Wet sclerophyll forest

Regrowth Benefits - Management Guideline

Prepared by

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Summary

- Wet sclerophyll forest is found in all Australian states except for South Australia and the Northern Territory. It occurs in areas of high rainfall, often between open eucalypt forest and rainforest (where present).
- In Queensland, wet sclerophyll forest is mostly found in the south-east, and as a narrow ecotone bordering the western edge of rainforest in the Wet Tropics.
- Regeneration of wet sclerophyll forest in Queensland can be maintained with low-moderate levels of fire or mechanical disturbance.
- The intense crown fires that characterise the renewal of wet sclerophyll forest in the southern states are not required for the regeneration of this vegetation type in Queensland.
- Rainfall and past clearing history have a large influence on carbon accumulation rates and standing carbon stocks in wet sclerophyll forest, but ongoing management can also have a large effect.
- Standing stocks of above ground carbon in mature wet sclerophyll forest in Queensland range from about 100 to more than 500 tonnes of carbon per hectare (i.e. 370 to more than 1800t CO_2-e ha^{-1}).
- Conservative estimates of carbon accumulation rates in wet sclerophyll forest regrowth are between 6 to more than 30 tonnes of CO_2-e (carbon dioxide equivalent) per hectare per year.
- Cattle grazing can be compatible with reforestation in wet sclerophyll forest, 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.
- Timber harvesting can be compatible with reforestation in wet sclerophyll forest, although it will slow the rate of carbon accumulation and reduce carbon stocks in the short term.
- Regrowing wet sclerophyll forest will benefit wildlife, especially plants and animals that are strongly dependent on wet sclerophyll forest for habitat.

Description

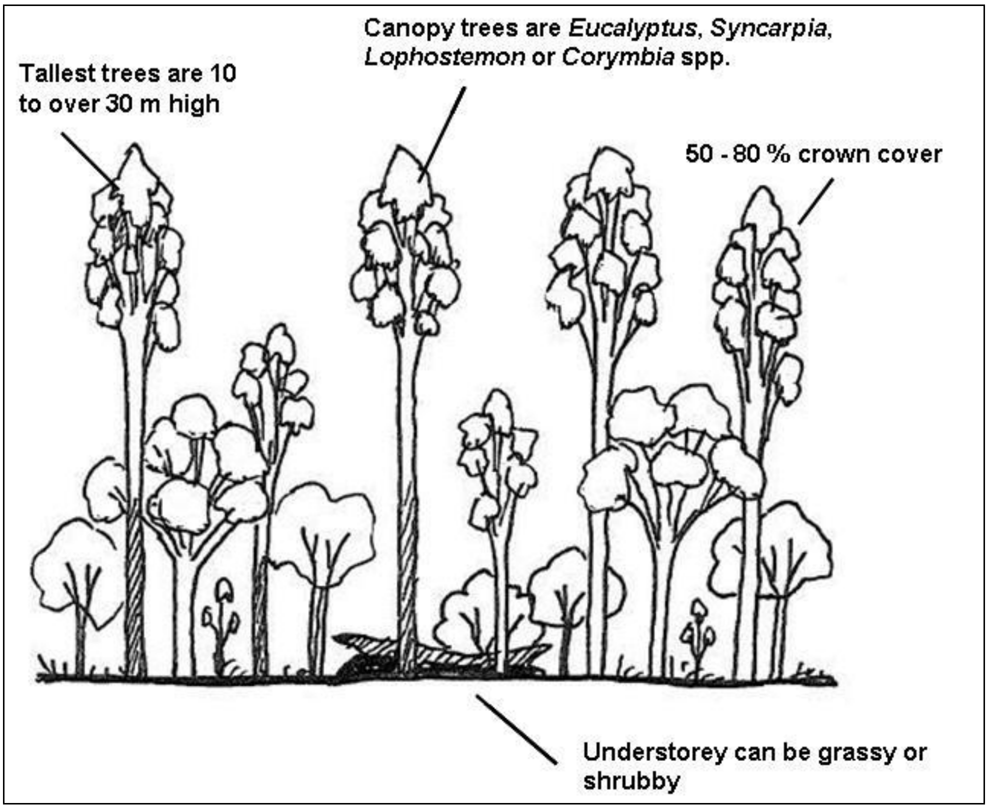


Figure 1: Structural features of wet sclerophyll forest

Wet sclerophyll forests (also known as tall open-forests) are unique to Australia (Ashton 1981). In Queensland, wet sclerophyll forests usually have these features:

- Eucalypts (including flooded gum (*Eucalyptus grandis*), blackbutt (*E. pilularis*), blue gum (*E. saligna*), red mahogany (*E. resinifera*), turpentine (*Syncarpia glomulifera*), brush box (*Lophostemon confertus*) and sometimes bloodwoods (*Corymbia* spp.) are the tallest trees, and form the upper canopy layer.
- The height of the tallest canopy trees can range from 10 m to over 30 m.
- Canopy cover can vary from 50 – 80% (approximate crown cover; Queensland Herbarium 2011).
- The understorey may be composed of rainforest plants, or be grassy with a sparse shrub layer, or be a combination of both.
- Several tree species may be present in the canopy at any one site. The species composition may vary depending on the local climate, topography, soil type and management history.

Wet sclerophyll forest tends to occur in areas of high rainfall between open eucalypt forest (also known as dry sclerophyll forest) and rainforest. In Queensland, wet sclerophyll forest is mostly found in south-east Queensland, and as a narrow ecotone bordering the western edge of rainforest in the Wet Tropics (Fig. 3).

Figure 2: Wet sclerophyll forest (photo R. Carpenter)

Management of reforestation projects may incorporate non-carbon income streams, such as timber or grazing. 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 managers aim to strike between carbon, biodiversity and other values. The trade-off between trees and timber is an important example.

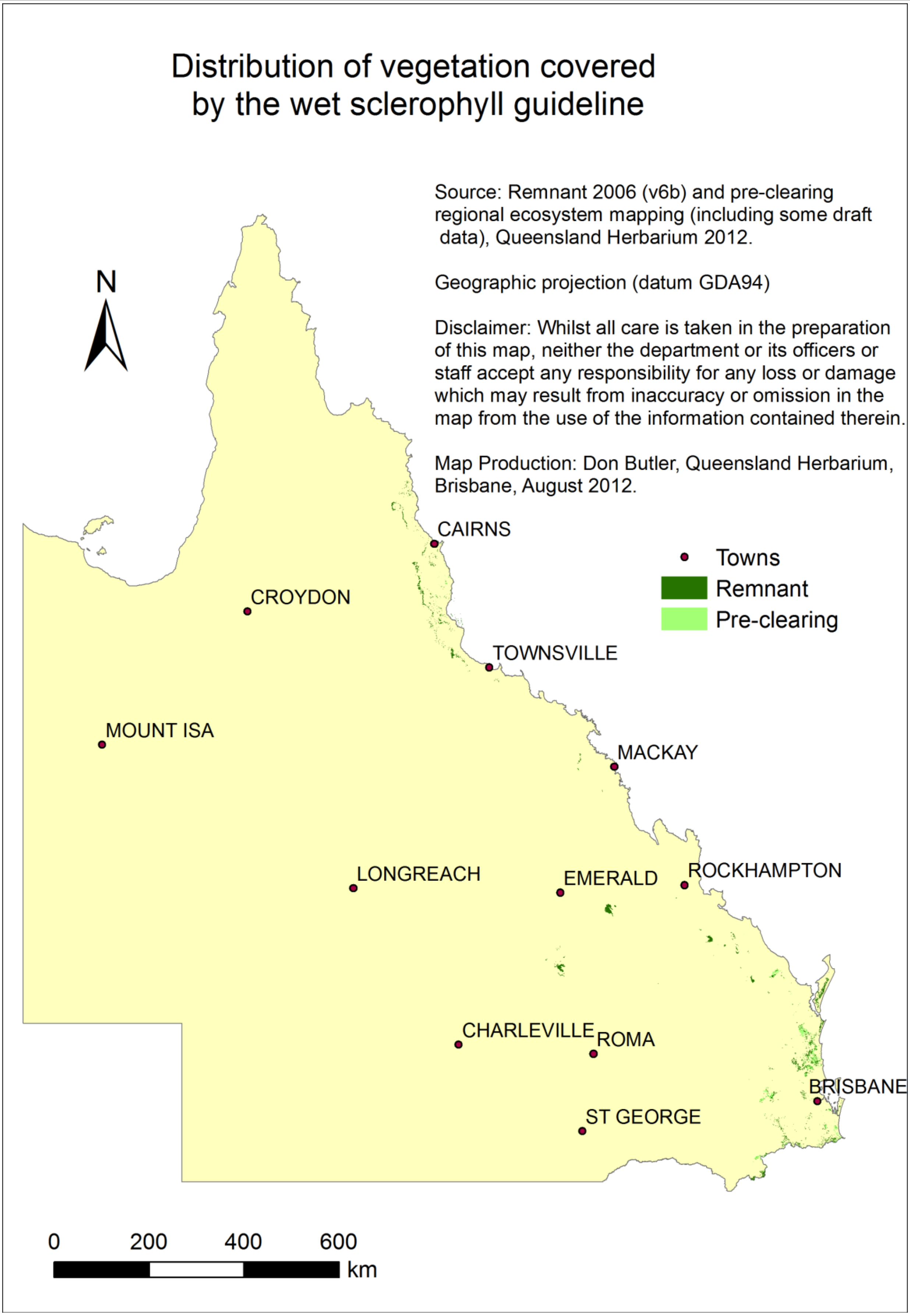


Figure 3: Map of wet sclerophyll forest distribution in Queensland

Ecology

Figure 4: Illustration of wet sclerophyll forest ecology (P. Peeters)

The restoration and management of wet sclerophyll forest is underpinned by what we know about the ecology of this vegetation type, including the effects of climate, clearing, fire and grazing.

Note that in these guidelines the term 'eucalypt' is used as a collective term for the *Eucalyptus, Lophostemon, Syncarpia* and *Corymbia* species that are dominant canopy species in wet sclerophyll forest in Queensland.

