



Planting to conserve threatened nomadic pollinators in NSW



Office of
Environment
& Heritage

Cover: Regent Honeyeater (*Anthochaera Phrygia*) - critically endangered species endemic to eastern Australia, Capertee Valley; Photo: Michael Todd

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Summary

Plant–pollinator mutualisms are fundamental to natural and agricultural systems. In Australia, several species of native plants produce large volumes of nectar and pollen, with an unusually high proportion of plants pollinated by vertebrates.

Highly mobile vertebrate pollinators (birds and bats) disperse pollen over large areas during feeding bouts, promoting out-crossing and increasing genetic variation in the plants and plant populations they visit. This genetic variation builds ecological resilience in ecosystems, increasing their capacity to withstand or adapt to pressures from anthropogenic change. Long-distance pollen flow is particularly important in highly fragmented landscapes. It may also provide a mechanism to help long-lived eucalypts withstand the challenges of climate change.

The times and locations of flowering in many eucalypts are relatively unpredictable. Nectar-feeding birds and bats move nomadically over long distances to maintain continuous access to productive habitat. These nomadic animals are vulnerable to loss of relatively small habitat areas – particularly those that provide resources at key times. These habitats cannot be conserved within general conservation programs as, for example, networks of protected areas; instead, they require sensitive management, including the restoration of areas outside reserves.

Several species of primarily nectar-feeding birds and bats are listed as threatened under the *Threatened Species Conservation Act 1995* (NSW). A consistent set of threats, including loss, degradation and fragmentation of feeding and roosting habitat (particularly on privately owned land) affects these animals. Actions to halt and reverse decline focus on habitat protection, restoration and regeneration.

A large number of habitat restoration, enhancement and regeneration projects are being planned, or are in the early stages of being realised in New South Wales, and various existing sites are being augmented. These programs provide an opportunity within existing initiatives to enhance feeding habitat and improve conservation outcomes for important mobile pollinators. Not only would actions to target nomadic pollinators help conserve pollinator networks; they would also build resilience in plantings, embed them in ecological processes that are played out over large spatial scales, and amplify the benefits of local conservation efforts.

Beneficial conservation outcomes for both nomadic pollinators and vegetation communities could accrue through the planting of trees that provide food during winter and early spring. This approach would increase feeding habitat during seasonal bottlenecks and establish potential food resources for a large number of species, including critically endangered regent honeyeaters, endangered swift parrots and other threatened and protected honeyeaters, lorikeets, flying-foxes and arboreal marsupials.

Key winter and spring food plants for nomadic pollinators are identified in this report, as are the vegetation communities that contain them. Recommendations for plantings in key regional areas are made, and the threatened pollinators that may benefit from the plantings are identified.

Introduction

Plant–pollinator mutualisms are fundamental elements of natural and agricultural systems. Plants provide food in the form of nectar and pollen and, in the process of harvesting that food, animals (insects, birds and mammals) pollinate the flowers of host plants. Animals provide essential pollination services to an estimated 88% of plant species globally (Ollerton et al. 2011). Their foraging behaviours and movements underpin the reproduction and genetic viability of plant species and influence the composition and resilience of plant communities.

In most regions of the world, agricultural crops and native plants produce relatively small amounts of nectar and are pollinated by insects (primarily bees and butterflies). However, in Australia, several species of Myrtaceae and Proteaceae allocate large amounts of ‘expendable energy’ to the production of prolific volumes of nectar, pollen and other exudates (Orians & Milewski 2007). Although Australian flowering plants are most frequently visited by insects, an unusually high proportion of species are also pollinated by vertebrates (Ford et al. 1979; Carthew and Goldingay 1997; House 1997; Phillips et al. 2010). Birds (primarily honeyeaters and lorikeets), mega-chiropteran bats, arboreal marsupials and rodents are pollen vectors for nectar-rich canopy trees of the genera *Eucalyptus*, *Corymbia*, *Angophora*, *Melaleuca*, *Callistemon*, *Banksia* and *Grevillea*. These plants produce dry fruits that often have limited mechanisms for dispersal. Pollen vectors are their main agents of gene movement.

In general, nectar production in forest and woodland systems is dominated by eucalypts (*Eucalyptus* and *Corymbia*) and melaleucas, whereas banksias provide the primary nectar source in many heath communities (Clemson 1985; Woinarski et al. 2000). Nectar volume and sugar concentration vary among species and through time, affecting the attractiveness of the plants to vertebrate pollinators (Law 1993; Woinarski et al. 2000; Sommerville & Nicholson 2005; Law & Chidel 2008, 2009). For example, grey-headed flying-foxes *Pteropus poliocephalus* use only 24% of the eucalypts that occur within their range (Eby & Law 2008).

Specialist plant–pollinator associations are rare in Australian Myrtaceae and Proteaceae. The flowers of these plants have largely generalist morphologies, with open, brush- or cup-like structures (House 1997). Their nectaries (nectar-secreting glands) are accessible to a range of animals, and pollen is presented on exposed anthers. Exclusion experiments and other studies have shown that pollination can be achieved by birds, bats, marsupials and rodents, as well as by insects (Paton & Ford 1977; Crome & Irvine 1986; Carthew & Goldingay 1997; House 1997; Phillips et al. 2010). Generalist pollination such as this enables plants to take advantage of whatever pollinator is in the area at the time of flowering, and it may have evolved in association with the characteristic low levels of spatio-temporal predictability of the floral resources of Australian plants (Fleming & Muchhala 2008). In turn, there is considerable overlap in the diets of co-occurring vertebrate pollinators (e.g. McGoldrick & MacNally 1998; Sharpe 2004; Saunders & Heinsohn 2008).

Importance of long-distance pollinators

Highly mobile vertebrate pollinators (birds and bats) provide pollination services that differ from those of more sedentary animals (e.g. Law & Lean 1999; Krauss et al. 2009). Their extensive foraging movements substantially extend the range of pollen flow beyond that generated by insects or non-flying mammals (Southerton et al. 2004), promoting out-crossing and increasing genetic variation in the plants and plant populations they visit (Krauss et al. 2009; Breed et al. 2012, 2015).

