Department of Science, Information Technology, Innovation and the Arts

Eucalypt Woodlands

Regrowth Benefits - Management Guideline

Great state. Great opportunity.

Queensland Government

Prepared by

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Disclaimer

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Summary

- Eucalypt woodlands occur over a large area of eastern Queensland, from the New South Wales border to Cape York Peninsula, and include the temperate woodlands of the New England Tablelands and Darling Downs, semi-arid box and ironbark woodlands throughout central Queensland, and some of the tropical savannas of northern Queensland.
- Estimates of living above-ground biomass for eucalypt woodlands which are at least 25 years old range from 41 to 113 tonnes per hectare (t ha^{-1}), which translate to about 70 to 195 tonnes of carbon dioxide equivalent (tCO_2-e) per hectare.
- The estimated peak carbon accumulation rate of reforestation in eucalypt woodland country ranges from about 1 to more than 3 tCO_2-e per hectare per year.
- Rainfall and past clearing history have a large influence on potential for reforestation and carbon accumulation in eucalypt woodland country, but ongoing management can also have a large effect.
- Continuous high grazing pressure, hot fires[1] and soil degradation will slow and may prevent the restoration of eucalypt woodlands, as these will inhibit tree establishment and growth.
- Livestock grazing can be compatible with reforestation in eucalypt woodlands, as long as grazing pressure is held at low to moderate levels, and strategic spelling is adequate to allow tree recruitment. Increasing the biomass of trees will reduce the carrying capacity for grazing.
- Regrowing eucalypt woodlands will benefit biodiversity, especially animals such as birds, reptiles and mammals that are strongly dependent upon eucalypt woodlands for habitat.

[1] In this guideline, the term ‘hot fire’ is equivalent to a moderate or high severity or higher fire . ‘Hot fires’ can occur whenever humidity and soil moisture levels are low, and they most commonly occur in the late dry season. In Queensland, this tends to be in winter or spring. See the National Parks, Recreation, Sport and Racing’s bioregional planned burn guidelines for definitions of fire severity for Queensland open forests and woodlands http://www.nprsr.qld.gov.au/managing/planned-burn-guidelines.html (2013).

Description

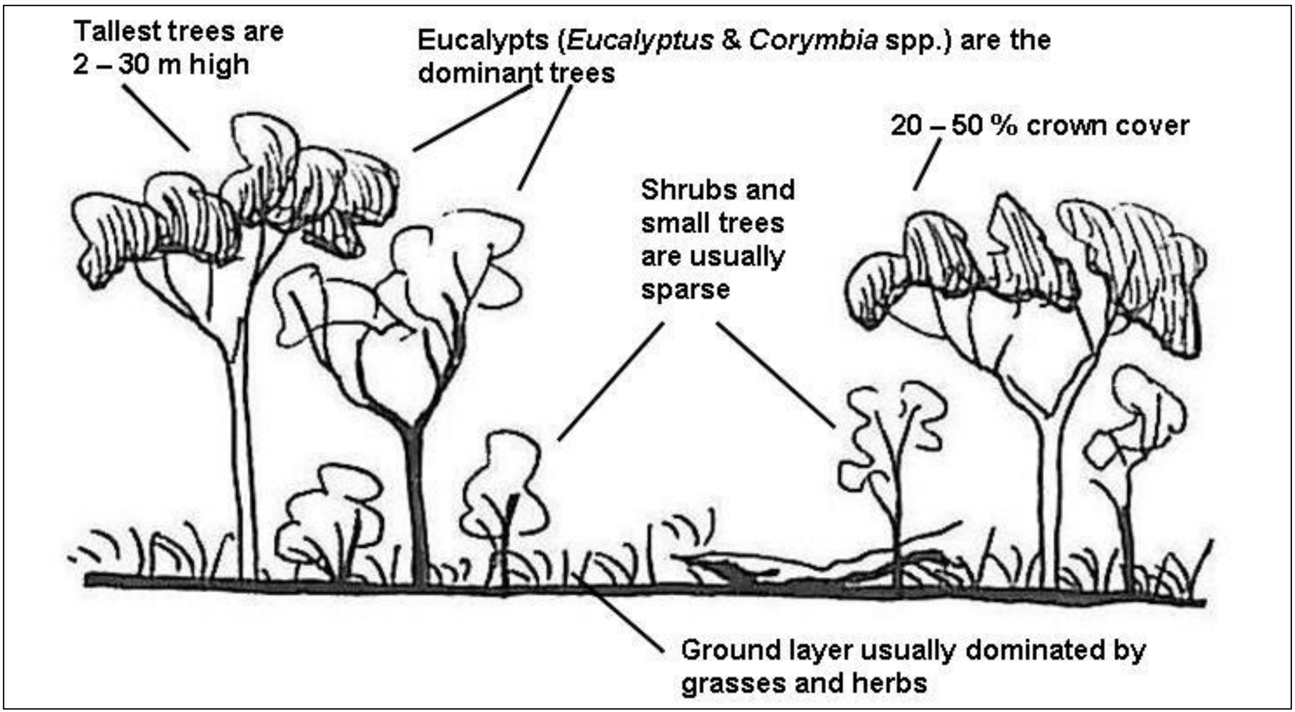

Figure 1: The structural features of eucalypt woodlands

Generally, eucalypt woodlands[2] in Queensland have the following features:

- Eucalypts[3] are the tallest trees, and form the upper canopy layer. They can range in height from 2 m to over 30 m, but are typically 15-25m tall.
- Canopy cover can vary from 20 – 50% for approximate crown cover (Queensland Herbarium 2011).
- The ground layer is more likely to be dominated by grasses and other herbs than by shrubs, and the species richness of native grasses and other herbs can be as high as 30 or more species (McIntyre & Martin 2001).
- Several species of *Eucalyptus* and/or *Corymbia* may be present in the canopy at any one site. The species composition may vary depending on the local climate and soil type.
- Some of the more common and widespread woodland tree species are poplar box (*Eucalyptus populnea*), silver-leaved ironbark (*E. melanophloia*), narrow-leaved ironbark (*E. crebra*), forest red gum or Queensland blue gum (*E. tereticornis*), mountain coolibah (*E. orgadophila*), Dallachy's gum (*Corymbia dallachiana*), cabbage gum or poplar gum (*E. platyphylla*), yellow box (*E. melliodora*), grey bloodwood (*C. clarksoniana*) and Moreton Bay ash (*C. tessellaris*).
- Shrubs and small trees may be present, but are usually sparse. There can be wide variation in the species composition and density of the shrub and small tree layer, which may relate to the local climate, soil type and management history of the site.

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[2] The term 'eucalypt woodlands' is used here to include 'tall eucalypt woodlands' and 'low eucalypt woodlands' (*sensu*;Specht 1981). This definition would include many tropical savannas but we focus this guideline on woodlands in central and eastern Queensland where clearing (and regrowth) has been most prevalent.

[3] ''Eucalypt' is used as a collective term for species of *Eucalyptus* and *Corymbia* (bloodwoods) in this guideline.

- Some of the more common and widespread shrub and small tree species found in eucalypt woodlands are false sandalwood (*Eremophila mitchellii*), wilga (*Geijera parviflora*), currant bush (*Carissa ovata*), hop-bush (*Dodonaea viscosa*), dogs-balls (*Grewia* spp.), Cypress pine (*Callitris* spp.) and numerous wattles (*Acacia* spp.).

Eucalypt woodlands tend to occupy the intermediate rainfall zone between the forests of high rainfall areas, and the shrublands and deserts of the arid interior (McIvor & McIntyre 2002). They occur over a large area of eastern Queensland, from the New South Wales border to Cape York Peninsula, and include the temperate woodlands of the New England Tablelands and Darling Downs, and some of the tropical savannas of northern Queensland. Most of the cleared woodland country lies east of a line from about Charters Towers to St George (Fig. 2).

Management of reforestation projects may incorporate non-carbon income streams, such as ongoing grazing or other products. The amount and type of uses that can be incorporated into carbon farming projects will vary depending on the methodology applied. The target density, structure and composition for reforestation will depend upon the balance that managers aim to strike between carbon, biodiversity and other values. The trade-off between trees and pasture is an important example.

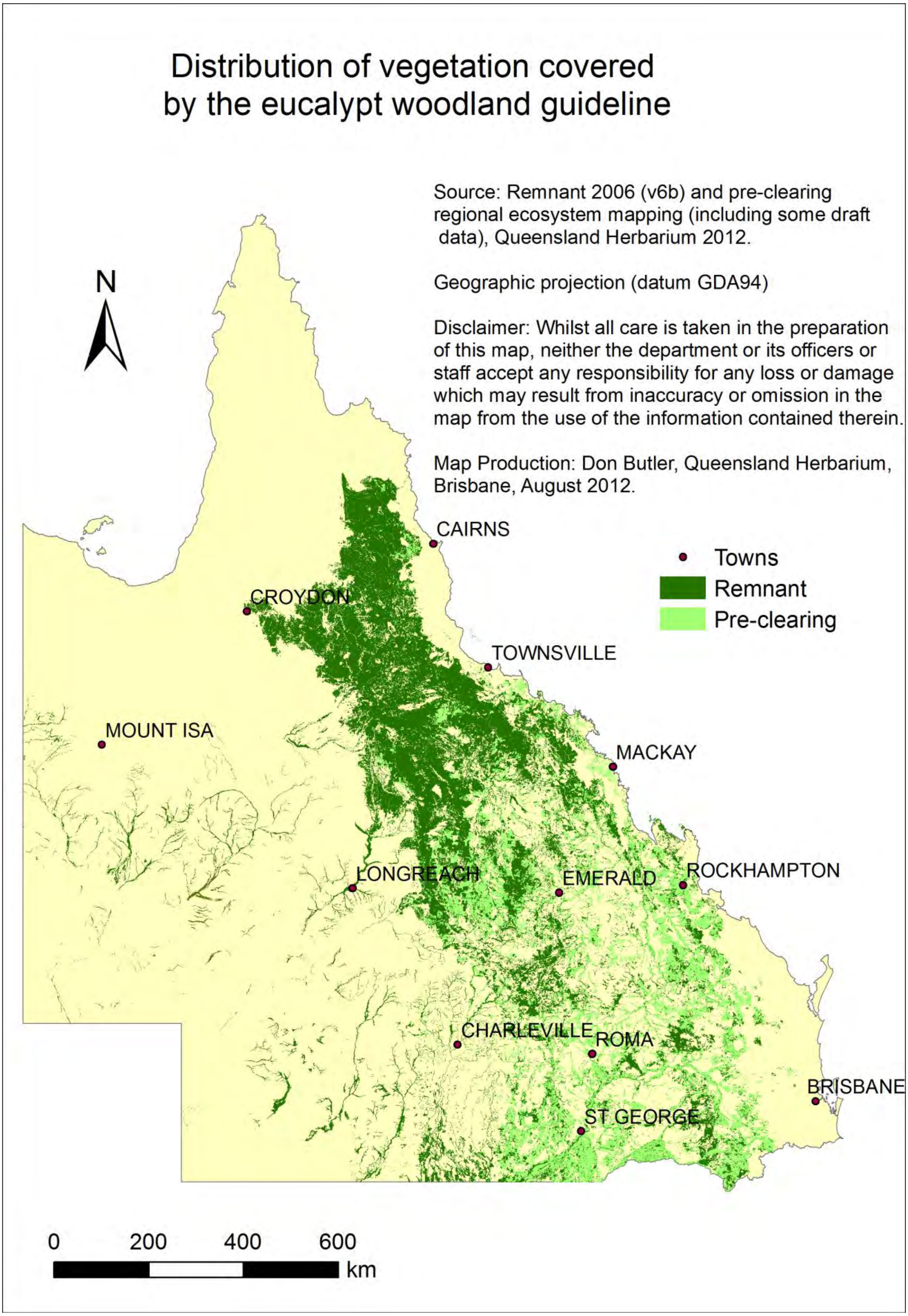

Figure 2: The pre-clearing and remnant distribution of eucalypt woodlands covered by this guideline in Queensland

Ecology

The restoration and management of eucalypt woodlands are underpinned by what we know about the ecology of this vegetation type, including the effects of climate, clearing, grazing, fire and drought. The biology of the dominant canopy trees of Eucalyptus and Corymbia species, has a large bearing on the ecology of eucalypt woodlands, and their management for carbon accumulation and wildlife conservation. Eucalyptus and Corymbia are closely related and in these guidelines the term ‘eucalypt’ is used as a collective term for both genera.

The biology of woodland eucalypts

Woodland eucalypts are usually single-stemmed, but tend to branch 5-10m from ground level. This means that most of their height is formed by the crown, rather than the stem (Williams & Brooker 1997).

Woodland eucalypts may flower every year (Burrows & Burrows 1992), but the flowering season may be highly variable between species and sites (House 1997). Both temperate and tropical eucalypt species are pollinated by insects, birds and bats (unlike many other temperate tree species in other parts of the world which are pollinated by wind) (House 1997).