Wet sclerophyll forest – a stage in succession towards rainforest

Wet sclerophyll forest is intimately associated with rainforest, and in many areas it is largely the effects of fire that allow wet sclerophyll forest to occupy sites that would otherwise be suitable for rainforest (Jackson 1968; Webb 1968). Other factors such as topography, drainage and substrate fertility also influence the distribution of wet sclerophyll forest (Webb 1968; Beadle 1981; Florence 1996), but fire plays a major role (Ashton and Attiwill 1994).

In the absence of fire, rainforest plants will often invade the understorey of a wet sclerophyll forest, and as they mature may eventually prevent the recruitment of eucalypt species (Ashton and Attiwill

1994; Cremer 1960; Jackson 1968). This results in the transformation of wet sclerophyll forest to rainforest, and the rainforest state will be maintained in the absence of major disturbance.

Wet sclerophyll forest may also have an understorey dominated by grasses and sedges (Keith 2004). In this case the recruitment and growth of shrubs and small trees, including rainforest species, are suppressed by frequent low intensity fires (Beadle 1981).

Regeneration - overview

It seems counter-intuitive that wet sclerophyll eucalypts are not only highly fire-sensitive, but are also highly dependent on fire for their survival (Ashton 1981). They are more easily killed by fire than most other eucalypt species, but they also germinate and grow best after disturbance such as fire. Most eucalypt species have features that allow them to survive hot fires (such as thick bark and lignotubers), but these features are absent, or only poorly-developed in the canopy species of wet sclerophyll forests (Ashton 1981). Two of the most widespread wet sclerophyll eucalypts that occur in Queensland do not possess lignotubers (the flooded gum *E. grandis* and blackbutt *E. pilularis*), but while the flooded gum can be killed by relatively low intensity fire, blackbutt may recover through epicormic shoots (Florence 1996). Most wet sclerophyll eucalypts have small seeds that do not remain viable in the soil for long (Ashton and Attiwill 1994), and are killed if exposed to fire. Wet sclerophyll eucalypts also tend to have a high light requirement for growth (Cremer 1960), and their seeds may have trouble germinating and surviving on undisturbed forest soil, particularly when thick leaf litter is present (Florence and Crocker 1962; Florence 1996).

The regeneration of wet sclerophyll forest is often associated with high intensity crown fires which kill the mature canopy trees (Ashton and Attiwill 1994), and this is the typical mode of regeneration in southern Australia. The relatively small seed capsules stored in the canopy somehow protect the tiny eucalypt seeds from the intense heat of a crown fire, and then release them after the fire has passed (Ashton and Attiwill 1994). Leaf litter is consumed by the fire; the resulting ashbed has increased availability of nutrients and reduced levels of inhibitory soil microorganisms, and the destruction of the canopy results in high light levels. These are ideal conditions for the growth of wet sclerophyll eucalypts, provided there is enough moisture, and severe weather events (e.g. frosts) do not occur (Florence 1996). In south-eastern Australia, repeated high intensity crown fires have led to extensive areas of single-age wet sclerophyll forest, and the retreat of rainforest into small areas, often topographically protected from fire (Webb 1968).

High intensity fires are more likely to occur under weather patterns that bring hot, dry winds from the arid interior of the continent (Bureau of Meteorology 2009; Webb 1968), and these patterns are more frequent and severe in south-eastern Australia than in Queensland. In south-eastern Australia, such fire events occur in the summer months, which are also the driest of the year. The most dangerous fire weather is associated with summer cold fronts which impose high temperatures, low humidities and both strong and variable winds onto an already parched landscape (Bureau of Meteorology 2009; Webb 1968).

In contrast, the most dangerous fire conditions for southern Queensland are the westerly winds that occur at the end of the dry season in spring and early summer (Bureau of Meteorology 2009). In areas that support wet sclerophyll forest in north Queensland, most fires also occur in the drier part of the year (June – November) (Unwin *et al.* 1985). However, the resulting fires are usually surface fires, and are seldom intense enough to kill large areas of mature wet sclerophyll eucalypts (Webb 1968). High intensity crown fires are a rare event in Queensland, and the regeneration of wet sclerophyll forest often occurs under much lower levels of disturbance.

The wet sclerophyll eucalypts of Queensland can regenerate after high intensity fires by using similar strategies to their southern counterparts, but regeneration can also be triggered by more patchy, low level disturbance (e.g. low intensity surface fire, or mechanical clearing) (Florence 1996).

Wet sclerophyll forest in north Queensland

In north Queensland, wet sclerophyll forest forms a narrow ecotone between dry sclerophyll forest and rainforest (Webb 1968) along the western side of the near-coastal mountains (Webb and Tracey 1994). It seems that fires of the intensity required to generate and maintain larger stands of wet sclerophyll forest seldom occur in the Wet Tropics (Ash 1988), and low-moderate intensity fires are rapidly extinguished once they encounter rainforest (Unwin *et al.* 1985). Rainforest plants have invaded the wet sclerophyll forest in many areas, and canopy eucalypts do not appear to be regenerating (Unwin 1989; Harrington 1994; Russell-Smith and Stanton 2002; Harrington and Sanderson 1994). There are concerns that wet sclerophyll forest in north Queensland will be replaced by rainforest, to the detriment of species that rely on the former for food and shelter (e.g. the yellow-bellied glider, *Petaurus australis* unnamed subsp*;* Harrington and Sanderson 1994).

More details on the biology of canopy tree species

The seed of wet sclerophyll eucalypts is stored in capsules in the forest canopy, and is either gradually released after a number of years, or is released *en mass* after fire (Ashton and Attiwill 1994). *E. pilularis* seed is usually shed mostly in spring and early summer, but this can occur in any month if dry conditions are experienced (Florence 1996). Fire can accelerate seed shed by causing branch abscission and causing all the mature seed to be released in a few days or weeks (Florence 1996). The dispersal distance for *E. pilularis* seed is usually less than 8 m from the base of the parent tree (Florence 1996).

The undisturbed forest floor is unsuitable for the establishment of wet sclerophyll eucalypts, but good seedling establishment may be obtained after intense fire has exposed the mineral soil and removed the upper canopy (Florence 1996). Seedling establishment can also be significant when seeds fall on mineral soil that has been exposed and disturbed by the activities of logging machinery (King 1985; Florence 1996).

Even though *E. grandis* and *E. pilularis* do not develop lignotubers, their seedlings are capable of forming new shoots from epicormic bud strands at their base if they are damaged by agencies other than fire (Florence 1996). These new shoots, and the bud-bearing tissue itself, are sensitive to fire, and plants up to 3m height can be killed by even low intensity fires (Florence 1996). However, in the absence of fire, these seedlings can persist in the understorey of wet sclerophyll forest for many years, and are capable of rapid growth when released from competition (Florence 1996). The release of these non-lignotuberous seedlings from competition by partial clearing of the understorey and/or canopy is another way in which wet sclerophyll forest can regenerate in response to patchy disturbance.

Stocking rates of wet sclerophyll eucalypts will generally be higher when seedlings establish after high intensity fire, or clearing, that removes competition and exposed mineral soil (King 1985; Florence 1996).

Fire

Although wet sclerophyll eucalypts can regenerate after high intensity fire, such fire events should be avoided when regrowing wet sclerophyll forest for carbon or biodiversity because of the setback to tree growth and carbon stores, high carbon emissions, and the potential for risk to life and property. High intensity fire does not appear to be essential for the regeneration of most wet sclerophyll eucalypt species that occur in southern Queensland, so their regeneration can be maintained with patchy low intensity fire or mechanical disturbance. Extremely hot fire can eliminate both fire-sensitive eucalypts and understorey species, and exhaust soil seed stores, if it occurs at relative short intervals (e.g. less than 10 years), and can lead to the dominance of fire-tolerant plants, both native (e.g. acacias and bracken) and exotic (e.g. lantana).

Regular low intensity fires have been used to reduce fuel loads, manage weeds such as lantana, and maintain grassy understorey in some Queensland wet sclerophyll forests, yet frequent fires can have negative effects on tree growth and survivorship, and on soil nutrients and microorganisms. The following studies examined the effect of 2-year and 4-year prescribed burn frequencies at a wet sclerophyll forest at Peachester in south-eastern Queensland. The forest is dominated by *E. pilularis*, in association with *C. intermedia, E. microcorys, E. resinifera, S. glomulifera* and *L. confertus* (Guinto *et al.* 1999a). The diameter growth of *L. confertus* was enhanced by biennial burning, whereas that of *S. glomulifera* was depressed by both biennial and quadriennial burning regimes, and both burning treatments reduced the survival of these species (Guinto *et al.* 1999a). Mortality was also related to tree size, as biennial burning resulted in the death of all trees less that 10 cm in diameter (Guinto *et al.* 1999a). The recruitment of both *L. confertus* and *S. glomulifera* was adversely affected by burning, while the recruitment of all other species was negligible, regardless of treatment (Guinto *et al.* 1999a). Guinto *et al.* (1999b and 2001) also found that biennial burning reduced topsoil total N, soil N mineralisation and changed the soil organic matter composition, and also reduced the weight, organic matter and nutrient contents of the litter layer. They suggested that these long-term declines could have an adverse impact on existing and future vegetation growth. In addition, the structure of the soil fungal community was significantly altered by both burning regimes compared to unburned controls (Bastias *et al.* 2006), and microbial biomass (both bacterial and fungal) was 50% less in the 2-year burn treatment than the control or 4-year burn treatments (Campbell *et al.* 2008).

