Department of Science, Information Technology, Innovation and the Arts

Brigalow

Regrowth Benefits - Management Guideline

Great state. Great opportunity.

Queensland Government

Prepared by

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Summary

- Brigalow occurs over a large area of eastern Australia, from south of Narrabri in New South Wales, to Charters Towers in north central Queensland.
- The tendency of brigalow to sucker profusely after disturbance will assist in the restoration of this vegetation type, where brigalow is already present.
- Rainfall and past clearing history have a large influence on carbon accumulation rates and standing carbon stocks in brigalow, but ongoing management, particularly of stem density, can also have a large effect.
- Standing stocks of above-ground carbon in mature brigalow forest in Queensland range from about 50 to 125 tonnes of carbon per hectare which is about 180 to 458 tonnes of carbon dioxide equivalent (tCO_2-e) per hectare.
- Conservative estimates of carbon accumulation rates in active brigalow regrowth range between 3.3 to 5.5 tCO_2-e per hectare per year.
- Fires can slow and prevent brigalow restoration by inhibiting the establishment and growth of brigalow and other native plants, and by killing mature trees.
- Cattle grazing can be compatible with reforestation in brigalow, as long as grazing pressure is held at low to moderate levels, and strategic spelling is adequate to allow tree recruitment. Increasing the biomass of trees will reduce the carrying capacity for grazing.
- Regrowing brigalow will benefit biodiversity, especially animals such as birds, reptiles and land snails that depend on brigalow for habitat.

Description

Generally, mature brigalow vegetation in Queensland has the following features:

- Brigalow (*Acacia harpophylla*) is the most prominent woody plant, forming a canopy between about 9 and 25 m tall, often with other trees or shrubs.
- Other canopy trees may include belah (*Casuarina cristata*), red bauhinia (*Lysiphyllum carronii*) and the Queensland bottle tree (*Brachychiton rupestris*).
- Eucalypts (including poplar box (*Eucalyptus populnea*), Dawson gum (*E. cambageana*), and many other species) may also occur with brigalow and may form an open ‘emergent’ layer above the brigalow and/or belah canopy.
- Other wattles may also be present in the tree layer including gidgee (*Acacia cambagei*), blackwood (*A. argyrodendron*), myall (*A.pendula*) and yarran (the common name for *A. melvillei* and *A. omalophylla*).
- The shrub layer often includes wilga (*Geijera parviflora*), false sandalwood (*Eremophila mitchellii*) and yellowwood (*Terminalia oblongata*), but can also include many other species.
- The ground stratum (including grasses) is generally sparse.
- Canopy cover can vary from 20 – 80% (approximate crown cover, Queensland Herbarium 2011).

Brigalow occurs over a substantial geographic area of Australia, between the 20th and 31st degrees of latitude and with average annual rainfall ranging from about 500mm to 850mm. It includes a variety of vegetation types united by a suite of species that tend to occur on acidic and salty clay soils. Brigalow vegetation occurs in the Brigalow Belt (North and South), Darling Riverine Plains, Mitchell Grass Downs, Mulga Lands and South-east Queensland bioregions of Queensland, and also occurs in northern-central New South Wales (Butler 2008).

