Department of Science, Information Technology, Innovation and the Arts

Mulga

Regrowth Benefits- Management Guideline

Great state. Great opportunity.

Queensland Government

Prepared by
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Cover image D. Butler

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Contents

List of tables

List of figures

Summary

- In Queensland, mulga vegetation varies from low open woodland to open-forest.
- Mulga occurs over a large area of south-west Queensland, roughly bounded in the east and north by Roma, Longreach and Mt Isa.
- The above ground parts of woody plants in mulga vegetation could store about 30 to 150 tonnes of carbon dioxide equivalent (tCO_2-e) per hectare, at a site with 400 mm average annual rainfall.
- Mulga sites with average annual rainfall above 400 mm may accumulate from one to two tCO_2-e per hectare per year.
- Rainfall exerts strong control on growth and standing carbon stocks in mulga, but management can also have a large effect.
- Rates of carbon accumulation above ground in regrowing mulga will be greatest in young forests with relatively high rainfall.
- Browsing by livestock (especially sheep and goats) and macropods can limit the establishment and growth of small mulga trees, so careful management of grazing is required in the early stage of restoration.
- Drought and fire are the greatest risk to standing carbon stocks, but mulga typically supports limited fine fuels so fire is only likely to be a serious issue in young regrowth or where high densities of exotic grasses are present,mainly in the east.
- Livestock grazing can be compatible with reforestation in established mulga regrowth. Rest from grazing may be necessary to allow recruitment and growth of small mulga. Increasing the biomass of trees will reduce the carrying capacity for grazing.
- Regrowing mulga will benefit biodiversity, especially animals such as small song birds that are strongly dependent upon ‘mature’ mulga for habitat.

Description

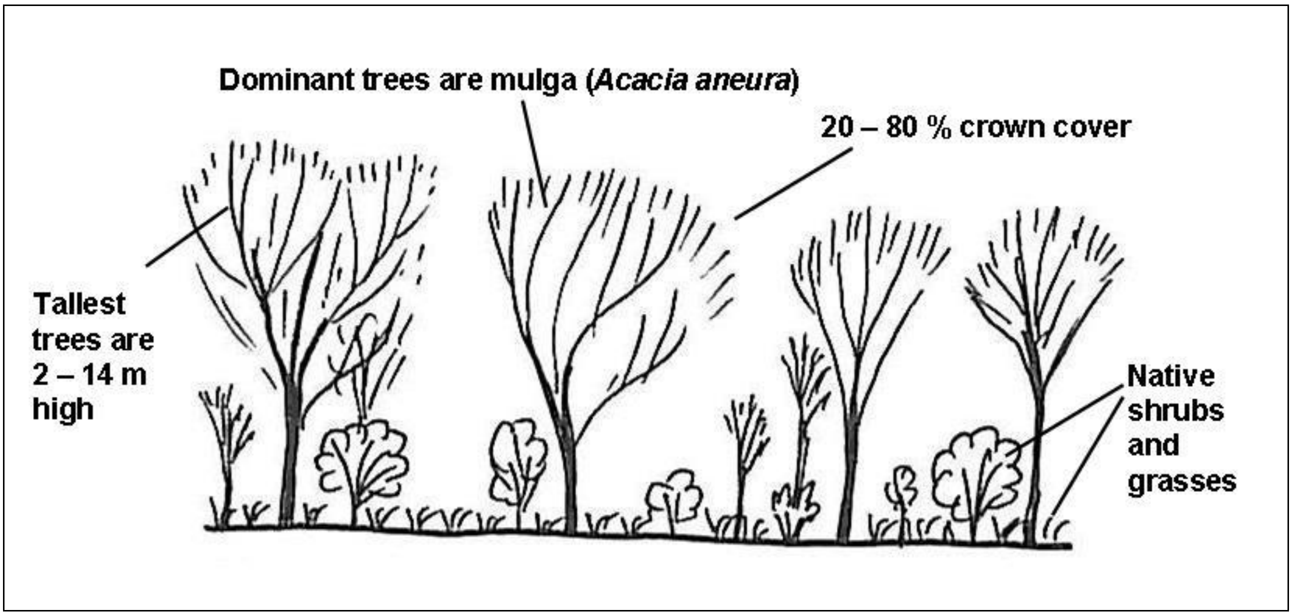


Figure 1: Structural features of mulga

Generally, mulga vegetation in Queensland has the following features (Fig. 1):

- Mulga (*Acacia aneura*) is the most prominent woody plant, forming a canopy between about 2 and 14 m tall, often with other trees or shrubs.
- Eucalypts like poplar box (*Eucalyptus populnea*), silver-leaved ironbark (*E. melanophloia*) and gum-barked coolibah or forest-gum (*E. intertexta*) are important canopy species in more productive areas. Other eucalypts that occur in mulga country include Yapunyah (*E. ochrophloia*) and Napunyah (*E. thozetiana*) and River Red Gum (*E. camaldulensis*).
- Canopy cover can vary from 20 – 80% (approximate crown cover; Queensland Herbarium 2011).
- It is found on red earth plains, sandplains or on harder shallow soils.

Mulga (*A. aneura*) (Fig. 2) is one of Australia's most iconic and widespread species, occurring in every mainland Australian state except Victoria. In Queensland, mulga is characteristic of a wide range of arid and semi-arid vegetation communities, from low and open shrublands on stony soils, to open-forests ten or more metres tall that occupy deep soils on extensive red earth plains. It often co-occurs with eucalypts, other acacias and various other arid shrubs and trees. Mulga has its stronghold in the Mulga Lands in Queensland's south-west (Fig. 3) but it also extends north through the western Mitchell Grass Downs and west into the Channel Country.

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 depend on the methodology being 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 pasture is an important example.

Figure 2: Remnant mulga.

