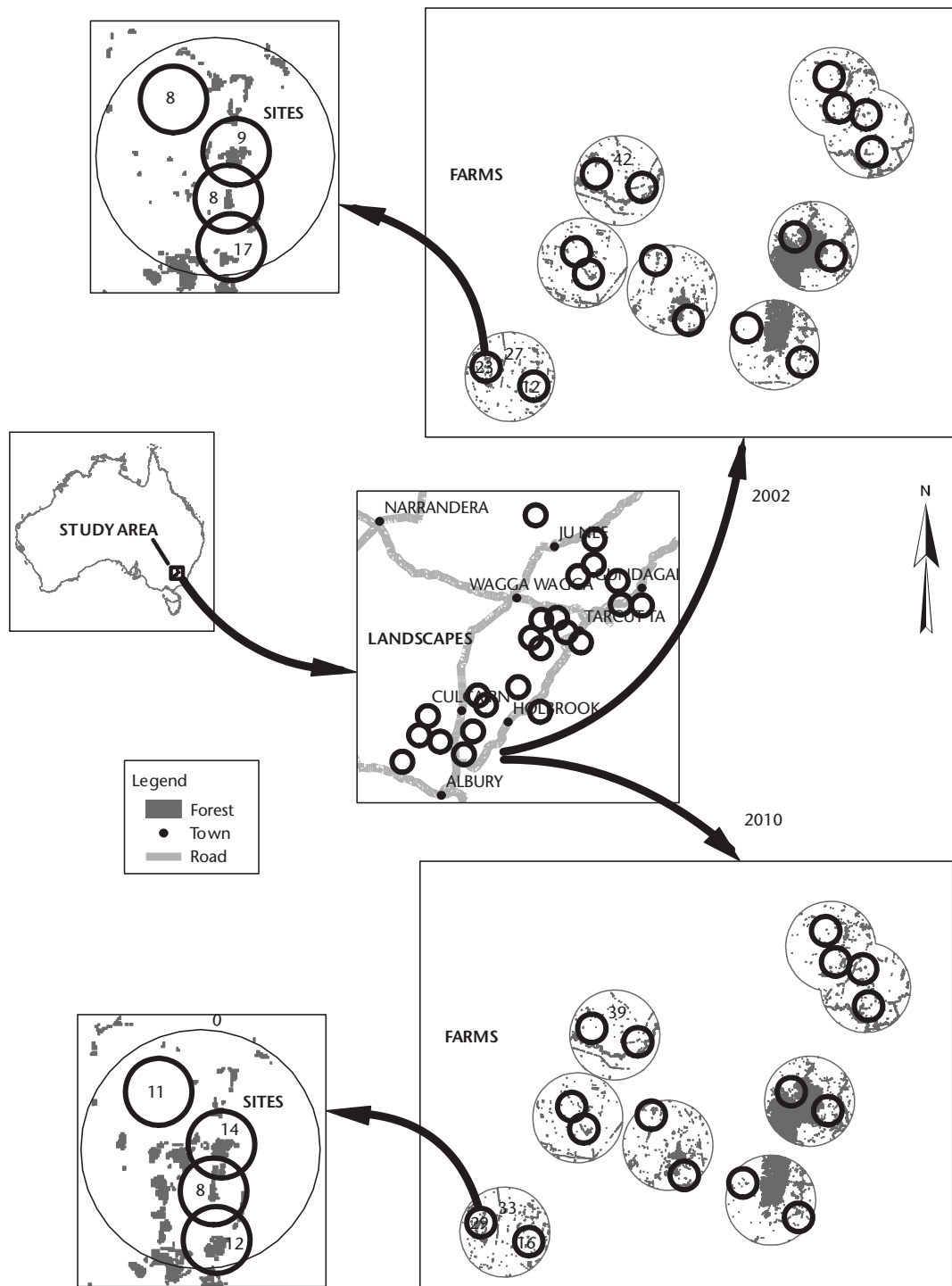


Figure 8.27: Temporal changes in woody biomass cover on farms across the South West Slopes Restoration study. The hierarchically nested study design shows sites (2 ha in size) within farms (circled), which are ~1500 ha in size and farms within landscapes (10 000 ha areas) at two time points (2002 and 2010). The background in grey shows the spatial coverage of forest extent in 2002 and 2010. The numbers inside the circles correspond to the number of species of birds found on a landscape, on a farm or on a site.

detected over decadal time frames or that ecological barriers are obstructing ecosystem development. Work is continuing to track the ecological development of the restoration plantings over a longer period to determine whether there is a gradual convergence of features with reference woodlands or whether the putative barriers effectively stall progression of development. Subsequent research has identified three factors that act as potential restoration barriers or at least underpin lags in the restoration trajectory. First, the pasture soils contain a negligible native seed bank

(Nichols *et al.* 2010), limiting the potential for *in situ* recruitment of native plant species. Second, the dispersal capability of many plants species is likely to be limited (Lomov *et al.* 2009), limiting the potential for colonisation of native species from *ex situ* sources such as patches of remnant woodland. Third, the soils of former agricultural land retain a substantial excess of nitrogen above that characteristic of soils supporting remnant woodlands. These conditions have been found to promote growth of exotic grasses and forbs, while inhibiting establishment and growth

Box 8.7: The value of replantings for birds

Over the past two decades, billions of dollars have been expended in south-eastern and south-western Australia to revegetate areas (Fig. 8.28) of previously cleared temperate eucalypt woodland (State of the Environment 2006 Committee 2006; Hajkowicz 2009). The importance of replanted areas for biodiversity has not been well quantified. However, data gathered from surveys of planting sites on the South-west Slopes of New South Wales have indicated that these areas have significant value for some vertebrate groups, particularly birds. These values are particularly strong where plantings are close to other plantings or large patches of remnant native eucalypt woodland (Lindenmayer *et al.* 2010c, 2012b). For example, birds of conservation concern often recorded in such kinds of plantings include the Red-capped Robin (*Petroica goodenovii*), Rufous Whistler, Speckled Warbler (*Pyrrholaemus sagittatus*), and Flame Robin (*Petroica phoenicea*) (Lindenmayer *et al.* 2010c, 2012b). Notably, there are no clear temporal trends for birds in plantings (e.g. an increase in species richness or detections of a given species with time since establishment). Rather, there are marked inter-year variations in bird detections, but a good year for a particular species does not necessarily correspond to a good year for all species (Lindenmayer *et al.* 2010c) (Fig. 8.29).