Many tropical and subtropical eucalypt species drop their fruits annually (Williams 2009), only weeks or months after flowering (Burrows &Burrows 1992; Williams & Brooker 1997) and fire is generally not needed to trigger seed release in tropical eucalypt species (Williams & Brooker 1997). A study of four woodland eucalypt species in central Queensland found that most seed was released in the warmer months, when the probability of rainfall is greatest (Burrows &Burrows 1992). This timing would give the greatest chance of seedling germination and survival (Burrows &Burrows 1992).[4] High levels of seedling recruitment tend to occur only in high rainfall years, and when the timing of seed drop coincides with good rains (Williams 2009). Eucalypt seed has short term viability on the soil surface due to lack of hard seed coat, and predation by ants can be significant (Hodgkinson *et al*. 1980; Burrows &Burrows 1992; House 1997).

Most seeds of woodland eucalypts fall close to and generally within two or three times the height of the parent tree. This means that reforestation in many sites will be strongly limited by seed supply or will be highly patchy around seed sources. However, eucalypt seed can be very easy to collect and spread in large numbers. Capsules can be cut from trees after they have matured but are still closed, and will open as they dry. For example, it is possible to collect and store capsules in paper bags, leave them to dry and release thousands of seeds. Seeds can be mixed with sand, dirt, or some other ‘extender’, and then broadcast by hand or with machinery at a suitably wet time. Seedling establishment of savanna eucalypts may be enhanced on sites that are recently burnt and slashed (Williams 2009), presumably because of reduced competition from other plants.

Soon after seedling germination and establishment, most eucalypts begin to develop a lignotuber (Bell & Williams 1997), which is a woody, rounded growth surrounding the base of the stem. It contains substantial food reserves and many dormant buds. Trials on *Eucalyptus populnea* and *E. melanophloia* have shown that even relatively small seedlings can survive repeated fires once their lignotuber has

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[4]This is in contrast to many eucalypt species from southern Australia, which store seed in the canopy for more than a year, unless fruits are prematurely opened by fire (Williams &Brooker 1997). The establishment of these southern eucalypts from seed is most likely to occur after a fire, as fires tend to trigger the mass-release of seed, while also reducing competition from other plants and providing an altered microenvironment (Bell &Williams 1997).

developed beyond about 4 mm diameter, which takes about six months to a year (Fensham *et al*. 2008; Wardell-Johnson *et al*. 1997). Seedlings with lignotubers may survive in a suppressed state for many years, with little increase in height, if their growth is slowed by fire, herbivores or competition with other plants (Fensham & Bowman 1992; Bell & Williams 1997). In this way a ‘bank’ of small but persistent plants can become established (Burrows & Burrows 1992), which can grow rapidly once conditions are favourable.

Woodland eucalypts do not require fire or the catastrophic death of most adult trees for tree regeneration to occur (McIntyre 2002). As a result, trees of several age groups are usually present in healthy (i.e. self-sustaining) woodlands (McIntyre 2002). Eucalypt woodlands can regenerate prolifically after clearing, especially if scattered trees are retained (Back *et al*. 2009). The regenerative capacity of eucalypt woodlands is demonstrated by the ongoing effort that is required to control regrowth of this vegetation type in southern and central Queensland (Burrows *et al*. 1988). Indeed, in central Queensland, grazing animals, predominantly cattle and kangaroos appear to have little impact on eucalypt regrowth, even under drought conditions (Burrows & Burrows 1992). However, the capacity for eucalypt regeneration can be lost if tree density, health or age decline, and viable seeds are no longer produced (McIntyre 2002).

Competition between grass and trees

The structure of woodland that is, trees with a grassy understorey reflects the competition between woody plants and grasses for soil water during alternating wet and dry periods (Walker & Noy-Meir 1982). Grass roots are restricted to the upper soil layers, where moisture is often scarce and is utilised by both trees and grass. However, the lower soil layers retain moisture for longer and only tree roots reach down to these layers.

Trees also ‘pump’ nutrients from these deeper soil layers onto the soil surface in their falling leaves. Therefore, even though they are competing for similar resources in the upper soil layers, both trees and grasses can coexist in a woodland system. Other factors that influence the competition between trees and grasses include fire, grazing, soil texture and possibly soil nutrients (Walker & Noy-Meir 1982). The herbaceous yield of pasture in a range of eucalypt woodlands in Queensland has been found to decrease with increasing tree basal area (Scanlan & Burrows 1990). This has led to the common practice of tree clearing to improve pasture productivity in many Queensland woodlands that are used for grazing (see ***Clearing*** below).

Woody thickening

When densities of woody plants (trees and shrubs) increase in a woodland or pasture this is known as ‘woody thickening’. Woody thickening has traditionally been viewed in a negative light by Queensland pastoralists, since pasture production declines at high tree density (Walker *et al*. 1986) and with increasing tree basal area (Scanlan & Burrows 1990; Burrows 2002). However, understanding the phenomenon of woody thickening could assist landholders seeking to capture carbon by regrowing trees on cleared woodland country.

There has been some debate about whether widespread woody thickening has occurred in Queensland since European settlement (Burrows 2002). There seems to be broad acceptance that increased livestock grazing and changed fire regimes since European settlement tend to favour the increase of woody plants (Fensham *et al*. 2009; Burrows *et al*. 2002). But there is disagreement about how widely spaced woodland trees were prior to European settlement. Some claim that the landscape was much more open (Burrows 2002), while others conclude that dense vegetation was not uncommon (Fensham 2008). Some landscape-level woody thickening certainly has occurred in the latter half of the 20th century (Fensham *et al*. 2003; Lunt *et al*. 2006), but the rate of change varies considerably from place to place.

Whether thickening reflects the relatively high frequency of wet periods since the 1950s or a response to land management for pastoral production remains debatable. However, this debate is of limited relevance to carbon farming, as the capacity of the site to grow trees today is much more important than how dense the trees were 150 years ago. Indeed, there is some evidence that increased atmospheric carbon dioxide may encourage more vigorous growth of woody plants by increasing their water use efficiency (Fensham *et al*. 2009). Provided other resources like nutrients are not strongly limiting, increased water use efficiency will increase the capacity of a deforested woodland site to grow trees, and will assist the efforts of landholders to farm carbon by reforestation.

It is important to note that the maximum carbon state of woodland is more likely to consist of a relatively low density of big trees, rather than a 'thicket' of small to medium-sized trees. This is because a few big trees hold far more carbon than a large number of small or medium trees (see ***Farming carbon*** below for more details). So it is in the interests of carbon farming to maximise the height and diameter of existing trees. This may involve the selective thinning of smaller trees, or applying patchy, low severity fires to reduce sapling densities. Thinning also occurs when drought and competition among trees to results in tree dieback.

Tree dieback

The decline and premature death of mature woodland eucalypts has been observed in many parts of Queensland (Wylie *et al*. 1992; Fensham & Holman 1999). Tree dieback appears to have a number of causes, and these may result in the death of all or part of the tree.

Drought-related dieback is an infrequent but important natural phenomenon of low-rainfall savanna environments (Fensham *et al*. 2009), including the savannas of north Queensland where extensive tree death has been recorded after severe droughts (Fensham & Holman 1999). If a stand succumbs to dieback, both large and small trees can be affected, although there is also substantial patchiness in dieback on a landscape level (Fensham & Holman 1999). This patchiness may be partly explained by competition between trees (Dwyer *et al*. 2010). In addition, some ironbark and box-barked eucalypts with shallower root systems may be more susceptible to drought-induced tree death than more deeply rooted bloodwoods (*Corymbia spp.*), which can probably access moisture in deeper soil layers (Fensham & Fairfax 2007).

In other, slower, cases of dieback, cycles of defoliation are followed by epicormic resprouting and growth, reduced flowering, and increasing numbers of bare, dead branches in the tree canopy. Initial defoliation may be caused by drought, insects or other factors. In response, there is rapid production of epicormic shoots, which are high in nitrogen, and this can allow insects numbers to increase sufficiently to continue tree defoliation (Landsberg & Wylie 1983). Successive generations of insects may be maintained at high densities by the continued regrowth of epicormic shoots (Landsberg & Wylie 1983). Many factors appear to contribute to this form of dieback, including tree clearing, herbivory by insects, livestock grazing, salinity and waterlogging, and their effects can vary with locality (Wylie *et al*. 1992; McIntyre 2002). In addition, this type of dieback is generally more severe in areas of intensive land management (Landsberg & Wylie 1988). A survey of tree dieback in central and southern Queensland found the highest dieback ratings on properties with the largest percentage of their area devoted to improved pasture, and where fertiliser had been used on crops and pastures (Wylie *et al*. 1992).

There are also suggestions that the loss of native animals and plants from rural landscapes may contribute to tree dieback (McIntyre 2002). For example, in some areas, the abundance of aggressive miner birds tends to increase with the amount of the landscape that is cleared (Eyre *et al*. 2009). These territorial miners displace smaller insect-eating birds, and this may cause insect outbreaks (McIntyre 2002). Other natural insect-controllers such as echidnas, sugar gliders and wasps may be unable to regulate insects in cleared landscapes, as the other habitat features that they require like fallen timber and a diversity of understorey shrubs are scarce or absent (McIntyre 2002). It is likely that allowing natural vegetation to regrow – and leaving understorey vegetation and fallen timber – will lessen the risk of this type of dieback affecting woodland eucalypts.

Clearing

Tree clearing has been employed in many of the grazed eucalypt woodlands of Queensland to promote increased pasture production, but has been generally more common in southern and central Queensland than northern Queensland (Burrows *et al*. 1988). Common methods of killing trees are stem injection of herbicide, ringbarking and especially mechanical clearing. In many cases, Queensland woodland eucalypts appear to regrow readily after clearing, provided that healthy trees are nearby to provide seed, rainfall is adequate and the soil surface has not been excessively degraded (Burrows *et al*. 1988; Ludwig & Tongway 2002; McIntyre 2002; Back *et al*. 2009). Regrowth may arise from the recruitment of new seedlings, but is more likely to develop from root suckers, resprouting from stumps, and from a ‘bank’ of seedlings and saplings that were present before the site was cleared. While this has been problematic for pasture maintenance, it can be useful for farming carbon by reforestation.

Tree removal has been found to increase herbage production in a range a different woodland types (Walker *et al*. 1972; Walker *et al*. 1986; Burrows 2002). However, soil nutrients often decline in cleared lands so that initial gains in pasture production may not be sustainable over time (Sangha *et al*. 2005). Also, the benefits of tree removal are less clear in the more open woodlands of tropical north-east Queensland, where clearing may improve pasture yield but lessen pasture quality (Jackson & Ash 1998). Soils under eucalypt canopies in north Queensland woodlands were also found to have higher nutrient levels, which increased growth in pasture plants (Jackson & Ash 2001). Soils can also become more exposed when trees are cleared, due to decreased canopy cover and leaf litter, and this can increase rain-splash and soil crusting (Ludwig & Tongway 2002). This leads to reduced water infiltration, increased run-off and erosion (Ludwig & Tongway 2002).

Therefore the combination of trees with pasture is likely to provide multiple benefits for carbon accumulation, pasture quality, and soil health. The retention of fewer, larger trees rather than dense thickets of small trees is the best option for maximising carbon (see the ***Farming carbon*** for more details), and this will also result in optimal pasture for grazing, plus the added benefits of microclimate changes, shade and protection for livestock (e.g. McKeon *et al*. 2009 describe some of the benefits of combining trees with pasture, using case studies from Southern Queensland).

Tree clearing also includes thinning, where some trees are left for timber production and/or shade and shelter. Thinning may increase the rate and amount of carbon accumulated through woodland restoration, but it is often expensive. It may be more cost-effective for landholders to maintain forested areas as distinct paddocks, or as tree strips (e.g. McKeon *et al*. 2009), rather than attempt to maintain low tree density in pastures by resisting the trees’ capacity to multiply. Any thinning undertaken while restoring woodlands for carbon should retain the dead timber on site as debris, as this will contribute to carbon storage.

Fire

Woodland eucalypts can regenerate without fire (McIntyre 2002), as the death of canopy trees and other disturbances such as digging by animals, flooding, and storms provide opportunities for seedling establishment (Wardell-Johnson *et al*. 1997). But frequent fires may also encourage the establishment of eucalypt seedlings (Burrows *et al*. 1988), especially if fires coincide with capsule ripening and do not burn through the canopy (Burrows &Burrows 1992). Very young eucalypt seedlings are usually killed by fire (e.g. Williams 2009), but both seedling and adult eucalypts can survive low to moderate severity fires once a lignotuber is formed, after about six months to a year (Wardell-Johnson *et al*. 1997; Fensham *et al*. 2008). The presence of a lignotuber enables a plant to resprout from the base of the stem, but beyond a certain height (>1.5 m for Corymbia clarksoniana) saplings also develop the ability to resprout from the upper stems and branches (epicormic resprouting, P. Williams *pers. comm*.). This gives saplings the ability to survive low to moderate severity fires and to maintain their height (P. Williams *pers. comm*.), which is advantageous for carbon storage and accumulation rates.