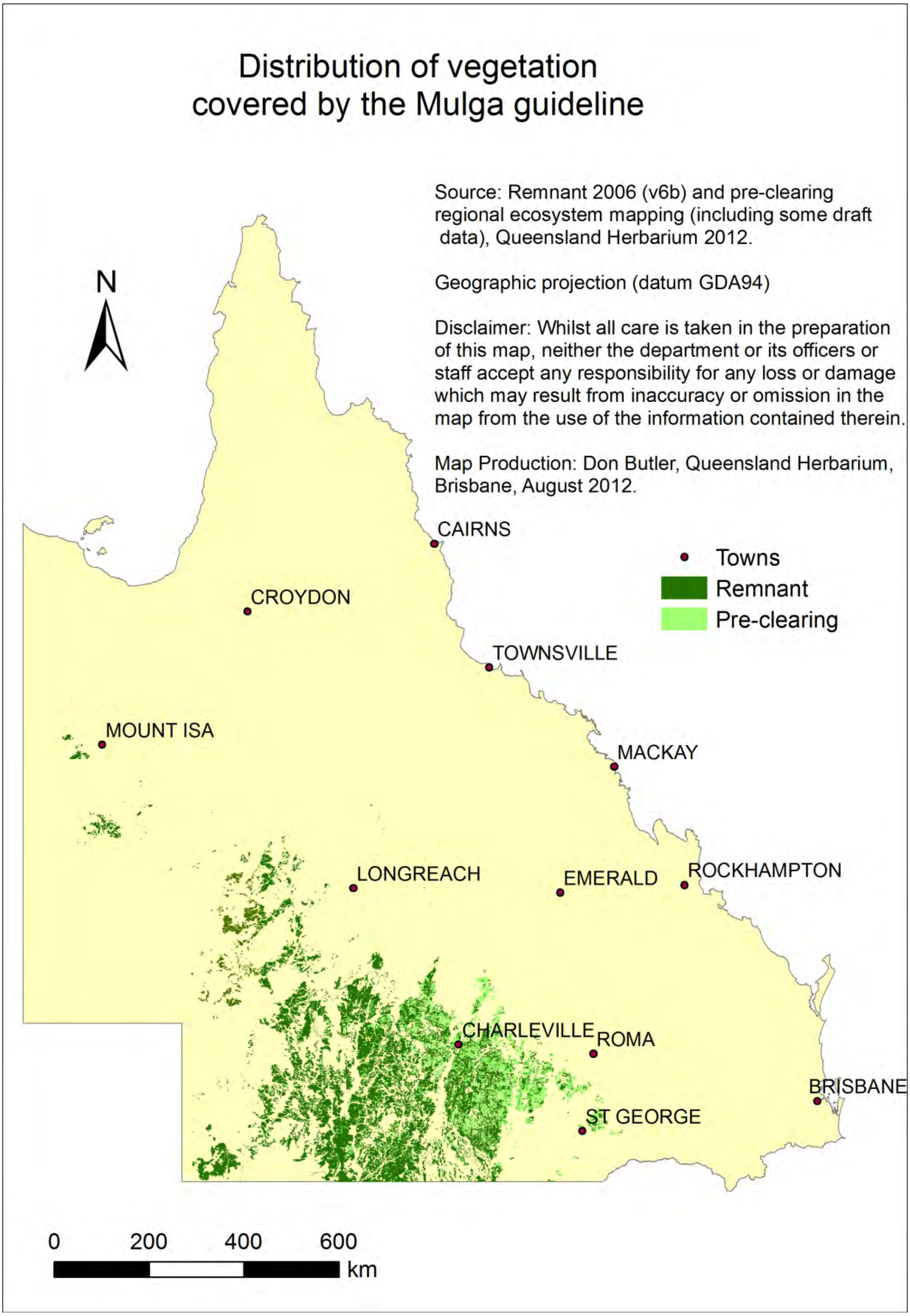


Figure 3: Map of mulga distribution in Qld

Ecology

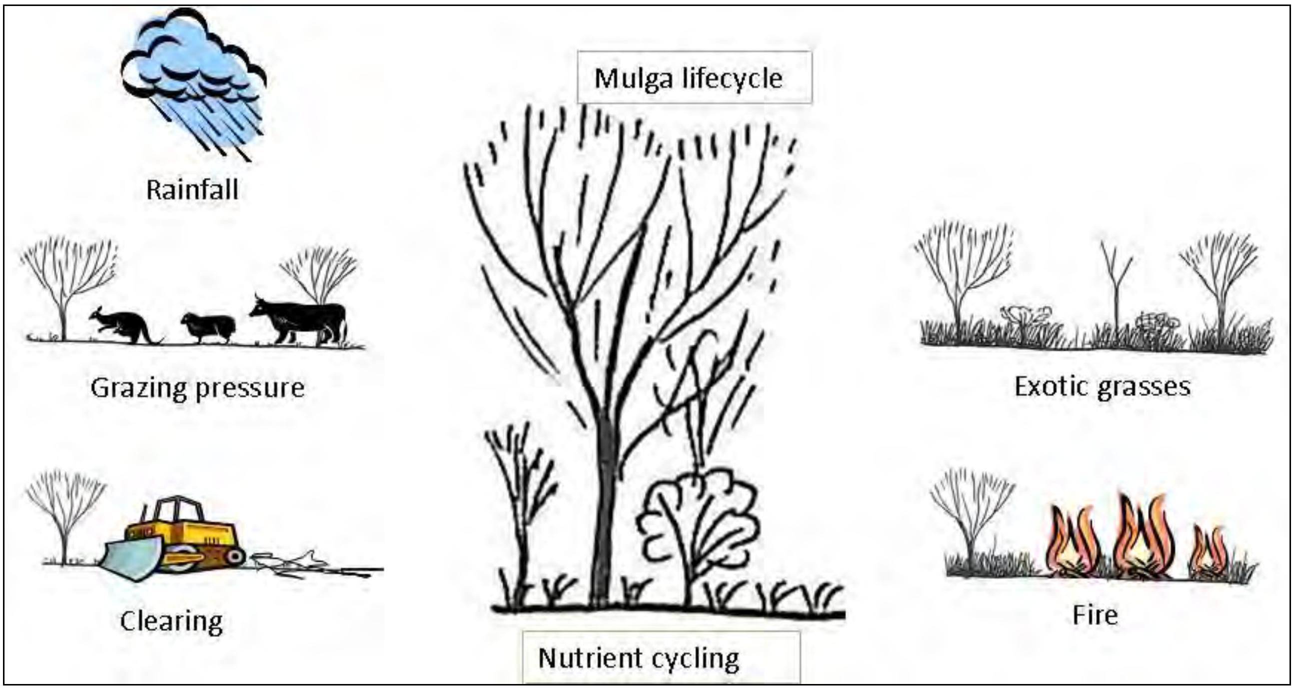


Figure 4: The restoration and management of mulga vegetation is underpinned by what we know about its ecology, particularly the effects of climate and disturbances such as clearing, grazing, fire and weeds (Pressland& Graham 1989). As the mulga tree (*Acacia aneura*) is the dominant life-form of mulga vegetation, its biology has a large bearing on the ecology mulga vegetation, and its management for carbon accumulation and wildlife conservation.

The biology of mulga (*Acacia aneura*)

Flowering of *A. aneura* occurs throughout the year (but not every year), mainly from April to July, and especially after good rains (Simmons 1987). Seed is not set every year (Simmons 1987) and not all trees of reproductive size set seed in any one year (Burrows 1973). Pods appear to mature only in the period September to December (Pedley 1978), and seed appears to take about 10 months to mature (Simmons 1987). Seed will germinate without fire, but a greater proportion of seeds will germinate after exposure to fire (or at least heat; Hodgkinson & Oxley 1990). Mulga seedling regeneration is reportedly most spectacular after heavy summer rain, but will occur in most years if stocking rates are low (less than 1 sheep per 5 ha; Burrows *et al.* 1988).

Optimum temperatures for *A. aneura* seed germination are relatively high (29-30^{o}C), and limited evidence suggests that mulga shoot growth is greatly restricted during winter, even when the water regime is favourable (Nix &Austin 1973). Therefore, (Nix &Austin 1973) suggest that dry matter production for *A. aneura* is at a maximum around 30^{o}C and with upper and lower thresholds for growth at about 38^{o}C and 10^{o}C respectively.

Reported height-growth rates of mulga in Queensland range from 22 cm yr^{-1} (ungrazed, average for wet and dry periods, (Brown 1985); ~30 cm yr^{-1} (Beale 2004, cited in Beeton *et al.* 2005); to 30-41 cm yr^{-1} (ungrazed, wet periods) Brown 1985). According to (Beale 2004, cited in Beeton *et al.* 2005) mulga in south west Queensland can reach a trunk diameter of 20 cm in 20 years. Individuals of *A. aneura* have been estimated to live for around 250 years at Koonamore Station in South Australia (Crisp 1978).

Mulga is capable of replacing itself without fire (as the seed germinates without fire (Hodgkinson&Oxley 1990), and low levels of fuel (particularly in the ground layer) of mulga woodlands (where exotic grasses are absent) mean that they are unlikely to burn (B. Wilson & R. Fensham *pers. comm.*; Fensham *et al.* 2011a). However, sufficient fuel to carry a fire can build up following rare periods of high rainfall, combined with low total grazing pressure, and if exotic grasses are present (see ***Fire*** below).

Rainfall and temperature

High soil temperatures (combined with moisture deficits) may be a major factor limiting germination of *A. aneura* in summer, but germination is possible during most of the cooler months (Burrows 1973). Recruitment success is also enhanced by the ability of mulga seedlings to survive prolonged periods of moisture stress (Burrows 1973). *A. aneura* is very drought and moderately frost resistant (Simmons 1987), but Nix and Austin (1973) observed that the distribution of *A. aneura* in Australia corresponded with areas that had some probability of rainfall throughout the year. Areas with regular summer or winter drought appeared to be unsuitable for *A. aneura* (Nix & Austin 1973).

Nix and Austin (1973) identify a bioclimatic zone for mulga which has a marginal to fair growing season and low, but relatively continuous water regimes due to both summer and winter rain. They also define an eastern sector that has more favourable water regimes (<250 mm summer rainfall and <110 mm winter rainfall in 8 years out of 10), and is considered the optimum environment for *A. aneura* based on size, density and community structural development (Nix & Austin 1973). This 'optimal zone' also corresponds to the area where buffel grass is currently prolificin the mulga woodlands of Queensland (R. Fensham *pers. comm.*).

Brown (1985) observed relatively high rates of mortality for young *A. aneura* trees during dry periods, irrespective of grazing pressure. Extreme drought can also kill mature mulga trees (J. Neldner *pers. comm.*).

Competition between grass and trees

The structure of a woodland, that is trees with a grassy understorey, is thought to be determined by the competition between woody plants and grasses for available soil water during alternating wet and dry periods (Walker & Noy-Meir 1982). Grass roots are restricted to the upper soil layers, and in this layer they out-compete tree roots for water. However, the lower soil layers retain their 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, 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 woodlands in Queensland has been found to decrease with increasing tree basal area (Walker *et al.* 1972; Beale 1973; Scanlan & Burrows 1990a; Burrows 2002). 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).

Grazing pressure

Grazing pressure from sheep and goats can slow and prevent the recruitment and growth of mulga (Harrington 1979; Brown 1985; Fensham *et al.* 2011b; Witt *et al.* 2011), and continued high grazing pressure can also lead to soil degradation (Jones &Burrows 1994).