Figure 8.28: A replanted field site in the South West Slopes Restoration study in New South Wales (photo by David Lindenmayer).

Box 8.7: (Continued)

The positive outcomes for birds in plantings is not replicated for other groups such as arboreal marsupials and reptiles which are often absent or rare in these areas, most likely because of the absence of key structural features such as large trees with hollows and large logs (Cunningham *et al.* 2007).

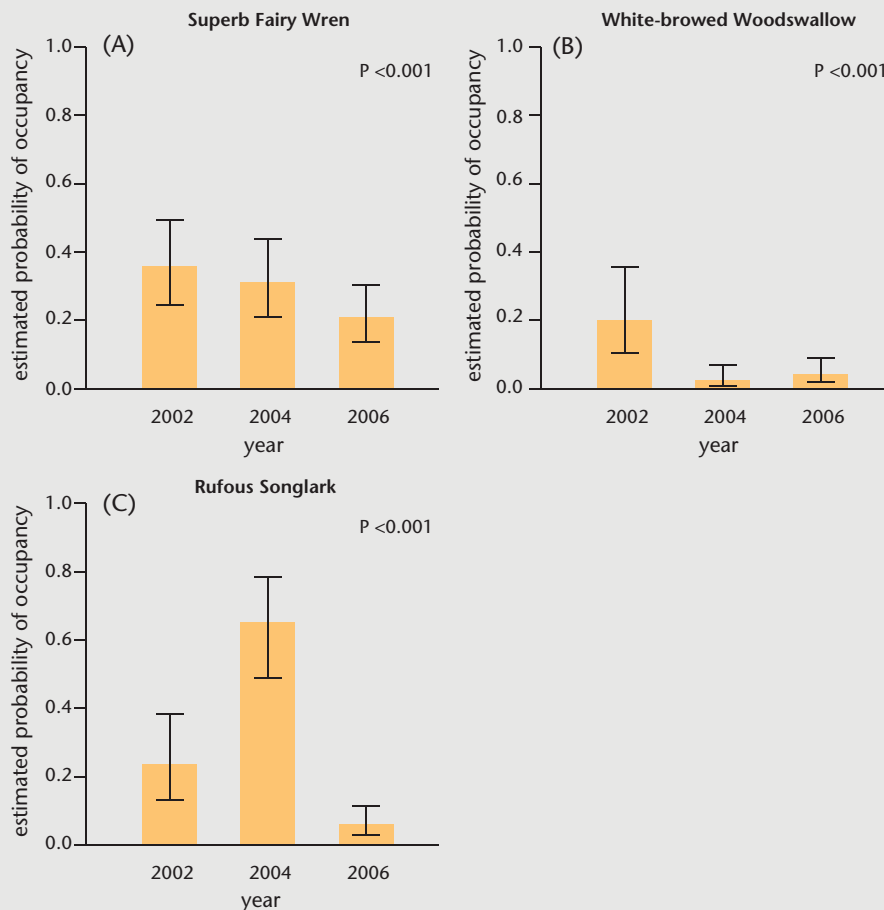


Figure 8.29: Contrasting year effects for: (A) the Superb Fairy Wren (*Malurus cyaneus*); (B) Rufous Songlark (*Cincloramphus mathewsi*); and (C) the White-browed Woodswallow (redrawn from Lindenmayer *et al.* 2010c).

of native ground layer species (Morris and de Barse 2012), consistent with findings in other grassy woodland ecosystems (Prober *et al.* 2005; Prober and Wiehl 2012).

These primary barriers identified in this and other studies currently limit the diversity and complementarity of native woodland biota represented in restoration plantings. Ongoing experimentation at long-term study plots will help to help resolve the mechanisms involving these barriers and to explore the relative merits of alternative management strategies to

overcome them (Rumpff *et al.* 2011). This work will not only improve the management of existing plantings, but will also inform the design and management of future restoration plantings to improve their performance.

DISCUSSION

Temperate woodlands are among the most heavily disturbed and modified ecosystems in Australia (State of the Environment 2011 Committee 2011)

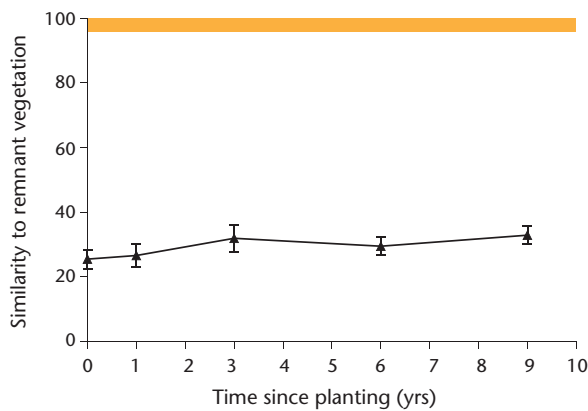


Figure 8.30: Trends in compositional similarity of revegetated sites to remnant native vegetation in the first decade since planting. Data are means (and 95% confidence intervals) of pairwise Bray–Curtis similarity values ($n = 18$) between planted sites of each age and reference sites supporting remnant/regrowth native woodland. The shaded area represents the 95% confidence intervals of pairwise similarity between six reference woodland sites ($n = 36$). The lack of convergence between the trajectory and the shaded bar suggest little colonisation of native species represented in the woodland reference sites (data from Wilkins *et al.* 2003).