Fire tends to suppress the growth of small woodland trees (Williams *et al*. 2003), rather than kill them, but the effects of fire are highly variable (Tothill 1971; McIntyre 2002). For example, soil moisture conditions can influence the ability of eucalypt seedlings to survive fire (Fensham *et al*. 2008), as can the timing of a fire (e.g. Williams 2009). Also, decreased seed production has been observed in savanna eucalypts following a late dry season burn, but not an early dry season burn (Williams 2009).

Regular annual or biennial burning may prevent seedlings from joining the 'bank' of lignotuberous saplings that can tolerate fire, and this may reduce tree density over time (Williams 2009). Fire has also been used to limit tree growth in eucalypt woodlands by keeping saplings in reach of grazing animals (Burrows *et al*. 1988). Wet years often promote the prolific growth of both grass and trees, and if this fuel escapes burning in poplar box woodlands, it can result in greater woody plant dominance (Walker *et al*. 1981). However, if an increased density of trees is desired for carbon farming, it makes more sense to suppress most fires, and use grazing rather than fire to reduce fuel loads if possible.

Fires of moderate- to high-severity and above will also consume coarse woody debris and will tend to topple large trees, especially those with hollows (Eyre *et al*. 2010, Parnaby*et al*. 2010).

Grazing pressure

Cattle grazing has been shown to reduce eucalypt recruitment in northern Queensland, but not prevent it altogether (Scanlan *et al*. 1996). In this study, the population of woody plants increased during a drought period, with a greater increase in exclosed areas than grazed areas (Scanlan *et al*. 1996). In many semi-arid eucalypt woodlands, e.g. box and ironbark, it appears that a run of seasonally wet years are required to ensure seedling establishment, and persistence will only occur if the grazing pressure is low after the initial establishment (J. Neldner *pers. comm*.). However, it has also been reported that grazing animals, predominantly cattle and kangaroos have little impact on eucalypt regrowth in central Queensland even under drought conditions (Burrows & Burrows 1992). Also, increased livestock grazing and changed fire regimes since European settlement tend to favour the increase of woody plants (Burrows *et al*. 2002; Fensham *et al*. 2009).

Heavy grazing does reduce termite species richness and activity, and this appears to be associated with the deterioration of soil hydraulic properties (Holt *et al*. 1996). This northern Queensland study concluded that high grazing pressure has a negative effect on soil fauna, and soil hydraulic conductivity (Holt *et al*. 1996), and this can lead to degradation of the soil surface and reduced recruitment of eucalypts.

Therefore carbon farming in Queensland eucalypt woodlands should be compatible with light to moderate levels grazing pressure, but heavy grazing may suppress the recruitment and growth of eucalypts and/or lead to soil degradation.

Weeds

The millions of hectares of cleared woodland country in Queensland host numerous introduced and naturalised plants. It is unlikely that most of these species have a substantial negative effect on eucalypt recruitment or growth, given the tendency of eucalypts to regrow across these cleared woodlands (although, this needs to be confirmed by data or good anecdotal observations). Nonetheless, weeds do have serious impacts on woodland biodiversity. For example, buffel grass is arguably the most abundant introduced species in cleared woodland country and has been shown to impact on the native plant species richness of eucalypt woodlands (Fairfax & Fensham 2000). However, it does not appear to affect eucalypt recruitment, growth and survival.

Rainfall

Eucalypt woodlands tend to occupy the intermediate rainfall zone between the forests of high rainfall areas, and the shrublands and deserts of the arid interior (McIvor & McIntyre 2002). The rainfall experienced by the semi-arid woodlands of eastern Australia is also extremely variable, thanks to the El Nino – Southern Oscillation (ENSO) phenomenon (Johnson 2003). In dry periods the establishment of eucalypt seedlings can be limited or prevented, so that recruitment of trees is episodic and related to rainfall patterns (Johnson 2003; Williams 2009). Extended drought may also cause dieback and/or death of trees (see 'Tree dieback' above), and will certainly slow growth and make reforestation difficult. In areas without young regenerating eucalypts already present, reforestation may depend on a good supply of viable seeds, and adequate follow-up rain for their germination and establishment.

Ecological model

The ecological model for eucalypt woodlands (Fig.3) summarises the dynamics of this vegetation type into five main condition states, and identifies factors that cause transitions between states. Mature eucalypt woodlands are converted into other condition states in the following ways:

Tree thinning, clearing or dieback of mature eucalypt woodland (State 1) can reduce carbon stocks and produce an open woodland (State 2) or grassland (State 4).

Heavy grazing of mature eucalypt woodland, with or without heavy rainfall, can produce areas of bare, compacted soil, through the agents of both water and wind erosion, creating a degraded open woodland (State 3) or grassland (State 5).

The most rapid increase in carbon stocks for open woodland (State 2) will be achieved by hastening its development into mature eucalypt woodland (State 1). This transition may occur slowly under a range of conditions, but will be accelerated if there is adequate rainfall, no clearing and no hot fires[5]. Similar conditions facilitate increases in carbon stocks from the other states, but states without a eucalypt seed source will require direct seeding or tube stock planting. Degraded states may also require soil rehabilitation.

Carbon stocks in a mature eucalypt woodland (State 1) will be maintained close to their capacity if there is adequate rainfall, no clearing and/or hot fires. Grazing should be compatible with carbon farming as long as the mortality of mature trees is equal to the recruitment of new trees into the canopy. For more information see ***Managing tree density*** below.

Other state-and-transition models have been developed for Queensland eucalypt woodlands (Hall *et al*. 1994; Orr *et al*. 1994; Ludwig & Tongway 2002), but these are largely focussed on maximising pasture production rather than tree recruitment and growth. The target tree density and vegetation structure for a particular site will depend upon the desired balance between trees, pasture, biodiversity and any other relevant values chosen by the land manager.

In time, climate variability may also alter the potential 'mature' structure and floristic composition of eucalypt woodlands (e.g. Prober *et al*. 2012). This is because changes in rainfall, temperature, levels of carbon dioxide and other factors may affect the reproduction, growth and competitive ability of the plants and animals that are currently part of the eucalypt woodland ecosystem. Over time, some species may become difficult to grow on a site they once occupied, because of the effects of climate variability, and these species may become locally extinct. Other native species that were not previously recorded may appear, if conditions become more suitable for them. It is not known how quickly these changes will take

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[5] In this guideline, the term 'hot fire' is equivalent to a moderate or high severity or higher fire . 'Hot fires' can occur whenever humidity and soil moisture levels are low, and they most commonly occur in the late dry season. In Queensland, this tends to be in winter or spring. See Appendix 1 for definitions of fire severity for Queensland open forests and woodlands.

place, although changes in the distribution and behaviour of some species have already been observed (e.g. Hughes 2003; Chambers *et al*. 2005; Beaumont *et al*. 2006).

Until more is known about the influence of climate variability on native species, it is best to maintain or restore the native vegetation that occurred on a given site within the last 150 years or so, as this vegetation is most likely to maximise both the sustainable carbon and biodiversity potential of the site. In many cases it will also be the easiest type of vegetation to grow. Another way to buffer your site against the effects of climate variability is to establish and conserve a wide range of native plant and animal species that are associated with the type of vegetation that occurred on your site (within the last 150 years or so). If some species become less suited to the conditions and are lost, others should be ready to take their place, and this may minimise any impact on the overall structure and dynamics of the ecosystem.

Farming carbon

This guide focuses on managing and accumulating carbon in above-ground plant biomass and coarse woody debris, because they are the most stable and readily verified component of land based carbon stores. However, management to accumulate carbon in above-ground biomass is also expected to increase soil carbon stocks. Biomass is directly proportional to carbon, as carbon makes up about 50% of all biomass. Carbon farming might not always mean bringing eucalypt woodland country back to its full carbon capacity as soon as possible. Some carbon returns might be traded-off against other land-uses, such as livestock grazing, which may limit carbon accumulation rates. Low to moderate levels of livestock grazing appear to be compatible with reforestation in eucalypt woodland country.

Above-ground carbon in eucalypt woodland is stored in living trees and shrubs, but also in dead standing trees, fallen timber and litter. Estimates of living above-ground biomass for eucalypt woodlands (which are at least 25 years old) range from 41 to 113 t ha^{-1} (Table 1), which translate to about 70 to 195 tonnes of carbon dioxide equivalent per hectare (tCO_2-e ha^{-1}).

The estimated peak carbon accumulation rate of reforestation in eucalypt woodland country ranges from about 1 to more than 3 tCO_2-e per hectare per year. This peak is expected to occur when the woodland is between 10 and 20 years old.

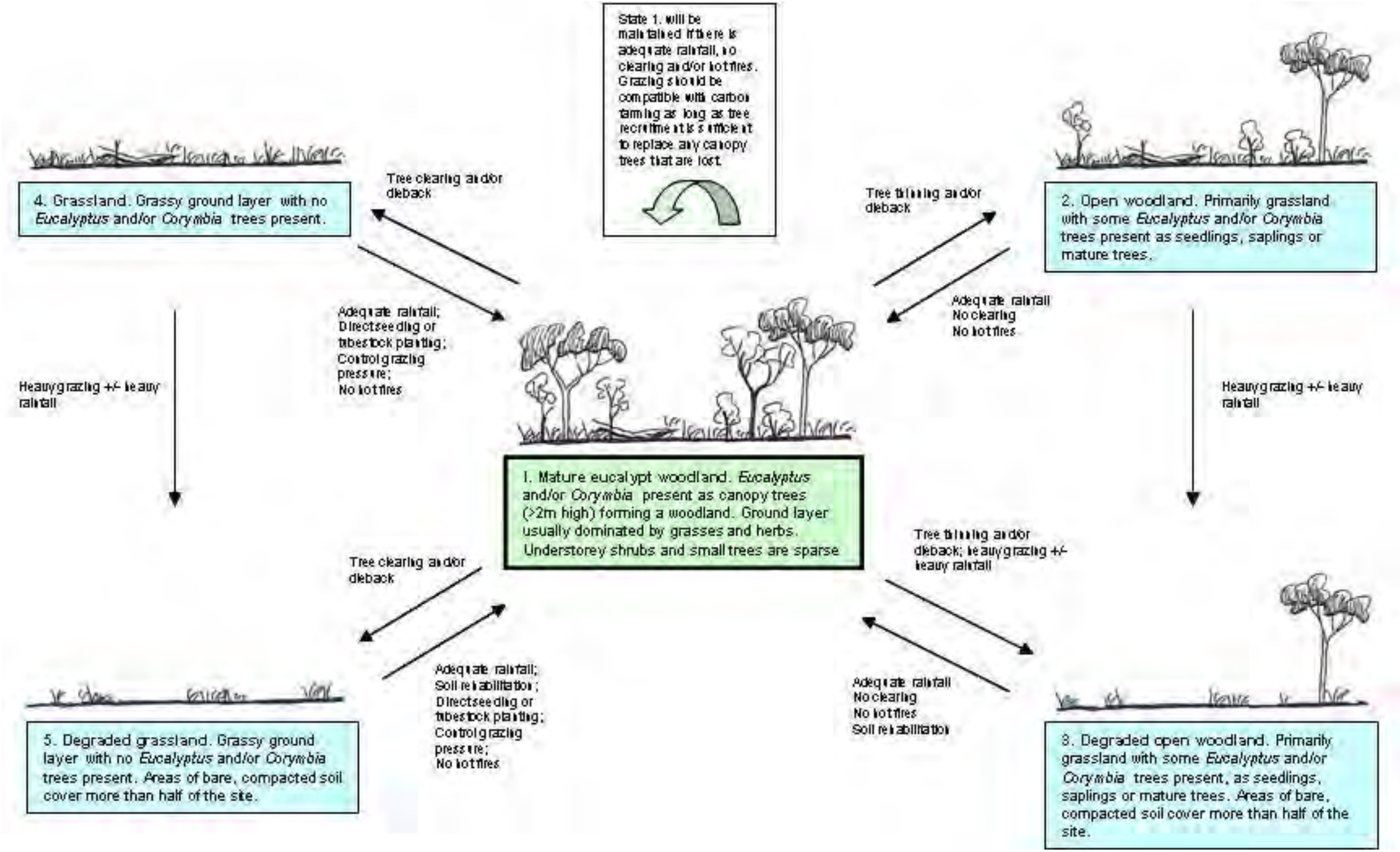


Figure 3: Ecological model for eucalypt woodlands in Queensland

Table 1: Living above-ground biomass estimates for eucalypt woodlands, with associated site data; figures in brackets are standard errors; data from Fensham *et al.* 2003; and Burrows *et al.* 2002