Feeding by Australian nectar-feeding birds and bats can be highly dynamic. Inter- and intra-specific competitive feeding behaviours, including territoriality (in bats) and aggressive displacement (in birds) increase the frequency and distance of movements between flowers,

trees and plant populations (Ford 1979; Eby 1996; Birt 2004; Saunders & Heinsohn 2008). Movements of hundreds of metres are not uncommon, and several species move many kilometres between patches of flowering plants in order to meet high energy requirements (Collins & Rebelo 1987).

The most expansive foraging movements are associated with flying-foxes. Feeding movements of nectar-feeding grey-headed flying-foxes and little red flying-foxes *Pteropus scapulatus* have been documented in telemetry studies (Birt 2004; Eby 1991a, 1996; Roberts 2012). Distances between communal roosts and feeding areas range from less than 1 kilometre to 60 kilometres, with mean values of 10 to 15 kilometres. During their nightly feeding bouts, flying-foxes visit multiple flowers on individual feeding trees and multiple feeding trees within stands of flowering trees of the same species, typically spaced hundreds of metres apart. About 30% of individuals visit more than one discrete feeding area (two to five) per night, separated by 1 to 28 kilometres. Flying-foxes fly over cleared and highly disturbed habitats between successive feeding areas and frequently visit isolated trees in agricultural and urban landscapes. Tens of thousands of individuals migrate to mass flowerings of eucalypts, melaleucas and banksias. They collect and carry viable pollen grains in the fur on their heads and shoulders (McCoy 1990), and they have the capacity to generate complex, widespread patterns of pollen dispersal across both intact and highly fragmented landscapes.

The home ranges of radio-tagged eastern blossom bats *Syconycteris australis* are smaller than those recorded for *Pteropus* (Law 1993; Law and Lean 1999). The former species has been recorded commuting 50 metres to 4 kilometres between roosts and feeding sites, visiting four or five feeding areas each night, and travelling 100 metres to 6.8 kilometres (mean 750 metres) between successive feeding areas. Blossom bats also feed in highly fragmented landscapes, overflying cleared land and using isolated trees. However, unlike flying-foxes they have not been recorded feeding in flowering trees in urban areas. They roost solitarily, making it difficult to assess the number of animals feeding on a given resource, although the density of animals feeding in a local area increases with increasing nectar production (Law 1994).

Information on the foraging behaviours of nectar-feeding birds comes from direct observations and banding studies (e.g. Saunders & de Rebeira 1991; Geering & French 1998). The feeding distances recorded by these methods are likely to be underestimates, and little is known about the patterns of feeding activity beyond relatively small observable areas. The feeding distances observed in honeyeaters vary among species and are generally understood to be shorter than those described for bats. Nonetheless, movements between fragments isolated by greater than 10 kilometres have been recorded (Saunders & de Rebeira 1991), and many species are known to transit cleared and disturbed land, feeding in small remnants and on isolated trees (Fischer & Lindenmayer 2002). Porter (1992) found that rainbow lorikeets feed within a 35-kilometre radius of communal roosts; they use multiple feeding areas within this radius and visit several trees in each feeding area.

Molecular studies of pollen flow in plants pollinated by honeyeaters give an indirect measure of feeding movements and demonstrate the influence of pollinator mobility on the genetic structure of plant populations (Byrne et al. 2007; Krauss et al. 2009; Breed et al. 2012, 2015; Llorens et al. 2012). General conclusions are that birds generate high levels of pollen dispersal between local plant populations; the patterns of bird-generated pollen dispersal track the distribution of flowering plants and are less concentrated around parent trees than are the patterns created by insects; and nectar-feeding birds carry and disperse pollen gathered from multiple plants, producing fruits with seeds that have multiple sires (Krauss et al. 2009). Each of these elements increases the rate of outcrossing and the genetic diversity of progeny and populations. Although genetic work is yet to be conducted on plants visited by nectar-feeding bats, their role in generating genetically diverse plant populations can be

inferred from the heavy pollen loads they carry, the distances they move between feeding trees and feeding areas, and the generalist structures of the flowers they visit (Law & Lean 1999).

The high levels of genetic variation generated by mobile pollinators enhance the ecological resilience of vegetation communities and increase the communities' capacity to withstand or adapt to external pressures (Kremer et al. 2012). The distinctive services provided by these pollinators can be even more important in highly modified landscapes. Habitat loss and fragmentation alter the distribution and density of plants, influencing the diversity, abundance and foraging behaviours of pollinators (Montero-Castano & Vila 2012). Reduced plant density following fragmentation can increase inbreeding and reduce pollen diversity in plants that are pollinated by wind and insects (Eckert et al. 2010). These shifts reduce the fitness of offspring and can be particularly detrimental to outcrossing species such as eucalypts (Keller & Waller 2002; Breed et al. 2012). However, mobile pollinators dampen these impacts (Byrne et al. 2007; Krauss et al. 2009; Llorens et al. 2012; Breed et al. 2015). For example, Breed et al. (2015) found that although habitat fragmentation can increase self-pollination and decrease pollen diversity in eucalypt species pollinated by insects only, pollen diversity was maintained in a eucalypt pollinated by mobile birds. This effect was independent of plant density, so that heavy outcrossing and high pollen diversity were also recorded in very small fragments and isolated trees. The result was attributed to the capacity of some birds to move freely within agricultural landscapes and fly long distances across cleared and modified land and between isolated habitat patches.

Long-distance gene flow facilitated by mobile pollinators also has the potential to increase the capacity of long-lived tree species to withstand climate-change-driven rapid shifts in local conditions. Pollen movement is of particular importance to species such as eucalypts that produce dry, hard fruits that have limited capacity to move long distances (Kremer et al. 2012). Within their ranges, trees species contain populations with genotypes adapted to contrasting local environments (Savolainen et al. 2007). Long-distance pollen dispersal provides a mechanism for the flow of genetic information between these populations, thus increasing local genetic variation and potentially increasing the likelihood that a population will be pre-adapted to the changed conditions it encounters. This pre-adaptation helps increase the resilience and persistence of functional systems.