Kangaroos may also contribute to total grazing pressure in the Mulga Lands (Page *et al.* 2000; Page & Beeton 2000), although there was no evidence of either red or grey kangaroos eating mulga in non-drought conditions during a year-long Queensland study (Griffiths & Barker 1966). However, it seems that while sheep, goats and macropods often destroy mulga seedlings, cattle are less likely to eat them (R. Fensham *pers. comm.*; anecdotal observations of landholders).Termites can also add to the effects of grazing pressure during drought, but only in areas where the cover of mulga trees has been lost (see ***Clearing*** below) (Watson *et al.* 1973; Noble 1997).

Sustained grazing pressure can also result in dense stands of so-called ‘woody weeds’, especially low unpalatable shrubs like *Eremophila* spp. (Harrington 1979).These woody weeds are native species and a natural component of many mulga vegetation types. Fire might be used to limit their density (Noble 1997) but are unlikely to occur because fine-fuel levels are typically low in mulga woodlands. Woody weeds are unlikely to seriously inhibit restoration of mulga.

Increased plant species richness and recruitment of mulga has been observed when grazing pressure is reduced (Fensham *et al.* 2011b; Witt *et al.* 2011). This suggests that changes to the structure and floristics of mulga vegetation caused by grazing may be reversed by reducing total grazing pressure. However, plant establishment and growth may be retarded once soils have lost their A-horizon through erosion (Pressland & Cowan 1987; Fensham *et al.* 2011a; Fensham *et al.* 2011c) making restoration of mulga vegetation where there are large areas of bare ground may be more problematic.

The exclusion of grazing in mulga lands has been linked to increased soil water infiltration rates, and water availability, which is likely to minimise the ‘leakage’ of resources and improve plant germination and survival rates (Witt *et al.* 2011).

Clearing

Large areas of mulga have been cleared of trees and shrubs by chaining (dragging a large chain between two bulldozers) to improve pasture, and mulga trees are also felled to provide fodder for stock (Beeton *et al.* 2005). Broadscale clearing continued until 2005, while clearing for fodder harvesting is still occurring (Fensham *et al.* 2011a). Clearing of trees and shrubs changes the structure of mulga vegetation, but the floristic composition of cleared areas can be similar to remnants (Fensham *et al.* 2011c). This indicates that cleared areas that are allowed to regrow need not be floristically depauperate compared to remnants (Fensham *et al.* 2011c).

Significant decreases in soil carbon have been correlated with the clearing of mulga (Harms *et al.* 2005), and the conversion of mulga to buffel grass pasture (Dalal *et al.* 2005a; Mathers *et al.* 2006; Kirschbaum *et al.* 2008). In addition, the loss of soil nitrogen is greater than the loss of soil carbon when mulga is converted to buffel grass pasture, which results in higher carbon to nitrogen (C:N) ratios in soil (Dalal *et al.* 2005b). This decrease in soil fertility raises questions about the long-term sustainability of using cleared mulga areas for pasture (Dalal *et al.* 2005b).

The removal of mulga trees can also exacerbate the effects of grazing pressure during drought, through the activities of harvester termites (Watson *et al.* 1973). These termites usually gather dry grasses and forbs, but will collect mulga leaf litter if these foods are scarce. During drought conditions, harvester termites were found to destroy the bases of grass tussocks, which prevented the rapid regeneration of grassed areas, and led to severe erosion of these areas (Watson *et al.* 1973). But this only occurred when sheep were also present, and mulga leaf litter was scarce because mulga trees had been removed (Watson *et al.* 1973). The large (2-3 m diameter), hard-topped termite nests, which are built at or just below the soil surface, can also impede water penetration and seed lodgement, and these inhibitory effects can persist for 70 years or more (Watson *et al.* 1973). Nests can occupy up to 20% of the soil surface in dense colonies, and termite population growth has been linked to the loss of mulga and favourable growth conditions for grass (Watson *et al.* 1973).

Figure 5: Mulga site after clearing

Fire

Fire causes increased mortality of mulga (Wright &Clarke 2007) and other fire-sensitive trees and shrubs, and tends to encourage the survival and expansion of grasses. However, *A. aneura* does have some ability to resprout after fire (Hodgkinson 1998; Wright &Clarke 2007), and fire can trigger the germination of *A. aneura* seed (Hodgkinson & Oxley 1990), so that only intense or repeated fires remove it altogether. As mulga does not need fire to germinate, it is likely that the mulga will regenerate naturally (given adequate rainfall) if fire is excluded and seed is available. Landholders have also observed that fire in mulga lands can set the soil surface hard, which reduces water infiltration and increases runoff.

Therefore the recommended fire management for mulga vegetation is fire exclusion (Department of National Parks, Recreation, Sport and Racing 2012). Mature mulga vegetation, in the absence of exotic grasses, rarely produces enough ground fuel to carry a fire, except in very wet years. When grass fuel loads are sufficient to carry a fire within mulga, then patch burning of the surrounding fire-tolerant vegetation can be used to prevent fire from spreading into the mulga (Department of National Parks, Recreation, Sport and Racing 2012). Patchy, low- to moderate severity burns within the mulga patch may also be carefully applied, when soil moisture is high, to reduce the likelihood of more severe fires (see ***Management actions*** below).

Buffel grass (*Cenchrus ciliaris*) is an exotic pasture grass species that is widely distributed in Queensland. Its success in the more arid western parts of the Mulga Lands has been limited, and it is currently only common in the more eastern stands of mulga. Interestingly, this eastern area also corresponds to an optimum environment for *A. aneura* identified by (Nix &Austin 1973).

High densities of buffel grass increase the frequency and intensity of fire in acacia woodlands by increasing ground fuel loads (Franks 2002; Butler &Fairfax 2003). Buffel grass had a negative impact on the recruitment and growth of many native ground cover species in poplar box woodlands,which also contained mulga, in Queensland (Franks 2002) and accelerated the degradation of a remnant gidgee (*Acacia cambagei*) and brigalow (*Acacia harpophylla*) woodland through increased fire (Butler &Fairfax 2003).

It is likely that buffel grass has similar impacts on native plant species and fire where it forms dense swards elsewhere in mulga vegetation. Even sparse buffel grass cover can affect native animals in Australia's arid lands (Smyth *et al.* 2009).

When exotic grasses such as buffel are present, restoration of mulga is likely to need both exclusion of fire and control of exotic grasses. Grazing might be used to limit fuel accumulation and fire risk from exotic grasses, but it will have a cost from the damage caused to other plants, including mulga, which might reduce carbon accumulation rates.

Nutrient cycling

The state-and–transition models above describe the temporal variation in the different states of mulga vegetation. However, successful restoration of the target state of the ecosystem may need to consider other aspects of ecosystem function. For example, the spatial 'patterning' of mulga into groves and intergroves appears to be important for nutrient cycling within the ecosystem (Tongway & Ludwig 1990). Soil from *A. aneura* groves had higher levels of organic and exchangeable nutrients (and plant cover) than soils in the intergroves which indicated that nutrients and organic matter are accumulated in and tightly cycled by the *A. aneura* groves (Tongway & Ludwig 1990). Higher quantities of exchangeable calcium, magnesium and potassium were found in the surface layers of the soils beneath mulga compared to deeper soils, which suggests that these ions may be absorbed by mulga roots at depth, and then released at the soil surface through the decomposition of mulga litter (Tongway & Ludwig 1990).

The grove-intergrove system is maintained by the effect of micro-topography on water flow, and the system can cease to function in paddocks that are heavily grazed by sheep (Tongway & Ludwig 1990). Therefore high total grazing pressure, or at least high grazing pressure by sheep, may have a negative impact on the productivity of patterned landscapes by disrupting nutrient cycling (Tongway & Ludwig 1990). The removal of perennial grasses from groves by grazing also appears to reduce the water supply to mulga, and this can cause the premature death of *A. aneura* during low rainfall periods (Anderson & Hodgkinson 1997). Continued grazing of these systems will prevent the restoration of landscape processes necessary for the survival of mulga and its associated flora (Anderson & Hodgkinson 1997).

Disruption of the grove-intergrove system may also lead to a decline in soil health and stability, as perennial plants protect the soil from rainfall-induced erosion, modify the local soil climate by shading, maintain favourable soil physical properties, and favour high activity of soil micro-flora and fauna (Tongway & Ludwig 1990). Through these mechanisms, long-lived grove-intergrove systems also favour landscape stability and may also serve as refugia during times of environmental stress for a wide range of organisms (Tongway & Ludwig 1990). Even though conspicuous groving occurs in only 10-20% of Queensland mulga vegetation (J. Neldner *pers. comm.*.), similar ecosystem processes are likely to be supported by the accumulation of woody debris and preservation of perennial grass tussocks in mulga vegetation of any configuration.