Location	Vegetation	Age	Notes	Living above ground biomass T ha^{-1}		No. of sites	References
				Start	End		
Central Queensland	*E. creba* intact woodland	At least 30 years since clearing or thinning	Only eucalypts measured		113 (26)	1	Burrows *et al.* 2002 Aust J bot
North Eastern Australia	*E. creba* intact woodland	At least 30 years since clearing or thinning	Only eucalypts measured; basal area of dominant eucalypts>75% basal area all woody plants		85 (16)	11	Burrows *et al*. 2002 Aust J bot
Central Queensland	*E. melanophloia* intact woodland	At least 30 years since clearing or thinning	Only eucalypts measured		41 (9)	1	Burrows *et al*. 2002 Aust J bot
North-eastern Australia	*E. melanophloia* intact woodland	At least 30 years since clearing or thinning	Only eucalypts measured; basal area of domeuc>75% basal area all woody plants		60 (9)	12	Burrows *et al*. 2002 Aust J bot
Central Queensland	*E. populnea* intact woodland	At least 30 years since clearing or thinning	Only eucalypts measured		70 (10)	1	Burrows *et al*. 2002 Aust J bot
North-eastern Australia	*E. populnea* intact woodland	At least 30 years since clearing or thinning	Only eucalypts measured; basal area of domeuc>75% basal area all woody plants		70 (7)	10	Burrows *et al*. 2002 Aust J bot
Central Queensland	*E. melanophloia* intact regrowth woodland	3 years since clearing	Only eucalypts measured		5 (1)	1	Burrows *et al*. 2002 Aust J bot
Central Queensland	*E. melanophloia* intact woodland and other Eucalyptus spp. woodland on level sand sheets	At least 25 years since clearing or thinning	Eucalypt on sand (1951-1996): only trees and shrubs measured	44 (1)	53 (1)	29	Fensham *et al*. 2003
Central Queensland	*E. populnea* and *E. melanophloia* intact woodland on or gently undulating texture contrast soils formed on clay sheets or shales.	At least 25 years since clearing or thinning	Eucalypt on texture contrast soils (1952-1993); only trees and shrubs measured		82 (4)	25	Fensham *et al*. 2003

Carbon storage and tree size

Table 2: Amounts of above-ground dry matter, carbon and CO_2 equivalent stored in eucalypts of different diameters; based on Williams *et al.* 2005; note figures are approximate only

Tree dbh (cm)	Dry matter (kg)	Carbon (kg)	CO_2 equivalent (kg CO2-e)
5	5	3	10
30	458	215	790
60	2565	1206	4424

Large trees hold far more carbon than small trees (Table 2) because the amount of carbon held increases exponentially as the trunk diameter of a tree increases (Fig. 4). For example, the carbon held in an average very large tree (~60 cm trunk diameter) is approximately equivalent to that held in nearly 500 smaller trees (~5 cm trunk diameters) (Fig. 5).

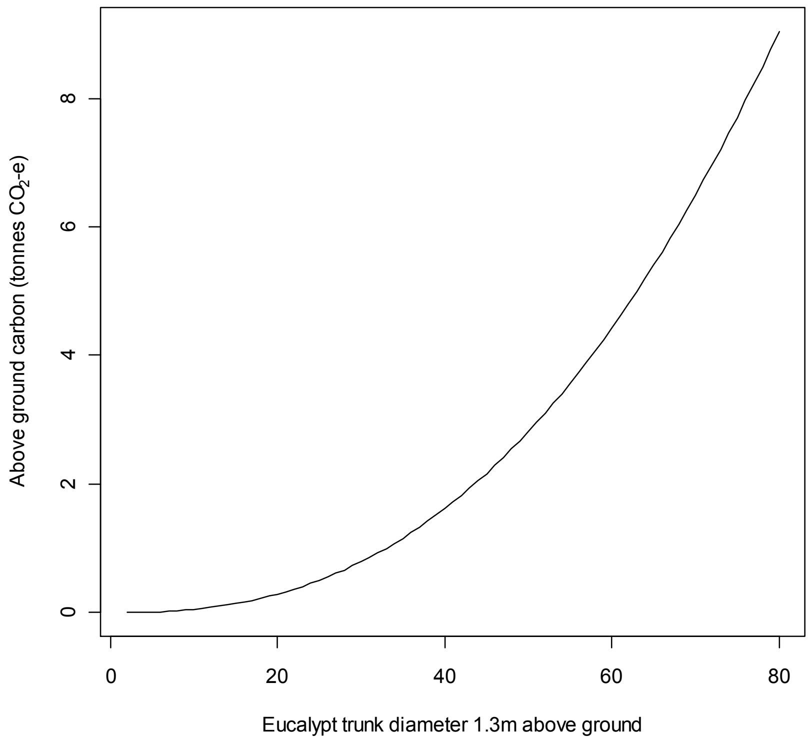
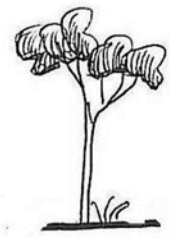


Figure 4: Relationship between eucalypt trunk diameter and above-ground carbon; based on Williams et *al.* 2005

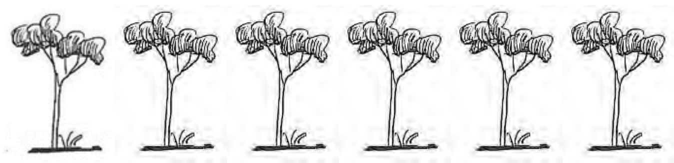
Approximately the same amount of carbon is stored above-ground in:

One 60 cm dbh



or

Six 30 cm dbh



or

482 x 5 cm dbh

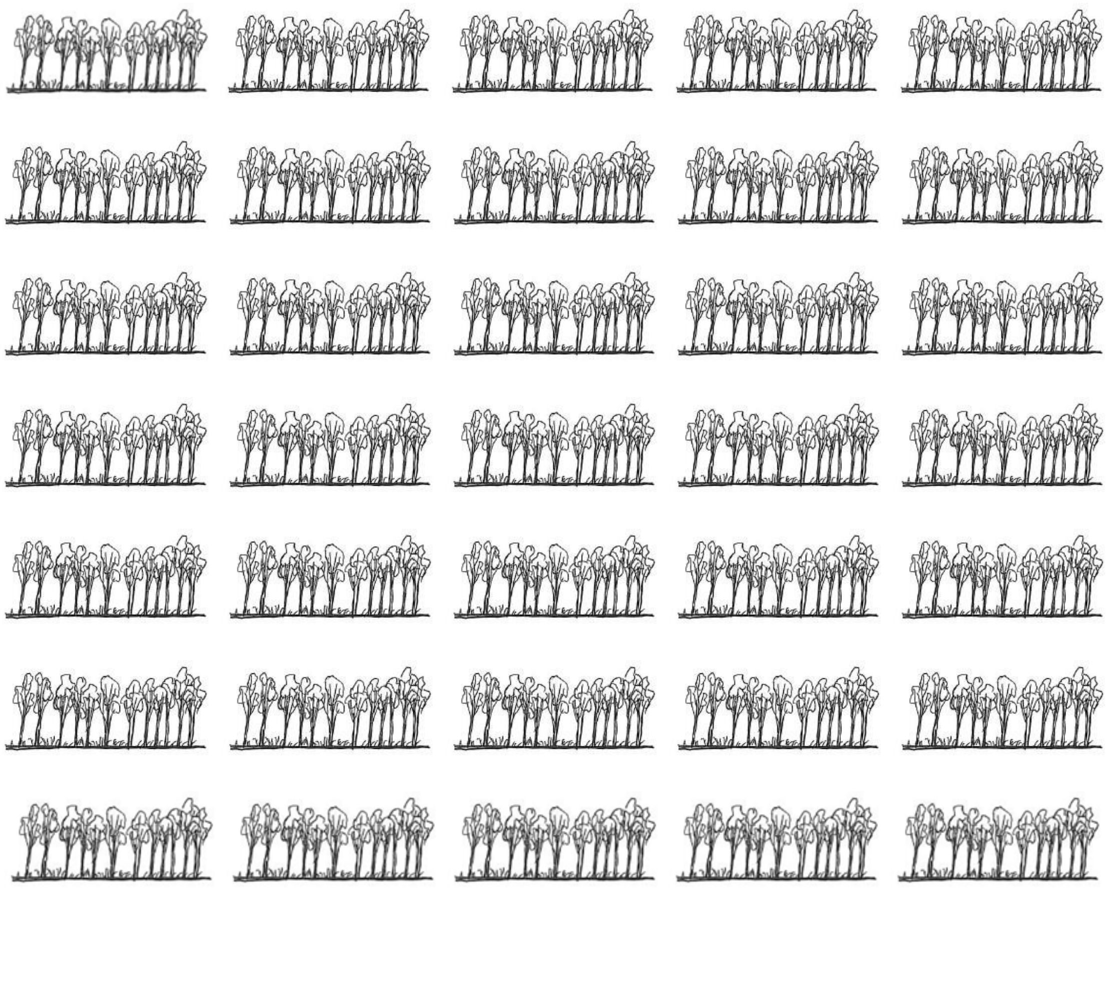


Figure 5: The relative amount of carbon stored in average eucalypts of different sizes: based on Williams *et al.* 2005; dbh = main stem diameter at 1.3 m height

Trade-offs between trees and pasture

It is important to note that increasing the basal area of trees in grassy woodlands tends to result in decreased pasture yield. This has been observed for a variety of woodland types in Queensland, including eucalypt woodlands (Fig. 6). It should be possible to combine carbon farming of regrowth with livestock production6, but landholders should consider how increased tree growth may impact on their pasture yield.

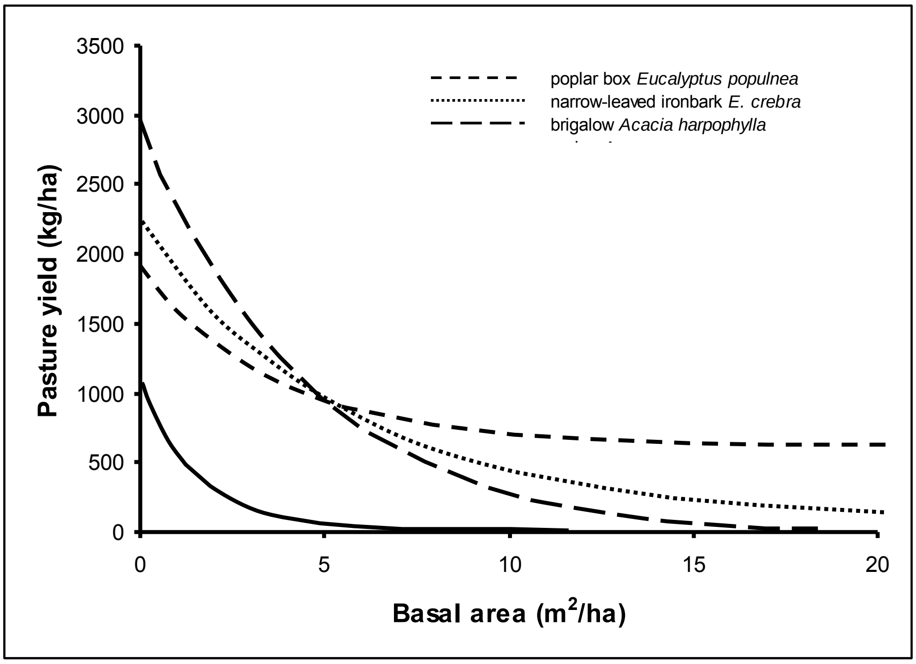


Figure 6: Relationships between tree basal area and pasture yield for a range of woodland tree species from sites in Queensland; redrawn from Burrows 2002; data originally derived from Beale 1973 (*A. aneura*); Scanlan & Burrows 1990 (*E. populnea* and *E. crebra*); Scanlan 1991 (*A. harpophylla*)

[6] This will depend on the CFI methodology being used

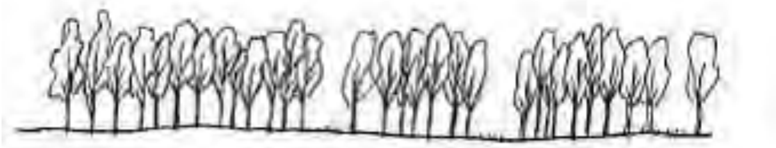
Grow big trees to maximise carbon

A few big trees can hold far more carbon than a large number of small or medium trees (Fig. 5). So it is in the interests of carbon farming to maximise the height and diameter of existing trees, which may be achieved by reducing tree density in dense regrowth. This may involve the selective thinning of smaller trees, or allowing drought and competition among trees to result in natural rates of tree dieback and thinning.