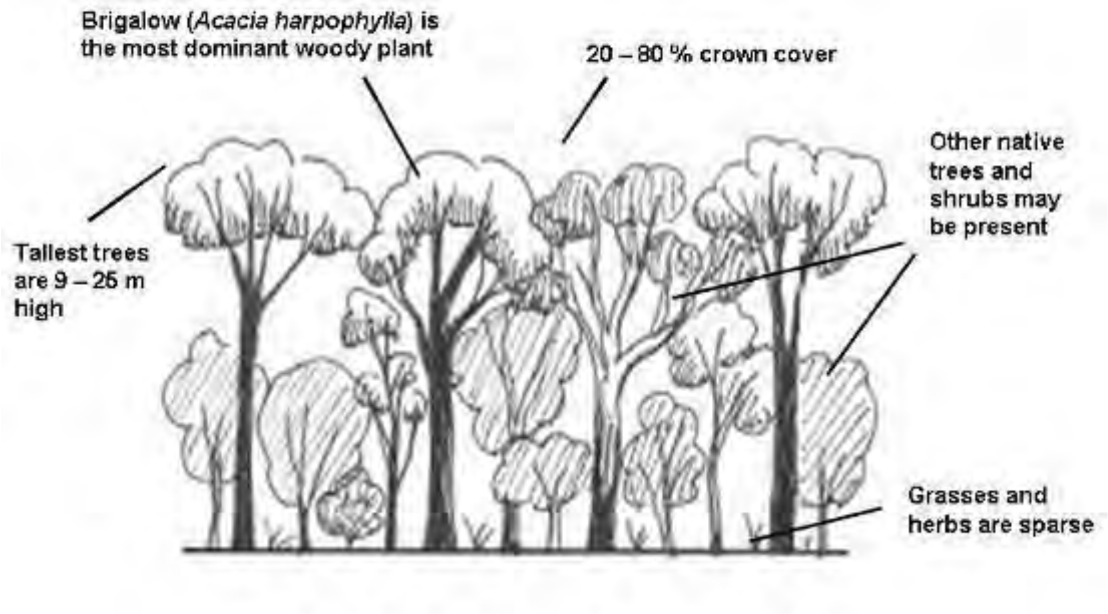

Figure 1: Structural features of brigalow vegetation

Figure 2: Brigalow with belah and a diverse shrub layer at Barakula in southern Queensland (Image: D. Butler, DSITIA)

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

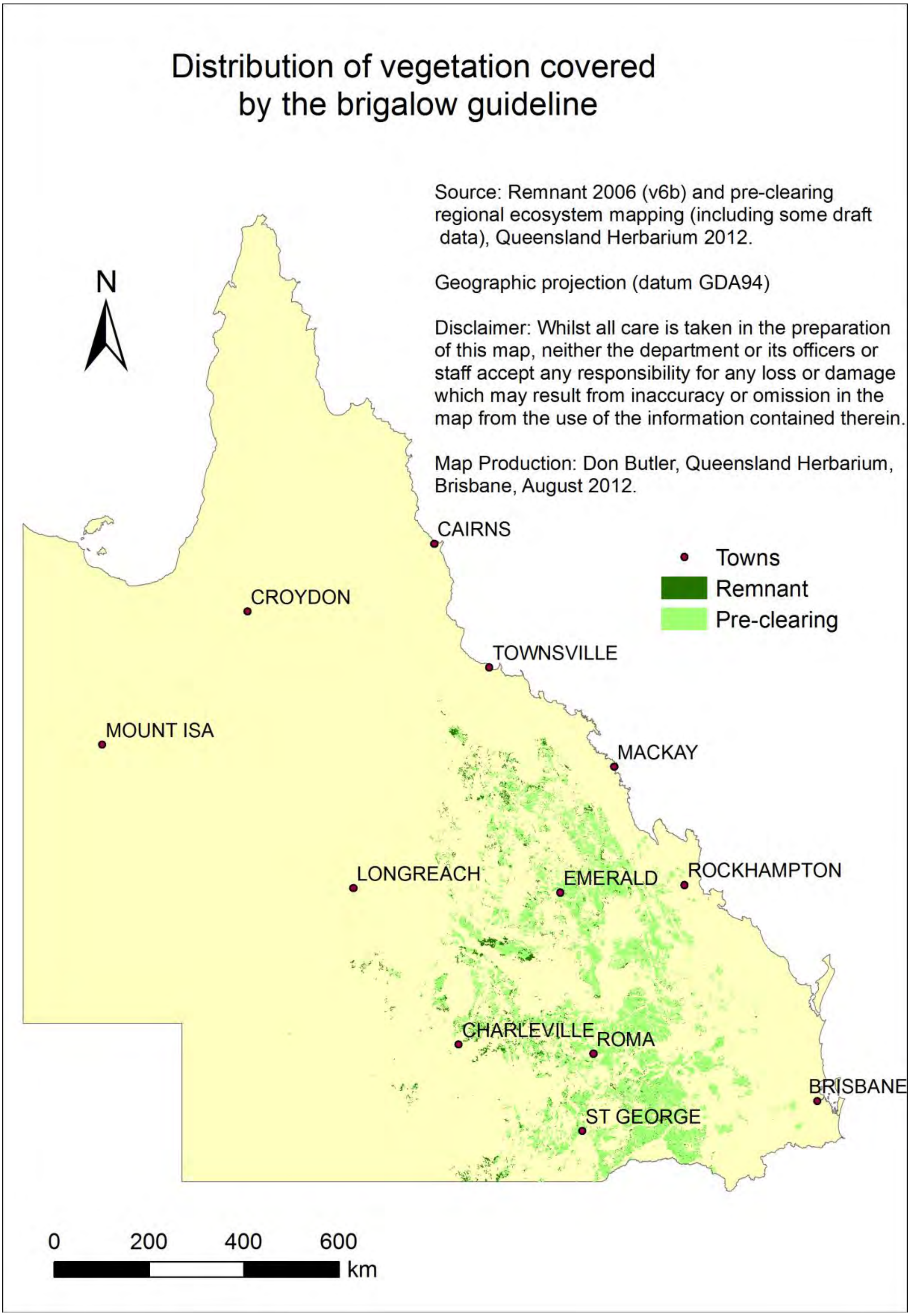

Figure 3: The distribution of pre-clearing and remnant brigalow vegetation in Queensland