Migration patterns of mobile pollinators

In south-east Australia, a range of birds and bats feed primarily on nectar through the year and undertake long-distance, largely nomadic migrations as they track changes in the distribution of that resource (Ford et al. 1979; Eby 1991b; McGoldrick and McNally 1998; Birt 2004; Saunders & Heinsohn 2008; Roberts et al. 2012). Mass flowerings of eucalypts are the most important contributors of nectar and pollen to the diets of highly migratory birds and bats. These trees are known for irregular patterns of flower production, which are often related to changes in recent climatic conditions (Law et al. 2000; Keatley et al. 2002; Law & Chidel 2008). Rich, annually unreliable floral resources drive long-distance nomadic movements.

Banding results show pronounced variation among species and genera in the migratory movements of honeyeaters (Higgins 1999; Phillips et al. 2010). Regent honeyeaters can track resources over distances exceeding 500 kilometres, and distances greater than 200 kilometres have been recorded for other species of honeyeater (Higgins 1999). Swift parrots migrate from breeding sites in Tasmania to overwinter in Victoria, New South Wales and Queensland (Saunders & Heinsohn 2008). Differences among years in the areas used by these species are consistent with nomadic movements and confirm the species' capacity to track highly variable resources. Flying-foxes move hundreds of kilometres between successive roosts, and cumulative movements over periods of several months can exceed

1000 kilometres (J Martin & J Welbergen Botanic Gardens Trust Sydney, unpublished data; Eby 1991b, 1996; Roberts 2012; Tidemann & Nelson 2004). Extreme seasonal and annual variations in the numbers of animals occupying camps reflect nomadic movements that track flowering events (Eby 1991b, 1996; Birt 2004).

Migratory and nomadic pollinators serve as identifiable linkages between the distant habitat areas they visit. Their movements demonstrate rhythms in ecological processes that play out over large spatial and temporal scales. Nomadic pollinators use a range of otherwise disconnected vegetation communities during annual and multi-annual cycles. They create interdependencies between these sites by providing resources for shared pollinators. Not only do these relationships embed individual feeding habitats in ecological processes that occur at very large spatial scales: they can also amplify the benefits of local conservation efforts that target points of weakness. For example, migratory and nomadic species are particularly vulnerable to the loss of small areas of highly productive bottleneck habitats (Brower & Malcolm 1991; Runge et al. 2014).

Challenges to conserving nomadic pollinators

Maintaining plant–pollinator mutualisms is an important goal of many conservation programs. Pollinator populations are in decline worldwide, and there are increasing concerns over current and future disruption to the services they provide. The deteriorating status of invertebrate pollinators in agricultural crops has been a central focus of attention because of the economic and social implications of crop failure (Potts et al. 2010). However, there is also evidence of global declines in the abundance of vertebrate pollinators in natural systems, and the potential for cascading effects on plant species and communities is a matter of increasing concern (Dixon 2009; Regan et al. 2015).

The same pressures that threaten vegetation communities affect the mobile pollinators that service them. Habitat loss, degradation and fragmentation reduce the density of nectar-secreting plants to the detriment of nectar-dependent animals. Changes in climate, including an increased frequency of extreme temperature and rainfall events, affect the timing and intensity of flowering in eucalypts (Law et al. 2000; Keatley et al. 2002). Flowering patterns are altered in species-specific ways that can introduce gaps in nectar secretion at both local and regional scales and increase the intervals between periods when food is abundant (Butt et al. 2015). Gaps in the complementary timing of flowering can increase mortality and affect reproduction in nectar-dependent animals (McFarland 1986; Eby 1999 and unpublished; Sharpe 2004).

The long-distance movements of nomadic and migratory wildlife compound the detrimental impacts of human activities on these species (Brower & Malcolm 1991). Conservation outcomes for these species are only as effective as the status of the most vulnerable habitat they visit (Fleming & Eby 2003; Runge et al. 2014). Added challenges are associated with conserving nomadic species such as long-distance bird and bat pollinators in Australia. Provision of continuous food over vast areas can be achieved only when multiple potential habitat options are available at any time. Conservation strategies for these animals require broad-scale, dynamic programs that engage a range of stakeholders and identify and secure priority management sites (Fleming & Eby 2003; Runge et al. 2014).

In New South Wales, several species of birds, bats and marsupials that feed primarily on nectar are listed as threatened under the *Threatened Species Conservation Act 1995* (Table 1). A consistent set of threats affects these animals. These threats include loss, degradation and fragmentation of feeding and roosting habitat; reductions in the number of mature trees; impacts of invasive species; inappropriate fire regimes; and the influence of drought and climate change on flowering phenology and nectar production. Actions to halt and reverse decline focus on protection, restoration and regeneration of habitat.

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Table 1: Bird and mammal pollinators listed as threatened in New South Wales under the *Threatened Species Conservation Act 1995*

Scientific name	Common name	Status		Distribution (IBRA region)	Habitat type	Migration	Winter flower diet
		NSW	C'wealth				
<i>Birds</i>							
<i>Anthochaera phrygia</i>	Regent honeyeater	CE	CE	SEQ, NNC, NAN, SB, BBS, NSS, SEH, SEC	Open forest, woodland	Nomadic	WB, MIB, SM, SG
<i>Certhionyx variegatus</i>	Pied honeyeater	V		MUL, SSD, MDD, COP, DRP	Semi-arid shrubland, grassy woodland	Nomadic	emu bush, yapunyah
<i>Gavicalis fasciogularis</i>	Mangrove honeyeater	V		SEQ, NNC	Mangrove, forest, woodland	Local	FRG
<i>Melithreptus gularis gularis</i>	Black-chinned honeyeater	V		SEQ, NNC, NET, BBS, DRP, SB, NSS, RIV	Open forest, woodland	Nomadic	WB, MIB, FRG
<i>Glossopsitta porphyrocephala</i>	Purple-crowned lorikeet	V		NSS, RIV	Open forest, woodland	Nomadic	WB, MIB
<i>Glossopsitta pusilla</i>	Little lorikeet	V		SEQ, NNS, NET, NAN, SB, BBS, NSS, SEH, SEC, RIV	Open forest, woodland	Resident & nomadic	WB, MIB, SM, SG, PB
<i>Lathamus discolor</i>	Swift parrot	E	E	SEQ, NNC, NET, SB, NSS, SEH, SEC	Open forest, woodland	Nomadic	WB, MIB, SM, SG
<i>Mammals</i>							
<i>Pteropus poliocephalus</i>	Grey-headed flying-fox	V	V	SEQ, NNC, NET, NAN, BBS, SB, SEC, SEH	Closed and open forest, woodland, heath and swamp	Resident & nomadic	WB, MIB, SM, SG, FRG, CB, PB, NGIB
<i>Syconycteris australis</i>	Common blossom bat	V		SEQ, NNC	Rainforest, forest, heath	Local	FRG, CB, PB
<i>Cercartetus nanus</i>	Eastern pygmy possum	V		SEQ, NCC, NAN, SB, SEH, SEC, NSS	Rainforest, forest, woodland, heath	Resident	CB
<i>Petaurus australis</i>	Yellow-bellied glider	V		SEQ, NCC, NAN, SB, SEH, SEC, NSS	Forest	Sedentary	SM, SG, FRG, CB, WB

