

# White cypress pine (*Callitris glaucophylla*): a review of its roles in landscape and ecological processes in eastern Australia

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**Abstract.** *Callitris glaucophylla* (J.Thompson & L.Johnson, white cypress pine) woodlands are an important vegetation community over relatively large areas of continental eastern Australia. *C. glaucophylla* communities were originally reserved because of their value to the timber industry, but renewed attention is being placed on these woodlands because of their putative role in the conservation of native plants and animals. The pre-European distribution of *C. glaucophylla* was altered dramatically in the past century because of a combination of grazing by domestic livestock and feral animals, altered fire regimes and weed invasion. Today, the majority of *C. glaucophylla* woodlands are highly fragmented remnants, with many managed as formal forestry reserves. Selective logging during the past 30 years has led to a community that is dominated by single-aged stands, often at high densities, leading to the perception that *C. glaucophylla* communities are severely degraded and floristically depauperate. Increased interest in the structure and function of grassy woodlands in eastern Australia over the past decade has led to a re-evaluation of the importance of this vegetation community for habitat and for maintaining essential ecosystem processes. The timing of this review is appropriate because (1) much has been published on the ecological role of *C. glaucophylla* over the past decade in Australia, although mostly in unpublished reports, and (2) there is a need to resolve some of the conflicting issues relating to the value of *C. glaucophylla* woodlands for healthy soils and vegetation. Here, we review the ecological role of *C. glaucophylla*, with an emphasis on eastern Australia, drawing on a range of published and unpublished literature. We describe the characteristics and distribution of *C. glaucophylla* in eastern Australia, its role in soil and ecological processes, and the impacts of fire and grazing. Finally, we discuss the management of *C. glaucophylla* for a range of landuses.

## Introduction

White cypress pine has an extensive geographic distribution and is found throughout inland Australia in all mainland states (Marshall 1964; Thompson and Johnson 1986; Spencer 1995). Vegetation communities containing *C. glaucophylla* have historically been cleared for grazing and agriculture (Lacey 1973; Forestry Commission of NSW (FCNSW) 1989; Mitchell 1991), and the current distribution of *C. glaucophylla* is restricted to isolated patches, often on soils or landforms too steep for clearing, or in forested remnants (Lacey 1973; Knott 1995). *C. glaucophylla* woodlands once occupied a substantial component of New South Wales (NSW) and southern Queensland (Attiwill and Clayton-Greene 1984; FCNSW 1989; Binnington 1997). However, populations in Victoria, South Australia, Western Australia and the Northern Territory are relatively small (Lacey 1973). Today, *C. glaucophylla* exists predominantly in state forests, national parks and on private land held under freehold or leasehold tenure. Throughout western Queensland

and NSW, *C. glaucophylla* remains the principal timber species managed for forestry (Lacey 1972). The largest remaining stands of cypress pine forest (270 000 ha) are held within the Pilliga Management Area of State Forests of NSW (SFNSW; Knott 1995). Other extensive regions of *C. glaucophylla* occur in the Cobar region of western NSW (Anon. 1969; Cunningham *et al.* 1992) and between Dalby and Roma in southern Queensland (Lacey 1973).

*Callitris glaucophylla* is a small to medium tree with a single trunk, occasionally reaching heights up to 30 m and in some circumstances it may appear stunted. It produces seed cones with six valves, in copious quantities, which are usually dropped shortly after maturity (Garden 1956). The crown foliage appears thicker and more conical in shape in open stands than in the sparse, flat-topped trees of dense stands (Lacey 1973). *C. glaucophylla* is known to hybridise with *C. preissii*, and hybrid populations occur throughout the Flinders Ranges, the Murray River and

the mallee regions of South Australia, Victoria and NSW (Thompson and Johnson 1986). The glaucous foliage and inland distribution distinguishes *C. glaucophylla* from the similar coastal species, *C. columellaris* (Thompson and Johnson 1986).

Despite its continental and widespread distribution in Australia, information on the role of *C. glaucophylla* in soil and landscape processes is poorly documented, fragmented and often obscured in unpublished reports and grey literature. This review focuses on the principle range of *C. glaucophylla* in eastern Australia, particularly NSW and Queensland, and where available and appropriate, reference is made to information from other States. The objectives of the review are to (1) describe historical land-use practices and how they influence modern distributions and densities of *C. glaucophylla*; (2) consider the mechanisms by which woodlands dominated by *C. glaucophylla* modify landscape, soil and ecological processes; (3) describe the importance of *C. glaucophylla* woodlands as habitat for plants and animals; and (4) describe alternative management of remaining stands as we learn more about the importance of these communities.

### *Callitris glaucophylla* community types

#### Pre-European distribution of *C. glaucophylla*

Apart from isolated locations, limited data are available on the pre-European distribution of *C. glaucophylla*. Pollen records from the Great Anabranch of the Darling River in south-western NSW have provided information about the historical extent of *C. glaucophylla* in the dry areas of southern Australia. Prior to 4500 years before present, the *C. glaucophylla*–*C. gracilis* association was common in the flora, possibly occurring along sand dunes (Cupper *et al.* 2000). The high frequency of carbon particles in the pollen record 4500–2000 years before present suggests the prevalence of fire in the area. Contrary to what is known

about the sensitivity of *Callitris* species to fire (Wilson and Mulham 1979; Bowman *et al.* 1988; Bowman and Harris 1995; Bradstock and Cohn 2002), they are relatively well represented in the pollen record (Cupper *et al.* 2000). As aridity continued to increase between 2000 and 1845 years before present, *C. glaucophylla*–*C. gracilis* declined in the paleo-record (Cupper *et al.* 2000). This is not surprising, as although they are strongly xerophytic, severe droughts are known to kill the species (Clayton-Greene 1981; FCNSW 1988a). Following European settlement in the Darling Anabranch in the mid-nineteenth century, the decline in *C. glaucophylla* in the pollen record is likely due to its clearing by the settlers, particularly for fence posts and building materials (Cupper *et al.* 2000).

#### Contemporary distribution of *C. glaucophylla*

Originally, *C. glaucophylla* woodlands occurred as a mosaic with a mixed community of various eucalypts and other tree species such as *Allocasuarina luehmannii* (Boland *et al.* 1984). Today, however, in many *C. glaucophylla*-dominant areas throughout southern NSW, more than 80% of the total tree basal area is *C. glaucophylla*, mainly resulting from selective and systematic removal of associated eucalypts by ringbarking (Lindsay 1967). The then FCNSW, now SFNSW, ringbarked trees until the 1970s as part of a regular program to eradicate ‘useless timber’ (Curby 1997; Allen 1998). However, this practice was not restricted to the FCNSW; pastoralists also routinely ringbarked on their properties. Their activities were not properly supervised or limited to eucalypts, and cypress pines were also eliminated (Curby 1997).