It appears that fire is needed to regenerate and maintain wet sclerophyll forests in northern Queensland (Russell-Smith and Stanton 2002). According to Unwin (1989), it is likely that the amount of grass fuel in the grassy forests adjoining the wet sclerophyll forest and rainforest is regularly reduced by livestock grazing. This means that the intensity of fire necessary to allow the regeneration of wet sclerophyll eucalypts seldom occurs. Although (Unwin 1989) observed the establishment of *E. grandis* ahead of the expanding rainforest (and perhaps without fire) the likely survival of these plants was later questioned by another observer (see Russell-Smith and Stanton 2002). It is unclear whether patchy low intensity fire or mechanical disturbance is a viable alternative method of regenerating wet sclerophyll eucalypts in northern Queensland. A range of eucalypt and rainforest species were observed to survive and/or recruit in wet sclerophyll forest when subjected to repeated, moderate-intensity fires (Williams *et al.* 2011). However, the eventual fate of these individuals, and their impact on longer-term forest dynamics, is not yet known.

Dense understorey vegetation

Wet sclerophyll eucalypt seedlings have a high light requirement for growth (Cremer 1960), and their establishment and survivorship may be reduced or prevented by high densities of understorey shrubs and trees (Floyd 1966; Florence 1996). The use of fire to prepare a site for direct seedling may reduce competition from fire-sensitive plant species, but it may also stimulate the germination of fire-tolerant shrub species such as *Acacia* and *Dodonaea* if their seed is present in the soil (Floyd 1966).

Eucalypts have long lifespans (100+ years), so a high rate of seedling recruitment (e.g. every 1-10 years) is not necessary to ensure the replacement of old trees when they die. Therefore the patchy disturbance of understorey vegetation to allow tree recruitment may only be needed if recruitment is obviously being suppressed over an extended period of time.

Techniques to remove woody understorey plants and restore the grassy understorey of wet sclerophyll forest are currently being trialled by the Australian Wildlife Conservancy in north Queensland (Kanowski 2011). These involve the removal of understorey plants by herbicide application and slashing, then burning the resulting fuel. Preliminary results suggest that fire alone may not be sufficient to restore a grassy understorey (Kanowski 2011). Repeated slashing and herbicide application may be required to reduce the abundance of woody plants, as many rainforest and eucalypt forest shrubs and trees resprout after fire (Williams *et al.* 2011).

Bell miner-associated dieback

Substantial areas of wet sclerophyll forest in southern Queensland and northern New South Wales are affected by bell miner-associated dieback (BMAD); Wardell-Johnson *et al.* 2006). BMAD is described as “a form of tree canopy dieback that can be diagnosed by the presence of over-abundant populations of psyllid insects (*Glycaspis* spp.) often with over-abundant Bell Miner birds (*Manorina melanophrys*)” (NSW Scientific Committee 2008). BMAD results in the defoliation of wet sclerophyll tree species, such as *E. saligna* and *E. grandis*, and can also lead to poor tree recruitment and tree death (NSW Scientific Committee 2008).

The precise causes of BMAD are the subject of much debate, as numerous factors are apparently associated with the phenomenon. These include disturbance by logging, changes to forest structure, weed invasion, altered fire regimes, and the high abundances of psyllids and bell miners (Wardell-Johnson *et al.* 2006; NSW Scientific Committee 2008), and the many interactions between these factors add even more complexity. For example, the *Glycaspis* psyllids feed on the phloem sap of canopy eucalypts, and produce a sugary cover (lerp) where they are attached to the leaves. Bell miners feed on the lerps, and unlike other birds, the bell miners appear to enhance the survival of psyllids by dislodging the lerp with their tongue, and not harming the insect (Haythorpe and Mcdonald 2010). Bell miners are also highly territorial and discourage the presence of other insectivorous bird species. This may allow the psyllid population to multiply, providing the bell miners with more food, but also increasing the impact of the psyllids on their host trees. High levels of plant stress may also produce a negative feedback loop, as stress can increase the amount of amino acids in the plant sap, further assisting the psyllids and negatively impacting on the trees. Canopy cover is often lost when trees decline in health, and this increases the amount of light penetrating the forest.

Understorey shrubs can then grow more vigorously when more light is available, and in many areas affected by BMAD there are also dense thickets of understorey shrubs, such as lantana (Stone *et al.* 2008). As discussed above, a dense layer of understorey shrubs can suppress the germination and growth of mid- and upper-canopy plant species, and this can lead to a change in forest structure. This appears to suit the bell miners, who prefer to nest in thick vegetation between 2 and 5m in height (Stone 2005), and are often associated with areas that have a more open canopy (Stone *et al.* 2008). Altered fire regimes have been put forward as another cause of BMAD, but no consensus has been reached on what these are, and which fire regimes should be reinstated (Wardell-Johnson *et al.* 2006).

Although there are many theories about the causes of BMAD, and how it should be managed, many of these are not backed up by scientific evidence. This means that more research and adaptive management are needed to better diagnose and treat the problem (Bell miner Associated Dieback Working Group 2004, 2005, Wardell-Johnson *et al.* 2006). However, a recent trial involving the removal of lantana with a new herbicide technique (Somerville *et al.* 2011) has produced some promising results. The trial took place on a property in northern NSW that is affected by BMAD and infested with lantana. Good treatment of lantana, in normally inaccessible terrain, was achieved by using a 'splatter gun' to apply a narrow jet of herbicide mixture at 1 m intervals. Following the removal of lantana, the diversity of native plants in the mid-storey and understorey improved, and healthy canopies were re-formed on mature trees that were previously experiencing dieback. The growth of mid- and understorey plants also resulted in a more structurally diverse forest, with a range of height classes of trees, shrubs and ferns. The abundance of bell miners also declined at 3 out of 5 treatment sites when lantana was removed (Somerville *et al.* 2011). There is still much to understand about BMAD and its treatment, but if BMAD sites are also infested with lantana, it seems that lantana removal may be a good place to start.

Ecological model

The ecological model for wet sclerophyll forest in Queensland (Fig.5) summarises the dynamics of this vegetation type into nine main condition states, and identifies factors that cause transitions between states.

The target state to achieve maximum carbon is a wet sclerophyll forest with canopy eucalypts recruiting, and with either a shrubby (State 1) or grassy (State 2) understorey. Transitions between these and other condition states occur in the following ways:

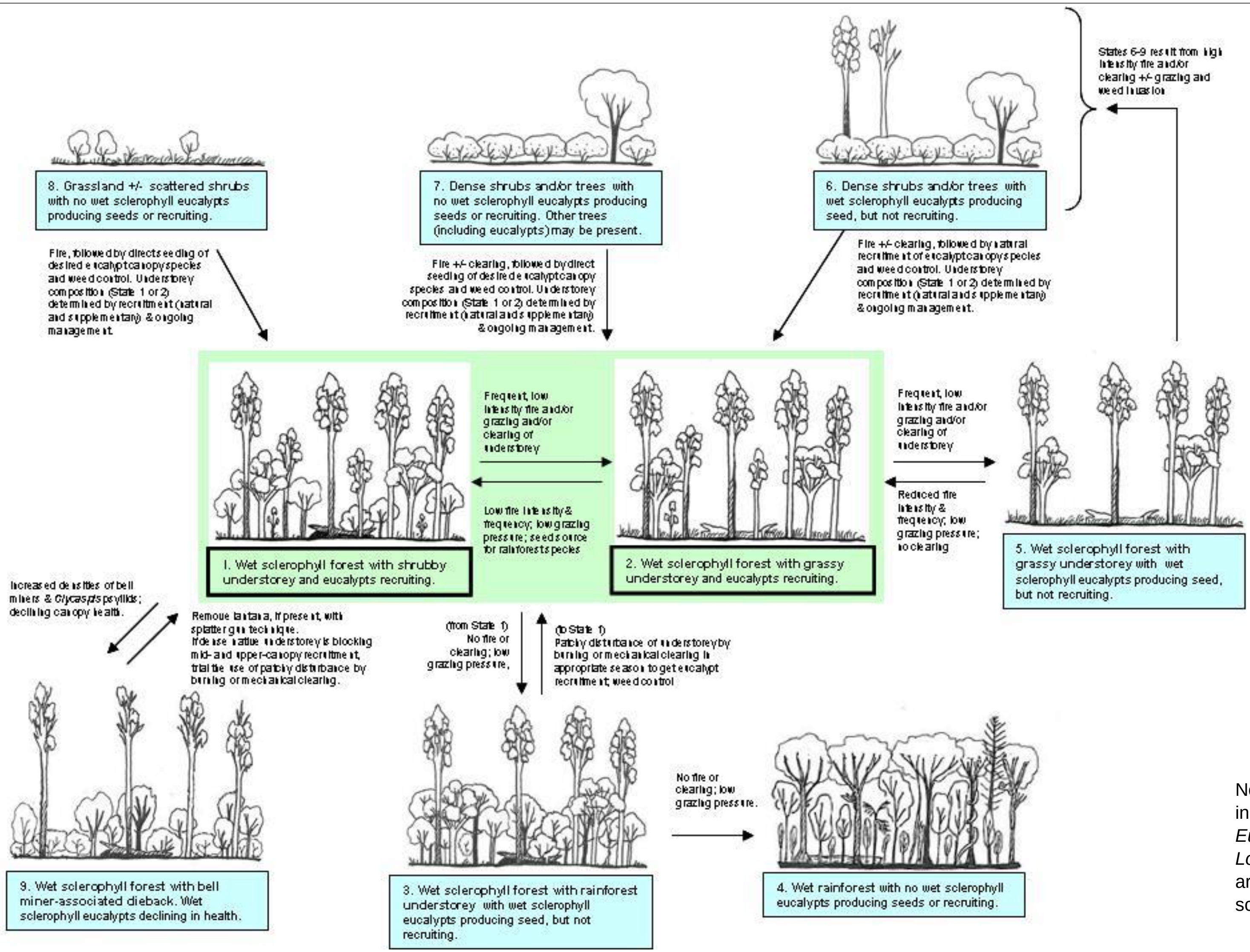
- Frequent, low intensity fire, or regular removal of woody understorey plants by other means will encourage the transition of State 1 to State 2, and then to State 5 (Wet sclerophyll forest with grassy understorey and no eucalypts recruiting).
- Repeated fires and/or selective harvesting is likely to reduce carbon stocks, and may result in the decline or loss of wet sclerophyll eucalypts (States 6-8).
- Increased densities of bell miners may also bring about the decline of wet sclerophyll eucalypts through bell miner associated dieback (State 9), which will also reduce carbon stocks.
- No fire or clearing may result in State 1 (Wet sclerophyll forest with a rainforest) transforming into State 4 (Wet rainforest).
- In most situations, the restoration of wet sclerophyll eucalypts will require the removal of competing woody plants and the exposure of soil by fire or mechanical clearing.
- States without a seed source for wet sclerophyll eucalypts (States 7 & 8) will require direct seeding to enable the establishment and growth of canopy trees.