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Table 1 continued: Bird and mammal pollinators listed as threatened in New South Wales under the *Threatened Species Conservation Act 1995*

Scientific name	Common name	Status		Distribution (IBRA region)	Habitat type	Migration	Winter flower diet
		NSW	C'wealth				
<i>Petaurus norfolcensis</i>	Squirrel glider	V	V	SEQ, NNC, NET, BBS, NAN, SB, NSS, SEC, SEH, RIV	Forest, woodland, heath and swamp	Sedentary	WB, MIB, SM, SG, CB, FRG, PB, NGIB
<i>Petaurus norfolcensis</i>	Squirrel glider (Wagga Wagga)	E pop		NSS	Open forest, woodland, riverine forest	Sedentary	WB, MIB
<i>Petaurus norfolcensis</i>	Squirrel glider (Barrenjoey)	E pop		SB	Forest, woodland, heath and swamp	Sedentary	SM, SG, CB, PB

Key to winter diet species: CB = coast banksia *Banksia integrifolia*; FRG = forest red gum *Eucalyptus tereticornis*; MIB = mugga ironbark *Eucalyptus sideroxylon*; NGIB = northern grey ironbark *Eucalyptus siderophloia*; PB = broad-leaved paperbark *Melaleuca quinquenervia*; SG = spotted gum *Corymbia maculata*; SM = swamp mahogany *Eucalyptus robusta*; WB = white box *Eucalyptus albens*

Key to IBRA (Interim Biogeographic Regionalisation for Australia) Regions: BBS = Brigalow Belt South; COP = Cobar Peneplain; DRP, Darling Riverine Plains; MDD, Murray Darling Depression; MUL = Mulga Lands; NAN = Nandewar; NET = New England Tablelands; NNC = NSW North Coast; NSS = NSW South Western Slopes; RIV; Riverina; SB = Sydney Basin; SEC = South East Corner; SEH, South Eastern Highlands; SEQ = South Eastern Queensland; SSD, Simpson Strzelecki Dunefields

Key to status: CE, critically endangered; E, endangered; E pop, endangered population; V, vulnerable

Habitat programs to conserve nomadic, long-distance pollinators

Although protected areas form the basis of land-based conservation programs in Australia, the nomadic, migration patterns of nectar-feeding birds and bats prevent them from being conserved in a static system of conservation reserves (Pressey et al. 2002; Runge et al. 2014). Instead, substantial efforts are needed to protect habitat and arrest its decline on both public and private land. This process must include sustainable management in production forests and broad-scale habitat restoration. The large numbers and expansive areas of planned or early-stage restoration plantings in New South Wales provide an opportunity to enhance feeding habitat for threatened mobile pollinators as part of existing initiatives by a range of organisations.

In recent years, substantial areas of cleared or heavily modified land in south-eastern Australia have been replanted in formal and informal habitat restoration programs funded through a range of organisations and initiatives (e.g. Landcare, Great Eastern Ranges Initiative, Greening Australia, NSW Environmental Trust, NSW Local Land Services and numerous local government and landholder programs). Lesser areas have been set aside for natural regeneration. Most revegetation work on agricultural land is multifunctional and aims to not only conserve biodiversity but also to control soil salinity, provide shelter for stock, reduce evaporation from wind, and create carbon plantings or commercial eucalypt timber plantations. Few land restoration and rehabilitation programs in New South Wales aim to enhance habitat for threatened pollinators, although some local initiatives have focused on areas known to be used by critically endangered regent honeyeaters and endangered swift parrots (e.g. the Capertee Valley Regent Honeyeater Recovery Project). Equally, the establishment of animal-mediated pollination in plantings is typically not a goal of restoration; nor is it used as a measure of success.

Can revegetation sites provide suitable habitat for nomadic pollinators? Programs monitoring the ecological benefits of revegetation plantings and regeneration sites are relatively recent and generally report on bird occupancy in young plantings (5 to 25 years old) (e.g. Kavanaugh et al. 2007; Munro et al. 2011; Law et al. 2014; Smith et al. 2015). The results of these studies are encouraging and indicate that mobile species locate to, and inhabit, rehabilitation sites. For example, the species richness of the bird assemblages recorded in natural regeneration sites, multi-species plantings, 'woodlot' plantings and large-scale plantations containing few species increased over time. These parameters differed significantly from those on cleared land within 10 years and reached the levels recorded in nearby remnant vegetation within 20 years, although the species composition differed.

Most revegetation work in New South Wales has been done in the last 20 years. Although some species of eucalypt flower precociously in less than 10 years after planting, the lag time to flowering in many species exceeds the age of these plantings and the benefits to nectar-dependent species are yet to be realised (Vesk et al. 2008). Nonetheless, the high levels of dispersability of nomadic nectar-feeders in New South Wales and the success of non-target plantings in attracting birds suggest that natural migration into restored areas can occur provided that plants that help migration across landscapes are made available (Dixon 2009).

Recommendations

An objective of this report is to identify those priorities for revegetation work that are supported by ecological principles and current knowledge and that fit in with local-scale actions and decision-making.

It has been proposed (Dixon 2009; Menz et al. 2011) that, if there is no comprehensive information available on the habitat requirements of pollinators, plantings to restore and conserve pollinator networks should prioritise plants that:

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1. address weak points in the network of habitats used by pollinators by providing food during bottlenecks of resource availability (bridging plants)
2. support diverse pollinator networks by providing food resources to a large number of species (framework plants)
3. provide rich resources that attract large numbers of pollinators (magnet plants).