and some vegetation types are 95–99% cleared, with the remaining areas often heavily degraded (Prober *et al.* 2005). Considerable research and management work is now being undertaken in Australia's temperate woodland environments (Hobbs and Yates 2000; McIntyre *et al.* 2002; Lindenmayer *et al.* 2010a; Zammit *et al.* 2010). Indeed, the past 20 years has seen a notable increase of restoration works by community members, land managers, local, state and federal governments, and non-government organisations aiming to tackle the key threatening processes in temperate eucalypt woodlands (Prober *et al.* 2005). Major research groups working in temperate eucalypt woodlands are located in all Australian states and territories (except the Northern Territory where temperate woodland, by definition, does not occur). However, only a small subset of the research projects within temperate eucalypt woodlands are long-term ecological investigations. The long-term studies undertaken to date contain a mixture of positive and negative results. Some of these are discussed further below

Trends in reporting rates for woodland birds

Positive results for increasing reporting rates for many species of woodland birds is encouraging (Lindenmayer and Cunningham 2011) and shows several interesting parallels with those of other presently unpublished studies in temperate woodlands in southern Australia, such as in the Australian Capital Territory and central New South Wales (Cunningham and Rowell 2006; Reid and Cunningham 2008; Bounds *et al.* 2010; Taws *et al.* 2012). However, these collective results are perhaps surprising given that other work (albeit largely cross-sectional) from other temperate woodland areas suggests that many species of woodland birds are in steep decline (Mac Nally *et al.* 2009; reviewed by Ford *et al.* 2001; Ford 2011). This suggests there might be large, inter-regional differences in temporal trends for woodland birds. Careful cross-study comparisons of data gathered using similar field protocols appears to be warranted to determine if this is the case.

Temporal trends in the cover of woody biomass

Several studies in south-eastern Australia have quantified an increase in the amount of woody biomass in areas formerly dominated by temperate eucalypt woodlands over the past decades (Lunt *et al.* 2010; Geddes *et al.* 2011). This is matched by increased cover of woody biomass across the South West Slopes Restoration study: between 2000 and 2010, the geometric mean of percentage vegetation cover increased from 4.9 to 5.7% at the landscape scale, 3.1 to 3.8% at the farm scale, and 1.9 to 2.8% at the site scale. Birds, mammals and reptiles have been monitored on the same farms and landscapes where temporal changes in woody biomass cover have been documented. A challenge in the coming years will be to: (1) determine whether there are links between sets of longitudinal trend patterns for vegetation and fauna; and (2) contrast the biotic changes on farms and in landscapes where there have and have not been temporal changes in cover levels of woody biomass. This work would attempt to determine if the patterns of vegetation change is also a process underpinning the pattern of faunal change.

Despite the trend for increasing cover of woody biomass in some of the areas targeted for research in the South West Slopes Restoration study of New South Wales, there are major concerns about the long-term decline in the abundance of large paddock trees

throughout temperate eucalypt woodland ecosystems (Manning *et al.* 2006a; Maron and Fitzsimons 2007; Fischer *et al.* 2009) and its implications for key ecosystem processes and biodiversity (Fischer *et al.* 2010a). Ongoing decline in the abundance of paddock trees

Box 8.8: PPBio long-term ecological research plots in subtropical eucalypt woodland of Karawatha Forest within the Australian Supersite Network

Jean-Marc Hero, Greg Lollback, Jon Shuker and Guy Castley

There are many kinds of woodlands in Australia (Lindenmayer *et al.* 2005) including subtropical woodlands (Hobbs and Yates 2000). The Program for Planned Biodiversity and Ecosystem Research (PPBio) has established long-term ecological research (LTER) plots along an east–west subtropical rainfall gradient/transect including sites in coastal subtropical eucalypt woodland (Karawatha Forest, Brisbane) as well as in coastal heathland (Cooloolool N.P), brigalow (Lake Broadwater NP, Dalby) and mulga-lands (Currawinya NP, Cunnamulla). PPBio is a meso-scale, multidisciplinary program designed for undertaking cost-effective and efficient ecological research and data collection (Magnusson *et al.* 2005, 2008; Costa and Magnusson 2010). PPBio LTER plots are based on a modification of the Gentry (1982) design, providing a standardised international model (<http://ppbio.inpa.gov.br/>) for biodiversity research (replicated globally in Australia, Brazil, Peru and Nepal). The PPBio approach can facilitate long-term ecological monitoring of key biotic and abiotic variables, while serving as a hub for ecological research responding to emerging and unforeseen priorities (Magnusson *et al.* 2005, 2008; Haughland *et al.* 2010; Hero *et al.* 2010). The PPBio standardised long-term ecological research plots focus on biodiversity measures that allow managers to monitor both the local impacts associated with local management practices (plots replicated within sites), and the long-term changes associated with changes in climate (standardised scale, plots and methodology among sites).

Karawatha Forest Park (KFP) is a 900 ha subtropical bushland reserve managed by Brisbane City Council. It is an International Long Term Ecological Research (ILTER) site, and a node within the SE Queensland Peri-urban Supersite of Australia's Terrestrial Ecosystem Research Network (TERN). KFP contains a variety of habitats ranging from dry eucalypt forests on sandstone ridges to wet heath adjacent to freshwater lagoons. In 2007, a grid was arbitrarily placed over the reserve with GPS trails and LTER plots evenly spaced at 500 m with ~33 km of fixed transects and 33 PPBio LTER plots (Fig. 8.31).

Each plot is based on a strip transect (250 m long) that follows the topographic contours (Magnusson *et al.* 2005). This design minimises variation in altitude, soil type, topography, and plant structure and composition within each plot (Magnusson *et al.* 2005), allowing a reliable measure of species abundance. The width of plot is variable (depending on the variable measured), and up to 21 m either side of, and perpendicular to, the plot midline. This includes a 1-m wide buffer strip on either side of the midline designed to concentrate impacts within this zone and minimise trampling within the study plot. Therefore each survey plot is 1 ha, with a length of 250 m and a total effective width of 40 m.

Data collected in the plots are publicly available together with the associated meta-data, such that they are available to land managers and other scientists. Data owners have a 2-year window to publish results before their data are released. Information about access to PPBio data is provided on the following website: www.griffith.edu.au/ppbio. To facilitate discovery and use of the data for the PPBio Karawatha Forest site the dataset is listed on the Research Data Australia (RDA) website: researchdata.andcs.org.au/karawatha-forest-park-terrestrial-plots. Data and metadata for the Karawatha Forest sites are also available from TERN's Australian Supersite Network website: www.tern-supersites.net.au.