This guideline advocates the restoration and management of wet sclerophyll forest by using patchy disturbance to trigger regeneration (Fig. 5) rather than high intensity crown fires (Fig. 6). This is because high intensity fires are highly hazardous and they also result in large losses of carbon from the ecosystem, and correspondingly large carbon emissions.

Carbon stocks in a mature wet sclerophyll forest (States 1 & 2) will be maintained close to their capacity if there is adequate rainfall and enough patchy disturbance or gaps in the understorey vegetation to allow the replacement of older trees with new recruits. Grazing and selective tree harvesting 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. The target tree density and vegetation structure for a particular site will depend upon the desired balance between trees, timber, pasture, biodiversity and any other relevant values chosen by the land manager.

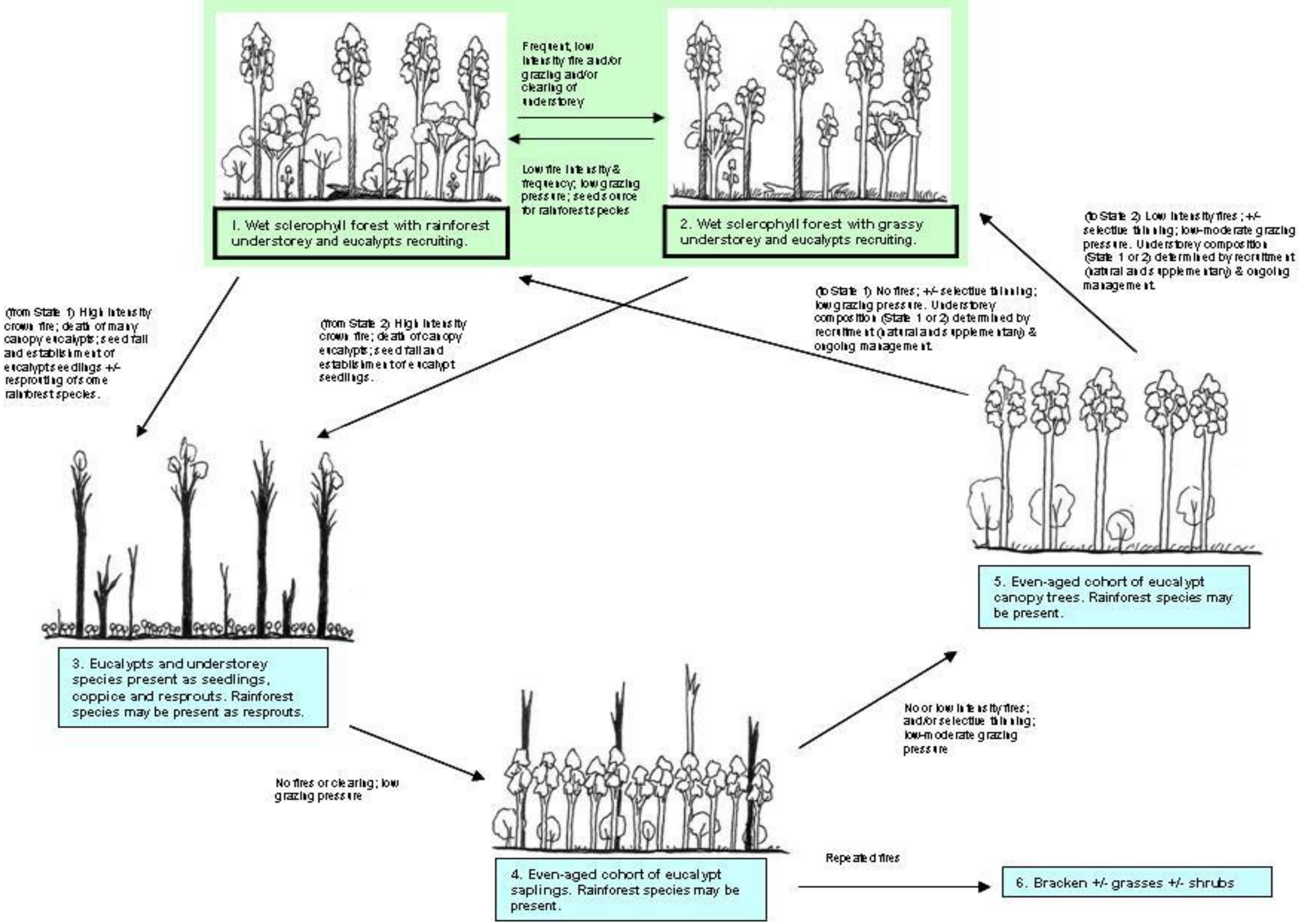
In time, climate variability may also alter the potential ‘mature’ structure and floristic composition of wet sclerophyll forest. This is because changes in rainfall, temperature, levels of carbon dioxide and other factors may affect the reproduction, growth and competitive ability of the plants and animals that are currently part of the wet sclerophyll 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 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 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 change is to establish and conserve a wide range of native plant and animal species that are/were 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 forest.



Note that the term 'Eucalypts' includes all species of *Eucalyptus, Syncarpia, Lophostemon* and *Corymbia* that are canopy dominants of wet sclerophyll forest in Queensland.

Figure 5: Ecological model for wet sclerophyll forest in Queensland. This model recommends patchy disturbance to maintain target states (1) and (2) rather than high intensity crown fire (See Fig. 6)



Note that the term 'Eucalypts' includes all species of *Eucalyptus, Syncarpia, Lophostemon* and *Corymbia* that are canopy dominants of wet sclerophyll forest in Queensland.

Figure 6: Response of wet sclerophyll forest to high intensity fire; this figure demonstrates how wet sclerophyll forest can regenerate after a destructive crown fire; only some states and transitions are shown

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 expected to also increase soil carbon stocks. Biomass is directly proportional to carbon, as carbon makes up about 50% of all biomass (Gifford 2000). Carbon farming might not always mean bringing wet sclerophyll forest back to its full carbon capacity as soon as possible. Some carbon returns might be traded-off against other land-uses, such as selective timber harvesting and livestock grazing, which may limit carbon accumulation rates. Selective timber harvesting and low to moderate levels of livestock grazing appear to be compatible with carbon farming in wet sclerophyll forest (see Management Actions below).

Above-ground carbon in wet sclerophyll forest is stored in living trees and shrubs, but also in dead standing trees, fallen timber and litter. Estimates of total living above-ground biomass for mature wet sclerophyll forest in Queensland range from about 200 to just over 1000 t ha^{-1}, which is equivalent to 100 to 500 t ha^{-1} of carbon and 370 to 1830 t ha^{-1} CO_2-e.

Regrowth of wet sclerophyll forest is estimated to accumulate from 6 to more than 30 t CO_2-e $ha^{-1}yr^{-1}$.

Carbon storage and tree size

Table 1: 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)
5	5.3	2.5	9.7
30	458	215	790
60	2565	1206	4424

Large trees hold far more carbon than small trees (Table 1) because the amount of carbon held increases exponentially as the trunk diameter of a tree increases (Fig. 7). 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. 8).

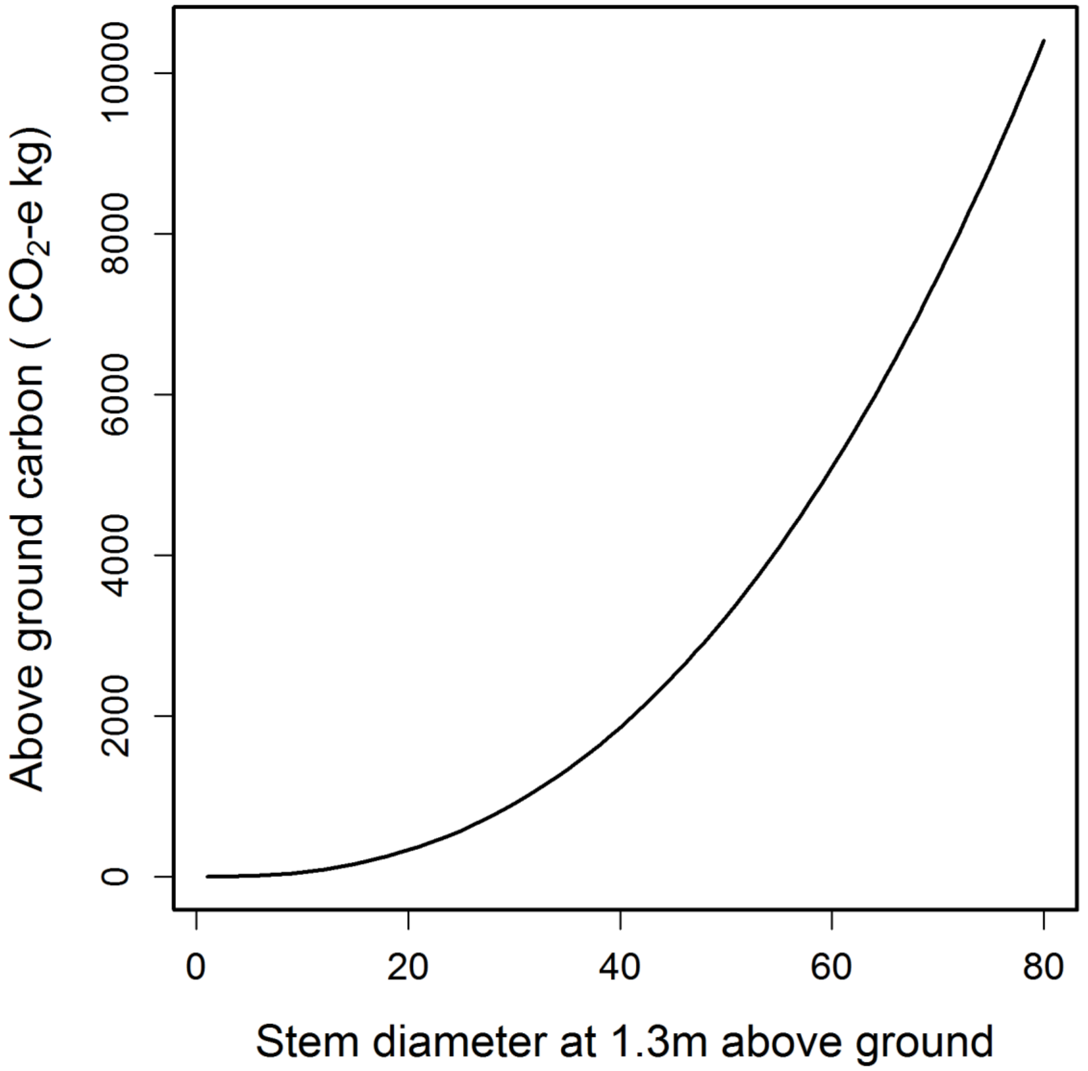


Figure 7: Relationship between eucalypt trunk diameter and above-ground carbon; based on Williams *et al*. 2005. This relationship is for woodland eucalypts but the pattern is very similar for all trees.