Where possible, the attributes of candidate plant species should be assessed systematically and at appropriate spatial scales.

This approach has already been applied to threatened nomadic pollinators in New South Wales. Data have been compiled from maps of state-wide patterns of habitat distribution for the swift parrot and grey-headed flying-fox (Eby & Law 2008; Saunders & Heinsohn 2008; Saunders et al. 2010) and from targeted state-wide surveys of these species and regent honeyeaters (Ingwersen et al. 2015; [National Flying-fox Monitoring Program](#)). Local assessments have also been considered (e.g. Oliver 2000; Roderick et al. 2013). Information on the other nomadic species listed in Table 1 has been acquired from a review of local-scale ecological studies and from sighting records held in the [Atlas of Living Australia](#) (accessed 15 August 2015). Data on plant distributions are also from records held in the *Atlas of Living Australia*. The recommendations below should be viewed as starting points. These recommendations have been made in the context of rapid environmental change and a limited but expanding knowledge base. Priorities will be refined and adjusted over time.

The general recommendation is that restoration plantings and natural regeneration for use by migratory pollinators in New South Wales should target trees that flower in winter and early spring (Table 2, Figure 1). There is consistent evidence that a resource bottleneck for vertebrate pollinators occurs in winter and early spring; that animals congregate on the available resources; and that resource limitation at these times affects body condition and mortality and reproduction rates in various species (McFarland 1986; Eby 1999 and unpublished; Sharpe 2004). Conservation benefits for vertebrate pollinators, including highly mobile, nomadic species, should accrue if we target the restoration and regeneration of diet plants that are productive at this time (Law et al. 2002). Additional benefits should include the provision of pollination services to winter-flowering plants during periods when the activity of insect pollinators is reduced (Frick et al. 2014) and an increased likelihood of pollen flow between restoration sites and remnant habitat, with related increases in the genetic diversity and resilience of plantings.

The winter–early spring resource bottleneck is associated with a period of low species richness in flowering diet plants and seasonal lows in the abundance of key alternative dietary items (particularly insects and fleshy fruits). For example, the areal extent of potential feeding habitat for grey-headed flying-foxes (i.e. the cumulative area of vegetation containing diet plants) is at an annual low during June–July; it is an estimated 16% of the potential habitat area available in December–January (Eby & Law 2008). Most winter-flowering trees occur in landscapes valued by humans for agriculture and development—primarily fertile slopes and plains on the inland slopes, coastal lowlands and coastal floodplains. These landscapes have been substantially cleared and are under ongoing pressure. The vegetation communities that contain many winter-flowering species have been reduced to small remnants. Levels of protection in conservation reserves are poor (in terms of both area and proportion), and several are listed as Endangered Ecological Communities under the Threatened Species Conservation Act (Eby & Law 2008; Saunders & Heinsohn 2008; Table 3). Winter nectar production for vertebrates is limited at higher altitudes and on the tablelands, reflecting the distribution patterns of winter-flowering trees (Figure 1b; Eby & Law 2008).

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Table 2: Distributions and flowering characteristics of winter- and early-spring-flowering plants recommended for use in restoration plantings and natural regeneration for nomadic long-distance pollinators in New South Wales. Productivity and reliability scores are from the work of Eby and Law (2008). They are assessed on a scale from 0 to 1.0. Australian trees vary substantially in the amount of nectar and pollen they produce and how frequently they flower. Productivity is a relative assessment of nectar production, and reliability is a measure of the frequency of substantial flowering events. The flowering phenologies of some species vary among regions. These variations are noted in the Comments column, and only regions that support winter or spring flowering are listed.

Scientific name	Common name	Distribution (IBRA regions)	Productivity score	Annual reliability	Monthly flowering schedule	Comments
<i>Banksia integrifolia</i>	Coast banksia	SEQ, NNC, SB, SEC	0.77	1.0	May–Sept	
<i>Corymbia maculata</i>	Spotted gum	SB, SEC	0.9	0.3	SB: Mar–Jul SEC: May–Sept	Flowering starts earlier in Hunter Valley than on South Coast
<i>Eucalyptus albens</i>	White box	BBS, NAN, NET, NSS, SB, SEH, SEC	0.7	0.3	May–Sept	
<i>Eucalyptus melliodora</i>	Yellow box	BBS, NAN, NET, NSS, SB, SEH, SEC	0.7	0.3	Oct–Dec	Flowering phenology is variable
<i>Eucalyptus paniculata</i>	Grey ironbark	SB, SEC	0.6	0.3	SB: May–Aug SEC: Sept–Jan	
<i>Eucalyptus robusta</i>	Swamp mahogany	SEQ, NNC, SB, SEC	1.0	1.0	May–July	
<i>Eucalyptus seeana</i>	Narrow-leaved red gum	SEQ, NNC	0.77	0.8	Aug–Oct	
<i>Eucalyptus siderophloia</i>	Northern grey ironbark	SEQ, NNC	0.9	0.6	June–Sep	Flowers earlier and more frequently on coastal lowlands than on ranges; main winter flowering occurs on coastal lowlands