Ecological model

The ecological model for mulga (Fig.5) summarises the dynamics of this vegetation type into seven main condition states, and identifies factors that cause transitions between states. It is most applicable to the so-called 'soft mulga' which occupies deeper soils. Mature mulga vegetation is converted into other condition states in the following ways:

- Grazing pressure and/or drought results in tree mortality and limits recruitment of trees and shrubs, which causes a transition from mulga open-forest, woodland or low woodland (State 1.) to mulga open woodland or low open woodland (State 2). Continued high levels of grazing pressure and/or drought leads to further declines in trees and shrubs and eventually transition to a grassland (State 3).
- Invasion of exotic grasses into mature mulga vegetation (State 1) causes a transition to State 5. Removal of mulga (e.g. by fodder harvesting) and/or fire can create more open mulga vegetation with exotic grasses (State 6). Continued high levels of grazing pressure and/or

clearing and/or drought and/or fire leads to further declines in trees and shrubs and eventually transition to a grassland dominated by exotic grasses (State 7).

The most rapid increase in carbon stocks for more open mulga vegetation (State 2) will be achieved by hastening its development into a mature mulga (State 1). This transition may occur slowly under a range of conditions, but will be accelerated if there is adequate rainfall, no clearing and low grazing pressure. Similar conditions facilitate increases in carbon stocks from the other states, but states with exotic grasses will need careful management of fuel loads and fire. Degraded states may also require soil rehabilitation.

Carbon stocks in mature mulga vegetation (State 1) will be maintained close to their capacity if there is low-moderate grazing pressure and adequate rainfall. 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.

This state-and–transition model (Westoby *et al.* 1989) differs from others proposed for mulga (e.g. Jones &Burrows 1994) in that the ‘target state’ is an open-forest, woodland or low woodland, and not a grassland; and the number of alternate states has been kept to a minimum for simplicity.

In time, climate variability may also alter the potential ‘mature’ structure and floristic composition of mulga vegetation. 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 mulga 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 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.

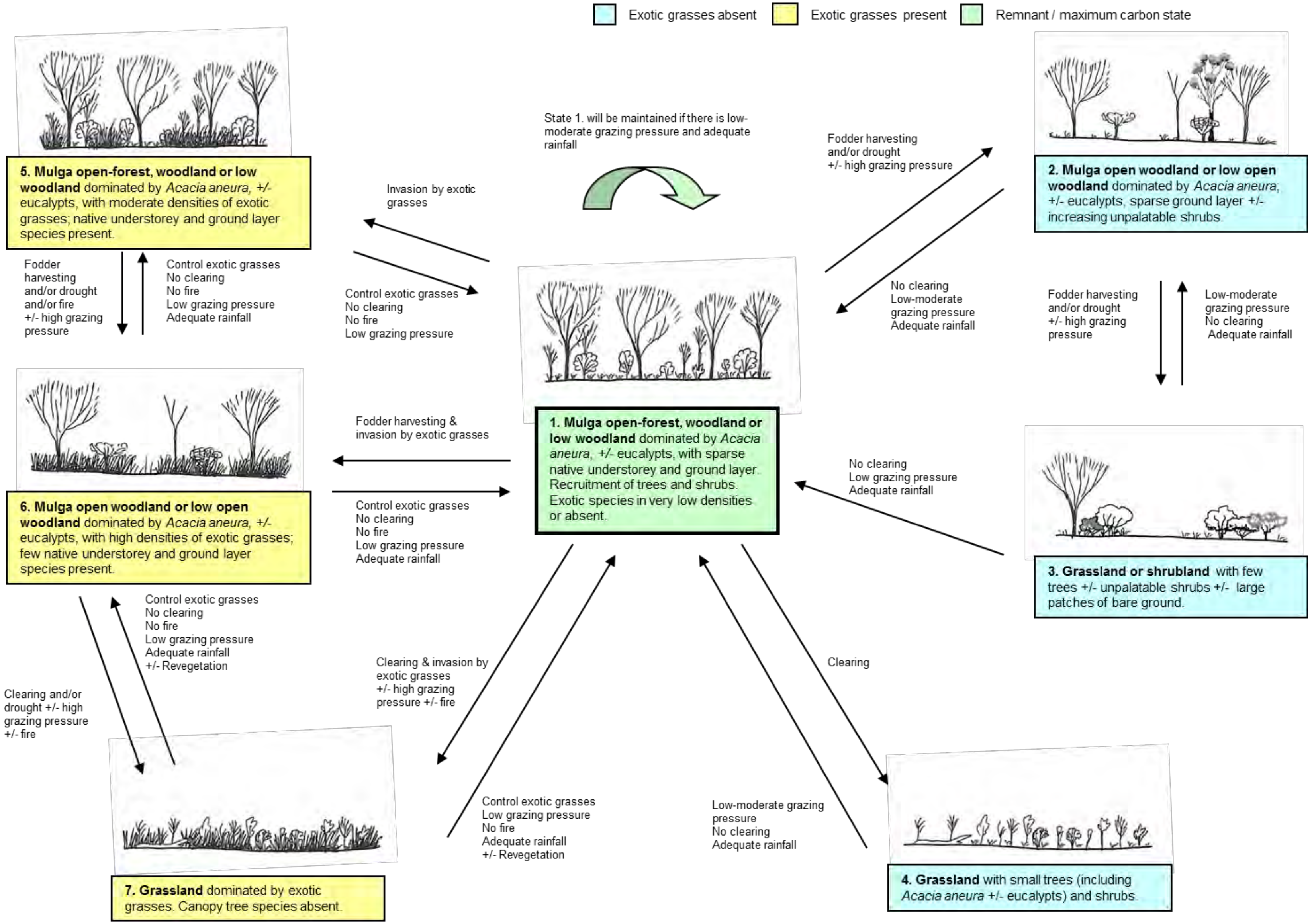


Figure 6: Ecological model for mulga in Queensland

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 mulga vegetation back to its full carbon capacity as soon as possible. Some carbon returns might be traded-off against other land-uses, such as fodder harvesting and livestock grazing, which may limit carbon accumulation rates. Low to moderate levels of livestock grazing appear to be compatible with reforestation in mulga vegetation.

Above-ground carbon in mulga vegetation is stored in living trees and shrubs, but also in dead standing trees, fallen timber and litter. The maximum amount of carbon stored by mature mulga at a given site depends on the site's average annual rainfall, with greater carbon capacity in locations with higher average annual rainfall. A site with 400 mm average rainfall could store 30-150 tonnes of carbon dioxide equivalent (tCO_2-e)per hectare (Fensham *et al.* 2012). The peak carbon accumulation rate for mulga sites with average annual rainfall above 400 mm is one to two tCO_2-e per hectare per year.

Carbon storage and tree size

Tree dbh (cm)	Dry matter	Carbon (kg)	CO_2 equivalent (kg)
5	8	4	15
30	530	249	913

Table 1: Amounts of above-ground dry matter, carbon and CO_2 equivalent stored in mulga of different diameters; allometry from Burrrows *et al.* cited in Eamus *et al.* 2000

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. 6). For example, the carbon held in an average large tree (~30 cm trunk diameter) is approximately equivalent to that held in 62 smaller trees (~5 cm trunk diameters) (Fig. 7).

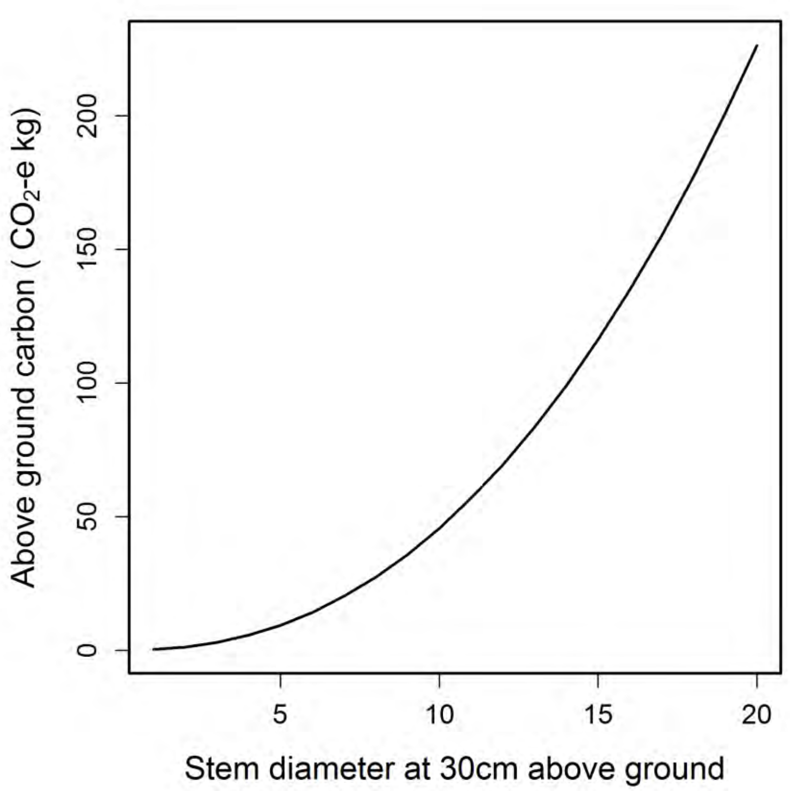
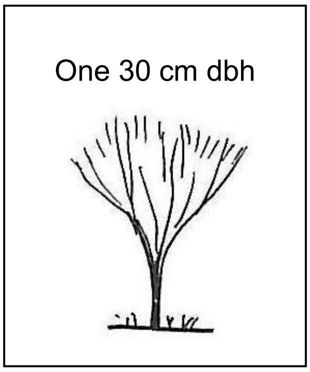