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

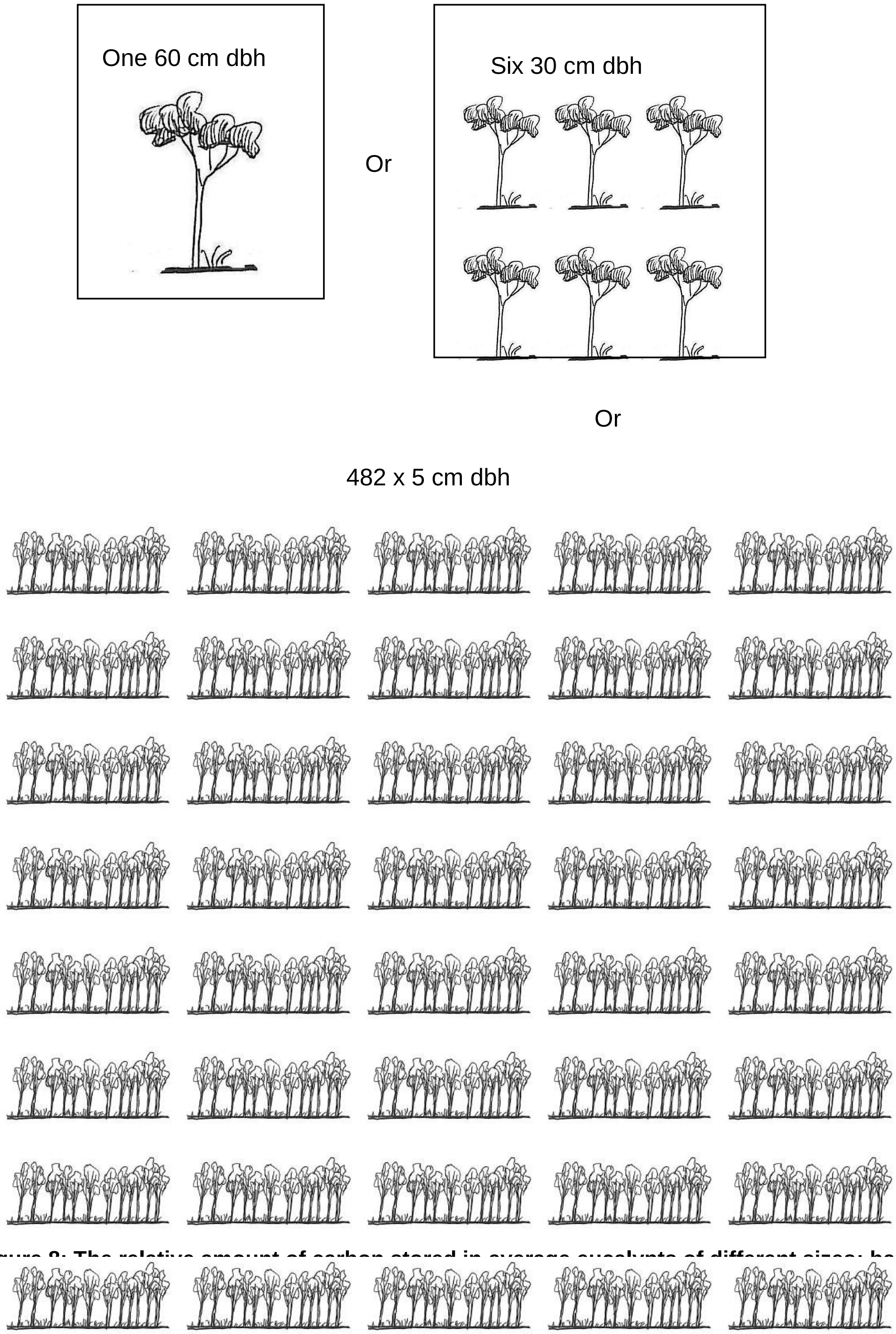


Figure 8: The relative amount of carbon stored in average eucalypts of different sizes; based on Williams *et al.*

Trade-offs between trees and pasture

It is important to note that increasing the basal area of trees tends to decrease pasture yield. This has been observed for a variety of woodland types in Queensland, including eucalypt woodlands (Fig. 9), and a similar relationship is likely to apply to wet sclerophyll forest. It may be possible to combine carbon farming of regrowth with livestock production[1], but landholders should consider how increased tree growth may impact on their pasture yield.

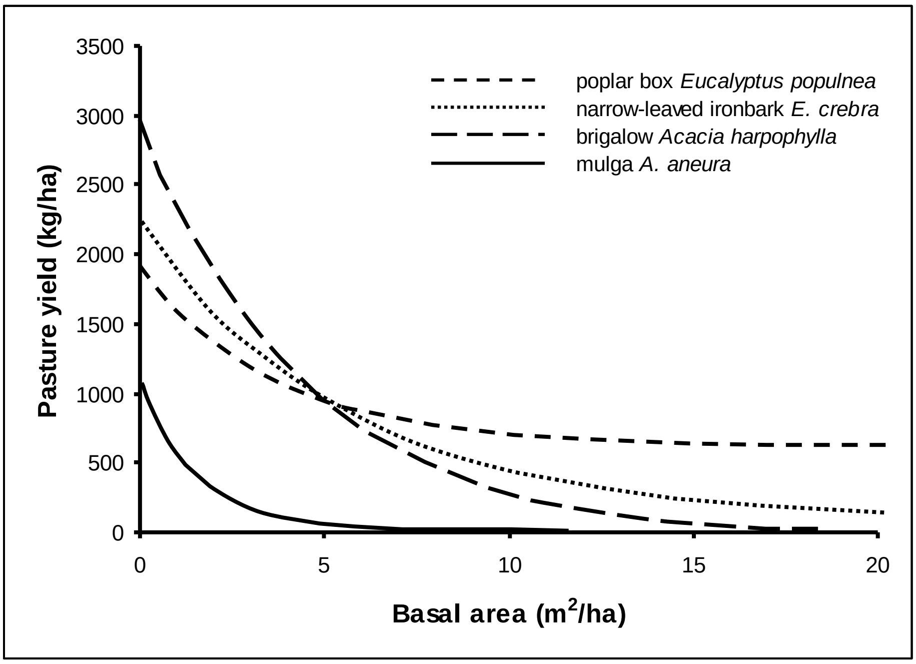


Figure 9: Relationships between tree basal area and pasture yield for a range of woodland tree species from sites in Queensland; redrawn from Burrows 2002; data originally derived from Beale 1973 (A. aneura); Scanlan 1990 (E. populnea and E. crebra); Scanlan 1991 (A. harpophylla)

[1] This will depend on CFI methodology being applied

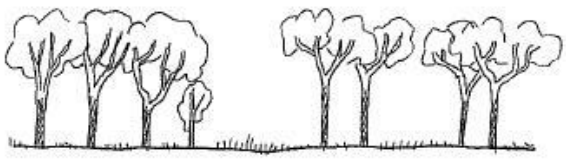
Grow big trees to maximise carbon

A few big trees can hold far more carbon than a large number of small or medium trees (Fig. 8). 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.

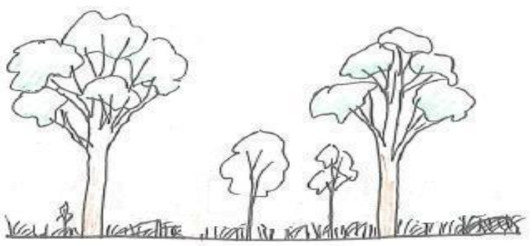
Pasture yield is still likely to be reduced by increasing tree basal area (Fig. 9), but a few large trees will hold far more carbon than many small ones, for the same basal area (Fig. 10).

a)

b)



c)



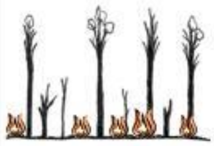
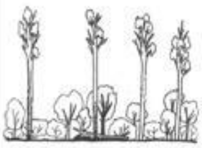
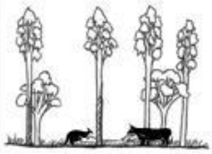
Tree dbh (cm)	Number of Trees	Carbon (m_2)	CO_2 equivalent (kg)
5	1528	3	14821
30	42	3	33529
60	11	3	46940

Figure 10: Potential variations in tree size, density and CO_2 equivalent stored for the same basal area; 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 wet sclerophyll forest is limited by rainfall, clearing, hot fires, competition with a dense understorey, bell miner-associated dieback and grazing pressure (Table 2). The total amount of carbon stored by wet sclerophyll forest, and the rate of carbon accumulation, can be maximised by removing these limits where possible.