Community alliances with *C. glaucophylla* and *Eucalyptus* species persist in some areas, despite extensive landscape modifications (Table 1). The rangelands in the eastern edge of the Western Division of NSW are dominated

**Table 1. Common *Callitris glaucophylla* associations in New South Wales**  
Adapted from Lacey (1973), Iwaszkiewicz and Semple (1988), Clayton-Greene and Ashton (1990) and Bowman and Harris (1995)

Commercial forests	Western Division
<i>Eucalyptus blakelyi</i>	<i>E. populnea</i> ssp. <i>bimbil</i>
<i>E. dealbata</i>	<i>E. intertexta</i>
<i>E. populnea</i> ssp. <i>bimbil</i>	<i>C. verrucosa</i>
Winter-dominant rainfall (southern NSW)	Summer-dominant rainfall (northern NSW)
<i>Allocasuarina luehmannii</i>	<i>E. crebra</i>
<i>C. gracilis</i> ssp. <i>murrayensis</i>	<i>E. dealbata</i>
<i>E. albens</i>	<i>E. melanophloia</i>
<i>E. blakelyi</i>	<i>E. microcarpa</i>
<i>E. conica</i>	<i>E. populnea</i> ssp. <i>bimbil</i>
<i>E. dealbata</i>	Snowy mountains
<i>E. dwyeri</i>	<i>E. albens</i>
<i>E. melliodora</i>	
<i>E. microcarpa</i>	
<i>E. sideroxylon</i>	

by the *C. glaucophylla*–*E. populnea* ssp. *bimbil* alliance (Lindsay 1967; Iwaszkiewicz and Semple 1988); further west *E. intertexta* supplants *E. populnea* ssp. *bimbil*, which is found on less favourable sites in higher-rainfall regions (e.g. rocky ridges and hills: Iwaszkiewicz and Semple 1988; Porteners and Ashby 1996). In the Quaternary dunefields and sand dunes in western NSW, *C. glaucophylla* is often associated with *C. verrucosa* (mallee pine) on sand ridges and deep sand sheets (Porteners and Ashby 1996). *Callitris* species persist in fire-prone mallee communities (Bradstock and Cohn 2002), despite most species being killed by fire (Bowman and Harris 1995). Throughout the southern Riverina in NSW, *C. glaucophylla* is often replaced with *C. gracilis* ssp. *murrayensis*, (murray pine; Cunningham *et al.* 1992; Driver and Porteners 2000), which is similar to *C. glaucophylla*, except that it has olive-green foliage and relatively larger, smooth cones (Porteners and Ashby 1996).

Within the rainshadows of the ranges and valleys of Kosciuszko National Park (NSW) and Snowy National Park, the stands of *C. glaucophylla* and *E. albens* are some of the few occurrences of *C. glaucophylla* east and south of the Great Dividing Range (Clayton-Greene and Ashton 1990). Since European settlement in the Snowy Mountains, the area has been heavily grazed by domestic and feral animals (e.g. rabbits) and burnt at a range of frequencies from frequent (to promote palatable pasture) to exclusion (Clayton-Greene and Ashton 1990; Pulsford *et al.* 1993). Altitude and aspect determine the distribution of the two species within the woodland. Northerly and westerly aspects below 550 m are dominated by almost pure *C. glaucophylla*, whereas cooler, southerly aspects at lower elevation and above 650 m are dominated by *E. albens* and perennial grasses (Clayton-Greene and Ashton 1990).

Populations of *C. glaucophylla* within the Northern Territory (Bowman and Latz 1993), Western Australia (Boland *et al.* 1984) and South Australia (Read 1995) are patchy, with very little published data on the species from Western Australia. The species is considered by some as a relict, in part because of its scattered distribution across Australia, as well as its association with rainforest species along Ilparpa Ridge in central Australia (Bowman and Latz 1993). Bowman and Latz (1993) suggested that the control of wildfire intensity was essential for the survival of the species in the MacDonnell Ranges. In the tropics of the Northern Territory, Western Australia and northern Queensland, *C. intratropica* is the predominant *Callitris* species (Lacey 1973), a close relative of *C. glaucophylla* with an affinity for sandy soils (Bowman *et al.* 1988).

### Environmental factors influencing the distribution of *C. glaucophylla*

#### *Influence of rainfall*

In eastern Australia, *C. glaucophylla* persists across a wide rainfall gradient. Commercially viable stands generally exist

within the 350–700-mm annual rainfall isohyets (Grant 1989), but the species is known to occur in regions of lower rainfall. The populations in central and Western Australia persist in areas with annual rainfall as low as 250 and 220 mm, respectively (Boland *et al.* 1984). Temperature and elevation also influence *C. glaucophylla* distribution. However, across the western region of NSW, temperatures are far more consistent through time than rainfall (Beadle 1948), and periods of drought are common (Lindsay 1967; FCNSW 1988b). Lower temperatures associated with increasing altitude restrict dispersal of *C. glaucophylla*, and only in the northern and tropical extent of its range is *C. glaucophylla* found at higher elevations (Lacey 1973). Within NSW, *C. glaucophylla* is found at elevations ranging from 90 m on the western plains to 750 m on the western slopes of the Great Dividing Range (Lacey 1973). Rainfall is known to be a major driver of groundstorey plant diversity in *C. glaucophylla* woodlands (Thompson and Eldridge 2005).

*Callitris glaucophylla* is susceptible to extended periods of low rainfall and severe drought; however, deaths resulting solely from drought are infrequent because of its rooting structure (Johnston 1975; see Ecology below). The roots are concentrated mainly in surface soils (Burrows *et al.* 2001; Eberbach 2003), and in western Queensland the Great Drought of 1898–1902 killed large numbers of trees, unlike any other drought (Harris and Lamb 2001). Moisture stress leads to a reduction in sparse crown density, desiccation of the bark, cracking of smaller branches and, eventually, bark and wood splitting (Iwaszkiewicz and Semple 1988). However, even severely affected trees will recover quickly provided that the cambium has not been destroyed. *C. glaucophylla* is equally susceptible to prolonged periods of above-average rainfall. High summer rainfalls in western Queensland in the mid-1970s led to prolonged waterlogging, a proliferation of crown dieback and ultimately increased mortality of some established stands (Harris and Lamb 2001).

#### *Influence of soils*

Although *C. glaucophylla* is found on a wide range of soil types, it occurs mainly on sandy, well drained soils (Lacey 1973; Cunningham *et al.* 1992; Spencer 1995) and rocky skeletal soils (Adams 1985; Bowman and Latz 1993). It is often supplanted by *C. endlicheri* (black cypress pine) on skeletal soils along its eastern geographic limit in NSW (Lacey 1973). Its preference for sandy-textured soils is thought to relate to the ease of water percolation through the soil profile. Because *C. glaucophylla* is susceptible to waterlogging, it is absent from finer-textured soils, particularly clays (Humphreys *et al.* 2001) and clay loams, except those with sloping topography or a gravelly profile (Lacey 1973).

*Callitris glaucophylla* is found on soils with a range of chemical properties, including pH ranging from 5.0 to 7.5 (Iwaszkiewicz and Semple 1988), bulk density from 0.68 to 1.68 Mg m<sup>-3</sup> (W. A. Thompson, unpubl. data)

and electrical conductivity from 0.09 to 0.49 dS m<sup>-1</sup> (Eldridge 1993).

### Ecology of *C. glaucophylla*

#### Seed production

A large amount of research has been undertaken on the factors influencing seed production and recruitment, owing to the value of *C. glaucophylla* as a forest timber. Seed drop typically occurs between October and January, and peaks in November and December (Lacey 1972) when at least 80% of viable seed is shed (Hawkins 1966). Fire is a critical factor in seed production. Seed production is depressed by burning (Hawkins 1966) and predation by wasps (e.g. *Epimegastigmus* spp.; Lacey 1973). Moderately burnt stands vary widely in their production of viable seeds for up to 5 years following burning (Hawkins 1966). Seed production is thought to peak on average every 3 years, with fewer seeds present during intervening years (Hawkins 1966).