The focus of our initial research is to examine the variation in biodiversity measures among the 32 plots (at the mesoscale). Results to date for woody stems, birds, mammals, frogs, reptiles, koalas and tree hollows have identified large scale variation in biodiversity estimates (e.g. see Fig. 8.32).

(Continued)

Box 8.8: (Continued)

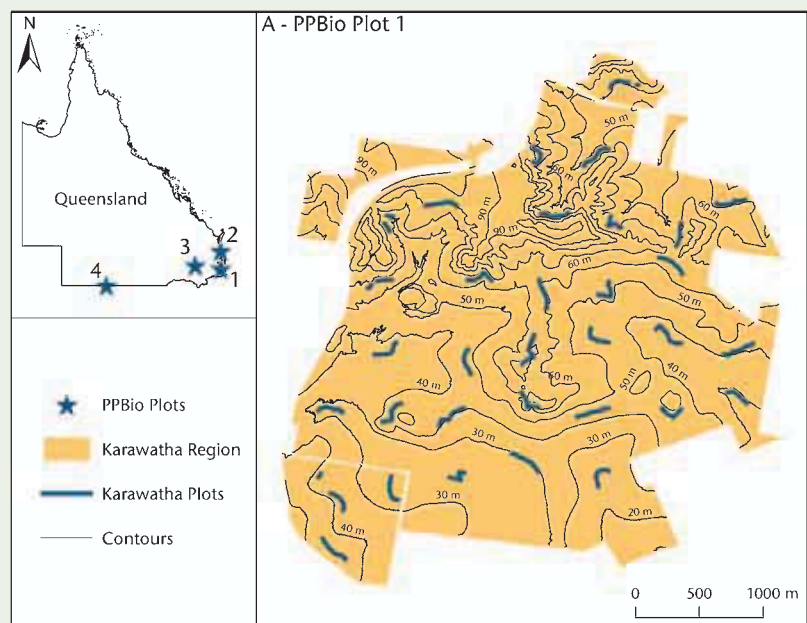


Figure 8.31: Locations of PPBio LTER sites in Queensland (1 = Karawatha Forest park, 2 = Cooloola National Park, 3 = Lake Broadwater, 4 = Currawinya National Park), with detailed map of permanent plots systematically spaced at 500 m intervals within Karawatha Forest Park (SEQ Peri-urban Supersite).

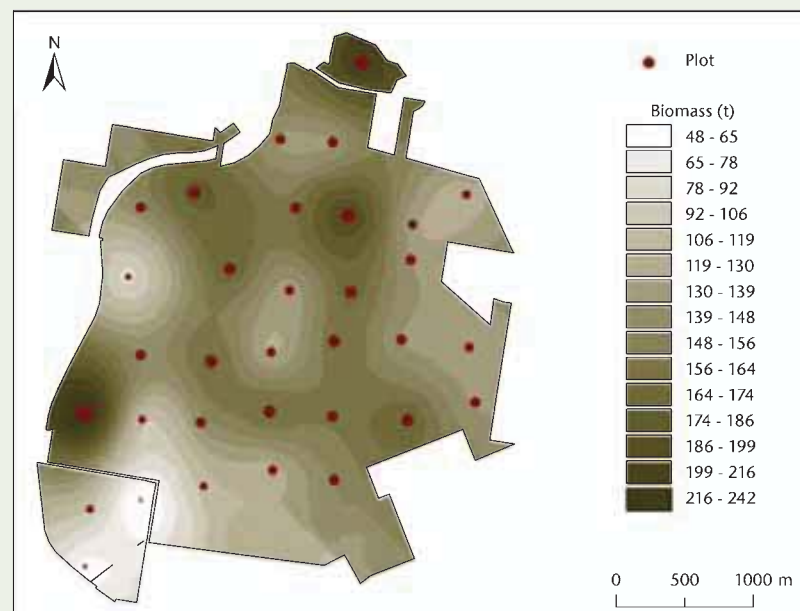


Figure 8.32: Biodiversity estimates from plots systematically placed on the landscape can be interpolated to produce contour maps and estimates of biomass for the entire area. The example here is for biomass of woody stems >1 cm DBH, with an average of 144.5 tonnes per hectare (standard deviation = 27.7 t/ha), and a total estimate of 123 874 tonnes of live woody biomass at Karawatha.

Box 8.9: A 'good news story' – successful revegetation of previously degraded farm

The property of Burnbank is near Ladysmith on the South West Slopes of New South Wales. It is owned and managed by Rick and Pam Martin. When the Martins bought their farm in the late 1970s, there was ~2% tree cover and it was beset by major problems like salinity and rising water tables. They embarked on an ambitious revegetation program and plantings now cover more than 14% of the farm with several areas of large block-shaped plantings (see Fig. 8.33).

Problems with salinity and rising water tables at Burnbank have been solved. There has also been an extraordinary response by wildlife. Detailed surveys by researchers from The Australian National University over the past 9 years have identified many native birds of conservation significance in the plantings at Burnbank. These include the Speckled Warbler, Diamond Firetail, Southern Whiteface, Red-capped Robin, Flame Robin, Hooded Robin and Crested Shrike-tit (Lindenmayer *et al.* 2010c).

There have been many other successes associated with restoration efforts in Australia's agricultural areas. For example, well-targeted revegetation efforts in north-eastern Victoria have been instrumental in assisting the recovery of the Grey-crowned Babbler (Robinson 2010).