Figure 7: Carbon stocks in a mulga plant as a function of trunk diameter; allometry from Burrrows *et al.* cited in Eamus *et al.* 2000

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



Or

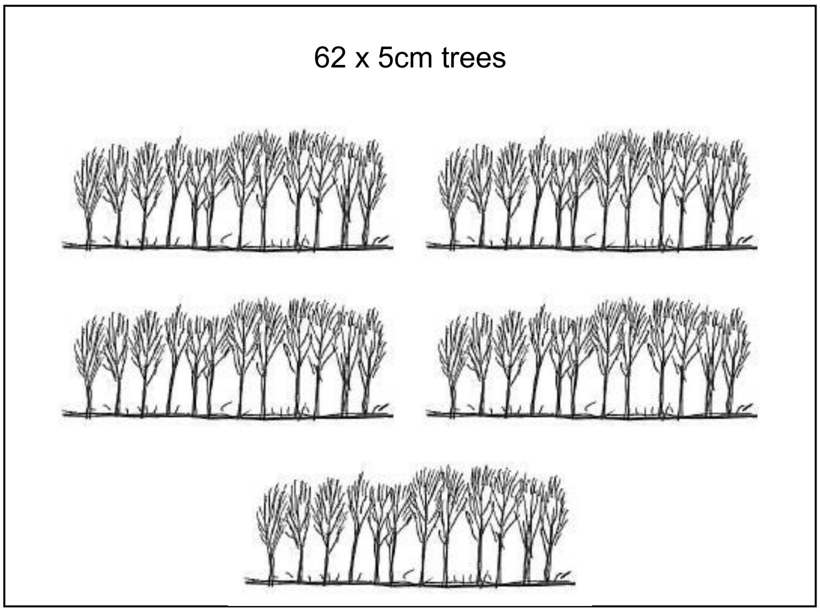


Figure 8: The relative amount of carbon stored in average mulga trees of different sizes:dbh = main stem diameter at 1.3 m height; allometry from Burrrows *et al.* cited in Eamus *et al*. 2000

Trade-offs between trees and pasture

It is important to note that increasing the basal area of trees in woodlands tends to result in decreased pasture yield. This has been observed for a variety of woodland types in Queensland, including mulga woodlands (Fig. 8). It should 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.

[1] This will depend on the details of the CFI methodology being used.

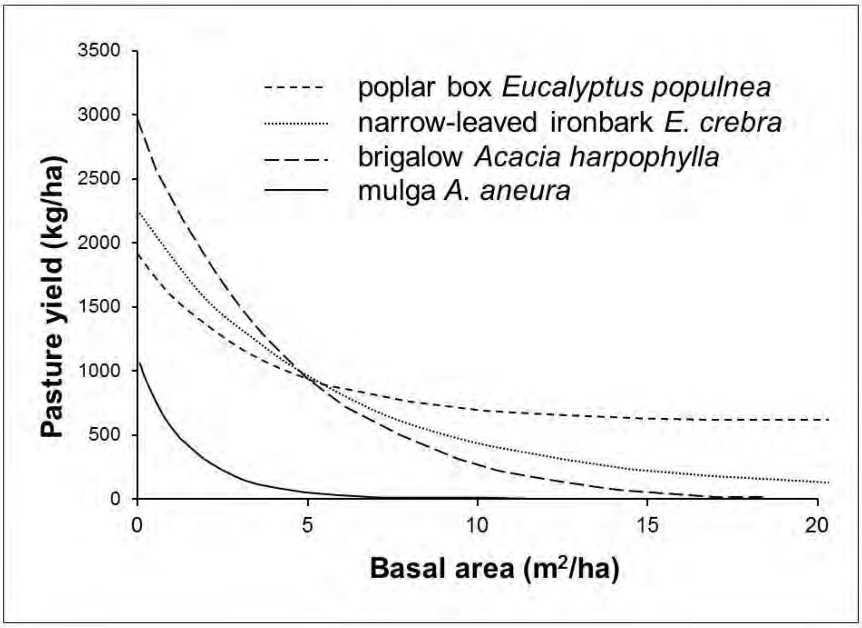


Figure 9: Relationships between tree basal area and pasture yield for a range of woodland tree species from sites in Queensland: redrawn from Burrows 2002; data originally derived from Beale 1973 (A. *aneura*); Scanlan & Burrows 1990b; (E. *populnea* and E. *crebra*); Scanlan 1991(A. *harpophylla*).

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. 7). 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. 8), but a few large trees will hold far more carbon than many small ones, for the same basal area (Table 2). 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 (Tongway & Ludwig 1990).

Table 2: 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 a lower density of larger trees (b) ; allometry from Burrrows *et al.* cited in Eamus *et al.* 2000

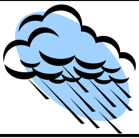
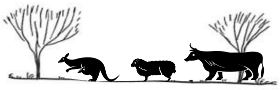
Tree dbh (cm)	Number of trees	Basal area (m^2)	CO_2 equivalent (kg)
5	1528	3	22918
30	42	3	38749

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).

Limits to carbon accumulation

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

Table 3: Summary of limits to carbon accumulation for mulga

Limits to carbon accumulation		Effect on carbon	
		Total carbon stored	Rate of carbon gain
	**Rainfall**	↑	↑
	**Grazing pressure**	↓	↓
	**Clearing**	↓	↓
	**Fire**	↓	↓

The limits to carbon accumulation in mulga are:

Rainfall – Increased rainfall will encourage plant growth and will increase carbon accumulation if other limiting factors are managed. Drought can kill both young and mature mulga trees.

Grazing pressure **–** levels of grazing pressure that remove native grasses, shrubs and small trees, and prevent the recruitment of trees and shrubs will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss (Witt *et al.* 2011). Modelling indicates that excluding both grazing and burning is the most effective way to increase the carbon stored by mulga vegetation (Howden *et al.* 2001).

Clearing – clearing mulga, including fodder harvesting, will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss.

Fire – large and intense fires result in net carbon loss by consuming the carbon stored in trees, shrubs, dead wood and litter. Repeated small fires reduce the rate of carbon gain by removing small trees and shrubs, and decrease the capacity of the vegetation to store carbon by limiting the recruitment of mulga and other fire-sensitive species. Modelling indicates that excluding both grazing and burning is the most effective way to increase the carbon stored by mulga vegetation (Howden *et al.* 2001).

Wildlife conservation

Figure 10: Animal species associated with mulga in Queensland: left: Major Mitchell's cockatoo (*Lophocroa leadbeateri*) feeding on the seeds of mulga; right: Hall's babbler (*Pomatostomus halli*); (Images: G. Chapman).

Figure 11: The yakka skink (*Egernia rugosa*)is a threatened species which has recently been found in mulga; and relies on fallen timber for sheltering and breeding sites , Eyre *et al.* 2010 (Image: DSITIA).

Mulga vegetation in Queensland supports many different types of native plants and animals, including at least 15 species listed as threatened, or near threatened (T. Eyre, DSITIA, *pers.comm.*, Silcock *et al.* 2011). A further 7 plant species associated with mulga woodlands may also be eligible for listing according to (Silcock *et al.* 2011).

Some notable species recently found in Queensland mulga are the yellow-naped snake *Furina barnardi*, yakka skink *Egernia rugosa* (Fig. 10) and kultarr *Antechinomys laniger*(Eyre *et al.* 2009) and the herb *Elacholoma hornii* (Wang *et al.* 2011). Bird species considered to be characteristic of mulga in Queensland include the splendid wren, red-capped robin, spiny-cheeked honeyeater, rufous whistler, crested bellbird, grey shrike-thrush and chestnut-rumped thornbill (Cody 1994; Fig. 11).

Figure 12: Some bird species characteristic of mulga vegetation in Queensland: left to right; Red-capped robin, rufous whistler, chestnut-rumped thornbill (Images: G. Chapman)

The koala can be found in mulga vegetation, especially in the northern and eastern parts of the Mulga Lands, and in association with eucalypts such as poplar box (*Eucalyptus populnea*)(Sullivan *et al*. 2003), although its range has recently contracted in this bioregion (Gordon et al. 2006). A recent study found that the tree-dwelling velvet gecko *Oedura marmorata* (Fig. 12) was associated with remnant mulga, while the ground-dwelling beaked gecko *Rhynchoedura ornata* was more common in regrowth mulga patches (Eyre et al. 2009).