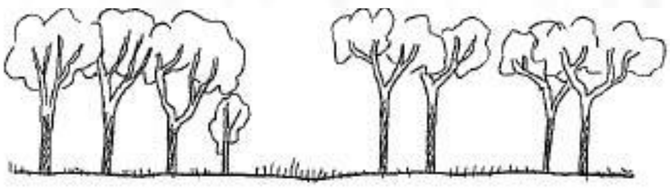
Increasing tree basal area is still likely to reduce pasture yield (Fig. 6), but a few large trees will hold far more carbon than many small ones, for the same basal area (Fig. 7). In addition, the retention of some trees has also been found to improve pasture quality due to inputs of nutrients and faster water infiltration under tree canopies than when trees are absent (Jackson & Ash 2001; Ludwig & Tongway 2002).

Therefore the combination of trees with pasture is likely to provide multiple benefits for carbon accumulation pasture quality and soil health. Retaining fewer, larger trees (rather than dense thickets of small trees) will maximise carbon, result in optimal pasture for grazing, and provide added benefits of microclimate changes, shade and protection for livestock (e.g. McKeon *et al*. 2009) describe some of the benefits of combining trees with pasture, using case studies from Southern Queensland).

a)



b)



c)

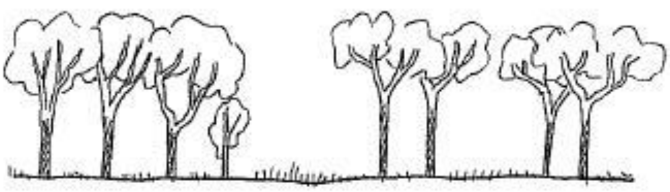


Figure 7: High density of small trees (a) stores less CO_2 equivalent than lower densities of larger trees (b and c); based on Williams *et al.* 2005

Limits to carbon accumulation

Biomass and therefore carbon accumulation in eucalypt woodland is limited by rainfall, clearing, soil degradation, fire, and grazing pressure (Table 3). The total amount of carbon stored by eucalypt woodland, and the rate of carbon accumulation, can be maximised by removing these limits where possible.

Site features		Effect on carbon	
		Total carbon stored	Rate of carbon gain
	Rainfall	↑	↑
	Clearing & thinning	↓	↓
	Soil degradation	↓	↓
	Hot fires	↓	↓
	Continuous high grazing pressure	↓	↓
	Seed limitation	↓	↓

Table 3: Summary of limits to carbon accumulation for eucalypt woodlands

The limits to carbon accumulation in eucalypt woodlands are:

Rainfall – Water is a critical resource for plant growth in woodlands. In dry periods the establishment of seedlings can be limited or prevented, so that recruitment of trees is episodic and related to rainfall patterns (Johnson 2003; Williams 2009). Extended drought may also cause dieback and/or death of adult trees (see ***Tree dieback*** above). Therefore reduced rainfall has the potential to limit both the amount of carbon stored, and its rate of accumulation.

Clearing and thinning – clearing eucalypt woodland will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss. Thinning trees and shrubs will also reduce carbon stores. But careful thinning of canopy trees when stem densities are high may also facilitate the growth of the remaining trees, and this may increase the amount of carbon stored in the long term.

Soil degradation - Soils can also become more exposed when trees are cleared, due to decreased canopy cover and leaf litter, and this can increase rain-splash and soil crusting (Ludwig & Tongway

2002). This leads to more wind erosion and also reduced water infiltration, increased run-off and water erosion (Ludwig & Tongway 2002). When soils are degraded in this way, the establishment and growth of eucalypts can be reduced or prevented, and this limits carbon storage and accumulation rates.

Hot fires – Hot fires[7] - fires of moderate to high severity and above can kill adult trees and consume the carbon in trees, shrubs, dead wood and litter. This reduces carbon stores and slows carbon accumulation rates. Although seedling and adult eucalypts can survive low to moderate severity fires once a lignotuber is formed (Wardell-Johnson *et al*. 1997; Fensham *et al*. 2008) the loss and replacement of above-ground parts will slow growth rates. Therefore, it is recommended that moderate- to high-severity fires are avoided when farming carbon in eucalypt woodlands.

Continuous high grazing pressure – Increased livestock grazing and changed fire regimes since European settlement appear to favour the increase of woody plants in woodlands (Burrows *et al*. 2002; Fensham *et al*. 2009). Therefore it seems that reforestation in Queensland eucalypt woodland country is compatible with some level of grazing pressure, as long as this does not suppress the recruitment and growth of eucalypts. Continuous high grazing pressure is not recommended if it prevents the recruitment of trees or leads to soil degradation. But strategic grazing management that reduces fire risk, and allows tree recruitment when rainfall is adequate, is likely to maximise carbon storage and accumulation rates. However, more information is needed to determine grazing regimes including timing and stocking rates that will allow the optimum production of trees.

Seed limitation – Most seeds of woodland eucalypts fall within a distance two or three times the height of the parent tree. This means that in many sites reforestation will be strongly limited by seed supply or highly patchy around seed sources, which can limit the amount and rate of carbon that is accumulated. However, seed collection and direct seeding can be used to remove this limit in many situations.

[7] In this guideline, the term 'hot fire' is equivalent to a moderate- or high-severity fire (or a fire of even higher severity). 'Hot fires' can occur whenever humidity and soil moisture levels are low, and they most commonly occur in the late dry season. In Queensland, this tends to be in winter or spring.

Wildlife conservation

Figure 8: Some animal species associated with eucalypt woodlands: left: Squirrel glider *Petaurus norfolcensis*; right: Jacky winter *Microeca fascinans* (Images from WildNet, DSITIA)

Eucalypt woodlands in Queensland support many different types of native plants and animals, including at least 124 threatened or priority species (Queensland Herbarium 2011). Restoring eucalypt woodlands therefore has great potential for conserving wildlife. Native species that occur in eucalypt woodlands include the squirrel glider (Fig. 8), brown treecreeper, grey-crowned babbler, squatter pigeon, jacky winter (Fig. 8), red goshawk and northern hairy nosed wombat, and the plant species *Callitris baileyi*, *Capparis humistrata*, *Homopholis belsonii*, *Rhaponticum australe* and *Trioncinia patens*. Numerous small to medium sized mammals as well as some birds such as the paradise parrot have already undergone serious declines or have even been lost from Queensland's woodland landscapes.

Most management actions that will accumulate carbon in cleared eucalypt woodland country such as not clearing regenerating trees, excluding hot fires, and reducing grazing pressure will also benefit wildlife. Habitat features that will help to conserve wildlife in eucalypt woodland include different types of shelter for wildlife, and a good, varied supply of food. Beneficial actions include the removal or control of weeds and feral animals. Landscape features, including the size and shape of habitat patches and their distance from each other, also have an influence on the potential of a site to conserve wildlife.

Figure 9: The bridled nailtail wallaby; once widespread throughout eastern Australia, now persists in only two locations in central Queensland and appears to prefer the transitional vegetation between brigalow forest and grassy eucalypt woodland; (Lundie-Jenkins & Lowry 2005)(Image:DSITIA).

Limits to wildlife conservation in eucalypt woodlands

Table 4:Summary of limits to wildlife conservation in eucalypt woodlands

Limits to wildlife conservation	Effect on wildlife	
	Total number of species	Total number of individuals
Range of shelter options e.g. tree hollows, fallen timber, shrubs, rocks	↑	↑
Good supply of food e.g. insects, nectar, pollen, seeds, leaves, small animals, grasses	↑	↑
Landscape features Large patch size, small edge-to-area ratio, close to other patches	↑	↑
Competitors and predators e.g. weeds, feral animals, aggressive native animals	↓	↓
 **Clearing & thinning**	↓	↓
 **Hot fires**	↓	↓
 **Continuous high grazing pressure**	↓	↓
 **Exotic grasses**	↓	↓

Shelter and food

Trees and shrubs, including a variety of size and age classes

Trees and shrubs provide nesting, shelter and feeding sites for many animals, including woodland bird species that forage mainly on the trunks and foliage of shrubs and trees like pardalotes, thornbills and treecreepers. A diversity of tree and shrub species that flower and fruit at different times is more likely to provide food including nectar, pollen, fruit and insects throughout the year for birds and other animals (McIntyre 2002). Shrub cover generally provides important nesting and foraging sites for small birds (Barrett 2000) and dense understorey shrubs can also discourage aggressive noisy miners and yellow-throated miners, which may otherwise exclude small birds (M. Maron *pers. comm*.).

It is also important for woodlands to have a variety of tree/shrub size and age classes including dead standing and fallen, as these will provide different resources for wildlife. For example, the occurrence of some bird species is associated with the presence of tree saplings in the mid-storey of woodlands (Martin *et al*. 2005). Jacky winters, which are robin-like birds associated with eucalypt woodlands (Fig. 8), showed a preference for nesting in eucalypts over 160 years old in a southern Queensland study

(Wood *et al*. 2008). A southeast Queensland study revealed a positive correlation between the abundance of squirrel gliders (Fig. 8) and the density of standing dead trees (Rowston *et al*. 2002). A study in the temperate woodlands of southern New South Wales found that different species of birds preferred different types of regrowth - plantings, resprout regrowth, seedling regrowth and old growth - and this was most probably related to differences in structural complexity among regrowth types (Lindenmayer *et al*. 2012). This suggests that more bird species will be supported if a range of vegetation growth types are represented in a given farmland area.

Tree hollows

Many native animals use tree hollows for shelter and nesting, and some also feed on prey found in hollows (Gibbons & Lindenmayer 2002). Woodland eucalypts tend to form hollows only when they develop into large trees (Williams & Brooker 1997), which can take centuries. Animals that use tree hollows in eucalypt woodlands include parrots, treecreepers, bats and squirrel gliders (Fig. 8). By retaining large trees which are more likely to contain or form hollows, you can provide valuable habitat for wildlife. Nest boxes can be provided if hollows are absent or scarce. Hollow bearing trees are susceptible to fire, so it can be a good idea to rake litter away from large habitat trees before application of management fires, and to only conduct burns when soil moisture is high.

Fallen timber

Fallen timber can provide shelter and feeding areas for birds (Barrett 2000), reptiles, frogs, mammals (Lindenmayer *et al.* 2003) and invertebrates. A number of woodland bird species such as robins and fantails use fallen timber as platforms to view, and then pounce on, prey on the ground, and treecreepers and thornbills often collect insects from fallen timber or the ground nearby (MacNally *et al.* 2001). In central Queensland, the bird assemblage was more likely to be closer to an 'intact' or 'benchmark' bird assemblage when there was substantial log cover (Hannah *et al.* 2007), and the rufous bettong appears to prefer sites with more logs (Price *et al.* 2010).

It can be tempting to collect fallen timber for firewood, or just to 'clean up', but leaving it in place will help to retain water and nutrients, and provide shelter and feeding opportunities for wildlife.

Large grass tussocks

Large perennial native tussock grasses provide food and shelter for wildlife and a refuge for grazing-sensitive plant species (Martin & Green 2002; McIvor 2002). These grasses are generally sensitive to high grazing pressure and may be difficult to re-establish once they have been lost from a site (McIvor 2002). The production of grass seeds which is an important resource for seed-eating birds can also be closely linked to fire (see ***Fire*** below).

Ground cover

Ground cover is essential for the survival of many reptile, mammal and ground-nesting/foraging bird species by providing foraging areas and protection from predators and the elements (Martin & Green 2002; Price *et al.* 2010). Components of ground cover can include large grass tussocks, fallen timber and leaf litter.

Rocks

Surface rocks and piles of boulders are important habitats for animals like reptiles and rocks embedded in the soil may provide animals protection from predators and fires (Lindenmayer *et al.* 2003). Some plant species may only be found in association with rocky areas.

Leaf litter

Litter suck as fallen leaves, bark and twigs provides shelter, nesting sites, and foraging sites for many invertebrates, birds, reptiles and small mammals. In central Queensland, the presence of the skinks *Lerista chordae* and *Menetia greyii* was positively correlated with increasing litter cover (Price *et al.* 2010). These small-bodied skinks shelter in dense litter and are disadvantaged by repeated fires and ongoing heavy grazing which consume or pulverise litter cover (Price *et al.* 2010).

Mistletoe

Mistletoe is a parasitic plant that forms clumps on the branches of trees and shrubs, and provides nectar, berries and nesting sites for many animal species (Watson 2001). Mistletoe can provide nectar and berries at times when these foods are scarce in the landscape (Watson 2001).

Invertebrates

Invertebrates include insects, spiders and other small animals with no backbones, and with six or more (or no) legs. A diversity of foraging habitats such as fallen timber, trees, shrubs, and leaf litter, will support a variety of invertebrates which can provide food for other animals and pollinate plants.

Fungi

Many Australian mammals eat fungi, especially those that produce fruiting bodies underground such as truffles, and many fungi also have symbiotic relationships with native plants (Claridge & May 1994). It is not known how abundant or diverse such fungi are in eucalypt woodlands, or how important they are as a food source to animals, or as symbionts of plants. Research is needed to better understand the importance of fungi for wildlife conservation in eucalypt woodlands, and if significant, how to best manage this resource.