Figure 8.33: Burnbank Farm, which is owned by Rick and Pam Martin (photo by David Lindenmayer).

need rigorous monitoring to quantify if projected losses actually eventuate and if predicted changes in species closely associated with these trees (such as the Superb Parrot; see Manning and Lindenmayer 2009) and several other woodland taxa (Fischer *et al.* 2010a) are realised. The need to conduct repeated and long-term measurements of paddock trees is critical, given issues such as clearing as part of attempts to increase farm productivity by reducing impediments to farm machinery (Maron and Fitzsimons 2007) as has been proposed in parts of Victoria (Victorian Farmers Federation

2010). In New South Wales, a similar policy position that allows more land manager flexibility and control over native vegetation may be adopted. Currently, the NSW government is undertaking a review of the regulations for the *Native Vegetation Act 2003*. According to the government (NSW Office of Environment and Heritage 2012), the purpose of this review is to better:

- empower the farming community to protect the environment and manage farms sustainably
- cut red-tape

- improve service delivery
- clarify and remove ambiguity
- increase transparency
- maintain the environmental standard set by the *Native Vegetation Act 2003*.

However, in reality these ‘reforms’ are likely to lead to large losses in populations of scattered paddock trees, and small remnants of native vegetation in order to allow land managers more opportunity to take advantage of seasonal conditions, save time and save money. Unfortunately, this cannot be achieved without environmental impacts, despite what the government might report.

The fate of restoration plantings

Despite widespread investment in restoration plantings to resolve environmental problems in woodland landscapes, the outcomes of relatively few projects have been systematically monitored and evaluated (Wilkins *et al.* 2003; see also Box 8.12. The long-term studies reviewed in this chapter suggest mixed outcomes for different components of woodland ecosystems. As the plantings age, there is evidence of development of vegetation structural attributes that provide habitat for a range of fauna, as well as increased abundances of birds and return of functions such as insect pollination and seed dispersal. On the other hand, the oldest plantings are still comparatively species-poor in vascular plants and insects. The plantings lack many species that typify remnant woodlands, and there is only weak evidence that these species are entering the re-established ecosystems over time. These results highlight the need for policies that place higher priority on the retention of existing woodland remnants, rather than offsetting their loss, and for adaptive management with new technologies to support improved performance of restoration plantings (Wilkins *et al.* 2003; Maron *et al.* 2012).

Positive and negative environmental and biodiversity outcomes

The three long-term plot networks established in the temperate eucalypt woodlands and explored here have produced a number of training and education

outcomes (Box 8.13) as well as valuable insights on longitudinal trend patterns, including several unexpected outcomes. **Some positive outcomes to date are:**

- Some species of birds have exhibited increasing reporting rates, including several birds of conservation concern. These changes have occurred during prolonged periods of drought that marked many of the years in the 2000s (Lindenmayer and Cunningham 2011).
- There has been a significant positive increase in the amount of woody vegetation cover in many farms and landscapes (Cunningham and Lindenmayer unpublished data).
- Replanted areas on farms provide valuable habitat for a range of bird species, including taxa of conservation concern (Lindenmayer *et al.* 2010c, 2012b) (see Boxes 8.7 and 8.9).

Not all temporal trends from the long-term plot networks established in the temperate eucalypt woodlands are positive. **Some negative outcomes to date include:**

- There have been significant declines in some species of arboreal marsupials such as the Common Ringtail Possum.
- There are ongoing declines in some bird species of conservation concern such as the Black-chinned Honeyeater.
- There has been a lack of regeneration in many areas of temperate woodland (Weinberg *et al.* 2011), including in old growth temperate woodland (Lindenmayer *et al.* 2012b).
- There has been limited evidence of substantial recovery of the native herbaceous ground layer in revegetated sites (Wilkins *et al.* 2003; Nichols *et al.* 2010) although some improvements have been recorded after the careful control of livestock grazing (Lindenmayer *et al.* 2012b).

Some limitations of current work

An important limitation in work on temperate eucalypt woodlands is the absence of large tracts of intact vegetation that have remained relatively undisturbed by human activities (although the Great Western

Woodlands of south-western Australia are an important exception, see Box 8.10) (Recher *et al.* 2010). The existing network of travelling stock reserves are arguably the most extensive and least disturbed areas of temperate eucalypt woodland in south-eastern Australia (Spooner 2005; Lentini *et al.* 2011).

Travelling stock reserves are government-owned land originally set aside to allow graziers to drive their stock to market, although they also were an important of food for stock during droughts. Travelling stock reserves have generally been subject to less grazing pressure and vegetation clearing than

Box 8.10: The Mulligans Flat–Goorooyarroo Woodland Experiment

Adrian Manning

The Mulligans Flat–Goorooyarroo Woodland Experiment in northern Australian Capital Territory is a long-term ecological experiment that is integrating restoration and research to provide evidence for sound conservation management (<http://www.mfgowoodlandexperiment.org.au/>). It is a partnership between the Australian National University, the Australian Capital Territory Government, CSIRO and the James Hutton Institute (Scotland) (Manning *et al.* 2011; Shorthouse *et al.* 2012), and is funded by Australian Research Council grants and cash and/or in-kind from the research partners. The aim of the experiment is to find ways of improving critically endangered box-gum grassy woodland for biodiversity. It has been designed in collaboration with expert statisticians, and provides the ideal experimental framework for investigating ecological communities across multiple spatial scales (Manning *et al.* 2011). The design consists of four ‘sites’ of 1 ha within each of 24 ‘polygons’ across two adjacent nature reserves (Manning *et al.* 2011). A set of key ecosystem manipulations have been chosen to investigate how to reverse the decline in the biodiversity. These manipulations are: (1) the addition of 2000 tonnes of dead wood to increase structural complexity (four treatments: (a) zero, (b) 20 tonnes in dispersed pattern, (c) 20 tonnes in clumped pattern, (d) 40 tonnes); (2) the exclusion of kangaroos; (3) the application of fire as a key disturbance (twenty-four 1-ha sites in Goorooyarroo); and (4) exclusion of digging effects of bettongs (twelve 1-ha sites in Mulligans Flat) (Fig. 8.34B). Vegetation density was used as a stratifying variable and is also considered a treatment in analyses. The partnership with the Australian Capital Territory Government was critical in successfully planning and implementing the experimental treatments (Fig. 8.34) (Manning *et al.* 2011; Shorthouse *et al.* 2012). These manipulations have been applied in a randomised incomplete block design that maximises the accuracy with which the effects and interactions can be estimated (Manning *et al.* 2011). Response variables include: birds, small mammals (Manning *et al.* 2011), reptiles (Manning 2013), invertebrates (Barton *et al.* 2009, 2010) plants (McIntyre *et al.* 2010), soils, soil microbes and fungi.