Most management actions that will accumulate carbon in mulga such as reducing grazing pressure, not clearing vegetation, and excluding fire 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 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.

Limits to wildlife conservation in mulga

Table 4: Summary of limits to wildlife conservation in mulga

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, rocks	↑	↑
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	↓	↓
Grazing pressure 	↓	↓
Clearing 	↓	↓
Exotic grasses 	↓	↓
Fire 	↓	↓

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 mulga bird species like the spiny-cheeked honeyeater, rufous whistler, chestnut-rumped thornbill and grey shrike-thrush (Fig. 11) that forage mainly on the foliage of shrubs and trees (Recher & Davis Jr. 1997; Pavey & Nano 2009). A diversity of shrub species that flower and fruit at different times throughout the year will provide food, including nectar, pollen, fruit and insects for birds and other animals.

Shrub cover generally provides small birds with important nesting and foraging sites (Barrett 2000) and protection from aggressive honeyeaters (Maron *et al.* 2011). However, dense vegetation in mulga ecosystems can have different effects on small birds, depending on the height and type of the plants in question. A dense layer of low shrubs < 1 m in height such as *Eremophila* spp. tends to have a negative influence on the abundance of small birds (Eyre *et al.* 2009). This is possibly because a dense layer of low shrubs may restrict the feeding of ground-foraging insectivorous birds (Eyre *et al.* 2009). But a dense layer of mulga trees at 5 - 7 m height is beneficial to small birds, as they tend to forage in this part of the canopy (T. Eyre *pers. comm.*).

High densities of low shrubs also have a negative influence on the diversity of terrestrial reptiles in mulga vegetation, possibly by reducing the area of open ground where reptiles can bask (Eyre *et al.* 2010).

Increasing numbers of large trees in the landscape is generally good news for birds and reptiles, as more species are found in areas with numerous large trees (Eyre *et al.* 2010). For example, increasing numbers of large, live trees also had the greatest influence on velvet gecko *Oedura marmorata* abundance in mulga vegetation (Eyre *et al.* 2009; Fig. 12).

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, cracks and crevices

Many native animals use tree hollows for shelter and nesting, and some also feed on prey found in hollows (Gibbons & Lindenmayer 2002). Mulga trees develop deep crevices and cracks, rather than hollows, but these are used in a similar way by animals (Eyre *et al.* 2010). Eucalypts that form hollows may also be present in some stands of mulga. In southwest Queensland, hollows may take over 100 years to form in eucalypts, and cracks and crevices may take up to 60 years to develop in mulga (Eyre *et al.* 2010) so these features are highly valuable for wildlife, and not readily replaced once destroyed.

Figure 13: Animals that use tree hollows, cracks and crevices in mulga vegetation: top left: little pied bat *Chalinolobus picatus* (Image: DSITIA); top right: white browed treecreeper (Image: G. Chapman); bottom: marbled velvet gecko *Oedura marmorata* (Image: DSITIA).

Animals that use tree hollows found in mulga vegetation include bats like the little pied bat (*Chalinolobus picatus*), birds such as the white-browed treecreeper, and reptiles including the marbled velvet gecko *Oedura marmorata* (Fig. 12). By retaining large, old and dead standing trees which are more likely to contain or form hollows, cracks and crevices 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, nesting and feeding areas for birds (Barrett 2000), reptiles, frogs and mammals (Lindenmayer *et al*. 2003; Eyre *et al*. 2010), and greater amounts of fallen timber tend to support more reptile species (Eyre *et al*. 2010). Soil mounds associated with fallen mulga trees also have higher water infiltration rates and have higher levels of nutrients; are inhabited by termites, ants, spiders and other invertebrates; and can support a higher number and biomass of plant species compared to soils adjacent to these mounds (Tongway *et al.* 1989). A number of bird species such as robins (Fig. 11) and fantails use fallen timber as platforms to view, and then pounce on, prey on the ground, and treecreepers and thornbills (Figs. 11 and 12) 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 for easier mustering, but leaving it in place will help to retain water and nutrients in mulga woodlands, and ease housing and food shortages for wildlife.

Perennial native grass cover

Perennial native grasses provide food for seed-eating birds like finches and pigeons, places to forage for small mammals, and large tussocks provide shelter and nesting sites for reptiles and birds (Eyre *et al.* 2010). Native grasses tend to grow at lower densities than buffel grass, and are therefore less likely to promote and carry large fires (Eyre *et al.* 2010).

Litter

Litter (fallen leaves, bark and twigs) provides shelter, nesting sites, and foraging sites for many invertebrates, birds, reptiles and small mammals (Eyre *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) and can sometimes be the main source of nectar for honeyeaters in mulga vegetation (Recher & Davis Jr. 1997).

Rocks

Surface rocks and piles of boulders are important habitats for animals like reptiles. 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.

Invertebrates

Invertebrates include insects, spiders and other small animals with six or more (or no) legs. A diversity of foraging habitats like fallen timber, trees, shrubs, leaf litter will support a variety of invertebrates which can provide food for other animals, pollinate plants, and even assist in water infiltration by burrowing into the soil (Tongway *et al.* 1989). For example, a wide variety of bird species were observed feasting on an outbreak of geometrid moth caterpillars associated with mulga trees (Recher & Davis Jr. 1997).

Fungi

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

Figure 14: Some shelter and food resources for wildlife found in mulga vegetation

Landscape features

Large patch size

Small patches of habitat may be able to support populations of some plant and animal species like 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). 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). Some mulga bird species (i.e. the brown treecreeper (Fig. 14), weebill, white-browed treecreeper (Fig. 12), red-capped robin (Fig. 11) and yellow-rumped thornbill) are more likely to be found in large intact tracts of remnant mulga (Eyre *et al.* 2009).

Figure 15: The brown treecreeper (*Climacteris picumnus*) is more likely to be found in large intact tracts of mulga than small patches (Image: G. Chapman)

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). Creating a 'patchwork' of small cleared areas by fodder harvesting mulga can also increase edge effects, to the detriment of wildlife. These greater edge-to-area ratios in mulga can encourage increased abundances of larger predatory birds like butcher birds, which tends to have a negative effect on small woodland birds. In this case, it is better to clear the same total area of mulga in the one large block and therefore also leave a larger block of uncleared vegetation, than to clear it in a number of small patches (T. Eyre *pers.comm.*).

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). For example, velvet geckoes (Fig. 12) are unable to cross gaps between isolated patches of mulga woodland (Eyre *et al.* 2010). 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).

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). The most serious weed in mulga is buffel grass (see below), although it currently affects a fairly small area of mulga in Queensland. Feral herbivores such as goats contribute to levels of grazing pressure in mulga, and feral predators such as cats impact on small animals, including ground-nesting birds. Weed management actions that have adverse effects on wildlife by destroying habitat should be avoided if possible, or implemented in stages.

Aggressive native species

The abundance of yellow-throated miners, an aggressive native bird species, has a negative effect on abundance of small song birds in mulga vegetation (Eyre *et al.* 2009). Yellow-throated miner abundance also tends to increase with the amount of the landscape that is cleared (Eyre *et al.* 2009; see ***Clearing*** below). Dense vegetation in mulga ecosystems may also provide small birds some protection from miners, but the height of the vegetation is important. While small birds appear to benefit from dense mulga at around 5-7 m height, they also appear to be disadvantaged by dense low shrubs like *Eremophila* spp. at < 1 m height (T. Eyre *pers. comm.*).

Exotic grasses

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 which also contained mulga, 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). Cody (1994) observed that robins were scarce in mulga sites with thick grass, probably because thick grass cover appears to be unsuitable for the 'perch and pounce' foraging technique of these birds. Several birds found in mulga (e.g. the red-capped robin and crested bellbird) are typically perch hunters that pounce on patches of bare ground to capture invertebrate prey (Pavey & Nano 2009). Therefore the presence of dense swards of exotic grasses, are likely to prevent or limit the natural foraging behaviour of these birds. High densities of buffel grass increase the frequency and intensity of fire in acacia woodlands by increasing ground fuel loads (Franks 2002; Butler & Fairfax 2003), and this can have negative impacts on birds (see ***Fire*** below).