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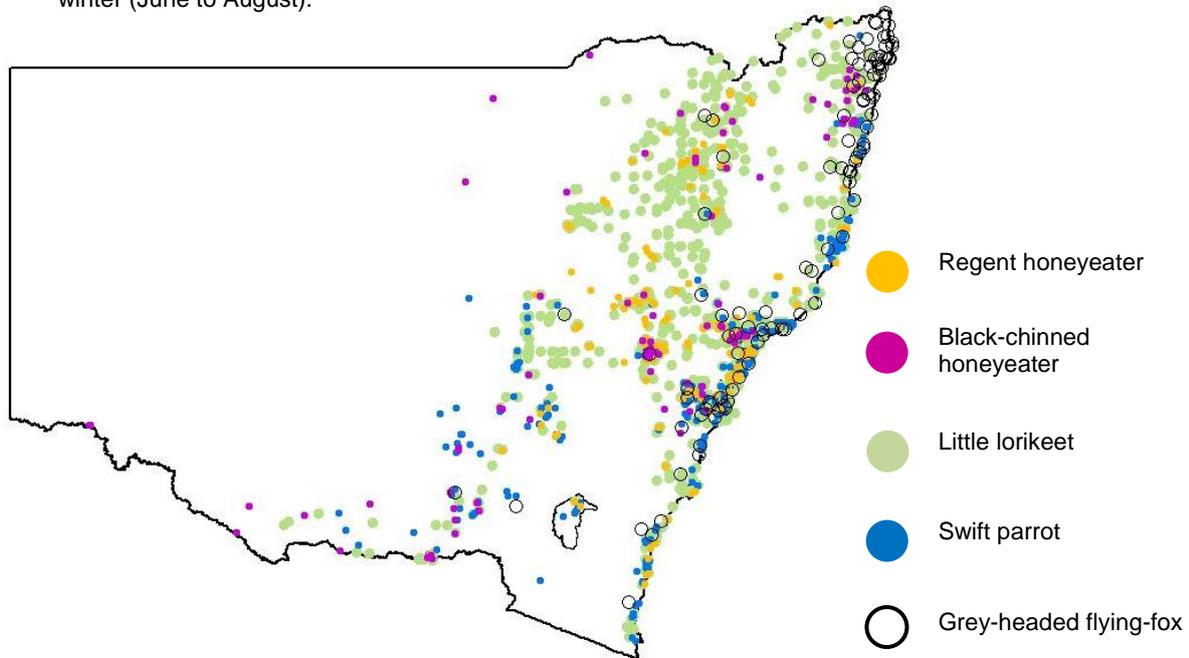
Table 2 *continued*: Distributions and flowering characteristics of winter- and early-spring-flowering plants recommended for use in restoration plantings and natural regeneration for nomadic long-distance pollinators in New South Wales. Productivity and reliability scores are from the work of Eby and Law (2008). They are assessed on a scale from 0 to 1.0. Australian trees vary substantially in the amount of nectar and pollen they produce and how frequently they flower. Productivity is a relative assessment of nectar production, and reliability is a measure of the frequency of substantial flowering events. The flowering phenologies of some species vary among regions. These variations are noted in the Comments column, and only regions that support winter or spring flowering are listed.

Scientific name	Common name	Distribution (IBRA regions)	Productivity score	Annual reliability	Monthly flowering schedule	Comments
<i>Eucalyptus sideroxylon</i>	Mugga ironbark	BBS, NAN, NET, NSS, SB	0.7	0.3	May–Sept	May flower during summer, see Oliver (2000)
<i>Eucalyptus tereticornis</i>	Forest red gum	SEQ, NNC	0.9	0.8	June–Aug	Flowering starts progressively later at higher latitudes and altitudes; main winter flowering occurs on coastal lowlands in SEQ and NNC
<i>Melaleuca quinquenervia</i>	Broad-leaved Paperbark	SEQ, NNC	0.9	0.8	May–June	Main flowering period is autumn in SB. Flowers through June in SEQ and the northern half of NNC
<i>Syncarpia glomulifera</i>	Turpentine	SEQ, NNC, SB, SEC	0.6	0.6	Sept–Oct	

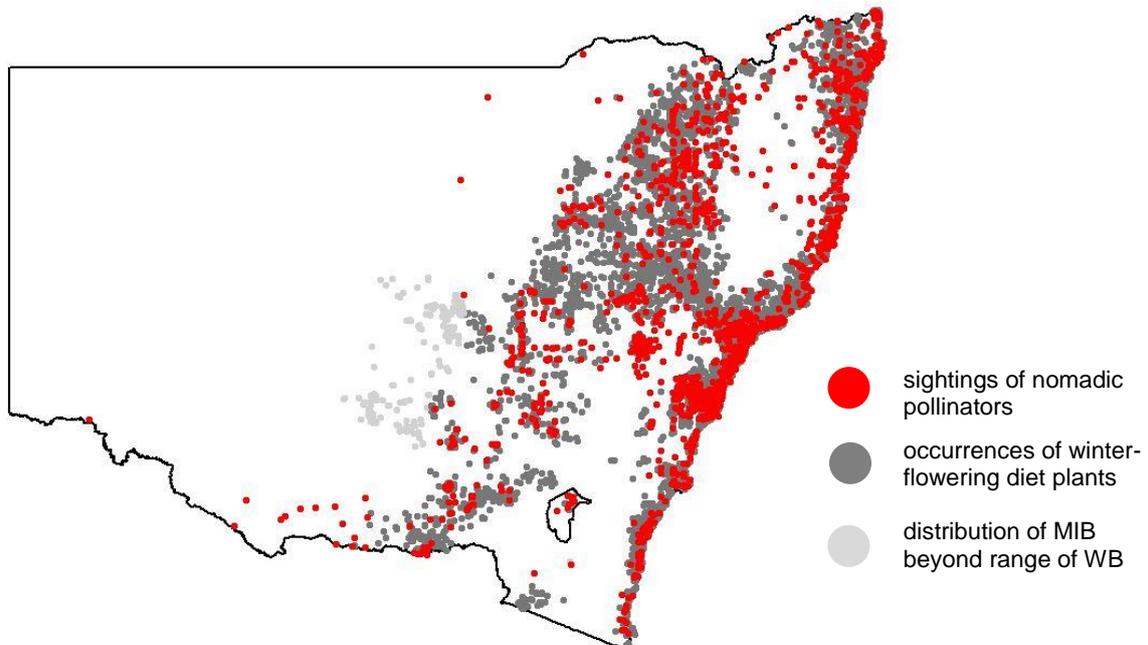
Key to IBRA (Interim Biogeographic Regionalisation for Australia) Regions: BBS = Brigalow Belt South; NAN = Nandewar; NET = New England Tablelands; NNC = NSW North Coast; NSS = NSW South Western Slopes; SB = Sydney Basin; SEC = South East Corner; SEQ = South Eastern Queensland; SEH, South Eastern Highlands

Figure 1: Associations between sightings of nomadic pollinators during winter months and winter-flowering diet species in New South Wales. Data for bird and tree species are from the *Atlas of Living Australia* (accessed 15 August 2015). Data for the grey-headed flying-fox are based on winter occupation of known roost sites from the *Atlas of Living Australia* and the *National Flying-fox Monitoring Program*.

(a) Recent sightings (1995 to present) of five nomadic pollinators in New South Wales (see Table 1) during winter (June to August).