#### Recruitment

Recruitment of *C. glaucophylla* is constrained by climate (particularly rainfall), grazing, health of the mature stand and fire. Recruitment is highly episodic (Hawkins 1966; Lacey 1972; Spooner *et al.* 2002) and tends to occur following periods of good seasons, defined primarily by 1 or 2 years of wet summers (Wilson *et al.* 1997) and below-average summer temperatures (Nicholson 1997). Recruitment tends to occur in waves, producing even-aged stands beneath large parent seed trees. In western NSW, successive waves of regeneration occurred during the 1870–1880s, 1950s (Curby 1997; Allen 1998; Grant 1989), 1970s, and more recently in the 1980s (Eldridge *et al.* 2003) and 2003 (R. Bradstock, pers. comm. 2004).

Grazing by sheep, cattle and rabbits suppresses the growth and survival of seedlings (Lacey 1972). In many areas the population structure comprises individuals in the same age (and size) class, partly attributed to invasions by the European rabbit (*Oryctolagus cuniculus*) which reached plague proportion on the western slopes of NSW between 1879 and 1897 (Grant 1989; Curby 1997). Rabbits ate pine seedlings, halting regeneration for up to 60 years in some areas (Harris and Lamb 2001). Suppression of *C. glaucophylla* by rabbit grazing continued until myxomatosis was introduced to control rabbits in the 1950s (Lacey 1973; Grant 1989). In the Riverina District of NSW, significantly higher recruitment has been recorded in ungrazed exclosures than at grazed sites (Spooner *et al.* 2002). Fire also influences the recruitment of *C. glaucophylla*. However, given the prolific number of cones in trees in dense stands, overall recruitment is unlikely to be limited even at high tree densities or at sites after burning.

#### Growth and development

Data on the growth of *C. glaucophylla* indicate that rates are slower in the more southern locations (e.g. Narrandera and Riverina Districts) than at sites in northern NSW (FCNSW 1988b). Lower growth rates are thought to be related to the incidence of summer rainfall and hence the increased potential for waterlogging in the root zone (FCNSW 1988b).

*Callitris glaucophylla* is known to grow in dense patches, when it is referred to as 'whipstick pine', where there is strong competition for water and nutrients (Anon. 1969; FCNSW 1988b). Pine stands lack a defined system of self-thinning; rather, growth halts in the majority of stems and the tree can remain in such condition for extended periods (Lacey 1972; FCNSW 1988a). This period where the trees occupy almost all available space is known as 'lock up' (Horne and Robinson 1987; Horne 1990b; Nowland 1997). Negligible growth occurs during this period. This is reputed to reduce ground cover and increase the risk of soil erosion (Nowland 1997), although the degree to which cover is reduced is likely to be dependent on grazing (Eldridge *et al.* 2003).

Mortality of *C. glaucophylla* attributed to periods of low rainfall is infrequent. Trees are able to survive in dry environments by producing feeder roots, which enable the trees to exploit subsoil moisture (Johnston 1975). The majority of roots occur in the top 0.2 m (Eberbach 2003) and density typically declines with depth. Feeder roots, which extend up to 6 m from the trunk (Eberbach 2003), make the species susceptible to waterlogging, although this is relatively uncommon (Johnston 1975).

### *Callitris glaucophylla* and landscape processes

#### Hydrological processes

The two main soil-texture types (fine-textured and coarse-textured soils) supporting *C. glaucophylla* woodland differ markedly in their response to rainfall (Eldridge and Freudenberger 2005). Infiltration rates on fine-textured soils (loams to clay-loams) are generally low to moderate, averaging 16.7 mm h<sup>-1</sup> under dense saplings (D. Eldridge, unpubl. data), 25.6–33.1 mm h<sup>-1</sup> under dense *C. glaucophylla* with sparse groundstorey plant cover, and up to 45.9 mm h<sup>-1</sup> under more open woodlands with scattered *C. glaucophylla*–*E. populnea* (Eldridge and Koen 1993; D. Eldridge, unpubl. data). In the western Riverina, infiltration data for *C. glaucophylla* woodlands indicate significantly greater sorptivity, the early phase of infiltration and steady-state infiltration, under ponded conditions underneath both *C. glaucophylla* and *E. microtheca* trees (means = 265 mm h<sup>-0.5</sup> and 117 mm h<sup>-1</sup> for sorptivity and infiltration, respectively) than with open and cultivated sites (means = 50 and 19 mm h<sup>-1</sup>, respectively; Eldridge and Freudenberger 2005). Infiltration is often very low directly under the canopies of *C. glaucophylla* because of water

repellency in the soils owing to a proliferation of fungal hyphae (Bond and Harris 1964). These fungi repel water and create hydrophobic conditions (Savage *et al.* 1969).

Infiltration under *C. glaucophylla* on coarse-textured (sandy) soils is markedly affected by soil biota (ants and termites), which are common components of pine woodlands (Eldridge 1993). The funnel ant (*Aphaenogaster barbigula*) is widely distributed on sandy soils dominated by *C. glaucophylla* in eastern Australia where it constructs large funnel-like nest entrances (Eldridge 1993). Increasing density and size of nest entrances results in higher rates of ponded infiltration in these soils and greater depth of water penetration into the soil (Eldridge 1993). The above-ground structures of the nest entrance are thought to prevent runoff water from penetrating into the subterranean colony.

Associations of mosses, lichens, liverworts and other microbiota, which form a biological soil crust (West 1990), are common components of *C. glaucophylla* woodlands. Differences in infiltration rates may be explained by the fact that surfaces without biological soil crusts have intrinsically lower infiltration rates because of the eroded nature of their surfaces (Mücher *et al.* 1988; Greene and Tongway 1989). Disturbance or removal of soil crusts may lead to an increase in infiltration on these soils in the short term, but over time the soils are likely to become compacted and crusted (physical soil crusts), leading to reductions in productivity (Eldridge 2002).

#### *Wind and water erosion processes*

We are unaware of any empirical data on rates of wind erosion from *C. glaucophylla* woodlands. However, given the density of trees, wind erosion is not likely to be a significant factor (J. F. Leys, pers. comm. 2003). Water erosion on soils typical of *C. glaucophylla* communities occurs as a result of a combination of weakly coherent surface soils, moderate slopes and a sparse cover of vascular plants. Although we have no empirical data on erosion rates from these soils, rates of the order of 1000 kg ha<sup>-1</sup> year<sup>-1</sup> are probable (Eldridge and Pickard 1994) under 1 in 5 years and 20-min rainfall events, particularly given the tendency of these soils to commence ponding after ~4 mm of rainfall (D. Eldridge, unpubl. data).

There is considerable debate, however, about whether water erosion results directly from the paucity of vascular vegetation under thickening *C. glaucophylla* stands, or whether the interaction of management (particularly grazing) and climate (rainfall) results in declining cover (Eldridge *et al.* 2003). Declining ground cover results in increased erosion (Andrews 2003), but there are no empirical data to support the notion that increased soil erosion is linked directly to increased density of *C. glaucophylla* (Eldridge *et al.* 2003).