Ecology

The restoration and management of brigalow vegetation is underpinned by what we know about its ecology, particularly the effects of climate and disturbances such as clearing, grazing, fire and weeds. As the brigalow tree (*Acacia harpophylla*) is the dominant life form of brigalow vegetation, its biology has a large bearing on reforestation in brigalow country, and on best practice management for carbon accumulation.

The biology of the brigalow (*Acacia harpophylla*)

The leaf tissue[1] of brigalow is more resistant to desiccation than mulga (*A. aneura*), even though brigalow occurs in higher rainfall country than mulga (Connor & Tunstall 1968). This may be linked to the heavier texture, and often higher salinity of the soils associated with brigalow (Connor & Tunstall 1968), and the high probability of soil water deficits in autumn and spring (Nix 1994). Water loss from brigalow leaves is minimal, and plants do not shed leaves in adverse conditions. As a result, brigalow leaves have the ability to maintain a positive carbon balance over a wide range of environmental conditions, and this species is very productive in a relatively low-rainfall, high-evaporation environment (Tunstall & Connor 1975). Brigalow can also tolerate high salt levels, even though growth under these conditions is reduced (Gates 1972; Reichman *et al*. 2006).

Brigalow has a well-developed lateral (horizontal) root system, and plants are often joined together by these roots, forming colonies (Johnson 1964). A characteristic of brigalow is its ability to produce shoots from these lateral roots, known as suckering, in response to disturbance (Johnson 1964). The suckering response of brigalow is influenced by seasonal conditions and severity of damage (Johnson 1964).

More suckers are produced if brigalow is damaged when soil moisture is low, when trees have been recently disturbed (i.e. sucker brigalow – see below), or where brigalow stems are rapidly destroyed by activities such as lopping, chopping or pulling rather than if they are slowly killed by ring barking or aerial herbicide spraying for example (Johnson 1964). Fire can also cause suckering, although very hot fires may also cause severe damage to roots, and prevent regeneration (Johnson 1964). There is also some evidence that the production of suckers following pulling and burning is more prolific on deep gilgaied clay soils (Johnson 1964). It has been suggested that stem and root surface damage by the now-extinct megafauna may have been a factor that led to the development of the suckering response of brigalow (Nix 1994). Blade ploughing can be used to prevent brigalow from suckering, and effectively remove brigalow from a site, by destroying the lateral root system.

Suckering is the main means of reproduction, as brigalow does not flower every year, and seed production is rare (Johnson 1964). Brigalow seeds have no dormancy period, germinate rapidly once wetted (Johnson 1964; Coaldrake 1971), and remain viable in soil for less than a year (Johnson 1964). As a result, it is unusual to find brigalow seedlings in natural landscapes (Butler 2008), and revegetation of brigalow by direct seeding or planting tube stock is possible, but may be limited by that amount of seed produced, and its limited storage period (unlike many acacias).

If mature brigalow trees are removed from a site due to clearing for example, and many suckers are produced brigalow can take the form known as ‘sucker brigalow’, where all brigalow plants have a low branching habit and are generally less than 4 m in height (Johnson 1964). High densities of suckers may develop into another form of brigalow known as ‘whipstick brigalow’ after about 30 years (Johnson 1964). Whipstick brigalow typically consists of high densities of many straight, slender stems about 4 to

[1] The terms ‘leaf tissue’ and ‘leaves’ are used here for simplicity, even though brigalow and mulga have phyllodes (which are flattened leaf stalks) rather than true leaves.

8m tall with spindly or dead lower branches (Johnson 1964). Although it is assumed that whipstick brigalow will eventually grow into mature brigalow, it is not known how long this will take (Johnson 1964). Judicious thinning may ease the competition between the numerous stems and accelerate the development of a mature structure (Dwyer *et al*. 2010).

Rainfall

The pre-clearing distribution of brigalow fits into a bioclimatic zone that is found nowhere else on the planet, with rainfall highs in summer and winter (with most rain falling in summer), and a high variability in seasonal and annual rainfall (Nix 1994). The average annual rainfall of this zone ranges from about 500 mm to 750 mm (Butler 2008). Mature brigalow can develop into open forests of 50-80% canopy cover in high rainfall areas and form woodlands of 20-50% canopy cover in drier areas (Johnson & Burrows 1994; Nix 1994). At its wetter margin brigalow vegetation can grade into dry rainforest such as semi-evergreen vine thicket or softwood scrub with *A. harpophylla* present as an emergent tree (Johnson & Burrows 1994; Nix 1994).