Emerging from the research partnership with the Australian Capital Territory Government was the idea of building a predator-proof sanctuary at Mulligans Flat (<http://www.mulligansflat.org.au/>; Fig. 8.34). This resulted in the construction of a predator exclusion fence that has provided a unique opportunity to examine the effects of the reintroduction of a locally extinct ecosystem engineer, the Tasmanian Bettong, on ecosystem restoration. The successful translocation of bettongs from Tasmania to the ACT involved many staff from the partners, organisations and the Tasmanian Government. Two questions are being posed: (1) how does the reintroduction of an ecosystem engineer affect the woodland ecosystem and the restoration process?; and (2) how does the current state of the ecosystem and management treatments affect bettongs?

The experimental framework in the Mulligans Flat–Goorooyarroo Woodland Experiment has attracted further collaboration and the site is developing into an ‘outdoor laboratory’ for woodland research. In the future, further reintroductions and monitoring of the ecosystem effects of treatments will help inform adaptive management and restoration of box-gum grassy woodlands in the long term.

(Continued)

Box 8.10: (Continued)

Figure 8.34: The Mulligans Flat–Goorooyarroo Woodland Experiment has four key treatments: (A) addition of 2000 tonnes of deadwood; (B) reduction of kangaroo grazing with exclusion fences; (C) prescribed burning of twenty-four 1-ha sites in Goorooyarroo; and (D) exclusion of Tasmanian bettongs from twelve 1-ha sites in Mulligans Flat (photos by Adrian Manning).

elsewhere in agricultural landscapes (Spooner 2010; Lentini *et al.* 2011). Therefore, they make an important contribution to the conservation of biodiversity in temperate eucalypt woodland environments in many parts of eastern Australia (Lindenmayer *et al.* 2010b). However, they remain legally unprotected and are vulnerable to degradation. We suggest that greater attention to legal protection of remnant vegetation is needed in this ecosystem. Enhanced protection may require drawing on novel conservation approaches in conjunction with traditional nature reserve models, such as covenanting schemes in association with management networks (Prober *et al.* 2001). Legislation of alternative management goals for the existing travelling stock route network in New

South Wales, and greater public contribution to support their on-ground management, would be a pioneering means to capitalise on one of the most significant opportunities to conserve temperate eucalypt woodlands and their historical droving legacy. New initiatives to better protect travelling stock routes is particularly urgent given current intentions to sell parts of them in New South Wales and Queensland (Lentini *et al.* 2011).

MANAGEMENT AND POLICY IMPERATIVES

There are several important areas of policy and on-ground management that need to be dealt with in

Box 8.11: The establishment of a Supersite in the Great Western Woodlands, Western Australia

The Great Western Woodlands region is extraordinary in that it has remained relatively intact since European settlement, owing to the variable rainfall and lack of readily accessible groundwater for livestock. As other temperate woodlands in Australia and around the world have typically become highly fragmented and degraded through agricultural use, the Great Western Woodlands offer an important opportunity to understand the functioning of relatively intact woodland landscapes. The Great Western Woodlands are also globally unique in that nowhere else do 20 m tall woodlands occur at as little as 250 mm mean annual rainfall.

In 2011, the Terrestrial Ecosystems Research Network funded the establishment of the Great Western Woodland Supersite to undertake long-term ecological studies on woodland processes and biodiversity. A focus of the Supersite is an 'OzFlux' station at Department of Environment and Conservation-managed Credo Station near Kalgoorlie (Fig. 8.35). This will monitor the energy, water and carbon balance of mature semi-arid eucalypt woodland. Long-term plots to monitor flora, fauna and hydrology are being established within the OzFlux tower footprint and more widely along fire and climatic gradients. These will help develop a better understanding of the key driving processes in woodlands, and characterise temporal variability and long-term directional change associated with climate and land use change.



Figure 8.35: Salmon gum (*Eucalyptus salmonophloia*) woodlands at the proposed conservation reserve at Credo Station near Kalgoorlie are being monitored as part of the Great Western Woodlands Supersite (photo by Suzanne Prober).

temperate eucalypt woodlands. We briefly discuss some of these in the remainder of this section.

First, there is an urgent need to increase the area of temperate woodland that is conserved in formal

protected areas (such as nature reserves and national parks). This is critical because some temperate eucalypt woodland types are very poorly represented in the current reserve system. This will be important for

Box 8.12: Tracking success and failure

Temperate eucalypt woodlands have been the focus of huge efforts in landscape restoration such as through fencing to control grazing pressure by domestic livestock (Spooner *et al.* 2002; Prober *et al.* 2011) and planting (Munro and Lindenmayer 2011). A major limitation to much of this work in temperate woodlands has been a difficulty in quantifying how effective it has been (Driscoll *et al.* 2000; Lindenmayer *et al.* 2010c). Indeed, an understanding of the response of biodiversity to management interventions remains a significant knowledge gap in many agricultural systems worldwide (Wilson *et al.* 2009). A study in the western Murray catchment of southern New South Wales (Lindenmayer *et al.* 2012c) has begun to investigate this problem using a large-scale, blocked and replicated cross-sectional study comprising 104 sites in four key 'management' classes: (1) agricultural production sites characterised by traditional grazing; (2) short-term conversion sites in which investments to improve conservation had recently (<2 years ago) been made; (3) long-term conversion sites where investments to improve conservation values were made >7 years ago; and (4) travelling stock reserves (TSR) which have traditionally been subject to limited vegetation clearing and grazing pressure over the past 150 years. The work has demonstrated that management intervention may shift some key characteristics of woodland vegetation typical of agricultural production sites towards those of 'benchmark' travelling stock reserves and that these alterations in characteristics are, in turn, important for bird biota. In particular, small-bodied, non-seed eating and open-nesting bird species were significantly more likely to occur in TSRs than in production sites. In addition, differences in bird species richness and assemblage composition could be explained by readily quantifiable relationships with vegetation structure and condition (i.e. native shrub cover, native ground cover, native plant species richness, percentage overstorey regeneration and the amount of bare ground) (Lindenmayer *et al.* 2012c). Despite these valuable initial results, data on the costs of different management actions are not available, making it impossible to conduct the logical next stage of such analyses – which is to quantify the cost-effectiveness of different activities through determining the amount of biodiversity gained in return for dollars invested. This kind of information is critical for inclusion in future work.

the iconic woodlands that do remain, including the Great Western Woodlands. In addition, it is critical to monitor the status of biodiversity and ecosystem integrity within existing (and new) temperate eucalypt woodland nature reserves and national parks. Such monitoring has been extremely rare to date, but it is essential to determine if changing the tenure status of areas of temperate eucalypt woodland actually results in positive outcome for biodiversity.