Studies near Cobar in western NSW have demonstrated that patches of trees (*E. populnea*, *C. glaucophylla*) and native shrubs (such as *Eremophila* spp.) trap runoff and

sediment to a much greater extent than do patches devoid of trees (Harrington *et al.* 1981). Reduced runoff, and hence lower levels of erosion, is attributed to greater levels of leaf litter and soil nutrients under the tree canopies. This litter is known to enhance infiltration and reduce runoff and soil loss (Geddes and Dunkerley 1999). Erosion modeling using the SOLOSS model (Rosewell 1993), with data from the semi-arid woodlands (Shelley 1990), suggests that erosion declines as the canopy cover of trees increases (Eldridge *et al.* 2003). However, above ~40% groundstorey vegetation cover, tree canopy cover has very little impact on erosion. Taken together, these results suggest that management practices that reduce the cover of groundstorey vegetation are likely to result in accelerated levels of erosion (Eldridge *et al.* 2003). In some woodlands, leaf fall from mature *Eucalyptus* trees with projected canopy covers of 10–15% is expected to increase ground cover by up to 30%, which, along with shed bark and wood, contributes to about half of the cover needed to prevent excessive soil loss under tree canopies (Scanlan *et al.* 1996). This is likely to be similar under *C. glaucophylla* stands. Dense stands of *C. glaucophylla* produce large amounts of litter (Lacey 1972; Harris *et al.* 2003), in the order of 2286 kg ha<sup>-1</sup> year<sup>-1</sup> (Hart 1995). After rainfall sufficient to initiate overland flow (~25 mm over 1–2 h), litter accumulates in litter dams that form perpendicular to the slope (Eddy *et al.* 1999). These litter dams produce mini-catchments, preventing the offsite removal of sediments and producing nutrient-enriched microsites for the germination of vascular plants.

Thus, although groundstorey (vascular plant) cover may decline under dense stands of *C. glaucophylla*, other types of cover (biological soil crusts and litter) frequently compensate.

As indicated above, biological soil crusts are common components of *C. glaucophylla* woodland soils (Eldridge 1999). They reduce erosion by three main mechanisms. First, they provide a physical barrier at the surface, which reduces the erosive energy of raindrops. Second, lichens, in particular, create an uneven surface that tends to pond water, thus reducing water flow across the surface and restricting the erosive power of water. Third, organisms in the crust, such as cyanobacteria, produce gels and polysaccharides, which bind small soil particles into non-erodible aggregates, stabilising the surface (West 1990; Eldridge and Greene 1994a; Eldridge 1998). Biological soil crusts are common even under dense *C. glaucophylla* (W. A. Thompson, unpubl. data) and are extremely effective at reducing soil erosion by both splash erosion and overland flow.

#### *Callitris glaucophylla* and soil physical processes

The effects of *C. glaucophylla* trees on soil processes are not well documented. Consequently, for this review we have drawn on data from *Eucalyptus* woodlands where *C. glaucophylla* is a major component.

### Nutrient cycling

*Eucalyptus populnea*–*C. glaucophylla* woodlands are characterised by soils of low nutrient (nitrogen (N), phosphorus (P) and organic matter) status (Iwazkiewicz and Semple 1988). Organic carbon (C), sulfur (S) and N concentrations are low in surface soils (0.57, 0.02 and 0.25%, respectively; Eldridge 1993; Eldridge and Freudenberger 2005). Differences in nutrient concentrations are likely due to different processes operating at the scale of individual trees and processes moderated by soil biota associated with *C. glaucophylla* woodlands.

Removal of trees from the semi-arid woodlands has resulted in increased availability of water and N (Tunstall *et al.* 1981), demonstrating that trees deplete nutrients around their trunks (Gardner *et al.* 1990). However, studies of the effects of trees on soil properties in woodlands and savanna worldwide indicate higher levels of mineralisable N and extractable P, potassium (K) and calcium (Ca) in soils associated with tree canopies than in adjacent open grassland (e.g. Belsky *et al.* 1989; Belsky 1994). Within tree-dominated patches, concentrations of organic matter, total and available N, Ca, K, P, sodium (Na) and S have been found to be highest adjacent to the tree trunks, decline with distance within the canopy zone and reach their lowest concentrations in the open grassland (Belsky *et al.* 1989; Eldridge and Wong 2005).

Soil biota also contribute to soil nutrient levels in *C. glaucophylla* woodlands. Funnel ants excavate their nests in response to rainfall events which correspond to periods of overland flow and downslope sediment transport (Eldridge and Myers 1998). Litter trains comprising *C. glaucophylla* needles accumulate on the contour, often forming around the entrances to subterranean ant colonies. The deposition of litter against nest entrances and its burial by soil excavated from the nests significantly increase the concentrations of N, C and S in coarse-textured soils (Eldridge and Myers 1998). This leads to the development of small-scale spatial patchiness in soil nutrients, which is likely to influence other ecological processes such as germination and survival of vascular plants, and act as refugia for soil biota (Whitford and Kay 1999).

### Soil aggregation and formation

As with other trees, *C. glaucophylla* is likely to promote the development of healthy soils. Surface roots are likely to enhance macropore formation and therefore the stability of soil aggregates (Degens 1997). Increased soil aggregation beneath trees can also be attributed to soil biota such as invertebrates beneath the trees (Chilcott *et al.* 1997), which act to improve the physical and chemical conditions through the incorporation of organic matter into the soil (Vetaas 1992).

Soil biota such as ants, termites and earthworms enhance soil organic matter, soil structure and porosity, leading to

changes in bulk density and increased infiltration (Lobry de Bruyn and Conacher 1990; Eldridge and Pickard 1994). Long-term studies of biopedturbation in the coarse-textured soil of a *C. glaucophylla* woodland at Yathong Nature Reserve have indicated that ants bring to the surface an average of 3360 kg ha<sup>-1</sup> year<sup>-1</sup> of soil (Eldridge and Pickard 1994). These rates are undoubtedly conservative, given the large diversity of other macro-invertebrates (e.g. spiders and scorpions) common in similar soils in *C. glaucophylla* woodlands (Martin and Major 2001). The location and density of nest entrances change regularly, with turnover on average about twice yearly (Eldridge and Pickard 1994). The rates of nest turnover indicate that the total area of the soil surface is likely to be converted to a nest entrance within 200 years, again a conservative value given other invertebrates at these sites. Ant activity is likely to lead to the development of a new soil biomantle (Johnson 1990), which in the Yathong studies occurred at ~0.28 mm year<sup>-1</sup> (Eldridge and Pickard 1994).

### Carbon sequestration

Woodlands dominated by *C. glaucophylla* are effective sinks for carbon, both by the soil and the vegetation itself, particularly where the vegetation is structurally diverse (Eldridge and Wilson 2002). Dense layers of *Callitris* litter, as well as surface biota, contribute directly to soil C. Blue-green algae, other terrestrial algae, cyanolichens in biological soil crusts and free-living cyanobacteria in the soil have the potential to contribute organic C fixed in photosynthesis directly to the soil ecosystem (Beymer and Klopatek 1991). Studies from mixed *E. populnea*–*C. glaucophylla* woodlands have shown that soils directly under the crust have significantly more organic C than adjacent non-crust soil (Eldridge and Greene 1994a).

However, the greatest amount of carbon is being stored in the vegetation itself. Dense ‘whipstick’ *C. glaucophylla* and *C. endlicheri* stored ~8.7 t C ha<sup>-1</sup>, equivalent to the amount stored in scattered woodland trees and about half that of a dense woodland (Eldridge and Wilson 2002). Levels of carbon stored in vegetation were substantially greater than levels stored in the soil. Thus, from the perspective of Kyoto compliant activities and the development of methods to enhance carbon storage, changes to vegetation cover are likely to have a greater effect than changes to soil carbon content (Eldridge and Wilson 2002).