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 (e.g. wild dogs) and the presence of artificial watering points. Grazing pressure by stock, feral and native animals can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of mulga, grasses and understorey shrubs. Grazing pressure may result in lower plant species richness in mulga (Fensham *et al.* 2011b; Witt *et al.* 2011), and may be linked to declines in more palatable plant species (e.g. *Trachymene glaucifolia*), as well as increases in more tolerant species (e.g. *Sida aprica*), over time (Wang *et al.* 2011). High grazing pressure has also been linked to lower species richness of birds in eucalypt woodlands in southern Queensland (Martin &McIntyre 2007). Sustained grazing pressure can also result in dense stands of so-called woody weeds, especially low unpalatable shrubs like turkey bush (*Eremophila gilesii*) and this may have negative effects on small song birds (see ***Trees and shrubs*** above). However, many birds can coexist with moderate levels of grazing (Martin & McIntyre 2007), and grazing can also be an important management tool for controlling buffel grass (Butler & Fairfax 2003).

Clearing

Cleared mulga vegetation can support diverse assemblages of native grasses and forbs, which makes recovery of an intact community more feasible for mulga than for many other vegetation types. Exotic pasture grasses are perhaps the greatest threat to this situation because they displace native plants (Franks 2002). Currently, buffel grass has only become established in the far eastern Mulga Lands of Queensland, but it may spread further.

Clearing has its most obvious impacts on native animals in mulga. Clearing removes housing and food resources for animals, and encourages large and widespread birds like butcher birds, galahs and yellow-throated miners. Yellow-throated miner birds are particularly aggressive and their high abundance in young regrowth and in highly cleared landscapes has a negative impact on small bird species (Eyre *et al.* 2009). There is a suit of small song-birds associated with mulga (e.g. treecreepers, weebill, red-capped robins and yellow-rumped thornbill) that are largely restricted to older regrowth and remnant vegetation (Eyre *et al.* 2009).

Fire

Many bird species rely on long-unburnt vegetation (Woinarski 1999), and fire is known to cause increased mortality of mulga (Wright & Clarke 2007) and change the composition of the associated bird community (Leavesley *et al.* 2010). Mistletoe, which is an important resource for many birds, was most common in long-unburnt areas of mulga in central Australia (Leavesley *et al.* 2010). Fire also consumes fallen timber and litter, which provide food, shelter and nesting sites for many animal species (Eyre *et al.* 2010). Therefore the exclusion of fire, and the protection of long-unburnt areas, is recommended for wildlife conservation in mulga vegetation.

General fire guidelines for maintaining the overall biodiversity of mulga ecosystems are provided in the Regional Ecosystem Description Database (REDD) (Queensland Herbarium 2011) and in the Department of National Parks, Recreation, Sport and Racing’s bioregional planned burn guidelines (2012).

Table 5: Habitat values for selected plant and animal species associated with mulga vegetation

		Tree hollows cracks & crevices	Fallen timber	Trees & shrubs	Native Grasses	Litter	Mistletoe	Rocks	Insects
Mammals			✓		✓	✓			
Little pied bat	*Chalinolobus picatus*	✓							✓
Kultarr	*Antechinomys laniger*								✓
Koala	*Phascolarctos cinereus*			✓					
Birds					✓	✓			
White-browed treecreeper	*Climacteris affinis*	✓	✓	✓					✓
Brown treecreeper	*Climacteris picumnus*	✓	✓	✓					✓
Major Mitchell’s cockatoo	*Lophochroa leadbeateri*	✓		✓					

		Tree hollows cracks & crevices	Fallen timber	Trees & shrubs	Native Grasses	Litter	Mistletoe	Rocks	Insects
Red-capped robin	*Petroica goodenovii*		✓						✓
Chestnut rumped thornbill	*Acanthiza uropygialis*		✓	✓					✓
Splendid wren	*Malurus splendens*			✓					✓
Spiny-cheeked honeyeater	*Acanthagenys rufogularis*			✓			✓		✓
Rufous whistler	*Pachycephala rufiventris*			✓					✓
Crested bellbird	*Oreoica gutturalis*								✓
Grey shrike-thrush	*Colluricincla harmonica*			✓					✓
Mistletoe bird	*Dicaeum hirundinaceum*				✓		✓		
Reptiles				✓		✓			
Marbled velvet gecko	*Oedura marmorata*	✓							✓
Yakka skink	*Egernia rugosa*		✓					✓	✓
Insects		✓	✓	✓	✓	✓	✓	✓	✓
Spiders		✓	✓	✓	✓	✓	✓	✓	✓
Plants			✓					✓	

Management actions

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

To **maximise carbon** (by restoring the site to State 1 in Fig. 5), the management aims for all states are:

- Maximise the height and diameter of existing trees (mulga and/or eucalypts) within the productivity constraints of the site.
- Increase the density of large trees (mulga and/or eucalypts) 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 (mulga and/or eucalypts) 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 like 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 will probably have the strongest influence on the rate of mulga restoration and growth on your site. However, other factors, such as fire, grazing, and weeds, may also require management. The level of disturbance at 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 Fig. 15.
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).

Information on fire management is also available in the QPWS planned burn guidelines (Department of National Parks, Recreation, Sport and Racing 2012).

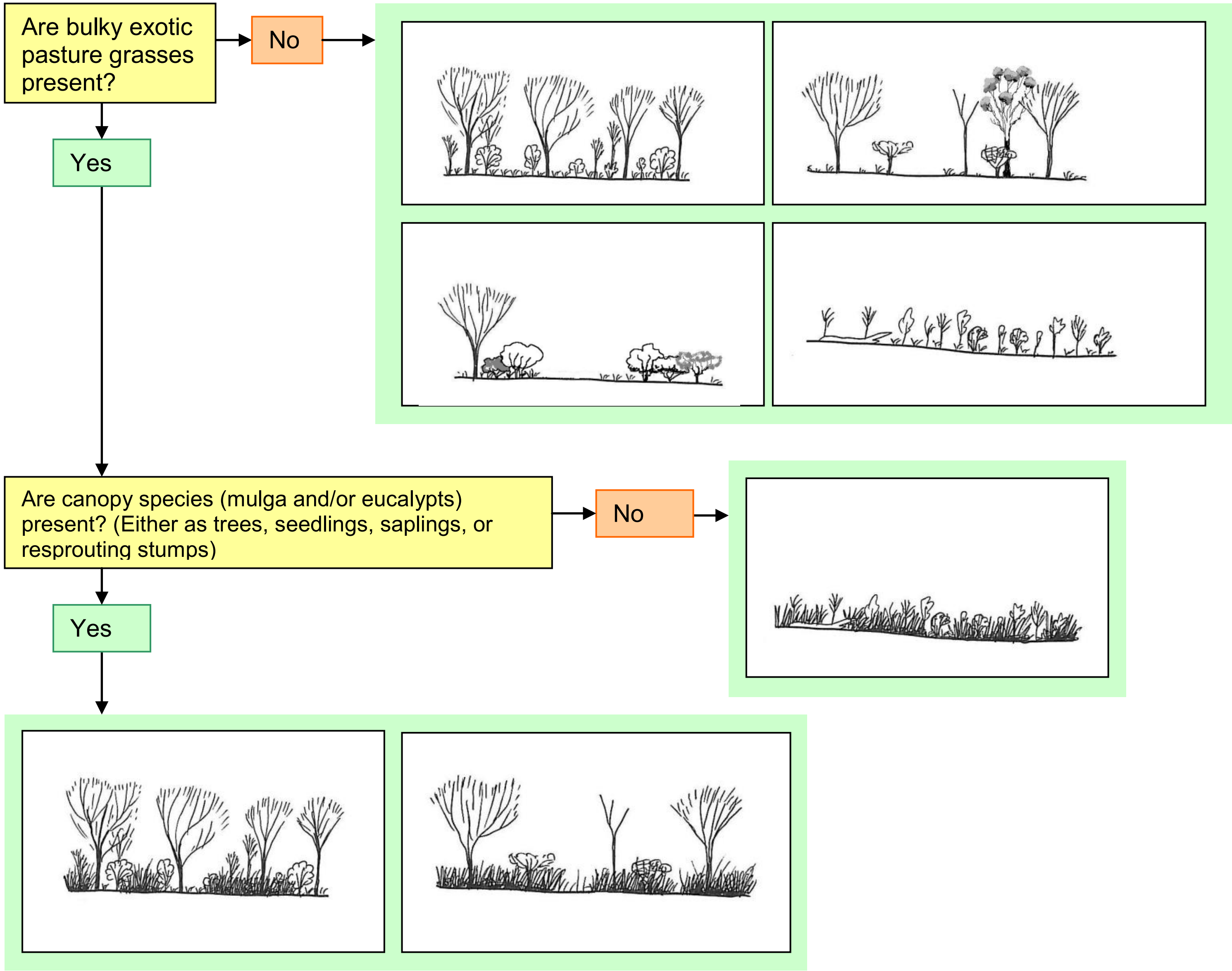


Figure 16: Key to mulga condition states that feature in the mulga ecological model (Fig. 6)

Table 6: The main management issues for each condition state for mulga;some condition states have been grouped because their management actions are the same

Condition state	Description	Main management issue
1, 2, 3 & 5	Canopy tree species (mulga or eucalypts) present, exotic grasses absent	Areas in these states should require little intervention to sustain or increase their carbon stocks.
4	Canopy tree species (mulga or eucalypts) and exotic grasses present	Management of exotic grasses and fire will be needed to maintain and increase carbon stocks.
6	Canopy tree species (mulga or eucalypts) absent, and exotic grasses present	Seed sources for canopy trees and control of exotic grasses will be critical to restoration of carbon stocks from this state.