A second important area for policy and on-ground management, which is broadly related to the one outlined above, is to secure the status of the travelling stock reserves (TSRs). TSRs are often the areas in best condition and support the largest amounts of biodiversity in temperate eucalypt woodlands (Spooner and Lunt 2004; Lindenmayer *et al.* 2012c). However, there is a risk that TSRs will be sold and subject to key drivers of degradation that have eroded the integrity of temperate eucalypt woodland

ecosystems elsewhere in agricultural landscapes, such as grazing and firewood harvesting (Possingham and Nix 2008; Lentini *et al.* 2011).

Third, irrespective of any additions to the protected areas network, most of remaining temperate eucalypt woodland will remain on private land. Therefore, it is critical to maintain investment in programs that foster conservation activities on private land such as management networks (Fitzsimons *et al.* 2012), the Environmental Stewardship Program managed by the Australian Government (Binney *et al.* 2010; Lindenmayer *et al.* 2012d) (see Box 8.14) and the BushTender program in Victoria (Department of Natural Resources and Environment 2002; Stoneham *et al.* 2003).

Fourth, new areas of work in temperate eucalypt woodlands need to identify the cost-effectiveness of management actions. That is, what activities yield the highest conservation returns for the funds invested in the context of a range of key conservation targets (e.g.

Box 8.13: Training and education outcomes

The three core long-term studies featured in this chapter have delivered a range of important training and education outcomes. For example, the Nanangroe Plantation Plot Network has developed an important training profile, not only for undergraduate courses and postgraduate research programs, but also as a location for field workshops for the education of plantation managers and staff from Catchment Management Authorities. The South West Slopes Restoration Study has been used as the basis for a suite of postgraduate research studies and numerous field workshops, field days and training programs for private landholders, staff from regional and state government agencies as well as staff from non-government organisations. Importantly, there has been extensive stakeholder interest in the findings derived from the South West Slopes Restoration Study and these have strongly influenced investment strategies such as those initiated by the Murray Catchment Management Authority as well as local-level restoration activities undertaken by individual property owners.

These practical applications of the long-term ecological research at Nanangroe and on the South West Slopes have been fostered through the publication of semi-popular books that have aimed to communicate scientific discoveries and their relevant to management practices (e.g. Lindenmayer *et al.* 2011; Munro and Lindenmayer 2011).

woodland birds or ground-layer plant diversity). Answers to these kinds of questions are essential to guide future investments in conservation on farms, as well as to determine the effectiveness of management interventions and highlight areas where new approaches might be needed. To do these kinds of analyses, data need to be gathered on what kinds of management inputs have occurred in a given area that has been targeted for investment. For example, how much fencing and weed control was done and how much did it cost? This needs to be combined with data quantifying the ecological benefits of these activities.

Finally, good scientific information is needed to guide evidence-based policy making and evidence-based management (Sutherland *et al.* 2004; Lindenmayer and Gibbons 2012). Although *ad hoc* short-term studies can make an important contribution to understanding of management effectiveness, the best approach to determining the success (or failure) of most kinds of management interventions will be through well-designed and implemented long-term studies that answer well-defined questions associated with the rigorous quantification of change. On this basis, we argue that it is essential to secure existing long-term studies and instigate new studies that will yield the data on which policy and management can be truly evidence-based.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Temperate eucalypt woodlands are among Australia's iconic ecosystems. However, they are also among some of the most extensively cleared and degraded ecosystems worldwide (Fischer *et al.* 2009). There has been considerable research effort in these ecosystems over the past two decades, but remarkably few are long-term ecological studies. We have presented data and briefly summarised the findings from three core studies and nine other studies in feature boxes including a newly established Supersite (Box 8.11 on p. 32) and landscape-scale Transect (Box 8.15) in Western Australia.

Major management efforts have been underway for several decades to mitigate the effects of some of the key threatening processes in temperate eucalypt woodlands. These have included significant vegetation restoration, particularly replanting. Indeed, some of Australia's largest environmental investments have been in temperate eucalypt woodlands. We suggest that data on temporal trends in animal and plant populations that have been generated from existing networks of long-term plots as well as information from new initiatives such as the woodland supersite in Western Australia (see Box 8.10) will be critically important for informing future management interventions and other environmental investments in

Box 8.14: The potential for long-term research through the Australian Government Environmental Stewardship Program (ESP)

The Environmental Stewardship Program (ESP) has employed a competitive auction process to contract individual land managers for up to 15 years to protect and manage nationally threatened ecological communities, including temperate eucalypt woodland (Binney *et al.* 2010). Management actions are aimed at tackling key drivers of change in temperate eucalypt woodland and they include (among others): invasive plant and animal control; and grazing management (i.e. active management of native and feral herbivores as well as domestic livestock). A monitoring program commenced in 2010 to track changes in vegetation condition and in populations of birds and reptiles on 153 patches of temperate woodland managed under the ESP's Box Gum Grassy Woodlands Project on farms ranging from southern New South Wales to south-eastern Queensland (Fig. 8.36). In addition, a matched control site was established on 115 of the 153 farms. Establishing matched stewardship and control sites on the same farm aims to determine if the observed changes on a stewardship site are due to management intervention rather than other factors, including those operating at larger spatial scales (e.g. climate, population fluctuations and wildfires). The work of the ESP's Box-Gum Grassy Woodlands monitoring program also aims to explicitly link changes in vegetation condition over time with changes in bird and reptile biota. Importantly, in the first two seasons of detailed field sampling, many records of threatened woodland birds and reptiles were gathered, indicating that areas of high-quality temperate woodland vegetation were captured in the Box Gum Grassy Woodlands Project (Lindenmayer *et al.* 2012d).