Clearing

The potential for brigalow to regrow after clearing is significantly influenced by the initial clearing method and subsequent land use. Chaining or pulling brigalow vegetation often leaves living stumps and roots that will resprout if further disturbance such as hot fires is minimal. When clearing is undertaken in this way, there is some evidence that the species composition of brigalow regrowth is strongly influenced by which species are present prior to clearing (Johnson 1981) and plant species diversity of older regrowth is similar to uncleared stands (Johnson 1997; Chandler *et al*. 2007). As a result, it is likely that brigalow that is left to regrow after chaining or pulling could eventually resemble mature stands of uncleared brigalow (Johnson 1997).

Chandler *et al*. (2007) inferred that more intensive efforts would be required to restore the structure and floristic composition of brigalow stands pulled once or repeatedly, compared to stands cleared by less severe means like ringbarking).

Brigalow restoration will be most difficult if the original vegetation has been removed altogether for example, by blade ploughing and aerial spraying with tebuthiuron (Scanlan 1991) and replaced by exotic grass species or crops. In this case natural regeneration of brigalow, vegetation will be unlikely without weed control and replacement of native vegetation with tube stock, or by direct seeding.

Tree clearing also includes thinning, where some trees are left for timber production and/or shade and shelter. Thinning of dense brigalow regrowth may be used to increase the rate and amount of carbon accumulated through brigalow restoration, but it is often expensive. It may be more cost-effective for landholders to maintain cleared and forested areas as distinct paddocks or as tree strips (e.g. McKeon *et al*. 2008), rather than attempt to maintain low tree density by resisting the trees' capacity to multiply. Any thinning undertaken while restoring brigalow for carbon should retain the dead timber on site as debris, as this will contribute to carbon storage.

Fire

Brigalow generally recovers from fire by suckering, and other plant species in brigalow forests can also survive fire and resprout (Butler 2008). However, very hot fires[2] can kill trees and shrubs (Butler & Fairfax 2003), prevent brigalow regeneration by causing severe damage to roots (Johnson 1964), and can greatly alter the structure of brigalow forests (Johnson & McDonald 2001; Butler & Fairfax 2003).

Fires are usually rare in mature brigalow vegetation (Moore *et al*. 1967) because of the scarcity of fine fuels, although extreme fire weather or other unusual circumstances (e.g. fuel loads created by prickly pear eradication in the early 1930s) sometimes result in hot fires[2] (Butler 2008). Fires in brigalow become more frequent and intense when exotic grasses invade or abut remnant patches. More open stands of brigalow, such as patchy brigalow regrowth or brigalow woodlands in low rainfall areas, are more susceptible to grass invasion because of increased light penetration (Butler 2008).

The spread of exotic grasses into brigalow patches can also be assisted by tree thinning, soil disturbance, and the movement of livestock and vehicles. With the exception of clearing, the most important threat to remnant and regrowth brigalow is fire fuelled by exotic grasses, like buffel grass (Butler 2008). Thus the control of grass fuel loads is an integral part of fire management in brigalow. Grazing, shading by trees and shrubs, herbicide control, low severity fires and even hand-pulling may be used to reduce grass fuel loads, and in this way reduce the incidence of wildfires (Butler & Fairfax 2003).

Figure 4: Mixed brigalow/gidgee woodland degraded by exotic grass invasion and subsequent fire in central Queensland (Image: D. Butler, DSITIA)

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

Nutrient cycling

Both brigalow and the often-associated belah (*Casuarina cristata*) can fix atmospheric nitrogen (Nix 1994). Soil total nitrogen and organic carbon have been shown to increase with canopy cover in an uncleared brigalow forest, probably because of nutrient inputs from decomposing litter (Dowling *et al*. 1986). Perhaps not surprisingly, the clearing of brigalow forests for pasture and cropping has been linked to declines in soil nitrogen and carbon (Graham *et al*. 1981; Radford *et al*. 2007), and productivity measures for grain and cattle also decline from a brief peak immediately after clearing (Radford *et al*. 2007). It is not known whether the restoration of brigalow vegetation in these areas will require, or benefit from, some kind of soil rehabilitation before native plants are replaced.