Landscape features

Large patch size

Small patches of habitat may be able to support populations of some plant and animal species such as invertebrates and lizards (Abensperg-Traun *et al.* 1996; Smith *et al.* 1996), and may be very important for the conservation of these life forms. But the long-term viability of small patches may also be questionable, and larger patches are generally better for conserving wildlife (Saunders *et al.* 1991; Bennett 2006). For example, a central Queensland study found that bird species richness increased with woodland fragment size (Hannah *et al.* 2007). Woodland patches must be large if they are to support viable populations of most mammal species because mammals typically occur at low population densities, and individuals may require large areas of habitat for survival (Cogger *et al.* 2003).

Small edge-to-area ratio

Woodland patches that are rounded in shape suffer fewer edge effects than patches of a similar size that are long and thin. Edge effects include increased weed invasion, predation, wind, sun and temperature, and all of these can have important impacts on wildlife (Saunders *et al.* 1991; Bennett 2006).

Close to other patches

Many animals like invertebrates and reptiles are unable to move large distances between suitable patches of habitat (Saunders *et al.* 1991), or face increased risk of predation if they attempt to do so (Cogger *et al.* 2003). Plant dispersal into new patches, and pollination between existing plant populations, can also be restricted by the distance between habitat patches.

How much of the landscape is cleared

The amount of suitable habitat remaining in a landscape has a large influence on the survival of wildlife (Boulter *et al.* 2000; Smith *et al.* 2012). Small patch size and large distances between patches will have stronger negative impacts on birds and mammals if more than 70% of the landscape has been cleared of suitable habitat (Andren 1994). In central Queensland, declines in some native mammals like the pale field rat, greater glider and eastern grey kangaroo, were observed at uncleared sites after clearing reduced the native vegetation cover of the region from 87% to 41% (Woinarski *et al.* 2006).

There is also an interaction between grazing and how much of the landscape is cleared, as cattle tend to congregate in the remaining patches of woody vegetation, particularly where they are surrounded by cleared land (Fairfax & Fensham 2000) and this increases trampling and the opportunistic grazing of shrubs and herbs.

However, if most of a landscape, or vegetation type, has been cleared, this also means that any remnants are very important for wildlife conservation, even if they are small or in poor condition. These remnants may still provide valuable source populations for restoring other parts of the landscape.

Competitors and predators

Weeds and feral animals

Weeds and feral animals are a major threat to wildlife in Australia (Williams & West 2000; Natural Resource Management Ministerial Council 2010). Since eucalypt woodlands are spread over a large area of Queensland they are subject to a variety of weeds like lantana, cactus species and rubber vine, and feral animals such as foxes, pigs and goats. The impact of these species on wildlife will vary considerably between sites, so the type and urgency of management actions should be determined on a site-by-site basis.

Management actions that have adverse effects on wildlife should be avoided if possible, or implemented in stages. For example, a short fire-return interval such as two burns in three years may reduce the abundance of some woody weeds like rubber vine, but this may also reduce the species richness and abundance of birds (Valentine *et al.* 2012).

Exotic grasses

Some exotic perennial grass species like buffel grass (*Cenchrus ciliaris*) have the capacity to dominate the ground layer of woodlands, and can have serious consequences on native flora and fauna (Grice 2006). Even low densities of buffel grass were found to have a detectable negative association with native ground vegetation, birds and ants in central Australia (Smyth *et al.* 2009). In the poplar box woodlands of south central Queensland, buffel grass was observed to have a negative impact on the recruitment and growth of many native plant species (Franks 2002), and there were significantly fewer species of native grass and forbs where buffel grass cover was greater than 5% (Eyre *et al.* 2009).

Increasing buffel grass cover was linked to decreasing counts of Carnaby's skink (*Cryptoblepharus carnabyi*) and the delicate mouse (*Pseudomys delicatulus*) in central Queensland (Ludwig *et al.* 2000), and had a negative effect on the probability of occurrence of a skink (*Lerista puctatovittata*) and a gecko (*Oedura ocellata*) in south central Queensland (Eyre *et al.* 2009). However, the latter study also showed that buffel grass cover had a positive effect on the probability of occurrence of two snakes (*Demansia psammophis* and *Furina diadema*) and another gecko species (*Gehyra variegata*) (Eyre *et al.* 2009).

The spread of Indian couch grass (*Bothriochloa pertusa*) is facilitated by high stocking rates of cattle, and it can dominate and replace native grass species like *Bothriochloa ewartiana* (Kutt & Fisher 2011). A study in north Queensland found that bird abundance and species richness declined with increasing frequency of Indian couch grass (Kutt & Fisher 2011). However, as high frequencies of Indian couch grass were strongly correlated with high grazing pressure, this individual impact of the exotic grass could not be determined (Kutt & Fisher 2011).

In summary, the presence of exotic grasses such as buffel and Indian couch grass, especially when they occur in high densities, is likely to have a wide range of negative effects on wildlife. Although the eradication of these grasses from a site may be neither possible nor necessary, it is important to manage their abundance, if possible, to minimise their impacts and restrict their spread.

Aggressive native species

Noisy miners and yellow-throated miners are large, aggressive honeyeaters found throughout much of Queensland. The density or presence of miners has been consistently negatively correlated with the richness, abundance and assemblage composition of woodland birds in eastern Australia (Maron *et al.* 2011), and the noisy miner appears to be the only large-bodied bird species that depresses the occurrence of small-bodied bird species over a range of districts from Victoria to Queensland (Mac Nally *et al.* 2012).

Bird species richness was observed to decline with increasing abundance of miners both yellow-throated and noisy in central Queensland with substantially reduced numbers of small arboreal insectivores such as the striated pardalote and weebill (Hannah *et al.* 2007). Another central Queensland study found that there was a 96% probability that small passerine bird abundance would be low at sites where noisy miner abundance was high (Howes *et al.* 2010). Three bird species, the brown thornbill, yellow-tufted honeyeater and eastern yellow robin were only recorded at sites free of noisy miners (Howes & Maron 2009). A northern Queensland study has also indicated that increased abundance of either noisy or yellow-throated miners can have harmful consequences for small passerine birds, even in a landscape that is largely intact (Kutt *et al.* 2012b).

Increased abundance of miners has been linked to increased grazing pressure and reduced understorey density (Howes & Maron 2009; Howes *et al.* 2010), and is one of many ecosystem changes that has been associated with pastoralism in Queensland (see ***Grazing pressure*** below). The factors which most influence miners appear to vary across ecosystems (Maron *et al.* 2011; MacNally *et al.* 2012), and the culling or removal of a native species is not always acceptable or practical. This means that management of miners is not always straightforward. One Queensland study at Carnarvon Station Reserve and Carnarvon National Park indicated that decreased understorey shrub density, increased grazing pressure and reduced stem density were linked to the increased abundance of noisy miners (Howes *et al.* 2010). Therefore, the manipulation of these factors may reduce miner abundance, but ongoing monitoring is needed to demonstrate the effectiveness of this type of management.

Grazing pressure

Total grazing pressure includes the combined effects of domestic livestock, feral animals and native herbivores. High populations of native herbivores may result from the control of predators like wild dogs and the presence of artificial watering points. Grazing pressure modifies the structure of eucalypt woodlands by removing shrubs, inhibiting the establishment of tree seedlings, the trampling and browsing of saplings, uneven grazing of the grass layer, and the production of a short homogeneous grass sward when grazing is heavy (Martin & Possingham 2005). This change in structure and removal of food sources has a negative impact on many native species associated with eucalypt woodlands.

Many native plant and animal species associated with eucalypt woodlands show preferences for certain levels of grazing (McIntyre *et al.* 2003; Martin & Possingham 2005; Kutt & Woinarski 2007; Kutt 2009), while others are present at all levels of grazing (Martin & Possingham 2005). Therefore, at a whole of landscape scale, the greatest number of species will be conserved if landscapes contain areas representative of the full suite of grazing pressures (McIntyre *et al.* 2003).

However, in Queensland, most of the landscapes that once supported eucalypt woodlands have a history of livestock grazing and this is also the dominant land use today. This means that most areas are subject to some level of livestock grazing, and areas that are not grazed by livestock are very rare. For example, McIntyre *et al.* (2003) estimated that ungrazed areas represented only 4% of their 152 km^2 study area in south east Queensland, and these areas were largely restricted to roadside reserves. This pattern of land use benefits species which prefer or tolerate grazed landscapes like the crested pigeon (Martin & Possingham 2005) and many of these ‘increaser’ species have become common and widespread nationally (Martin and McIntyre 2007). The species that prefer ungrazed areas are disadvantaged because these areas are less common in the landscapes and these ‘decreaser’ species become less abundant, and may become locally extinct (McIntyre *et al.* 2003).

A northern Queensland study found that the abundance and species richness of reptiles was greater in ungrazed than grazed areas, and that the species composition of bird and mammal assemblages was significantly related to grazing pressure (Woinarski & Ash 2002). They concluded that pastoralism leads to a substantial rearrangement of the vertebrate fauna. A separate study in southeastern Queensland found that the majority of bird species declined with increasing grazing pressure and foraging height preference was a good predictor of a species’ susceptibility to grazing (Martin & Possingham 2005).

High grazing pressure is inextricably linked to other factors that may also affect wildlife (Woinarski & Ash 2002), including increased abundance of aggressive miners (Martin and McIntyre 2007; Howes *et al.* 2010; see ***Aggressive native species***) and exotic grasses (Kutt & Fisher 2011). Heavy grazing led to a reduction in termite species richness and activity in a northern Queensland study, and deterioration in soil hydraulic properties (Holt *et al.* 1996). Tree dieback has also been observed on highly grazed sites in central Queensland, along with patches of bare ground and increases in unpalatable woody shrubs such as the currant bush (*Carissa ovata*)(Ludwig *et al.* 2000).

The maintenance of low to moderate grazing pressure, or ungrazed areas, is probably the best way to conserve wildlife while restoring eucalypt woodlands at the present time. This is because many native species can coexist with low to moderate grazing pressure, and ungrazed areas will conserve those species that are sensitive to any level of livestock grazing. For example, a southeastern Queensland study indicated that a rich and abundant bird fauna can coexist with moderate levels of grazing in uncleared sites (Martin & McIntyre 2007) and some bird species reached their highest abundance under moderate grazing pressure (Martin & Possingham 2005).

Sites with moderate grazing pressure also had higher numbers of herbaceous plant species than sites with high and low grazing pressure (McIntyre *et al.* 2003). If the ground layer has retained a large grass tussock structure, it is more likely that all plant response groups will have some representation, and ecosystem function will be maintained under moderate grazing (McIntyre *et al.* 2003). However some plant and animal species are associated with sites that have no grazing pressure (McIntyre *et al.* 2003; Martin *et al.* 2005), and the provision of these ‘no grazing pressure’ sites in the landscape are required to conserve these species. It is assumed that the native species which thrive in areas of high grazing pressure are not at risk of extinction at the present time.

Clearing and thinning

Uncleared eucalypt woodlands tend to have a more complex vegetation structure than cleared areas, including large and tall groves of trees, more open intergroves, native perennial grass clumps, shrub thickets, logs and termite mounds (Ludwig *et al.* 2000). Clearing destroys many plant and animal species, and also removes the food and housing of animals that depend on the plant species and structure found in mature woodlands. For example, significantly lower counts of grey butcherbird, striated pardalote, yellow-throated miner and pale-headed rosella were observed on cleared eucalypt woodland sites in central Queensland compared to uncleared sites (Ludwig *et al.* 2000). In northern Queensland, intact vegetation had higher bird species richness than cleared or thinned sites, with several species appearing to prefer intact vegetation such as the grey shrike-thrush, rufous whistler, grey-crowned babbler, crested bellbird, grey fantail, spiny-cheeked honeyeater and double-barred finch (Tassicker *et al.* 2006).

In central Queensland, higher bird species richness was also found in uncleared sites compared to cleared areas and regrowth (Hannah *et al.* 2007). Extensive vegetation clearance in central Queensland has been linked to significant changes in bird assemblages (Hannah *et al.* 2007), including decreases in a range of woodland birds (Woinarski*et al.* 2006). In northern Queensland, the change in bird species composition and species turnover was greatest in the most modified vegetation (Kutt *et al.* 2012a).

Tree thinning in eucalypt woodlands appears to benefit some common, widespread bird species, but was linked to an overall decline in bird species richness in a northern Queensland study (Tassicker *et al.* 2006). A large suite of woodland bird species had a positive relationship to increasing woody plant density, and these species increased in relative abundance with increasing vegetation thickening (Kutt & Martin 2010). Such species included the spiny-cheeked honeyeater, weebill, brown treecreeper and varied sittella.

The clearing of vegetation locally may have far-reaching effects. For example, clearing vegetation in Queensland may have also contributed to the decline of woodland birds in southern Australia, as several species which breed in the southern states over-winter in Queensland like the rufous whistler, square-tailed kite and dusky woodswallow (Ford 2011). The degradation and loss of this winter habitat may have led to a decline in breeding ranges and numbers further south (Ford 2011).