(b) Spatial associations between five species of threatened nomadic pollinators and winter-flowering food trees of the coastal lowlands and western slopes of New South Wales (Table 2).

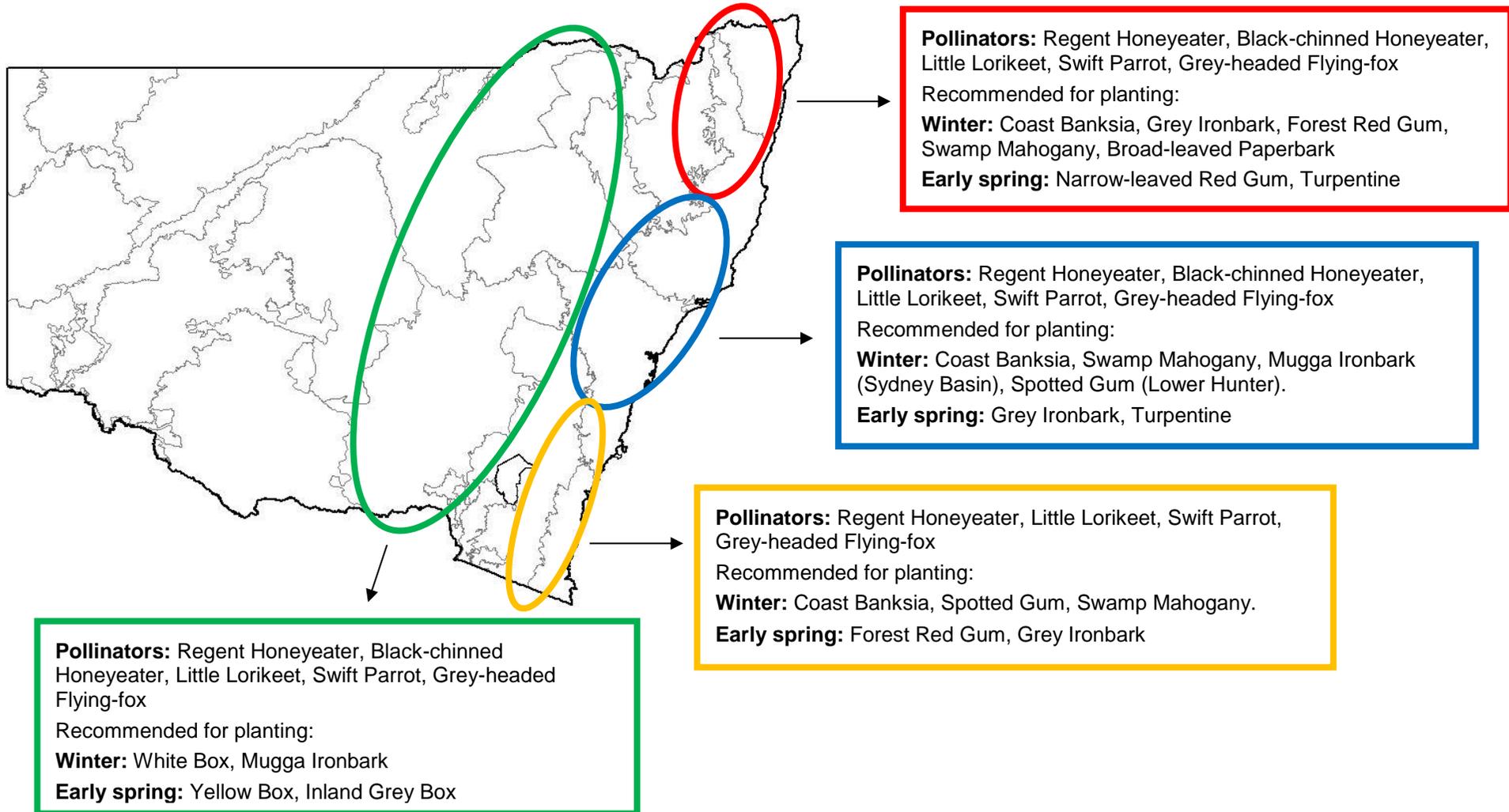


Winter-flowering diet plants include mugga Ironbark and white box on the Western Slopes; and coast banksia, forest red gum, broad-leaved paperbark, northern grey ironbark, spotted gum and swamp mahogany in coastal regions.

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Figure 1 continued

(c) Recommendations for restoration plantings and natural regeneration to enhance winter and early spring food for nomadic long-distance pollinators in New South Wales



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Table 3: Endangered Ecological Communities that contain key winter-flowering trees for nomadic pollinators in New South Wales

Community name	IBRA bioregion	Winter-flowering spp.	Comments
Bangalay Sand Forest of the Sydney Basin and South East Corner bioregions	SB, SEC	CB	
<i>Cadellia pentastylis</i> (ooline) community in the Nandewar and Brigalow Belt South bioregions	NAN, BBS	WB	
Central Hunter Ironbark – Spotted Gum – Grey Box Forest in the NSW North Coast and Sydney Basin bioregions	NNC, SB	SG, FRG	FRG winter flowering in North Coast bioregion only; spring flowering in south
Coastal Cypress Pine Forest in the NSW North Coast bioregion	NNC	CB	
Cumberland Plain Woodland in the Sydney Basin bioregion	SB	SG, GIB	
Elderslie Banksia Scrub Forest in the Sydney Basin bioregion	SB	CB	
Grey Box – Grey Gum Wet Sclerophyll Forest in the NSW North Coast bioregion	NNC	NGIB	
Hunter Floodplain Red Gum Woodland in the NSW North Coast and Sydney Basin bioregions	NNC, SB	FRG	
Hunter Lowland Redgum Forest in the Sydney Basin and NSW North Coast bioregions	SB, NNC	FRG, SG	FRG winter flowering in North Coast bioregion only
Inland Grey Box Woodland in the Riverina, NSW South Western Slopes, Cobar Penepplain, Nandewar and Brigalow Belt South bioregions	RIV, NSS, COP, NAN, BBS	WB	
Kurnell Dune Forest in the Sutherland Shire and City of Rockdale	SB	SM	
Littoral Rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	NNC, SB, SEC	CB, FRG	FRG winter flowering in North Coast Bioregion only
Low woodland with heathland on indurated sand at Norah Head	SB	PB	
Lower Hunter Spotted Gum-Ironbark Forest in the Sydney Basin Bioregion	SB	SG	
Maroota Sands Swamp Forest	SB	SM	
Moist Shale Woodland in the Sydney Basin bioregion	SB	FRG, SG	FRG winter flowering in North Coast bioregion