Dry rainforest or brigalow

Brigalow can develop into dry rainforest such as semi-evergreen vine thicket or softwood scrub, often with *A. harpophylla* present as an emergent tree given sufficient moisture, protection from fire, and a suitable seed source (Johnson &Burrows 1994; Nix 1994). If your site will support dry rainforest, it may be preferable to restore this vegetation type rather than 'pure' brigalow, as brigalow with dense dry rainforest is likely to accumulate more carbon and a shady dense tree and shrub layer will be more resistant to grass invasion.

Ecological model

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

Mature brigalow is converted into another condition state in the following ways:

- Disturbance of mature brigalow (State 1) and invasion of exotic grasses can reduce carbon stocks and create a grassy open forest or woodland (State 4).
- Major damage to mature brigalow (State 1) reduces carbon and causes suckering that produces 'sucker brigalow' (State 2) which may develop into 'whipstick brigalow' (State 3) if further disturbance is minimal.
- Clearing and blade ploughing of mature brigalow (State 1) reduces carbon stocks and wildlife habitat, and results in grassland or cropland with no native woody plants (State 6).
- Invasion of native rainforest species can cause the transition of mature brigalow (State 1) into dry rainforest (vine thicket, State 5).

Mature brigalow can be restored if the damaging processes cease, and their effects are counteracted by managing fire and grazing, controlling weeds, promoting brigalow suckering, and in some cases reintroducing native woody plants.

Carbon stocks in mature brigalow vegetation (State 1) will be maintained close to their capacity if there is adequate rainfall, no clearing and/or fires. Grazing should be compatible with carbon farming as long as the mortality of mature trees is equal to the recruitment of new trees into the canopy.

In time, climate variability may also alter the potential 'mature' structure and floristic composition of brigalow 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 brigalow 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 occurs or 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 or were associated with the type of vegetation that occurs/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.

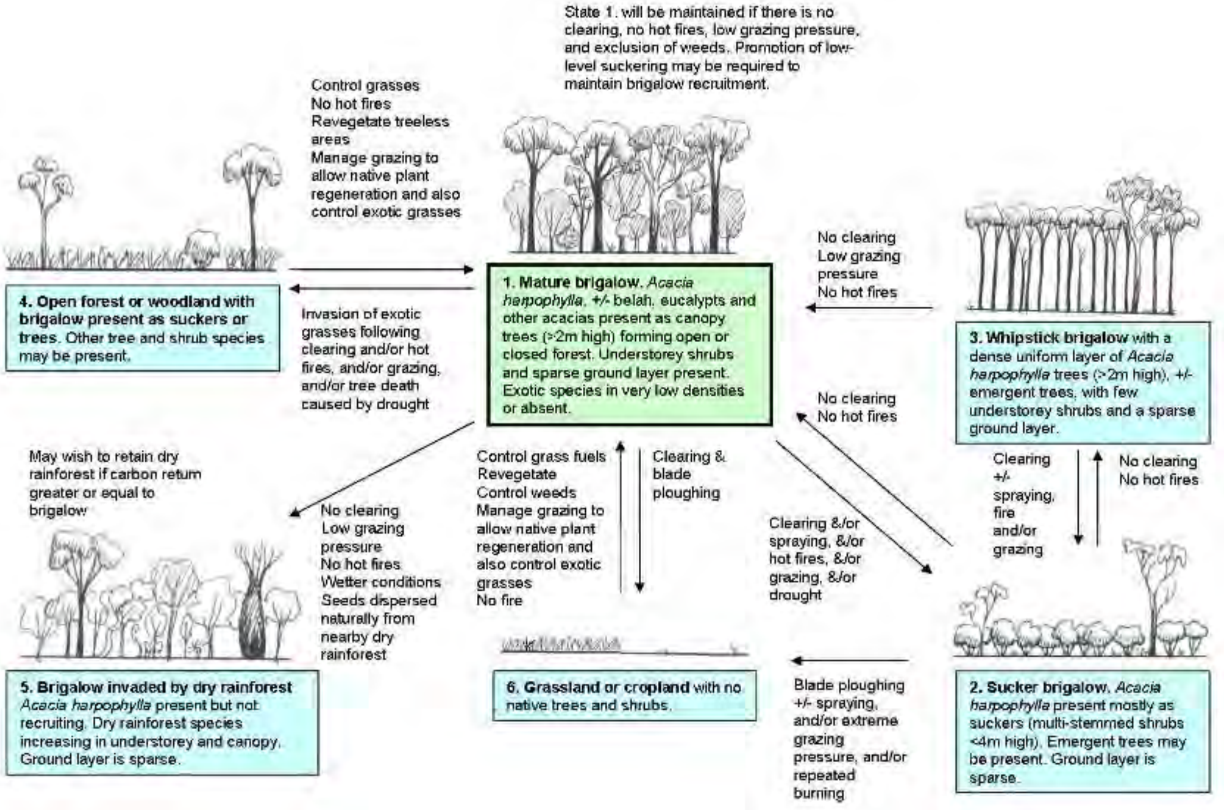


Figure 5: Ecological model for brigalow in Queensland

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 expected to also increase soil carbon stocks. Biomass is directly proportional to carbon, as carbon makes up about 50% of all plant biomass.