### *Callitris glaucophylla* woodlands as habitat for plants and animals

#### Vascular plants of *C. glaucophylla* woodlands

That *C. glaucophylla* woodlands are floristically rich is supported by many studies at regional and local scales in NSW (Table 2). A major review of the rangelands in NSW identified a list of 199 vascular plant species commonly

**Table 2. Diversity of vascular and non-vascular plants from *Callitris glaucophylla* communities from a range of studies in NSW**  
Non-vascular plants are indicated by asterisks

Location	No. of taxa	Reference
Wahgunyah State Forest, Finley	90	SFNSW (1996)
Cobar*	47	Eldridge (1999)
'Zara', Deniliquin	70	Stafford and Eldridge (2000)
Tottenham–Bobadah area	150	Shelly (2001)
MIA, Griffith	150	Eldridge (2002)
Savernake and Native Dog, Finley	194	Freudenberger and Stol (2002)
Northwestern NSW	160	DIPNR (unpubl. report)
MIA, Griffith*	~100	Eldridge (unpubl. data)
Savernake and Native Dog, Finley*	49	Freudenberger and Stol (2002); D. J. Eldridge, D. Freudenberger and T. B. Koen (unpubl. data)

associated within *E. populnea*–*C. glaucophylla* communities (Iwaszkiewicz and Semple 1988) and anecdotal evidence suggests that this figure depends on grazing management (Eldridge *et al.* 2003). A regional study across 83 sites, each 0.04 ha, between Eugowra and Poongah in NSW yielded over 350 vascular plant species from 52 families (Thompson and Eldridge 2005). More localised, detailed flora surveys of individual *C. glaucophylla*-dominant woodlands have generated up to 200 species (Table 2).

In general, larger remnants tend to have a greater diversity of flora (Spooner *et al.* 2002) and fauna (Murphy 1999) than smaller remnants. However, even small remnants can contain large numbers of species (both flora and fauna). For example, a 225-ha *Eucalyptus* spp.–*C. glaucophylla* remnant on the southwestern slopes near Wagga Wagga (NSW) contained 112 native (plus 53 exotic) plant species, as well as more than 90 native bird species and five native mammal species (Murphy 1999).

#### *Non-vascular plants of C. glaucophylla woodlands*

Little has been published on the non-vascular flora of *C. glaucophylla* woodlands (Table 2), although there is evidence that these groups are important in the function and stability of woodland communities (Eldridge and Greene 1994b; Eldridge and Koen 1998). The trunks of *C. glaucophylla* are known to provide suitable habitat for corticolous lichens (particularly *Flavoparmelia ferax*, *F. rutidota*, *Caloplaca citrina*) and bryophytes (mosses and liverworts), and the soil surface below their canopies supports a rich suite of arid-area lichens and bryophytes (Eldridge 1996; Eldridge and Tozer 1997). Communities within the semi-arid woodlands are dominated by the mosses *Triquetrella papillata*, *Eccremidium pulchellum* and *Bryum pachytheca* and the lichen *Endocarpon simplicatum* var. *bisporum* (D. J. Eldridge, D. Freudenberger and T. B. Koen, unpubl. data). More intensive studies of these woodlands are likely to reveal a greater number of taxa.

As indicated above, although vascular plants are often absent from dense *C. glaucophylla* woodlands (Nowland 1997; Eldridge *et al.* 2003), the soil surface is frequently dominated by non-vascular plants that form biological soil crusts. These plants may be the only form of ground cover in some areas during droughts, and may compensate for reduced groundstorey vegetation. Although the sandy soils in *C. glaucophylla* woodlands have typically low water-holding capacities, the soil provides sufficient moisture to support arid-area mosses which use a range of morphologies such as leaf curling and hair points to survive periods of water stress (Eldridge and Tozer 1997).

In a detailed study of non-vascular plants in relation to landscape patterning near Cobar (Eldridge 1999), taxa were separated clearly into groups corresponding with the three zones: runoff zones, interception zones and zones below *C. glaucophylla* canopies. Only two moss taxa (*Fissidens vittatus* and *Barbula hornschiuchiana*) were found under the *C. glaucophylla* canopies and the remainder was distributed in relation to soil erosion and stability, and litter cover. Eroded runoff zones supported sparse populations of 'erosion-tolerant' lichens (*Endocarpon rogersii*) and mosses (*Bryum argenteum* and *Didymodon torquatus*) and the intermediate interception zones were dominated by 'crust-forming' taxa capable of tolerating inundation by water. Pioneering, N-fixing lichens (*Collema coccophorum*, *Peltula* spp.) dominated the zones of active erosion at the lower edge of the canopies, whereas the 'opportunists', dominated by liverworts, occupied the shallow depressions at the margins of canopy and the interception zones (Eldridge 1999).

#### *Vertebrates of C. glaucophylla woodlands*

Stands of *C. glaucophylla* provide habitat for a variety of wildlife, some of which are regionally or locally threatened (Table 3). In the grassy box woodlands of eastern Australia, *C. glaucophylla* often represents the only mid-storey element in the landscape, providing an important habitat for birds.

**Table 3. Threatened and rare fauna found within *Callitris glaucophylla* woodlands in eastern Australia**  
TSCAB, Threatened Species Conservation Act Biological Database (DLWC 2001)

Organism	Status	Reference
Vertebrates		
Brush-tailed rock wallaby ( <i>Petrogale penicillata</i> )	Threatened	TSCAB
Greater long-eared bat ( <i>Nyctophilus timoriensis</i> )	Threatened	TSCAB
Inland forest bat ( <i>Vespadelus baverstocki</i> )	Threatened	TSCAB
Little pied bat ( <i>Chalinolobus picatus</i> )	Threatened	TSCAB
Squirrel glider ( <i>Petaurus norfolcensis</i> )	Threatened	TSCAB
Yellow-bellied sheathtail bat ( <i>Saccolaimus flaviventris</i> )	Threatened	TSCAB
Birds		
Australian bustard ( <i>Ardeotis australis</i> )	Threatened	TSCAB
Barking owl ( <i>Ninox connivens</i> )	Threatened	TSCAB
Black-breasted buzzard ( <i>Hamirostra melanosternon</i> )	Threatened	TSCAB
Brown treecreeper-eastern subspecies ( <i>Climacteris picumnus victoriae</i> )	Threatened	TSCAB
Bush stone-curlew ( <i>Burhinus grallarius</i> )	Threatened	TSCAB
Chestnut quail-thrush ( <i>Cinclosoma castanotus</i> )	Threatened	TSCAB
Diamond firetail ( <i>Stagonopleura guttata</i> )	Threatened	TSCAB
Gilbert's whistler ( <i>Pachycephala inornata</i> )	Threatened	TSCAB
Glossy black-cockatoo ( <i>Calyptorhynchus lathamii</i> )	Threatened	TSCAB
Grey-crowned babbler ( <i>Pomatostomus temporalis</i> )	Threatened	Kent <i>et al.</i> (2002), TSCAB
Grey falcon ( <i>Falco hypoleucos</i> )	Threatened	TSCAB
Hooded robin south-eastern form ( <i>Melanodryas cucullata cucullata</i> )	Threatened	TSCAB
Malleefowl ( <i>Leipoa ocellata</i> )	Threatened	TSCAB
Masked owl ( <i>Tyto novaehollandiae</i> )	Threatened	TSCAB
Olive whistler ( <i>Pachycephala olivacea</i> )	Threatened	TSCAB
Painted honeyeater ( <i>Grantiella picta</i> )	Threatened	TSCAB
Pied honeyeater ( <i>Certhionyx variegatus</i> )	Threatened	TSCAB
Pink cockatoo ( <i>Cacatua leadbeateri</i> )	Threatened	TSCAB
Regent honeyeater ( <i>Xanthomyza phrygia</i> )	Threatened	TSCAB
Southern scrub-robin ( <i>Drymodes brunneopygia</i> )	Threatened	TSCAB
Speckled warbler ( <i>Chthonicola sagittata</i> )	Threatened	TSCAB
Square-tailed kite ( <i>Lophoictinia isura</i> )	Threatened	TSCAB
Superb parrot ( <i>Polytelis swainsonii</i> )	Threatened	Kent <i>et al.</i> (2002), TSCAB
Swift parrot ( <i>Lathamus discolor</i> )	Threatened	TSCAB
Turquoise parrot ( <i>Neophema pulchella</i> )	Threatened	TSCAB
Reptiles and amphibians		
Golden-tailed gecko ( <i>Strophurus taenicauda</i> )	Rare	Hauenschild and Smith (1999)

Mammals, birds, reptiles and invertebrates use all levels of *C. glaucophylla* communities from the canopy to the soil surface. Large numbers of birds and reptiles reach their highest proportions in *C. glaucophylla* vegetation communities (Nix 1986; Paull and Date 1999).