It is encouraging to note that the regrowth of eucalypt woodlands supports about 75% of the bird species richness found in uncleared eucalypt woodlands, and as woodland regrowth develops, its faunal assemblages are likely to increasingly resemble those of intact woodlands (Hannah *et al.* 2007).

Fire

Changes in fire regimes like the season, frequency and severity of burns since European settlement have been implicated in the decline of many native species such as granivorous birds; (Franklin *et al.* 2005). However, there appears to be no one general fire regime that applies to all eucalypt woodlands, as native species have diverse responses to fire (Woinarski 1999; Martin & Green 2002; Valentine *et al.* 2007; Valentine & Schwarzkopf 2009; Williams 2009).

For example, a central Queensland study concluded that the bird assemblage was more likely to be closer to an ‘intact’ or ‘benchmark’ bird assemblage when the site was recently burnt (Hannah *et al.* 2007). But another central Queensland study found that woodland sites burnt in the previous year had a >90% probability of high abundance of noisy miners and low abundance of small passerine birds (Howes *et al.* 2010). However, it is clear that hot and intense fires may destroy tree hollows (Woinarski 1999), cause higher grass seed mortality and simplify vegetation structure (Valentine *et al.* 2007; Valentine & Schwarzkopf 2009), and burn relatively large areas (Whitehead *et al.* 2005), which can disadvantage animals which rely on patchy habitats, or a combination of burnt and unburnt habitats. Even low severity management fires can remove large hollow-bearing trees (Parnaby *et al.* 2010), which provide essential resources for many fauna.

Many bird species found in tropical savannas appear to have low sensitivity to fire frequency and fire frequency increase (Reside *et al.* 2011). However, if increased fire frequency occurs late in the dry season, this appears to be detrimental to most savanna-restricted bird species. The negative effects of increased fire frequency, and especially late-season fire frequency, on birds also appear to be more pronounced in the southern section of the tropical savannas, possibly because the amount and frequency of rainfall tends to be lower in these areas (Reside *et al.* 2011).

A study in the tropical savannas of northern Queensland found that species richness and overall bird abundance were lower in sites that were twice-burnt over a period of three years than sites that were unburnt, or only burnt once (Valentine *et al.* 2012). This was partly due to the decline of the fleshy-fruited shrub *Carissa ovata* at the twice-burnt sites. Species that avoided the twice-burnt sites included the great bowerbird, red-backed fairy wren, yellow honeyeater, Lewin’s honeyeater, noisy friarbird and rainbow lorikeet.

Probably the best fire management for wildlife conservation in eucalypt woodlands is to maintain a range of burning practices that create a fine-scale mosaic of fire histories in the landscape, including unburnt refugia (Woinarski 1999; Martin & Green 2002; Valentine *et al.* 2007) and to avoid hot fires, especially late in the dry season. An emphasis on burning early in the dry season, or early in wet season should reduce the incidence of the hotter and more destructive late dry season fires (Woinarski 1999). In tropical eucalypt savannas, the best way to maintain a supply of grass and other herb seeds is to produce a fine-scale mosaic of burnt and unburnt ground by implementing a series of low severity burns over a few months (‘progressive burning’; P. Williams *pers. comm.*).

If a mosaic of fire regimes is to be achieved, it is important to consider which regimes are most prevalent in the region or landscape. It may be most beneficial to wildlife to implement a fire regime that differs from the most common regimes in the region, or on neighbouring properties (Martin & Green 2002). To help preserve habitat trees land managers should consider raking litter and debris away from the base of such trees prior to burning.

General fire guidelines for maintaining the overall biodiversity of regional ecosystems are provided in the Regional Ecosystem Description Database (REDD)(Queensland Herbarium 2011).

Table 5: Habitat values for selected eucalypt woodland species

		Tree hollows	Fallen Timber	Trees & shrubs	Large grass tussocks	Litter	Open Ground	Mistletoe	Rocks	Insects
Mammals										
Squirrel glider	*Petaurus norfolcensis*	✓		✓						✓
Rufous bettong	*Aepyprymnus rufescens*		✓		✓	✓				
Delicate mouse	*Pseudomys delicatulus*		✓				✓		✓	✓
Gould's wattled bat	*Chalinolobus gouldii*	✓								✓
Birds										
Variegated fairy-wren	*Malurus lamberti*		✓	✓	✓					✓
Grey-crowned babbler	*Pomatostomus temporalis*		✓	✓		✓				✓
Brown treecreeper	*Climacteris picumnus*	✓	✓	✓						✓
Rufous whistler	*Pachycephala rufiventris*	✓		✓				✓		✓
Bush stone-curlew	*Burhinus grallarius*		✓		✓	✓	✓			✓
Mistletoe bird	*Dicaeum hirundinaceum*			✓				✓		✓
Reptiles										
Carliamunda (skink)	*Carlia munda*		✓		✓	✓				✓
Marbled velvet gecko	*Oedura marmorata*	✓		✓					✓	✓
Nobbi dragon	*Amphibolurus nobbi*		✓	✓	✓	✓			✓	✓
Plants			✓		✓	✓	✓		✓	

Management actions

This section is intended to help land managers create an action plan to achieve their goals. This can be farming carbon, conserving wildlife, or a combination of both.

To **maximise carbon** (by restoring the site to State 1 in Fig. 3), the management aims for all states are:

- Maximise the height and diameter of existing trees within the productivity constraints of the site.
- Increase the density of large trees to reach the typical tree density for the vegetation type. Alternately, managers can choose a lower target tree density, but this will prevent the site reaching its maximum carbon state.
- Ensure that the mortality rate of large trees is equal to the recruitment of new trees into the canopy, by allowing seedlings and saplings to develop into trees.

The management aims for **conserving wildlife** are the same as those for maximising carbon (above), with the addition of:

- Avoid actions that kill or injure wildlife such as clearing and fire
- Provide a range of shelter options and food resources for wildlife
- Manage fire and grazing to allow ongoing recruitment of all plant species
- Protect and restore landscape features that support wildlife
- Control competitors and predators that threaten wildlife like feral animals, weeds, and aggressive honeyeaters.

Rainfall and temperature will have a large influence on the potential for reforestation and carbon accumulation on your site. However, other factors, such as fire, grazing, and exotic grasses, may also require management. The history of the site will generally determine the amounts of initial effort and ongoing maintenance needed to restore it.

To determine which actions apply to your site:

1. Identify the condition state of your site by referring to the key to condition states (Fig. 10).
2. Select whether your goal is farming carbon, conserving wildlife, or both.
3. Compile a list of actions from Table 7 (below) that apply to both the condition state, and goal of your site (either ‘carbon’, ‘wildlife’, or both).
4. Refer to the ***Managing tree density*** section (following Table 7) for more details about how to achieve target tree densities using strategic grazing and fire management.

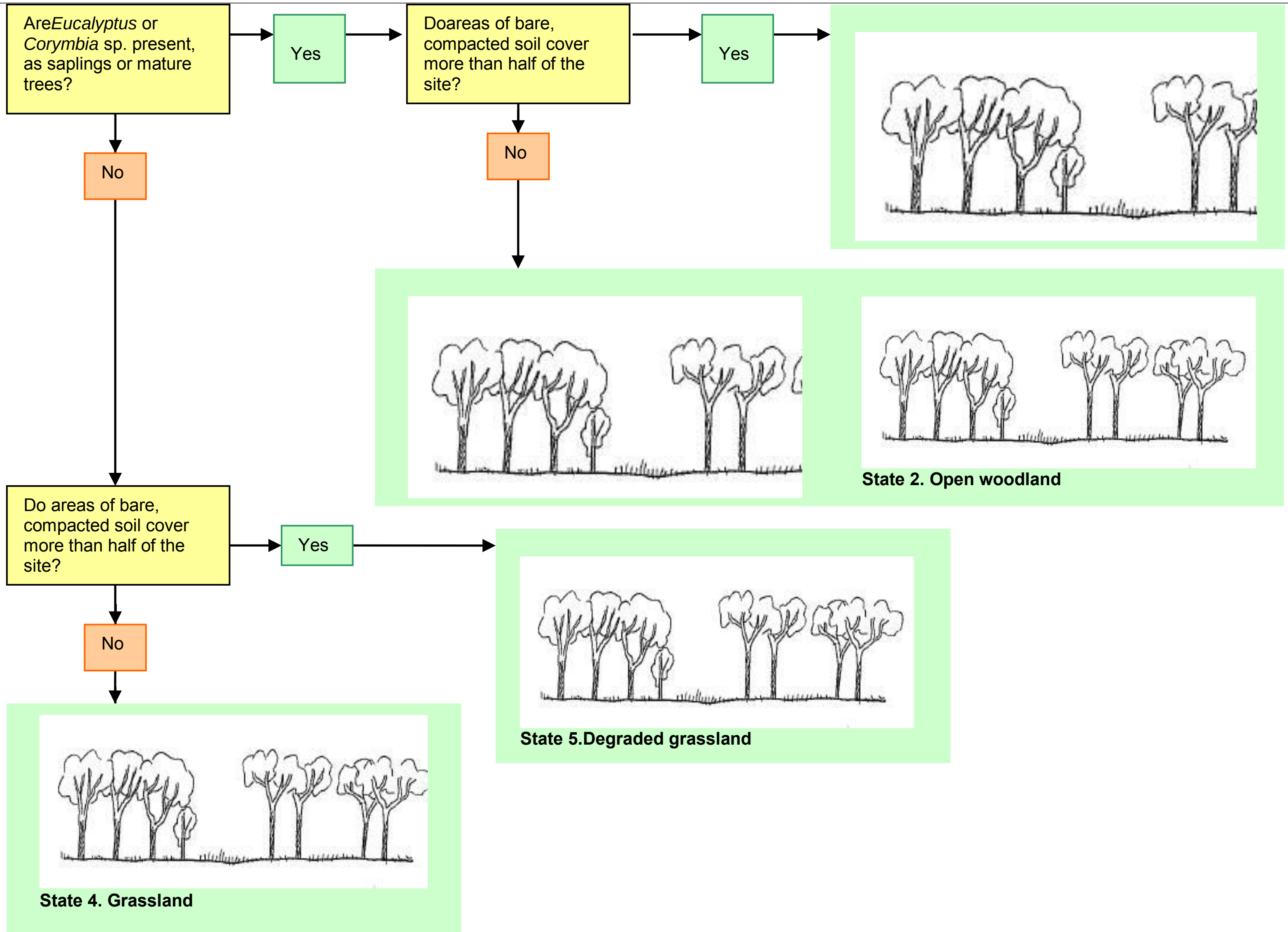


Figure 10: Key to eucalypt woodland condition states which feature in the ecological model (Fig. 3)

Table 6: The main management issues for each condition state for eucalypt woodlands; condition states 1 and 2 have been grouped because their management actions are the same

Condition state	Description	Main management issue
Condition state	Description	Main management issue
1 and 2	Canopy trees present, no extensive areas of bare soil**.**	Areas in these states should require little intervention to sustain or increase their carbon stocks.
3	Canopy trees and extensive areas of bare soil present.	Soil degradation impedes water infiltration and limits plant establishment and growth.
4	Canopy trees absent, no extensive areas of bare soil	Seed sources for trees and shrubs will be critical to restoration of carbon stocks from the grassland state.
5	Canopy trees absent, extensive areas of bare soil present	Both seed sources and conditions for plant establishment and growth can limit recovery of degraded grasslands.

Table 7: Management actions for restoring and maintaining eucalypt woodland vegetation; actions that maximise carbon are indicated by an upwards arrow in the 'carbon' column; those that conserve wildlife are indicated by an upwards arrow in the 'wildlife' column; ticks indicate which actions are relevant to which condition states. Some condition states have been grouped because their management actions are the same.