Carbon farming might not always mean bringing brigalow back to its full carbon capacity as soon as possible. Some carbon returns might be traded-off against other land-uses, such as livestock grazing, which would limit carbon accumulation rates. Low to moderate levels of livestock grazing appear to be compatible with restoration of brigalow vegetation.

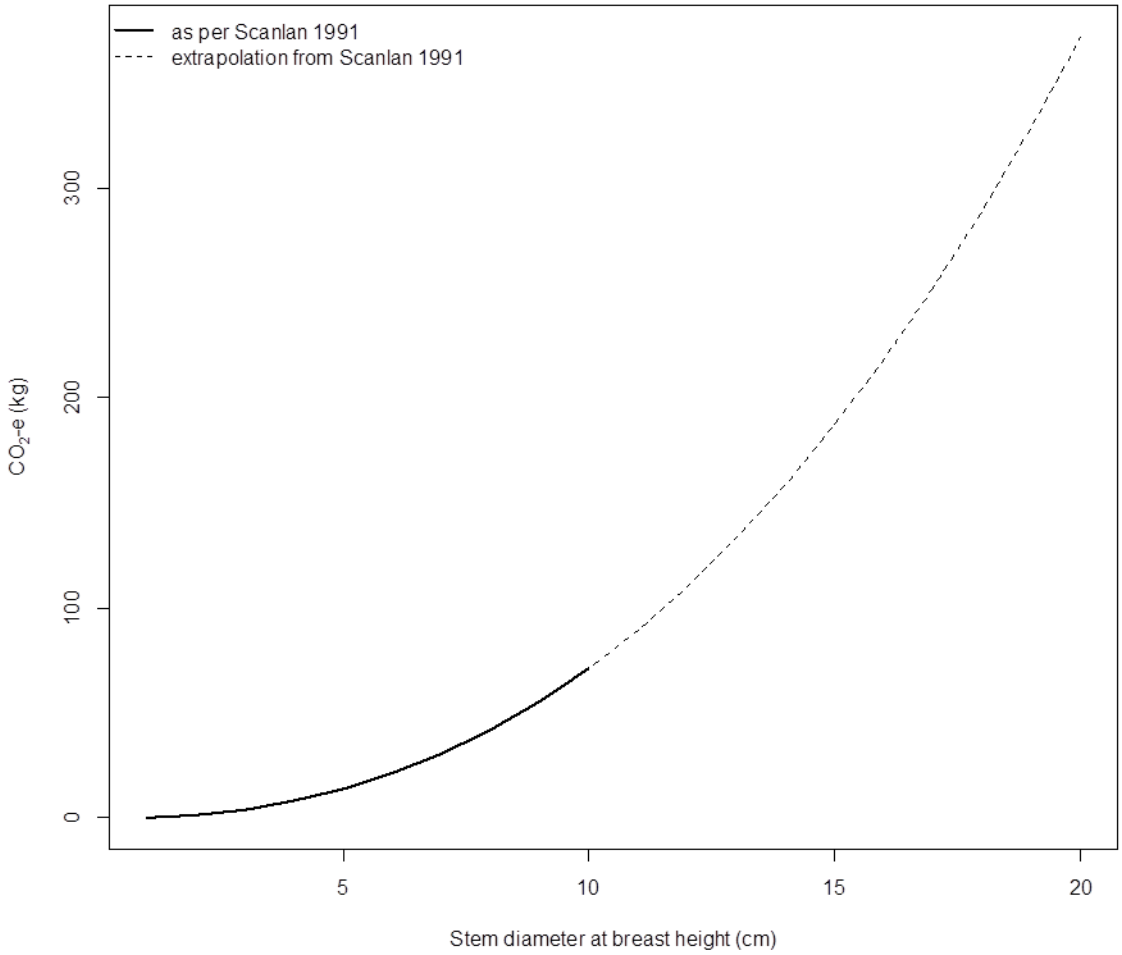


Figure 6: Relationship between above-ground carbon storage and stem diameter for brigalow trees; based on Scanlan 1991