The foliage of *C. glaucophylla* provides shelter for small birds, whereas cockatoos and galahs (*Cacatua roseicapilla*) are known to feed on the *C. glaucophylla* seeds (Hauenschild and Smith 1999). In northern Victoria, the abundance of red-capped robin (*Petroica goodenovii*) was highest in *C. glaucophylla* woodlands, and greater than in the surrounding eucalypt woodlands (Dowling *et al.* 2003). As the red-capped robin is territorial and offspring must disperse to establish new territories, the necessity of retaining roadside corridors and remnant vegetation is critical (Major *et al.* 1999a; Dowling *et al.* 2003).

Early bird surveys in *C. glaucophylla* woodlands recorded over 80 species (Pilliga scrub; Cleland 1919; Chisholm 1936). In NSW, more than 70 bird species have been recorded at several *C. glaucophylla* State Forests (FCNSW 1981; SFNSW 1996), including the vulnerable superb parrot (*Polytelis swainsonii*) and the painted honeyeater (*Grantiella picta*; M. Todd, pers. comm. 2003). Detailed studies, however, are yet to determine which species are residents or itinerants (SFNSW 1996). Mixed woodlands dominated by brigalow (*Acacia harpophylla*), gidgee (*Acacia oswaldii*), rosewood (*Alectryon oleifolius*) and *C. glaucophylla* are important habitats for painted honeyeaters, particularly those with high densities of mistletoe (Oliver *et al.* 2003).

At Roxby Downs, the most arid limit of *C. glaucophylla* in South Australia, the species is an important habitat for raptors, galahs, blue-bonnet parrots (*Northiella*



*haematogaster*) and the mulga parrot (*Psephotus varius*). Most nest sightings of wedge-tailed eagles (*Aquila audax*), little eagles (*Hieraetus morphnoides*) and black and whistling kites (*Milvus migrans* and *Haliastur sphenurus*, respectively) are in *C. glaucophylla* trees (Read 1995). In western NSW, wedge-tailed eagles frequently use *C. glaucophylla*, along with leopardwood (*Flindersia maculosa*) and beefwood (*Grevillea striata*), as nesting sites because they are often the tallest trees available (Sharp *et al.* 2001).

Several faunal surveys of cypress pine forests (FCNSW 1981; SFNSW 1996) and *C. glaucophylla*–*Eucalyptus* species woodlands (Shelly 1998) share common mammal sightings such as the eastern grey kangaroo (*Macropus giganteus*) and the common brushtail possum (*Trichosurus vulpecula*). Although most non-eucalypt woodlands often lack folivorous mammals, common brushtail possums cover a wide range of vegetation habitats (Strahan 1995; Woinarski *et al.* 1997). During surveys, six species of bats were recorded in Buckingham State Forest near Narrandera (FCNSW 1981), along with recordings of the lesser long-eared bat (*Nyctophilus geoffroyi*), which was also found at the nearby Wahgunyah State Forest (SFNSW 1996). Near Dalby, Queensland, the native delicate mouse (*Pseudomys delicatulus*) is known to burrow in the sandy soils of *C. glaucophylla* stands (Hauenschild and Smith 1999) and the Pilliga mouse (*Pseudomys pilligaensis*) is an obligate species known only to sandy substrates dominated by *C. glaucophylla* in the Pilliga State Forest (Strahan 1995).

Reptiles and amphibians are also relatively common in *C. glaucophylla* woodlands. The ornate burrowing frog (*Limnodynastes ornatus*) prefers sandy soils such as those of *Callitris* communities (Hauenschild and Smith 1999), and state forests in the Narrandera area are home to the red-groined toadlet (*Uperoleia rugosa*; FCNSW 1981; SFNSW 1996) and four additional frog species (FCNSW 1981). A biodiversity survey of woody weed communities of western NSW found an assortment of skinks, snakes, geckos, lizards and dragons (Ayers *et al.* 2001). In southern inland Queensland, the bark of older *C. glaucophylla* provides shelter for the rare golden-tailed gecko (*Diplodactylus taenicaudus*; Hauenschild and Smith 1999). Surveys of both isolated and remnant vegetation have demonstrated the necessity to retain old, hollow-bearing trees (Date *et al.* 2000, 2002; Law *et al.* 2000). For example, Date *et al.* (2000) recorded over 25 snake, bird and mammal species dependent on hollows in mature eucalypt–*C. glaucophylla* woodlands.

#### *Invertebrates of C. glaucophylla woodlands*

There is little knowledge of the invertebrate fauna associated with *C. glaucophylla* woodlands. Several surveys (Major *et al.* 1999b, 2003) have indicated that invertebrates inhabiting *C. glaucophylla* woodlands have not been adversely affected by habitat fragmentation, although it

is likely that disturbance-sensitive species have already disappeared (Major *et al.* 2003). *C. glaucophylla* woodlands are known to be a good habitat for ground-dwelling spiders (e.g. *Lycosid* spp., Martin and Major 2001) and the sandy soils support funnel ants which are thought to tend fungi growing on the roots of *C. glaucophylla* trees (E. A. Davison, pers. comm. 2002).

Several species of gall midges (Diptera: Cecidomyiidae) are associated with the Australian *Callitris* genus, some of which may inhibit *Callitris* reproduction and development (Kolesik 2000). The insect, *Diplosis frenelae*, is the most common producer of galls in *C. glaucophylla* (Lacey 1973). Other potential damaging insects include the cypress pine sawfly (*Zenarge turneri*), the cypress pine aphid (*Cinara tujafilina*) and the cypress pine jewel beetle (*Diadoxus scalaris*), with the latter occasionally causing death when feeding tunnels ‘girdle’ the tree (Lacey 1973).

#### **Ecology of *C. glaucophylla*: fire and grazing**

##### *The role of fire*

Fire is an important ecological phenomenon throughout much of the Australian continent, and many species need fire to regenerate (Bowman 1998, 2000; Pyne 1998; Bradstock *et al.* 2002). Extensive reviews have already been undertaken, examining the role of aboriginal burning on the landscape (Bowman and Panton 1993; Bowman 1998).

Dense stands of *C. glaucophylla* naturally preclude fire to some extent by suppressing understorey plant cover and enhancing breakdown of litter (Lacey 1973), as well as reducing wind speed (Wilson *et al.* 1997). The primary determinants of tree survival are fire intensity and the length of time that fire burns the base of the tree (Iwazskiewicz and Semple 1988). Trees are more vulnerable when regenerating (Lacey 1972) and, as a general rule, mortality is high for trees under ~1–2 m during mild fires. Unlike *Eucalyptus* species, the crowns of *C. glaucophylla* will not re-establish after fire (Iwazskiewicz and Semple 1988). Fire will also reduce seed production for up to 7 years after a severe fire (Hawkins 1966).