Table 2: Summary of limits to carbon accumulation for wet sclerophyll forest

Site features	Effect on carbon	
	Total carbon stored	Rate of carbon gain
 **Rainfall**	↑	↑
 **Clearing**	↓	↓
 **Hot fires**	↓	↓
 **Dense understorey vegetation**	↓	↓
 **Bell miner-associated dieback**	↓	↓
 **Grazing pressure**	↓	↓

The limits to carbon accumulation in wet sclerophyll forest are:

Rainfall - Variation in rainfall is likely to influence rates of tree recruitment and growth, and also fire frequency and intensity, in wet sclerophyll forest.

Clearing - Broadscale clearing of wet sclerophyll forest will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss. Careful selective harvesting of trees is still compatible with carbon farming, as this will not damage the health or growth potential of the forest, and may allow regeneration of eucalypts. However, selective harvesting will usually slow the rate of carbon gain, and reduce the amount of carbon stored.

Hot fires - Hot fires[2] (fires of moderate- to high-severity, and above) can kill trees, reduce growth rates, and will consume the carbon in trees, shrubs, dead wood and litter. This reduces carbon stores and slows carbon accumulation rates.

Dense understorey vegetation - The establishment and survival of wet sclerophyll eucalypt seedlings may be reduced or prevented by high densities of understorey shrubs and trees, and this will slow carbon accumulation rates and limit carbon stores. But if the understorey plants are rainforest species, another option for carbon farming is to allow the site to develop into wet rainforest.

Bell miner-associated dieback - BMAD is associated with the decline, and sometimes death of mature wet sclerophyll eucalypts, and poor recruitment of mid- and upper-canopy trees. This will slow carbon accumulation rates and limit carbon stores.

Grazing pressure – Carbon farming in Queensland wet sclerophyll forest appears to be compatible with low to moderate levels of grazing pressure which do not suppress the recruitment and growth of eucalypts. This combined land use is more suited to wet sclerophyll forest with a grassy understorey. High grazing pressure is not recommended if it prevents the recruitment of trees or leads to soil degradation. Strategic grazing management that reduces fire risk, and allows tree recruitment 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.

[2] 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. See Appendix for definitions of fire severity for Queensland open forests and woodlands.

Wildlife conservation

Figure 11: Some animal species associated with wet sclerophyll forest; left, Powerful owl, *Ninox strenua* (Image: L. Hogan DSITIA); right, Northern bettong, *Bettongia tropica* (Image: DSITIA).

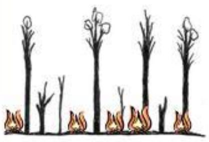
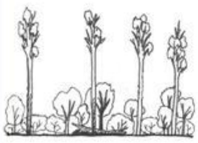
Wet sclerophyll forest in Queensland supports many different types of native plants and animals, including at least 25 threatened or priority species (e.g. Figs. 11 & 12), so restoring wet sclerophyll forest has great potential for conserving wildlife. Some threatened native species that occur in wet sclerophyll forest include the powerful owl (*Ninox strenua*), northern bettong (*Bettongia tropica*), yellow-bellied glider (northern subspecies; *Petaurus australis* unnamed subspecies), eastern bristlebird (*Dasyornis brachypterus*), the Hastings River mouse (*Pseudomys oralis*), and the plants *Boronia keysii* and *Daviesia discolor.*

Most management actions that will accumulate carbon in wet sclerophyll forest (such as not clearing vegetation, excluding hot fires and controlling dieback) will also benefit wildlife. Habitat features that will help to conserve wildlife in eucalypt woodland include different types of shelter for wildlife, a good (and 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 12: Some plant species associated with wet sclerophyll forest; left: *Boronia keysii* (Image: W. Smith DSITIA); right: *Daviesia discolor* (Image: D. Halford DSITIA).

Limits to wildlife conservation in wet sclerophyll forest

Table 3: Summary of limits to wildlife conservation in wet sclerophyll forest.

Limits to wildlife conservation	Effect on wildlife: Total number of species	Effect on wildlife: Total number of individuals
Range of shelter options e.g. tree hollows, fallen timber, shrubs, grasses	↑	↑
Good supply of food e.g. insects, nectar, pollen, seeds, leaves, small animals	↑	↑
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	↓	↓
 **Hot fires**	↓	↓
 **Bell miner-associated dieback**	↓	↓

Shelter and food

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

Trees and shrubs provide shelter and feeding sites for many animals, including insects, mites and spiders (Majer *et al.* 2000); bird species that forage mainly on the trunks and foliage of shrubs and trees (e.g. pardalotes, thornbills and treecreepers); and arboreal mammals such as gliders. The diet of some arboreal mammals consists mainly of eucalypt leaves (e.g. the greater glider) while others rely mostly on sap, flowers and insects (e.g. the yellow-bellied glider). Yellow-bellied gliders (*Petaurus australis*) make characteristic incisions in the stems of eucalypts to feed on sap, and these feeding points are then utilised by other gliders, birds and insects (Chapman *et al.* 1999).

More wildlife will be supported if a variety of tree and shrub species, sizes and ages are present, rather than a monoculture or forest with a simple age structure. For example, studies in northern Queensland have shown that the yellow-bellied glider prefers *E. resinifera* for sap feeding, but uses only hollows in *E. grandis* for shelter (Quin *et al.* 1996; Bradford and Harrington 1999). 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. Shrubs provide important nesting and foraging sites for small birds, and different species of shrubs support different assemblages of insects (Peeters *et al.* 2001).

Understorey structure – shrubby or grassy?

Wet sclerophyll forest can have an understorey that is mostly shrubby (often including rainforest plants) or mostly grassy. The type of understorey present is of little consequence for farming carbon, as long as the canopy trees are healthy and there is ongoing recruitment of wet sclerophyll eucalypts. However, the nature of the understorey does have important implications for wildlife conservation, as some species prefer dense understorey shrubs, while others depend upon a more open, grassy ground layer.

Wet sclerophyll forest with a grassy understorey is an important habitat for at least three threatened species – the northern bettong (*Bettongia tropica*), eastern bristlebird (*Dasyornis brachypterus*) and Hastings River mouse (*Pseudomys oralis*). The wet sclerophyll habitat becomes unsuitable for these species when grasses are replaced by rainforest shrubs. Actions to maintain a grassy understorey (e.g. by burning, see *Fire* below) are recommended for the conservation of these species (NSW Department of Environment and Climate Change 2005; Department of Environment and Resource Management 2010; Department of Environment and Resource Management 2011a). However, wet sclerophyll forest with an understorey of rainforest shrubs will provide habitat for many other species that prefer this type of vegetation.

If the landholder has a choice, and wishes to conserve wildlife, what is the best type of understorey to maintain? Perhaps the first step is to find out whether the threatened species that prefer a grassy understorey have been recorded on your site, or are likely to colonise your site if suitable habitat is present (Contact your local NRM group, QPWS office or EHP Threatened Species Branch for more information). This is because all three species have very restricted distributions and specific habitat requirements, and may not need to be considered if they are unlikely to ever occur on your site. However, if your site may provide habitat for the northern bettong, eastern bristlebird or Hastings River mouse, then the restoration and/or management of a grassy understorey should be a high priority for wildlife conservation at your site.

Tree hollows

Many native animals use tree hollows for shelter and nesting, and some also feed on prey found in hollows (Gibbons and Lindenmayer 2002). Animals that use tree hollows in wet sclerophyll forest include the yellow-bellied glider (*Petaurus australis*), powerful owl (*Ninox strenua*, Fig. 11), and Stephen's banded snake (*Hoplocephalus stephensii*). All reported den trees for the yellow-bellied glider in north Queensland have been in *E. grandis* (Bradford and Harrington 1999), so maintaining large canopy trees of this species is particularly important for the conservation of the glider in this region. A study of Stephen's banded snake in northern New South Wales found that snakes preferred to shelter in tree hollows, and *E. pilularis* and *Syncarpia glomulifera* were the favoured tree species (Fitzgerald *et al.* 2002).The presence of tree hollows in these species was highly correlated with tree diameter and increasing age (Fitzgerald *et al.* 2002). Another study in southern Queensland found hollows in more than 50% of *E. pilularis* trees that were greater than 100 cm in diameter (Wormington and Lamb 1999). Observations from NSW indicate that large hollows do not form in *E. pilularis* trees less than about 200 years old, and that hollows become limiting to possums and gliders when there are less than three hollow trees per hectare (Mackowski 1984). So you can provide valuable housing for wildlife by retaining large, old and dead standing trees (which are more likely to contain or form hollows). 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.

Fallen timber

Fallen timber can provide shelter and feeding areas for birds (Barrett 2000), reptiles, frogs and mammals (Lindenmayer *et al.* 2003). A number of bird species such as robins and fantails use fallen timber as platforms to view, and then pounce on, prey on the ground (MacNally *et al.* 2001). Treecreepers and thornbills often collect insects from fallen timber or the ground nearby (MacNally *et al.* 2001). It can be tempting to collect fallen timber for firewood, or just to 'clean-up', but leaving it in place will provide housing and feeding opportunities for wildlife.

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).

Rocks

Surface rocks and piles of boulders are important habitats for animals (e.g. 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 (fallen leaves, bark and twigs) provides shelter, nesting sites, and foraging sites for many invertebrates, birds, reptiles and small mammals.

Invertebrates

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

Fungi

Many Australian mammals eat fungi, especially those that produce fruiting bodies underground (e.g. truffles), and many fungi also have symbiotic relationships with native plants (Claridge and May 1994). Truffles are an important food source for the northern bettong, which is associated with wet sclerophyll forest, and neighbouring drier forest and woodland in north Queensland (Department of Environment and Resource Management 2010). It is not known how abundant or diverse such fungi are in wet sclerophyll forest, or how important they are as a food source to other animal species, or as symbionts of plants. Research is needed to better understand the importance of fungi for wildlife conservation in wet sclerophyll forest, and if significant, how to best manage this resource.