Above-ground carbon in brigalow vegetation is stored in living trees and shrubs, but also in dead standing trees, fallen timber and litter. Estimates of total above-ground biomass (living and dead) for mature brigalow forest in Queensland range from about 100 to just over 250 tonnes (t) ha^{-1} equivalent to 50 to 125 t of carbon per hectare or 180 to 458 tonnes of carbon dioxide equivalent (tCO_2-e) per hectare (Table 1). Living above-ground biomass is estimated to range from 98.9 to 118.8 t ha^{-1} (Table 1, Moore *et al.* 1967; Chandler *et al.* 2007; Dwyer *et al.* 2010a; Ngugi *et al.* 2011). Dead trees and coarse woody debris can therefore hold about as much above-ground carbon as living trees and shrubs in a mature brigalow forest. This stock of carbon in dead wood may take many centuries to accumulate and would be threatened by fire as well as trampling by large domestic stock.

Table 1: Above-ground biomass estimates for mature brigalow vegetation in Queensland with associated site data; figures in brackets are standard errors

Locations	Vegetation	Soil	Average annual rainfall (mm)	Stem density (ha^{-1})	Above-ground live biomass ($t\ ha^{-1}$)	Reference
Hannaford Scientific Reserve, Meandarra, south-central Qld.	Brigalow forest with occasional wilga	Gilgaied deep clay	560	2625	118.8 [live + dead = 252.3]	Moore *et al.* 1967
Bulli State Forest, eastern Darling Downs, Qld.	Open forest of brigalow and belah	Cracking clay with limited gilgai	578	3468 (557.8)	98.9	Chandler *et al.* 2007
Bulli State Forest, eastern Darling Downs, Qld.	Open forest of brigalow and belah	Cracking clay with limited gilgai	600	-	110.3 (26.7)	Dwyer *et al.* 2010a
Brigalow Research Station, 30km NW of Theodore, central Qld.	Open forest of brigalow and other species	Mosaic of loamy duplex soils, loamy earths, and clays	700	1885 (181)	117.2 (10.1)	Ngugi *et al.* 2011

The estimated biomass accumulation rate of brigalow regrowth ranges from 1.3 to 4.6 t ha^{-1} yr^{-1} for living biomass, and from 1.9 to 3.2 t ha^{-1} yr^{-1} for total biomass (living and dead)(Table 2)(Scanlan 1991; Chandler *et al.* 2007; Dwyer *et al.* 2010a). Biomass accumulation rates of 1.9 to 3.2 t ha^{-1} yr^{-1} equate to carbon accumulation of 3.3 to 5.5 t CO_2-e ha^{-1} yr^{-1}.

Table 2: Estimates of biomass accumulation rate for regrowth brigalow vegetation in Queensland, with associated site data

Location	Vegetation	Soil	Average annual rainfall (mm)	Stem density (ha^{-1})	Rate of live biomass gain (t.ha^{-1}yr^{-1})	Time period (years)	Reference
Brigalow Research Station, 30km NW of Theodore, central Qld.	Brigalow and blackbutt woodland. Most of the area cleared & re-pulled at different times	Duplex soil with a sandy-clay loam surface	700	-	1.4	4	Scanlan 1991
				15,000	4.6	10	
				12,350	2.8	15	
Bulli State Forest, eastern Darling Downs, Qld.	Open forest of brigalow and belah	Cracking clay with limited gilgai	578	16,856	2.1	27	Chandler *et al.* 2007
				2,024	1.3	39	
Bulli State Forest, eastern Darling Downs, Qld.	Open forest of brigalow and belah	Cracking clay with limited gilgai	600	1,000-17,000	1.9-3.2 (living and dead, prediction from model)	50	Dwyer *et al.* 2010

Carbon storage and tree size

Table 3: Amounts of above-ground dry matter, carbon and CO_2 equivalent stored in brigalow (*A. harpophylla*) of different diameters: based on Scanlan 1991; dbh = diameter measured at breast height (1.3 m); note figures are approximate only

Tree dbh (cm)	Dry matter (kg)	Carbon (kg)	CO_2 equivalent (kg)
2	0.9	0.4	1.5
10	41.4	19.4	71.3
20	215.9	101.5	372.1

Large trees hold far more carbon than small trees (Table 3) 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 (~20 cm trunk diameter) is approximately equivalent to that held in 254 smaller trees (~2 cm trunk diameters) (Fig. 7).