In eastern Australia, a combination of burning by Aborigines, wildfire, prescribed burning and fire exclusion has produced a patchwork of various stages of *C. glaucophylla* regeneration (Harris and Lamb 2001). Although prescribed burning (and wildfire) can be a useful strategy for reducing the cover and density of *C. glaucophylla* (Wilson and Mulham 1979; Hodgkinson and Harrington 1985), wildfire poses a major threat to forestry activities. Further, successful long-term conservation of the species depends on the active management to reduce the intensity of wildfires (Bowman and Latz 1993).

For commercial forestry, current fire management focuses on limiting the risk of wildfires by reducing fuel loads,

thereby minimising damage to trees. Grazing is the most effective method of reducing fuel loads (see Grazing below) and low-intensity fires are an effective method of controlling *C. glaucophylla* seedlings and reducing fuel loads, but are currently not practiced within the forestry industry (Date *et al.* 2000). Low-intensity burns would not only reduce the necessity for thinning non-commercial species, but also would lengthen the cutting cycle and promote a more diverse understorey (Date *et al.* 2000, 2002).

#### *Impact of grazing*

Many *C. glaucophylla* woodlands operating as either commercial or non-commercial forests are currently grazed by domestic and native animals (Johnston 1967; Wilson *et al.* 1997). Grazing has been proposed as a suitable method of reducing groundstorey biomass and hence the risk of wildfire while generating an income for SFNSW (Nicholson 1997; Wilson *et al.* 1997). Furthermore, timber harvesting and grazing are seen as being compatible land uses (FCNSW 1981). Intermittent, intensive grazing by sheep may be a useful management strategy in situations where it is desirable to control or thin dense pine regeneration. However, in general, cattle are preferred grazers as they are more effective at reducing the fire hazard by eating more from the top down (Wilson *et al.* 1997).

Grazing in *C. glaucophylla* woodlands can be problematic. Browsing by sheep and cattle may restrict pine regeneration (Lacey 1973; Johnston 1975), and SFNSW have been known to terminate grazing leases for *C. glaucophylla* forests in order to ensure sufficient regeneration of seedlings (Grant 1989). Rabbit grazing is also highly damaging to young pine seedlings (Lacey 1973; Curby 1997; Nicholson 1997; Allen 1998; Allcock and Hik 2004), reducing regeneration of rosewood and belah (*Casuarina cristata*) seedlings and increasing the spread of exotic shrubs such as African boxthorn (*Lycium ferocissimum*; Stafford and Eldridge 2000). Higher recruitment of *C. glaucophylla* has been observed under fenced (ungrazed by domestic animals) than unfenced (grazed) conditions, and grazing exclusion is probably the only profitable management alternative for *C. glaucophylla* woodlands (Spooner *et al.* 2002).

#### **Managing *C. glaucophylla* woodlands**

Stands of *C. glaucophylla* exist under various management regimes including grazing by native, domestic and feral animals, artificial thinning (i.e. commercial thinning and brush cutting) and natural regeneration (i.e. little or no management).

#### *Pre-European management of C. glaucophylla*

There is evidence that *C. glaucophylla* was of considerable interest to the Australian Aborigines (Bowman and Harris 1995; National Forestry Inventory 1998). Although aboriginal use of *Callitris* species is poorly documented

(Bowman and Harris 1995), it is known that the timber of both *C. glaucophylla* and *C. intratropica* was used to make 'spears, spear throwers, ceremonial objects, paddles and musical sticks', as well as fires and torches (Bowman and Harris 1995; Binnington 1997). The Aborigines benefited from more than just the use of white cypress timber; they created an adhesive by mixing pine resin and kangaroo dung, and the bark and foliage was used as a mosquito repellent (Binnington 1997). Aborigines used fire extensively to manage the landscape (Benson 1991; Price and Bowman 1994; Bowman 1998, 2000; Pyne 1998) but burning cycles ceased within the cypress pine zone with the expansion of agriculture and pastoralism by the early Europeans.

#### *Silvicultural management of C. glaucophylla*

The use of *C. glaucophylla* for timber commenced during the late 1800s, soon after Europeans recognised the value of the species. In 1876, the first Forest Reserve was dedicated in NSW, and regulations to limit both the size of harvested timber and methods to manipulate stand densities were introduced (van Kempen 1997).

State Forests of NSW performed the first silviculture manipulation of *C. glaucophylla* in 1893 when they thinned almost 500 ha of Wahgunyah State Forest (formerly Wahgunyah Timber Reserve; Grant 1989). From 1893 to 1902, 58 000 ha of regrowth pine were thinned by the Forestry Branch, and thinning then ceased until 1915–1916 (Grant 1989). From the establishment of the Forestry Commission of NSW in 1916, silvicultural practices have become a regular feature of *Callitris* pine State Forests (Grant 1989). From 1883, Timber Reserves were thinned by lessees under the supervision of the Forestry Commission; this continued until 1889, and then from 1909 the thinning came under the conditions of lease improvements (Grant 1989).

Although some sawmills have been abandoned over the last 50 years, *C. glaucophylla* forests continue to supply millable timber in Queensland and NSW. *C. glaucophylla* timber is durable and termite resistant (Baker and Smith 1910) and has a multitude of uses including house construction, flooring, cladding and fence posts (National Forestry Inventory 1998). The value of *C. glaucophylla* to forestry has led to research focused on silviculture. The significance of this species extends beyond the interests of state governments and private timber harvest yields.

The largest remaining stands of *C. glaucophylla* forests are held within the Pilliga Management Area, centred on the township of Pilliga in northwestern NSW. This *Callitris* forest covers 269 626 ha (64%) of the total of 421 218 ha of this management area (Knott 1995), and remains a significant resource for *C. glaucophylla* sawlogs as well as an important centre of history and management of *C. glaucophylla*.

The need for thinning the dense 'whip-like' stands of regenerating *C. glaucophylla* was apparent quite early (Johnston 1975). Lacey (1973) reported that after 20 years,

tree densities in excess of 125 000 trees ha<sup>-1</sup> were not unusual. In many state forests, estimated densities of regenerating pines varied from 163 000 trees ha<sup>-1</sup> (Horne 1990a) to 620 000 trees ha<sup>-1</sup> (Horne 1990b). Prior to using manipulative thinning techniques, control of white cypress pine regeneration was almost entirely by fire, either periodic wildfires or burning by Aborigines and settlers (Johnston 1975). Farmers settling into cypress pine country prior to 1920 were often required to thin dense, immature pine as part of a lease-improvement program (Lindsay 1967). Between 1925 and 1945, experimental thinning programs were established (Johnston 1975), and through the mid-western and southern regions of Queensland, large work gangs were engaged in manual thinning during the 1940s and the early 1970s (Johnston and Jennings 1991).

Current thinning practices include the use of manual (e.g. machetes) and mechanical (e.g. chainsaws) methods, as well as stock grazing. The results of various thinning trials in NSW and Queensland have been reported in recent decades (Lacey 1973; Johnston 1975; Horne and Robinson 1987; Horne 1990a, 1990b). Secondary regeneration needs to be controlled by varying levels of thinning to reduce the time taken for trees to reach a merchantable size (Horne and Robinson 1987; Horne 1990a, 1990b). In fact, in many areas of crown land such as pastoral leases in western NSW, leasehold agreements include clauses to encourage the growth and dominance of *C. glaucophylla* through both the removal of mature eucalypts and the thinning of pines (Date *et al.* 2000). Thinning may also provide biodiversity benefits by providing gaps in the canopy to improve regeneration and to increase structural complexity (Spooner *et al.* 2002).