Figure 13: Some examples of shelter and food resources for wildlife found in wet sclerophyll forest

Landscape features

Large patch size

Small patches of habitat may be able to support populations of some plant and animal species (e.g. invertebrates and lizards, Abensperg-Traun *et al.* 1996; Smith *et al.* 1996), but their long-term viability may be questionable, and larger patches are generally better for conserving wildlife (Saunders *et al.* 1991; Bennett 2006). Patches of remnant vegetation 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 exposure to 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 (e.g. invertebrates, 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). Numerous mammal species associated with wet sclerophyll forest (e.g. the yellow-bellied glider) are dependent on trees for food and shelter, and movement across open ground is very hazardous for these species. 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). 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).

Competitors and predators

Weeds and feral animals

Weeds and feral animals are a major threat to wildlife in Australia (Williams and West 2000; Natural Resource Management Ministerial Council 2010). The wildlife of wet sclerophyll forest is threatened by a range of weeds and feral species including pigs, cats, wild dogs, cane toads, camphor laurel and lantana (e.g. Department of Environment, Climate Change and Water NSW 2010; Department of Environment and Resource Management 2011a), so the control of weeds and feral species on your site will help to conserve wildlife.

For example, a study in southern New South Wales found that management of lantana increased the abundance, species richness, and recruitment of native plant species in wet sclerophyll forest (Gooden *et al.* 2009a). The same study also found that native plant species richness remained stable when lantana cover was less than 75% (Gooden *et al.* 2009b). Eradication of lantana from a site will benefit most species, but is often difficult to achieve. So if removal of lantana is not possible, maintaining lantana cover at less than 75% may still conserve many plant species.

Aggressive native species

See *Bell miner-associated dieback* below.

Clearing

Clearing destroys many plant species and also removes the food and housing of animals that depend on trees and shrubs. Animals which have little or no capacity for dispersal are severely impacted by land clearing.

Fire

Fire assists in the regeneration of wet sclerophyll forest by creating canopy gaps and exposing mineral soil, and fire also has a large influence on the understorey (i.e. shrubby versus grassy). Fire therefore plays an important role in the conservation of the plant and animal species that inhabit wet sclerophyll forest. Little is known about the impact of intense crown fires on the wildlife of wet sclerophyll forests in Queensland, but they are likely to be quite destructive to wildlife, especially where forests are already fragmented.

The wet sclerophyll habitat becomes unsuitable for three threatened species (the eastern bristlebird (*Dasyornis brachypterus*), northern bettong (*Bettongia tropica*), and Hastings River mouse (*Pseudomys oralis*) when grasses are replaced by rainforest shrubs, and certain fire regimes are recommended to maintain a grassy understorey (NSW Department of Environment and Climate Change 2005; Department of Environment and Resource Management 2010; Department of Environment and Resource Management 2011a). However, frequent fires can also be damaging to wildlife, and appear to be a major cause of Eastern Bristlebird decline in south-eastern Queensland and north-eastern NSW (Department of Sustainability, Environment, Water, Population and Communities 2010). Fire management plans for eastern bristlebird habitat in protected areas have been developed by the Queensland Parks and Wildlife Service (QPWS) (Department of Environment and Resource Management 2011a, Department of Sustainability, Environment, Water, Population and Communities 2010).

The northern bettong is likely to benefit from fires that burn small patches of habitat about every 3-4 years, and wetter habitat may require more intense burns to halt rainforest encroachment (Department of Environment and Resource Management 2010). Adaptive management is recommended to improve our understanding of the fire regime needed to conserve this species (Department of Environment and Resource Management 2010).

The following fire regime has been recommended for the Hastings River mouse in Queensland: 1. No burning during the breeding season from August to March; 2. Fires should only occur every five to ten years, or even less frequently; 3. A mosaic of burnt and unburnt areas is created; 4. One third of the site, or less, is burnt at any one time; 5. At least one third of the site is left unburnt for a minimum of five years (Department of Environment and Resource Management 2011b).

Hollow-bearing trees (living or dead) with senescent crowns are sensitive to fire, and mostly for this reason are a highly ephemeral resource (Eyre *et al.* 2010). In particular, the density of dead trees with hollows in eucalypt open-forests is strongly reduced by fire (both high-intensity wildfires, and less-intense but frequent burns (~ every 2-5 years) associated with grazing management) (Eyre *et al.* 2010), and this has a negative impact on animal species that rely on hollows. Frequent burns are likely to have a similar effect on dead trees in wet sclerophyll forests.

The best fire regime for wildlife on your site will depend on the current state of the wet sclerophyll forest, and on the species you are most interested in conserving. Contact your local NRM group, QPWS or DERM office for more information and advice. General fire guidelines for maintaining the overall biodiversity of regional ecosystems are provided in the Regional Ecosystem Description Database (REDD) (Queensland Herbarium 2011).

Grazing pressure

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.

Bell miner-associated dieback

Bell miner–associated dieback (BMAD) is described as “a form of tree canopy dieback that can be diagnosed by the presence of over-abundant populations of psyllid insects (*Glycaspis* spp.) often with over-abundant Bell Miner birds (*Manorina melanophrys*)” (NSW Scientific Committee 2008). BMAD results in the defoliation of wet sclerophyll tree eucalypts, and can also lead to poor tree recruitment and tree death (NSW Scientific Committee 2008). Species that rely on wet sclerophyll eucalypts for food and shelter are thus disadvantaged by BMAD. Plants and animals can also be affected by changes in forest structure brought about by BMAD. For example, the decline of canopy trees will eventually result in fewer hollows, with negative impacts on species that use hollows, such as owls, possums and Stephen’s banded snake (NSW Scientific Committee 2008). Increasing densities of understorey shrubs, often including lantana, is also associated with BMAD. This can prevent the recruitment of other native plant species (Gooden *et al.* 2009a) and suppress the development of mid- and upper-canopy layers. Bell miners also act aggressively towards other bird species, and exclude many other birds from their territories.

Controlling BMAD has clear benefits for wildlife conservation, but much still needs to be learnt about its causes and effective treatment. For more details, refer to the section on Bell miner-associated dieback on page 9.

Table 4: Habitat values for selected wet sclerophyll forest species

		Tree hollows, cracks & crevices	Fallen timber	Trees & shrubs	Grasses	Nectar/sap	Fungi	Insects
Mammals				✓				
Yellow bellied glider	*Petaurus australis*	✓				✓		
Northern bettong	*Bettongia tropica*				✓		✓	
Hastings river mouse	*Pseudomys oralis*		✓		✓		✓	✓
Birds								
Eastern Yellow robin	*Eopsaltria australis*		✓	✓				✓
Powerful owl	*Ninox strenua*	✓		✓				
White-naped honeyeater	*Melithreptus lunatus*			✓		✓		✓
Eastern bristlebird	*Dasyornis brachypterus*		✓	✓	✓			✓
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 or 2 in Fig. 5), 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.

Once the main management aims are achieved, carbon accumulation may be further improved by allowing the development of a mid-storey of trees and shrubs, as long as this does not impede the replacement of canopy eucalypts over time.

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 (e.g. clearing, 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 (e.g. feral animals, weeds)

Rainfall and temperature will have a large influence on the rate of reforestation and carbon accumulation on your site. However, other factors, such as fire, grazing, and the density of understorey vegetation may also require management. The history of the site will generally determine the amount of initial effort and ongoing maintenance that will be needed to achieve the desired level of reforestation.

To determine which actions apply to your site:

1. Identify the condition state of your site by referring to Fig. 14.
2. Select whether your goal is farming carbon, conserving wildlife, or both.
3. Compile a list of actions from Table 6 that apply to both the condition state, and goal of your site (either 'carbon', 'wildlife', or both).

More management information can be found in the QPWS planned burn guidelines (Department of National Parks, Recreation, Sport and Racing 2012a; Department of National Parks, Recreation, Sport and Racing 2012b and Department of National Parks, Recreation, Sport and Racing 2012c).