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2	3	4	5
Clearing and thinning							
1. No clearing of live trees and shrubs.	• Clearing eucalypt woodlands will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss. • Clearing removes plants and animals as well as the food and shelter of animals that depend on trees and shrubs. • Animals which have little or no capacity for dispersal are severely impacted by land clearing.	↑	↑	✓	✓		
2. Retain dead standing trees and shrubs, and fallen timber. Minimise or avoid collection for firewood, or 'cleaning-up'.	• Dead trees and fallen timber contribute to the amount of carbon stored. • Dead trees (especially those with hollows) and fallen timber are important shelter and foraging sites for wildlife.	↑	↑	✓	✓	✓	✓
3. Encourage the growth and survival of large trees.	• Healthy, large trees make a substantial contribution to the amount of carbon stored. • Large trees are more likely to contain and form hollows, provide shelter and foraging sites for wildlife, and they can take a very long time to replace.	↑	↑	✓	✓	✓	✓
Fire							

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2	3	4	5
4. Prevent and suppress moderate- to high-severity fires.	• Moderate- to high-severity fires result in net carbon loss by consuming the carbon stored in trees, shrubs, dead wood and litter. • Trees, shrubs, dead wood and litter that would be damaged or destroyed by fire all provide shelter and foraging sites for wildlife.	🡑	🡑	✓	✓	✓	✓
5. If grass fuel loads are likely to build up, conduct patchy, low-severity burns, when soil moisture is high, to reduce the risk of moderate- to high-severity fires.	• Repeated small fires can reduce the rate of carbon gain by removing small trees and shrubs, but small carbon losses are preferable to potentially larger losses from unplanned wildfire. • Reduces the risk of fire in the area to be restored (see **4**).	🡑	🡑	✓	✓	✓	✓
6. Use grazing management to reduce high fuel loads (needs to be balanced with allowing the establishment and growth of woody plants (see **10** below).	• Reduces the risk of fire in the area to be restored (see **4**).	🡑	🡑	✓	✓	✓	✓
7. Use grazing management or low severity burns, when soil moisture is high, to reduce high fuel loads in the surrounding vegetation, if the surrounding vegetation includes pasture.	• Reduces the risk of fire in the area to be restored (see **4**).	🡑	🡑	✓	✓	✓	✓
8. Maintain a range of burning practices that create a fine-scale mosaic of fire histories in the landscape, including unburnt refugia (Woinarski 1999; Martin & Green 2002; Valentine *et al*. 2007) and to avoid hot fires, especially late in the dry season	• Native species have diverse responses to fire, so a mosaic of low severity burns that are patchy in space and time should help to conserve the greatest number of species.		🡑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2	3	4	5
9. Rake litter and debris away from the base of large and hollow trees prior to prescribed burning.	• Healthy, large trees make a substantial contribution to the amount of carbon stored.	↑	↑	✓	✓		
Grazing							
10. Manage grazing to allow tree recruitment (see ***Managing tree density*** for more details).	• Uncontrolled grazing may reduce carbon gain and storage by disturbance to tree and shrub growth and establishment, and by trampling of woody debris and litter. • Uncontrolled grazing by stock can reduce shelter and food for wildlife by slowing the recruitment and growth of trees, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓	✓
11. Control macropods and feral animals (e.g. goats, pigs, rabbits) if they are in sufficient densities to prevent the recruitment of native trees and shrubs (see ***Managing tree density*** for more details).	• Uncontrolled grazing may reduce carbon gain and storage by disturbance to tree and shrub growth and establishment, and by trampling of woody debris and litter. • Uncontrolled grazing by feral and native animals can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of trees, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓	✓
12. Establish and maintain an intact pasture/ground layer with appropriate density of perennial ground layer species.	• An intact ground layer will reduce erosion and improve water infiltration. This will be beneficial for tree establishment and growth.	↑		✓	✓	✓	✓
13. Establish and maintain an intact ground layer of native plant species, with appropriate density of perennial ground layer species.	• A ground layer of native plant species will reduce erosion and improve water infiltration, and also help to conserve wildlife.	↑	↑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2	3	4	5
14. Manage domestic, native and feral herbivores to maintain low to moderate levels of grazing pressure.	• Uncontrolled grazing by domestic, feral and native animals can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of trees, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber. • Providing areas of low to moderate grazing pressure will favour many native plant and animal species that find it difficult to survive in highly-grazed landscapes.		🡅	✓	✓	✓	✓
Site preparation and plant establishment							
15. Rehabilitate soil in degraded areas by placing large branches and shrubs in elongated piles along contours (Ludwig & Tongway 1996; Tongway & Ludwig 1996).	• Woody debris placed along contours will reduce water runoff, and trap organic matter and seeds, and provide protected areas for plant establishment.	🡅	🡅		✓		✓
16. Use slashing or low severity fire, when soil moisture is high, to reduce the cover of herbaceous plants before direct seeding or tube stock planting.	• Improves the establishment and growth of woody plants by reducing competition.	🡅	🡅			✓	✓
17. Revegetate treeless areas with native trees and shrubs using direct seeding or tube stock, when good rains are expected.	• Establishment and growth of woody plants increases the rate and amount of carbon stored.	🡅	🡅			✓	✓
18. Establish a diversity of tree and shrub species.	• A diversity of woody plant species of different sizes and ages provides food and habitat for wildlife.		🡅	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2	3	4	5
Competitors and predators							
19. Prevent the introduction and spread of exotic grasses and other serious weeds. Vehicles, machinery, quad bikes and stock can all spread weeds.	• Exotic pasture species appear to have a negative impact on plant species richness and diversity, and the recruitment and growth of many native plant species.		↑	✓	✓	✓	✓
20. Control buffel grass by slashing or conducting low-severity burns at the end of its growing season (end of the wet season, approximately April), and then applying herbicide when it resprouts. Hand-pulling is also an effective but highly labour intensive method of control. Aim to get canopy shading by trees and shrubs for long-term buffel grass control.	• Exotic pasture species appear to have a negative impact on plant species richness and diversity, and the recruitment and growth of many native plant species.		↑	✓	✓	✓	✓
21. Use high grazing pressure by stock to control exotic grasses, once a sufficient number of native trees and shrubs are established;	• Exotic pasture species appear to have a negative impact on plant species richness and diversity, and the recruitment and growth of many native plant species.			✓	✓	✓	✓
22. Control feral animal species where these are having a negative impact on wildlife.	• Pigs, cats, foxes and goats are some of the feral species that may threaten native plants and animals through predation, competition and spreading disease. • Management actions that have adverse effects on wildlife should be avoided if possible, or implemented in stages.		↑	✓	✓	✓	✓
23. Control weed species where these are having a negative impact on	• Management actions that have adverse effects on wildlife should be avoided if possible, or implemented		↑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2	3	4	5
wildlife.	in stages.						
24. Use habitat modification to reduce the numbers of aggressive honeyeaters (noisy miners and yellow-throated miners) where these are having a negative impact on wildlife.	• Miners can have a strong negative influence on the abundance and species richness of other native birds. • Direct control of miners is not recommended. • Increasing the density of stems and understorey shrubs, and reducing grazing pressure, should help to discourage miners, and provide a more suitable habitat for small birds.		↑	✓	✓	✓	✓
Other actions for wildlife							
25. Retain and restore tree and shrub patches of different sizes, ages and stem densities.	• More wildlife species are likely to be supported if a range of vegetation growth types are represented in a given farmland area.		↑	✓	✓	✓	✓
26. Provide nest boxes if hollows are scarce	• Tree hollows provide important shelter and foraging sites for wildlife.		↑	✓	✓	✓	✓
27. Retain and protect large grass tussocks.	• Large perennial grass tussocks provide important shelter and foraging sites for wildlife.		↑	✓	✓	✓	✓
28. Retain and protect mistletoe on eucalypts and other woody plant species.	• Mistletoe provides nectar, berries and nesting sites for many animal species.		↑	✓	✓		
29. Retain and protect rocks and rock outcrops.	• Many animals use rocks or rocky areas for shelter, and some plant species may only be found in association with rocky areas.		↑	✓	✓	✓	✓
30. Retain and protect leaf litter (fallen leaves, bark, twigs).	• Many animals use leaf litter for shelter and foraging.		↑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2	3	4	5
31. Minimise or avoid the use of insecticides in areas to be restored, and prevent spray drift from adjacent areas.	• Invertebrates deserve protection in their own right, but also provide food for other animals, and ecosystem services such as pollination and seed dispersal.		↑	✓	✓	✓	✓
Other considerations							
32. Rainfall will have a large bearing on the success of management actions.	• Extended dry periods may cause the death of mature trees. • Try to revegetate with tube stock or by direct seeding only when good rains are expected.						

Managing tree density

The density of large trees has a large bearing on carbon storage and pasture production. The basic principle for maintaining or increasing tree densities is to make sure there are enough new trees to replace, or augment, the existing canopy trees. But not all 'new' trees are the same, as woodland eucalypts progress through distinct life stages before they develop into mature trees, and each life stage has a different level of tolerance to grazing and fire. This means that the management actions for maintaining or increasing tree density will vary, depending on what types of 'new' trees are present. Whether the landholder wishes to aim for typical large tree densities for the vegetation type (for maximum carbon) or reduced tree densities (for increased pasture production) it is important to understand how to manage different tree life stages to achieve the tree density required.

Life stages

For the purposes of this guideline, the three life stages of woodland eucalypts before they develop into mature trees are seedlings, short saplings and tall saplings (Table 8). In this scheme, seedlings are defined by the absence of a lignotuber and therefore they are usually killed if most shoots are removed by grazing or fire, as they have little capacity to resprout after damage. Once a seedling develops a lignotuber, it has the ability to resprout from the base if its upper shoots are removed. This life stage is termed a 'short sapling'.

In contrast, a 'tall sapling' has grown to a height that puts its upper branches beyond the reach of most livestock, macropods and feral herbivores. Plants in this category have also developed thicker bark on their main stem and larger branches, and the capacity to resprout from upper stems and branches (epicormic resprouting) after damage. This means that tall saplings are more likely to avoid grazing than the previous two life stages, as most herbivores cannot reach all of their branches and leaves.

Both types of saplings often survive low- to moderate-severity fires by resprouting, but the impact on their heights usually differs. The height of short saplings may be reduced (as their stems are killed or burnt, and they resprout from their lignotubers) while the height of tall saplings will be less affected (as their stems have more protection, and they can resprout from their canopies).

Management actions for the recruitment and conservation of different life stages are detailed in Table 9.

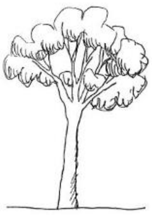
Tree density

Tree density can be **increased** by encouraging the establishment and growth of seedlings and/or saplings, so that the recruitment rate of new trees into the canopy is greater than the mortality rate of mature trees if present. The exact number of seedlings and saplings needed to produce a mature tree is difficult to define, as many factors will influence the survival and growth of seedlings and saplings such as rainfall, fire, grazing, and so forth.

A rough estimate of replacement ratios is:

These replacement ratios are based on ideal growing conditions, and the appropriate management of grazing and fire for the different life stages.

Table 8:Life stage traits for woodland eucalypts

	Life stage	Height (approx.)	Resprouting		Tolerance	
			Lignotuber	Epicormic	Grazing	Fire
	Seedling	Up to ~ 20 cm	no	no	Unlikely to survive if most shoots are removed.	Unlikely to survive fire.
	Short sapling	20 – 150 cm	yes	no	Likely to survive and resprout from base if most shoots are removed.	Likely to survive and resprout from base if most shoots are killed or burnt.
	Tall sapling	> 150 cm[8]	yes	yes	Probably beyond the reach of most herbivores; can resprout from base and upper stems / branches.	Likely to survive and resprout from upper stems / branches and base.
	Mature tree	Canopy height	yes	yes	Probably beyond the reach of most herbivores; can resprout from base and upper stems / branches.	Likely to survive and resprout from upper stems / branches and base.

To **maintain** tree density, the mortality rate of mature trees should be equal to the recruitment rate of new trees into the canopy. The time between tree death and replacement can be minimised by conserving a 'bank' of tall saplings scattered throughout the site. When a mature tree dies, it is likely that nearby saplings will grow to replace it.

The number of tall saplings needed to replace a mature tree will depend on many factors, but five saplings per mature tree may be the minimum required. If there are no tall saplings present, it is likely that larger numbers of short saplings and seedlings will be required to replace a mature tree, given the generally higher mortality rate of these earlier tree life stages. The replacement ratios provided above can be used as a rough guide for maintaining tree density in mature eucalypt woodlands.

The slow growth of woodland eucalypts, higher rates of mortality during droughts, and the episodic recruitment of seedlings in high rainfall years should all be considered when managing tree densities and preparing for tree replacement. A larger 'bank' of saplings and small trees may reduce pasture production but is more likely to enable the rapid replacement of large trees, and the maintenance of maximum carbon levels.

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[8] Based on the development of epicormic resprouting in *C. clarksoniana* when it is over 150 cm in height (P. Williams *pers.comm.*).

Table 9: Management actions for the recruitment and conservation of different tree life stages; these actions are in addition to the general management actions for condition states in Table 7

Life Stage	Management Actions
Seedlings	• Seedling establishment will be more successful when periods of unusually high rainfall coincide with, and continue after, seeds are released. • If using manual or machine seeding to establish seedlings, try to do this when a period of unusually high rainfall is expected. • Reducing the amount of herbage before seed drop (by slashing, grazing, or low-severity fire) may also assist seedling establishment. • Exclude livestock and exclude or control other herbivores until seedlings develop into short saplings. • Protect from fire.
Short saplings	• This life stage is still within the reach of most herbivores, so grazing pressure may need management until short saplings develop into tall saplings. • Reduce stocking rates and/or control or exclude native and feral herbivores if grazing is damaging saplings. • Protect from fire until short saplings develop into tall saplings.
Tall saplings	• No special grazing management should be required if enough tall saplings are present, as these are unlikely to be damaged by grazing. • Protect from high severity fires.

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