Figure 8.36: Measuring vegetation condition on an Environmental Stewardship Program Box Gum Grassy Woodlands Project control site (photo by Geoff Kay).

temperate eucalypt woodlands. On this basis, long-term plots in temperate eucalypt woodlands must clearly become a critical part of Australia's environmental infrastructure from which data can be used to

make informed, well-targeted, ecologically effective and cost-effective management decisions. Boxes 8.16 and 8.17 summarise emerging research needs and key management recommendations.

Box 8.15: The South West Transitional Transect*Stephen Van Leeuwen*

The South West Transitional Transect (SWATT) is a new initiative of the Australian Transect Network and the Western Australian Department of Environment and Conservation (DEC). The principal purpose of the transect is to measure selected biodiversity attributes and biophysical processes, that will inform key ecosystem science questions and assist with the development and validation of ecosystem models. SWATT (together with other transects within TERN) will enable benchmarking and subsequent monitoring of trends in ecological condition in response to continental scale biophysical processes such as climate change.

The SWATT is located in the south-west of Western Australian extending for over 1200 km from Walpole on the south coast to just beyond the former pastoral lease of Lorna Glen and into the Little Sandy Desert. The SWATT incorporates the internationally recognised biodiversity hotspot, the South-west Botanical Province (Myers *et al.* 2000; Hopper and Gioia 2004), a national biodiversity hotspot (Department of Sustainability, Environment, Water, Population and Communities 2009) and the evolutionarily significant, species rich South-west Interzone (Hopper 1979; Gibbons *et al.* 2010), which includes the globally significant Great Western Woodlands (GWW) (Watson *et al.* 2008). The SWATT also intercepts another two nationally significant transitional zones, the Triodia–Acacia line (Beard 1975) and the Menzies line (Butt *et al.* 1977).

Just over half of the SWATT is located in the rangelands, where land tenure is predominated by pastoral leases and the primary land-use activity is livestock grazing on unimproved lands. Thirty-five per cent of the SWATT occurs in the highly fragmented Western Australian wheatbelt where cereal and sheep production dominate. Only 5% of the SWATT is in the southern forests where some limited production forestry still occur, although the predominant land use is conservation. Just over 15% of the alignment intercepts land with conservation as its primary purpose.

The SWATT transect captures several biophysical gradients that drive species selection, influence community composition and determine assemblage distributional patterns across the landscape. Perhaps the most significant of these is the variation in climatic regimes, which is best exemplified by the key productivity driver: rainfall. On the south coast at Walpole, the median rainfall of 1325 mm/year is predominately consistent, predictable and is received across 185 days per year. These aspects of the rainfall regime decay with progression north and at Lorna Glen the median rainfall is 235 mm/year, and is episodic, highly unpredictable and there are only 29 rain days per year.

At the approximate midpoint on the SWATT, on the northern eastern side of the Greater Western Woodland on the former Credo pastoral lease is the Great Western Woodland Supersite. The SWATT plots established in the tall eucalypt forest near Walpole will co-occur with AusPlot Forestry plots, while beyond Credo in the rangelands new plots establish on route to Lorna Glen and beyond will also perform an AusPlots Rangelands function.

Box 8.16: Future, ongoing and emerging research and information needs

- Maintain long-term monitoring efforts associated with management interventions such as replanting and fencing to ensure that it is possible to gauge success and thereby continuously improve the effectiveness of management.
- Ensure that monitoring efforts gather data on both management inputs (e.g. when fences to control grazing pressure were established) and the management outcomes (e.g. temporal changes in the abundance of particular groups of biota) (Lindenmayer and Gibbons 2012).

Box 8.17: Key management recommendations

There are many prescriptions for the management of temperate eucalypt woodland that would be specific for particular locations and special habitats (e.g. granite outcrops – see Michael *et al.* 2008). Rather than create an extensive list of such specific recommendations, we outline below a small number of generic recommendations that will be broadly applicable across the vast majority of areas of temperate eucalypt woodland. These are:

- Continue to encourage the conservation schemes on private land, including rewarding programs that prevent clearing of temperate eucalypt woodlands and control damaging grazing regimes such as high-intensity set stocking.
- Maintain funding schemes that are clearly leading to successful outcomes such as those that have catalysed major restoration efforts – both natural regeneration and replanting.
- Secure the protection of the network of travelling stock reserves in New South Wales and Queensland.

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RECOMMENDED READING

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2. Hobbs RJ, Yates C (2000) 'Temperate Eucalypt Woodlands in Australia: biology, conservation, management and restoration'. (Surrey Beatty and Sons: Sydney.)
3. Lindenmayer DB, Archer S, Barton P, Bond S, Crane M, Gibbons P, *et al.* (2011) 'What Makes a Good Farm for Wildlife?' (CSIRO Publishing: Melbourne.)
4. Lindenmayer DB, Bennett AF, Hobbs RJ (Eds) (2010) 'Temperate Woodland Conservation and Management'. (CSIRO Publishing: Melbourne.)
5. Lunt ID, Eldridge DJ, Morgan JW, Witt GB (2007) A framework to predict the effects of livestock grazing and grazing exclusion on conservation values in natural ecosystems in Australia. *Australian Journal of Botany* **55**, 401–415.

RECOMMENDED WEB LINKS

1. The *Environment Protection and Biodiversity Conservation Act* list of Threatened Ecological Communities, <http://www.environment.gov.au/cgi-bin/sprat/public/publiclookupcommunities.pl>
2. Planting for Wildlife book, <http://www.publish.csiro.au/pid/6716.htm>
3. Australian Government Environmental Stewardship Program website, <http://www.nrm.gov.au/funding/stewardship/box-gum/index.html>
4. Grassy Box Woodlands Conservation Management Network website, <http://www.gbwcmmn.net.au/about>

BIOS

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