Table 3 continued: Endangered Ecological Communities that contain key winter-flowering trees for nomadic pollinators in New South Wales

Community name	IBRA bioregion	Winter-flowering spp.	Comments
Pittwater and Wagstaffe Spotted Gum Forest in the Sydney Basin bioregion	SB	SG, NGIB	
River-Flat Eucalypt Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	NNC, SB, SEC	FRG	FRG winter flowering in North Coast bioregion only
Subtropical Coastal Floodplain Forest of the New South Wales North Coast Bioregion	NNC	FRG, NGIB, SM	
Swamp Sclerophyll Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	NNC, SB, SEC	SM, PB	
Umina Coastal Sandplain Woodland in the Sydney Basin Bioregion	SB	CB	
Warkworth Sands Woodland in the Sydney Basin	SB	CB	
White Box Yellow Box Blakely's Red Gum Woodland	NNC, NET, NAN, BBS, SB, SEH, NSS	WB	

Key to winter diet species: CB = coast banksia *Banksia integrifolia*; FRG = forest red gum *Eucalyptus tereticornis*; NGIB = northern grey ironbark *Eucalyptus siderophloia*; PB = broad-leaved paperbark *Melaleuca quinquenervia*; SG = spotted gum *Corymbia maculata*; SM = swamp mahogany *Eucalyptus robusta*; WB = white box *Eucalyptus albens*

Key to IBRA (Interim Biogeographic Regionalisation for Australia) Regions: BBS = Brigalow Belt South; COP, Cobar Penepplain; NAN = Nandewar; NET = New England Tablelands; NNC = NSW North Coast; NSS = NSW South Western Slopes; RIV; Riverina; SB = Sydney Basin; SEC = South East Corner; SEH, South Eastern Highlands

Current knowledge indicates that a range of vertebrate pollinators would benefit from efforts to increase feeding habitat during the seasonal resource bottleneck. There is substantial overlap in the winter nectar diets of nomadic pollinators in New South Wales, although an exception is the pied honeyeater, which in western New South Wales feeds primarily on emu bush (*Eremophila* spp.) (Table 1). There is also a complete overlap in the regional areas used by the most mobile, wide-ranging species during winter (regent honeyeater, swift parrot, little lorikeet, grey-headed flying-fox; see Figure 1a). Species with more limited ranges use a subset of these plants and habitat areas.

Finally, although winter and early spring nectar resources in the forests of New South Wales are limited in terms of species richness and areal extent, the diet species included in Table 2 are highly productive (Eby & Law 2008). Mass flowerings attract large numbers of nectar-feeding birds and bats (e.g. McGoldrick & MacNally 1998; Eby 1991b; Law 1994).

The species recommended for planting are listed in Table 2. Regional areas indicated for plantings are shown in Figure 1c.

Key species and regional habitat areas include:

- on the fertile slopes and plains of the Western Slopes:
 - mugga ironbark *Eucalyptus sideroxylon*; white box *Eucalyptus albens*; and yellow box *Eucalyptus melliodora*
- on the coastal floodplains and alluvia:
 - forest red gum *Eucalyptus tereticornis*; swamp mahogany *Eucalyptus robusta*; broad-leaved paperbark *Melaleuca quinquenervia*; narrow-leaved red gum *Eucalyptus seeana*
- on the coastal lowlands and foothills:
 - grey ironbark *Eucalyptus paniculata*; northern grey ironbark *Eucalyptus siderophloia*; spotted gum *Corymbia maculata* (Hunter Valley and South Coast); turpentine *Syncarpia glomulifera*
- on the coastal dunes:
 - coast banksia *Banksia integrifolia*.

Additional considerations

1. It is important to take a long-term view in assessing the importance of restoration plantings and habitat regeneration to pollinator networks. Although some species of eucalypt flower precociously and individual trees may produce flowers in less than 10 years, other species do not start flowering until they are about 20 years old. Reliability of flowering and levels of productivity generally increase with age and size (e.g. Wilson & Bennett 1999; Oliver 2000; Law & Chidel 2008, 2009).
2. Mature trees with large boughs flower more intensively and produce greater volumes of nectar per flower than do younger trees or trees grown in conditions where their canopies are constrained (Law & Chidel 2008; Vesik et al. 2008). Planting at low densities speeds canopy development, increases rates of flower production with age and may reduce competition for water and nutrients. Planting at low densities also speeds the formation of tree hollows used as roosts by several threatened species of fauna.
3. Trees planted in riparian areas or on other sites that provide access to water (e.g. near farm dams) flower more frequently than trees planted in drier conditions (Wilson & Bennett 1999). The long-term benefits of planting in riparian zones may be more pronounced in inland areas.
4. In general, trees planted on more fertile soils may be more productive than trees planted on poorer soils (Clemson 1985), the exception being species, such as banksias, which adapted to infertile soils.
5. Flower density can be important for attracting pollinators. Large-area plantings or plantings near existing habitat may be visited by more individuals and more species (Lindell & Thurston 2013).
6. Aggressively competitive birds such as noisy miners *Manorina melanocephala* exclude many species of threatened honeyeaters (Maron et al. 2011; Bennett et al. 2014). Limiting habitat suitability for this species may help to control its impact (Clarke & Grey 2010). Noisy miners prefer remnant edges. Increasing the area of continuous vegetation cover (to greater than 36 hectares) and creating remnants with smoothed or rounded edges may help with control. Dense plantings of shrubs and tall ground-layer vegetation may also help, as may the use of *Acacia* species.
7. Plantings that are located close to existing mature trees with hollows are more likely to attract pollinators that roost in the hollows. However, it can take more than 100 years for

tree hollows to develop in new plantings (Gibbons & Lindenmayer 2002). Although nest boxes can be used to encourage some hollow-dependent species into plantings in the absence of mature remnant trees (Smith et al. 2015), many pollinators do not use these artificial roosts.

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