Despite its forestry value, *C. glaucophylla* has been shown to be a poor plantation tree in Australia, with inadequate form and lower growth rates in plantation-grown trees than with natural stands (Lacey 1973). In Malawi and South Africa, however, it is a successful plantation species and a useful source of timber (Lacey 1973).

#### *Managing for conservation*

One of the major issues facing conservation and *C. glaucophylla* woodlands is the paucity of reserves and the poor retention of the species within the current reserve system. In the Murrumbidgee Irrigation Area of south-western NSW, less than 10% of the pre-European cover of *C. glaucophylla* remains (Eldridge 2002), and this is typical of wider NSW. Land clearing in NSW, particularly in the wheat–sheep belt, has been, and continues to be, extensive (Sivertsen and Metcalfe 1995; Cox *et al.* 2001), despite the implementation of the NSW Native Vegetation Act 1997. Overriding pressures from agriculture and irrigation have resulted in substantial change to much of the original *C. glaucophylla* woodlands, with the result that remnant communities are generally found only on rocky ridges,

isolated sandhills (Stafford and Eldridge 2000) or in State Forests (Eldridge 2002). Although much of the environmental pressure of the 1970s and 1980s was not focused on dry inland forests, management practices in NSW and Queensland forests have changed (Dargavel and Kowald 2001). In some areas, *C. glaucophylla* forests are being administered for both silviculture and as wildlife habitat for plants and animals. State Forests of NSW has incorporated flora reserves into some cypress forests (i.e. Pilliga Management Area, Buckingbong State Forest, Wahgunyah State Forest); however, in NSW only 9% of cypress forests are retained in land classified as nature conservation reserves, with 60% designated ‘multiple-use forests’ (Binnington 1997). In western NSW, *C. glaucophylla* has been recorded in many National Parks (NP) and Nature Reserves (NR), including Yathong NR (NSW NPWS 1991), Nombinnie and Round Hill NR (Cohn 1995), Cocoparra NP (D. J. Eldridge, unpubl. data), Mungo NP (Westbrooke and Miller 1995), Kinchega NP (Westbrooke *et al.* 2001), Kajuligah NP and Tarawi NR (Westbrooke *et al.* 1998).

Forestry has shifted in recent decades from ‘multiple-use’ forests to the implementation of biodiversity standards (Dargavel and Kowald 2001). However, little is known about specific silvicultural practices that maximise the diversity of the *C. glaucophylla* understorey and therefore maximise its habitat value. Further, there is a need to identify administration procedures within State Forests of NSW, which encourage a high diversity of flora and fauna within *C. glaucophylla* forests, while at the same time yielding economic returns (Eldridge *et al.* 2003). For example, little is known of the impact on flora and fauna of artificial thinning techniques such as timber stand improvement which was carried out between the 1960s and 1980s, and commercial thinning with brush cutters and mechanical tree removal. Preliminary results of the impact of artificial thinning of 40-year-old stands of *C. glaucophylla* indicate increased diversity and abundance of bird and understorey plant communities (P. Cameron, Western Plains Zoo, Dubbo, pers. comm. 2001).

#### **‘Regrowth’ and vegetation clearance: management issues within *C. glaucophylla* woodlands**

Anecdotal information suggests that large areas of extant *C. glaucophylla* woodlands are considerably denser than they were prior to European settlement, and that this increase in density has purportedly exacerbated the reduction in vegetation cover. Studies to determine the structure of former *C. glaucophylla* forests (combining historical records and dendrochronology) have indicated that trees were large and well spaced prior to the early nineteenth century, at least in the lower Snowy River area of eastern Australia (Pulsford *et al.* 1993) and probably in the Riverina area (I. Lunt, pers. comm. 2004). After more than a century of logging, grazing, burning and feral animal activity,

present stands of regrowth are effectively 'locked up' for long periods.

The density and condition of *C. glaucophylla* woodlands vary widely across the continent, and are often influenced by prior management. Increasingly, as governments introduce restrictions on clearing such as the Native Vegetation Conservation Act 1997, Native Vegetation Act 2003 and Queensland Vegetation Management Act 1999, landholders, unable to clear large areas of *C. glaucophylla* and eucalypt woodland, have become increasingly concerned about the issue of native tree and shrub regeneration. Some claim that areas of dense regeneration, known colloquially as 'regrowth' or 'invasive scrub', hamper the grazing value of woodlands because of the reduction in groundstorey plants, particularly grasses (Nicholson 1997; Eldridge *et al.* 2003). For example, Cunningham *et al.* (1992) noted that in the Cobar area of NSW, dense thickets of young *C. glaucophylla* cover extensive areas. However, the inter-departmental report on scrub and timber regrowth in the Cobar–Byrock area noted that the proliferation of timber and scrub regrowth was not singularly responsible for the decline in productivity of pastoral lands (Anon. 1969). The report pointed out that widespread erosion, and the dire conditions of pastoralists in the Cobar area, attributed to extensive overgrazing by sheep and rabbits, was exacerbated by a prolonged drought in the late 1800s (Anon. 1969).

Others contend that *C. glaucophylla* woodlands have many other landscape and ecological benefits (Eldridge *et al.* 2003) and that broad-scale clearing could potentially be ecologically dangerous. In central NSW for example, the relatively rapid increase in clearing and cropping in semi-arid woodland areas has contributed to major environmental problems (Shelly 2001). There is currently 26 000 km<sup>2</sup> of woodland containing *C. glaucophylla* in Queensland; this constitutes ~12% of the pre-clearing area of the species (Wilson *et al.* 2002).

These rates of clearing are cause for concern because of habitat reduction and loss of ecosystem function. Although clearing may be profitable to individual landholders in the short term, there is a long-term risk of clearing on biodiversity and land degradation, which is carried by the wider community (Rolfe 2002). Vegetation clearance has a profound negative impact on biodiversity, and clearance and fragmentation have been known to result in a major reduction in both diversity and abundance of many faunal groups (Ludwig *et al.* 2000; Ford *et al.* 2001).

## Conclusions

*Callitris glaucophylla* remains an important species in semi-arid eastern Australia, both for commercial forestry and conservation. Research, which initially focused on silviculture, has widened to include not only the impact of climate and management on the tree species but its role in landscape and ecological processes. Although

extensive clearing has occurred through out much of the pre-European geographic distribution, *C. glaucophylla* still persists across much of its original range, albeit in small fragmented pockets.

Land management has affected much of the original community and recruitment structure. Clearing following land settlement led to much of the degradation of grazing lands. 'Whipstick' regeneration became more prevalent because of the prolific germination and survival of *C. glaucophylla* seedlings under favourable conditions and gaps left by other tree species that were intentionally removed from the community. Under these artificially 'managed' landscapes *C. glaucophylla* has been able to dominate the basal area and reduce the viability of grazing, helping to extend the notion that *C. glaucophylla*-dominated woodlands have low levels of landscape stability and function. However, ecological studies of *C. glaucophylla* woodlands have not always supported these assertions. Although thick stands often have reduced groundstorey vegetation, other forms of cover, such as biological crusts and litter ensure a stable surface. Despite the negative connotations associated with regrowth *C. glaucophylla* woodlands, relative stability, biodiversity, potential commercial viability (under appropriate management) and value for carbon credits suggest that the species warrants further study.

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