Table 7: Management actions for restoring and maintaining mulga 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		
				1,2, 3,4	5,6	7
Clearing and thinning						
1. No clearing of live trees and shrubs.	• Clearing mulga 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, 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, cracks and crevices) 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						
4. Prevent and suppress fire in the mulga vegetation to be restored.	• 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.	↑	↑	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition/state		
				1,2, 3,4	5,6	7
5. If grass fuel loads are likely to build up in the mulga vegetation to be restored, 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 coarse woody debris, and decrease the capacity of the vegetation to store carbon by limiting the recruitment of mulga and other fire-sensitive species. But small carbon losses are preferable to potentially larger losses from unplanned wildfire. • Reduces the risk of higher severity fire in the area to be restored (see 4). • May have negative impacts on small relatively immobile species, but these are preferable to the larger impacts of more extensive, and more severe hot fires on wildlife.	↑	↑	✓	✓	✓
6. Conduct low severity burns, when soil moisture is high, in the surrounding vegetation,***if this surrounding vegetation is fire-adapted.*** Aim to create a mosaic of burnt and unburnt areas around the Brigalow area to be restored.	• Reduces the risk of fire in the area to be restored (see **4**).	↑	↑	✓	✓	✓
7. Use grazing management to reduce high fuel loads in the mulga vegetation to be restored (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**).	↑	↑	✓	✓	✓
8. Use grazing management 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).	↑	↑	✓	✓	✓
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. • Helps to protect important habitat trees from scorching, and premature death	↑	↑	✓	✓	

Action	Benefits	Carbon	Wildlife	Condition/state		
				1,2, 3,4	5,6	7
Grazing						
10. Manage grazing to allow tree recruitment to reach or maintain the tree density required. (E.g. To maintain tree density, the mortality of mature trees needs to be equal to the recruitment of new trees into the canopy.). Sheep, goats and macropods can eliminate mulga seedlings, while cattle are less likely to. So if recruitment of mulga and/or eucalypt seedlings is needed, possible grazing strategies are: • Rest the area until sufficient mulga and/or eucalypt seedlings have grown higher than the upper limit of sheep browsing (120 cm according to Brown 1985). Then resume stocking with sheep. • Stock the area with cattle only until sufficient mulga and/or eucalypt seedlings have grown higher than the upper limit of sheep browsing (120 cm according to Brown 1985). Then resume stocking with sheep.	• 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 mulga, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition/state		
				1,2, 3,4	5,6	7
11. Control macropods and feral herbivores (e.g. goats) if they are in sufficient densities to prevent the recruitment of native trees and shrubs.	• 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 mulga, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓
Site preparation and plant establishment						
12. If areas of bare, eroded soil are present, leave fallen timber on the ground, and ensure that any management fires are not severe enough to destroy fallen timber. Large branches and cut shrubs can also be deliberately placed in elongated piles along contours.	• This has been shown to accumulate soil and litter, and promote the establishment and growth of perennial grasses in mulga (Ludwig & Tongway 1996; Tongway & Ludwig 1996). • This method is also likely to promote the recruitment of trees by rehabilitating soil and organic matter, and offering some protection from grazing animals.	↑	↑	✓	✓	✓
13. Use slashing or low severity fire to reduce the cover of herbaceous plants before ripping, direct seeding or tubestock/sucker planting.	• Improves the establishment and growth of woody plants by reducing competition.	↑	↑			✓
14. Encourage natural regeneration by resting the site from grazing for a month or two, immediately following good rains, then inspect for canopy tree seedlings. If no canopy tree species appear, the other options are direct seeding or planting tubestock**.**	• A good rain event or ripping may stimulate seed germination, if seeds are present in the soil.	↑	↑			✓

Action	Benefits	Carbon	Wildlife	Condition/state		
				1,2, 3,4	5,6	7
15. Revegetate treeless areas with native trees and shrubs (especially mulga and eucalypts) using direct seeding or tubestock.	• 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.	↑	↑			✓
16. Establish a diversity of tree and shrub species in areas without woody plants.	• A diversity of woody plant species of different sizes and ages provides food and habitat for wildlife.		↑	✓	✓	✓
Competitors and predators						
17. Prevent the introduction and spread of exotic grasses and other serious weeds. Vehicles, machinery, quad bikes and stock can all spread weeds. Regularly check disturbed areas (e.g. roadsides and firebreaks) and control new weed infestations before they become widespread.	• Weeds may reduce carbon gain and storage by reducing tree and shrub growth and establishment, and increasing the risk of fire. • 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.	↑	↑	✓	✓	✓
18. Control buffel grass by slashing or conducting low-severity burns at the end of its growing season (end of the wet season), and then applying herbicide when it resprouts. Hand-pulling or grubbing is also an effective (but highly labour intensive) method of control. Aim to increase canopy shading by trees and shrubs to assist with long-term buffel grass control.	• Weeds may reduce carbon gain and storage by reducing tree and shrub growth and establishment, and increasing the risk of fire. • 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.	↑	↑		✓	✓

Action	Benefits	Carbon	Wildlife	Condition/state		
				1,2, 3,4	5,6	7
19. Encourage dense growth of native trees and shrubs on site edges to suppress the growth of grasses**.**	• Limits grass fuel loads (especially buffel grass) on site edges, and reduces the risk of fire entering the site. • See **18** for other benefits of grass control.	↑	↑	✓	✓	✓
20. Use high grazing pressure by stock to control exotic grasses, once a sufficient number of native trees and shrubs are higher than the upper limit of stock grazing. But ease grazing pressure before there are negative effects on soil health and wildlife**.**	• Weeds may reduce carbon gain and storage by reducing tree and shrub growth and establishment, and increasing the risk of fire. • 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. • The level of grazing required to control buffel grass may be just as destructive to soil health and wildlife as the buffel grass itself. More trials are needed to assess the effectiveness and any negative impacts of this method.	↑			✓	✓
21. Control feral animal species in mulga where these are having a negative impact on wildlife and plant regeneration**.**	• The pigs, cats, foxes and goats 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.		↑	✓	✓	✓
22. 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.		↑	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition/state		
				1,2, 3,4	5,6	7
23. Reduce numbers of aggressive honeyeaters (yellow-throated miners) where these are having a negative impact on wildlife by**:** • Retaining large remnants of uncleared mulga; • Increasing the density of mulga trees at 5 – 7 m height; • Reducing the density of low shrubs < 1 m height (e.g. *Eremophila* spp.); • Reducing edge-to-area ratios. E.g. if fodder harvesting, clear one large patch instead of clearing the same area of land in numerous small patches.	• Miners can have a strong negative influence on the abundance and species richness of other native birds. • Direct control of miners is not recommended. • Modifying the structure of mulga vegetation in these ways will help to exclude miners and other predatory birds, and provide a more suitable habitat for small birds.		🡅	✓	✓	✓
Other actions for wildlife						
24. 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.		🡅	✓	✓	✓
25. Reduce the density of low shrubs < 1 m height (e.g. *Eremophila* spp.)**.**	• Reduced densities of low shrubs are likely to benefit small woodland birds and reptile species.		🡅	✓	✓	✓
26. Provide nest boxes if hollows are scarce	• Tree hollows provide important shelter and foraging sites for wildlife.		🡅	✓	✓	✓
27. Retain and protect mistletoe on mulga and other woody plant species**.**	• Mistletoe provides nectar, berries and nesting sites for many animal species.		🡅	✓	✓	

Action	Benefits	Carbon	Wildlife	Condition/state		
				1,2, 3,4	5,6	7
28. Retain and protect rocks and rock outcrops**.**	• Some plant species may only be found in association with rocky areas. • Rocky areas provide habitat for animal species including invertebrates.		↑	✓	✓	✓
29. Retain and protect leaf litter including fallen leaves, bark and twigs**.**	• Leaf litter provides habitat for animal species including invertebrates.		↑	✓	✓	✓
30. Minimise or avoid the use of insecticides in mulga vegetation 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						
31. Rainfall will have a large bearing on the success of management actions**.**	• Lower rainfall will have a negative overall effect on biomass accumulation. • Extended dry periods may cause the death of mature trees. • Recruitment and survival of mulga and eucalypt seedlings are heavily dependent on good rains. • Revegetation with tubestock or by direct seeding is highly risky, and will probably only be successful when good rains are expected.					

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