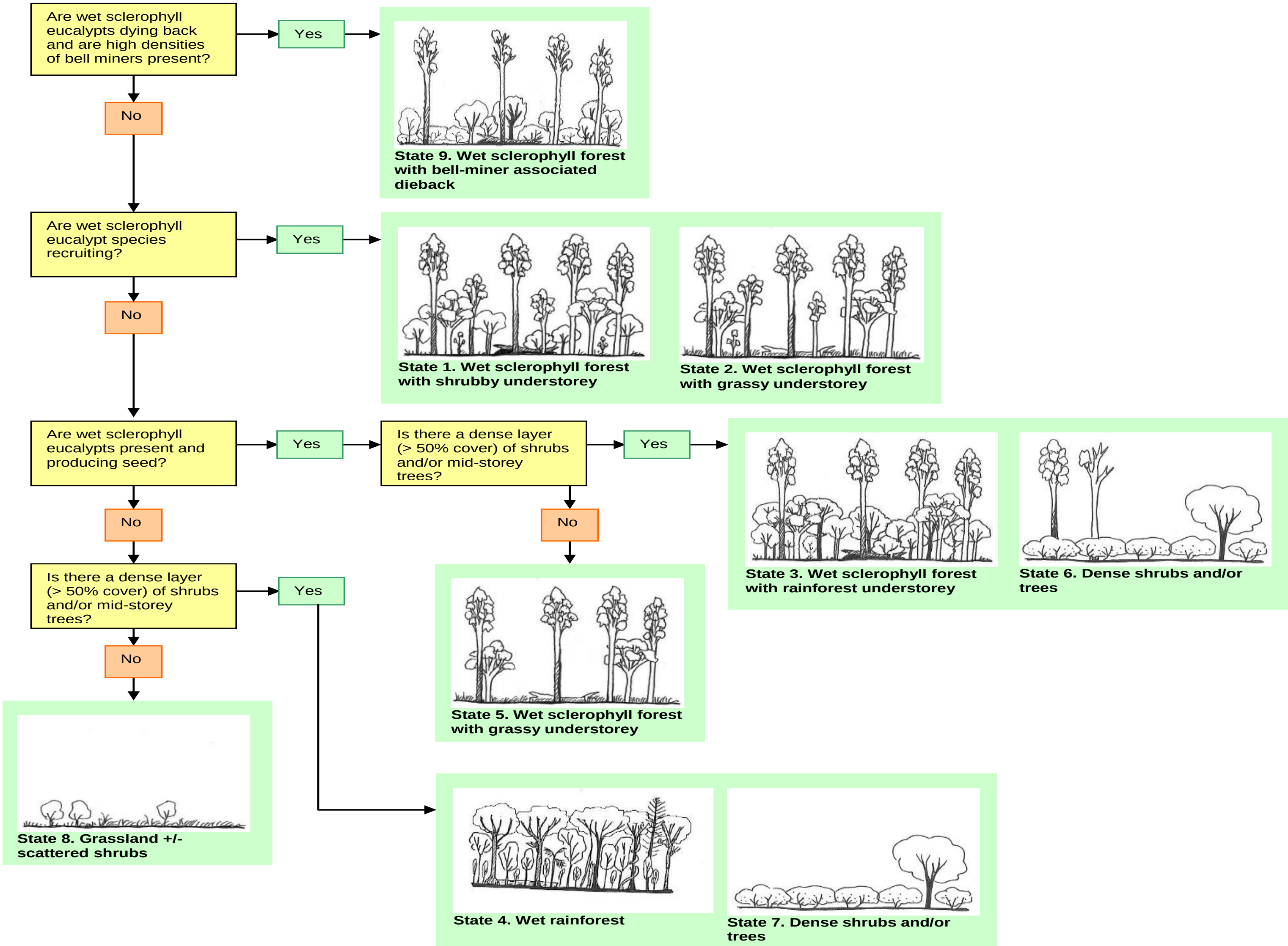


Figure 14: Key to wet sclerophyll forest 'states' which feature in the wet sclerophyll forest ecological model (Fig. 5).

Table 5: The main management issues for each condition state for wet sclerophyll forest. Some condition states have been grouped because their management actions are the same.

Condition state	Description	Main management issue
1 & 2	Wet sclerophyll canopy trees present and recruiting; shrubby or grassy understorey	Areas in these states should require little intervention to sustain or increase their carbon stocks.
3 & 6	Wet sclerophyll canopy trees present and producing seed; dense layer of shrubs &/or mid-storey trees present	Reduction in shrub / mid-storey tree cover may be needed to allow canopy tree recruitment.
5	Wet sclerophyll canopy trees present and producing seed; no dense layer of shrubs &/or mid-storey trees	Areas in these states may require changes to grazing or fire regimes to allow canopy tree recruitment to increase carbon stocks.
4 & 7	Wet sclerophyll canopy trees absent or not producing seed; dense layer of shrubs &/or mid-storey trees present	Seed sources (and/or tubestock) will be required to restore canopy trees. Reduction in shrub / mid-storey tree cover may be needed to allow canopy tree recruitment. However, if rainforest trees are dominant, (State 4) this may provide similar carbon stocks to wet sclerophyll forest. The additional benefits of restoring wet sclerophyll canopy trees for carbon farming may be marginal.
8	Wet sclerophyll canopy trees absent or not producing seed; no dense layer of shrubs &/or mid-storey trees	Seed sources (and/or tubestock) will be required to restore canopy trees.
9	Wet sclerophyll canopy trees present, and affected by bell miner-associated dieback	Reduction in shrub / mid-storey tree cover may be needed to remove habitat for miners and reverse symptoms of tree dieback.

Table 6: Management actions for restoring and maintaining wet sclerophyll forest; 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					
Clearing and thinning									
				1,2	**3,6**	**5**	**4,7**	**8**	**9**
1. No broadscale clearing of live trees and shrubs.	• Clearing wet sclerophyll forest will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss. • Careful selective harvesting is compatible with carbon farming, but this will reduce slow the rate of carbon gain, and reduce the amount of carbon stored; • Clearing removes plants and animals, and also removes 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 (this may involve thinning).	• 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									
4. If tree recruitment is needed, protect wet sclerophyll eucalypt seedlings from fire until > 3m in height.	• Wet sclerophyll eucalypts can be killed by fire in the early stages of growth.	↑	↑	✓	✓	✓	✓	✓	✓
5. 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.								
6. If the understorey is composed of grasses and non-rainforest shrubs, and fuel loads in the understorey 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. Do not use fire, if rainforest trees and shrubs are dominant in the understorey.	• 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 #5).								
	• Rainforest trees and shrubs are unlikely to burn, and therefore pose minimal fire risk.								
7. If the understorey is dominated by grasses, use grazing management to reduce high fuel loads (This 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 #5).	↑	↑	✓	✓	✓	✓	✓	✓

Fire									
8. If the surrounding vegetation is fire-adapted, use grazing management or low severity burns, when soil moisture is high, to reduce high fuel loads in the surrounding vegetation.	• Reduces the risk of fire in the area to be restored (see #5).	🡑	🡑	✓	✓	✓	✓	✓	✓
9. If the surrounding vegetation is fire-adapted, maintain a range of burning practices that create a fine-scale mosaic of fire histories in the landscape, including unburnt refugia, 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.		🡑	✓	✓	✓	✓	✓	✓
10. 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. • Helps to protect important habitat trees from scorching, and premature death.	🡑	🡑	✓	✓	✓	✓	✓	✓
Grazing									
11. If tree recruitment is needed, protect wet sclerophyll eucalypt seedlings from grazing until > 3m in height.	• 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 and preventing the recruitment and growth of trees, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.	🡑	🡑	✓	✓	✓	✓	✓	✓

Grazing									
12. Control macropods and feral animals (e.g. goats, pigs, and rabbits) if they are in sufficient densities to prevent the recruitment of native trees and shrubs (see next section ***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.	↑	↑	✓	✓	✓	✓	✓	✓
13. 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									
14. Reduce the cover of dense shrubs/mid-storey trees in areas where canopy tree recruitment is needed. Use patchy disturbance (e.g. selective clearing, herbicide or low-moderate intensity fire) to reduce shrub and/or mid-storey tree density. (Tree recruitment may be by natural seed sources, direct seeding, or tubestock planting). If rainforest trees are present in the understorey (State 4) this may not be necessary for the best carbon returns as rainforest is likely to store similar amounts of carbon as wet sclerophyll forest.	• Improves the establishment and growth of woody plants by reducing competition. • This action may have negative effects on wildlife by removing habitat/cover. To reduce these risks, reduce shrub cover in small areas only, and implement shrub removal in stages, over months or years.	↑			✓		✓		

Site preparation and plant establishment									
15. If the understorey is dominated by grasses, use slashing or low severity fire, when soil moisture is high, to reduce the cover of herbaceous plants before direct seeding or tubestock planting. Burning may be less desirable if this is likely to trigger the germination of high numbers of native or weedy shrubs from the soil seedbank.	• Improves the establishment and growth of woody plants by reducing competition.	↑	↑		✓				
16. Expose areas of mineral soil within patches when wet sclerophyll eucalypts are releasing seed, and when good rains are expected.	• Establishment and growth of woody plants increases the rate and amount of carbon stored. • A diversity of woody plant species of different sizes and ages provides food and habitat for wildlife.	↑	↑		✓	✓			
17. Revegetate treeless areas with native trees and shrubs using direct seeding or tubestock, when good rains are expected.	• Establishment and growth of woody plants increases the rate and amount of carbon stored. • A diversity of woody plant species of different sizes and ages provides food and habitat for wildlife.	↑	↑		✓		✓		
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.		↑	✓	✓	✓	✓	✓	✓
Competitors and predators									
19. Monitor the establishment of wet sclerophyll eucalypt seedlings and remove competing weeds / other native plants / vines (manually, or by careful application of herbicide).	• Removing competing plants will maximise the growth of wet sclerophyll tree species.	↑	↑		✓	✓	✓	✓	✓

Competitors and predators									
20. Avoid management actions that will lead to the development of a uniformly dense shrub layer. Such management actions may include removal or death of canopy trees; high levels of grazing pressure; or fire regimes that encourage the growth of shrubs at the expense of canopy trees or grasses.	• A uniformly dense shrub layer (> 50 % cover throughout the site) may prevent the recruitment of canopy trees.	↑		✓	✓	✓	✓	✓	✓
21. Control weedy shrubs (e.g. lantana) and exotic trees (e.g. camphor laurel) before they form a dense shrub layer.	• A uniformly dense shrub layer (> 50 % cover throughout the site) may prevent the recruitment of canopy trees.	↑	↑	✓	✓	✓	✓	✓	✓
22. Prevent the introduction and spread of serious weeds. Vehicles, machinery, quad bikes and stock can all spread weeds.	• Prevention is better than cure		↑	✓	✓	✓	✓	✓	✓
23. Control weed species where these are having a negative impact on wildlife.	• Management actions that have adverse effects on wildlife should be avoided if possible, or implemented in stages.		↑	✓	✓	✓	✓	✓	✓
24. 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.		↑	✓	✓	✓	✓	✓	✓

Competitors and predators									
25. Use habitat modification to reduce the numbers of bell miners where these are having a negative impact on canopy trees and wildlife. Remove lantana, if present, with a splatter gun, or other suitable technique. If dense native understorey is blocking mid- and upper-canopy recruitment, trial the use of patchy disturbance by burning or mechanical clearing.	• High densities of bell miners are associated with the dieback of some wet sclerophyll tree species.. • Miners can have a strong negative influence on the abundance and species richness of other native birds. • Direct control of miners is not recommended. • Decreasing the density of understorey shrubs / mid-storey trees should help to discourage bell miners, and allow canopy trees to develop.	↑	↑						✓
Other actions for wildlife									
26. 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.		↑	✓	✓	✓	✓	✓	✓
27. Provide nest boxes if hollows are scarce	• Tree hollows 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 (including fallen leaves, bark and twigs).	• Many animals use leaf litter for shelter and foraging.		↑	✓	✓	✓	✓	✓	✓
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	
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 tubestock or by direct seeding only when good rains are expected.

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