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

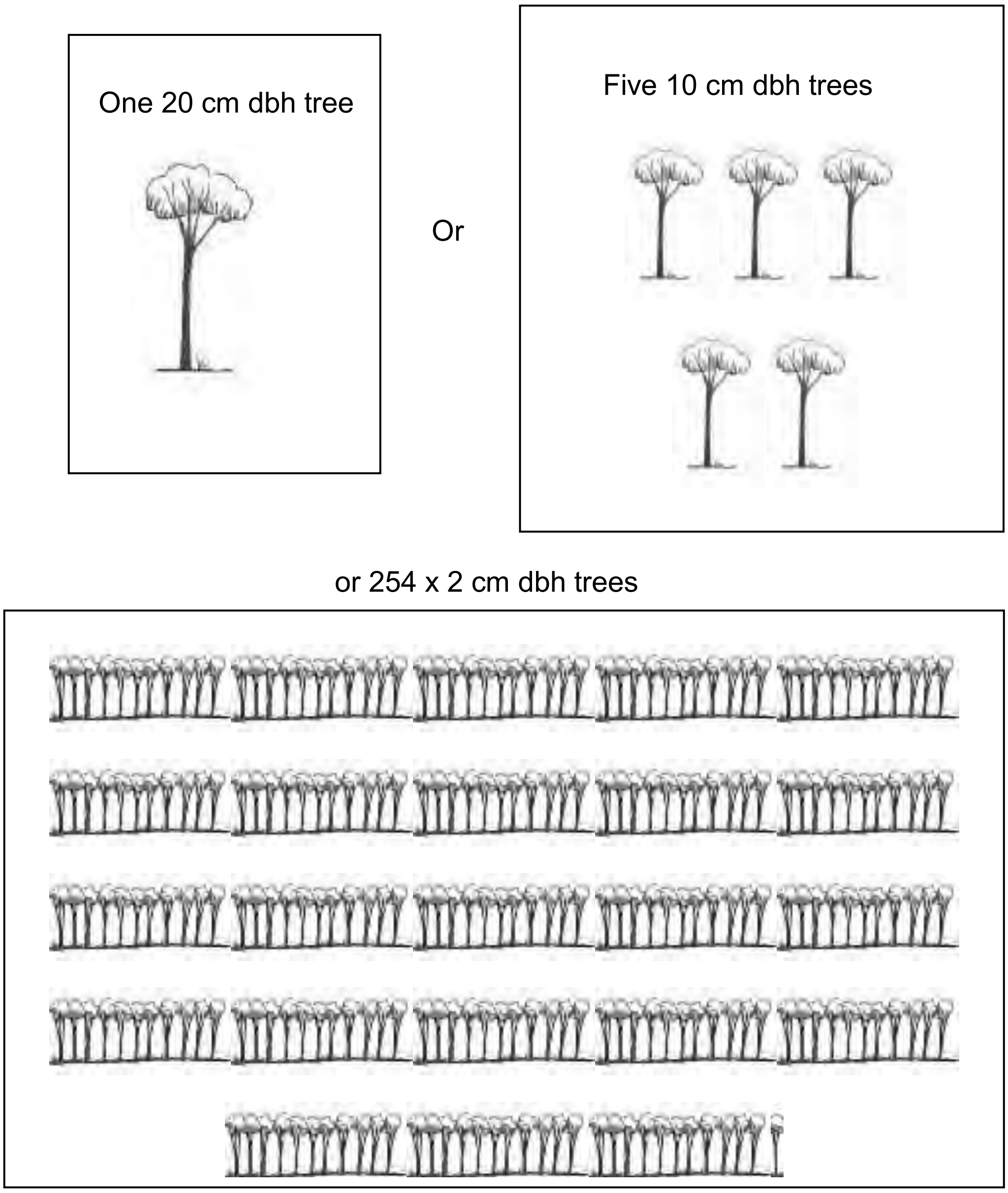


Figure 7: The relative amount of carbon stored in average brigalow trees of different sizes: based on Scanlan 1991; dbh = main stem diameter at 1.3 m height

Trade-offs between trees and pasture

It is important to note that increasing the basal area of trees tends to result in decreased pasture yield. This has been observed for a variety of vegetation types in Queensland, including brigalow (Fig. 8). It should be possible to combine carbon farming of regrowth with livestock production[3], but landholders should consider how increased tree growth may impact on their pasture yield. Retaining blocks or strips of trees within a pastoral paddock may provide opportunities to increase carbon storage while minimising the impact on pastoral productivity (e.g. Bray &Golden 2009; Donaghy *et al.* 2010). Tree strips may provide some pastoral advantages by acting as a windbreak stimulating pastoral production in a zone outside the competitive reach of the tree roots (e.g. McKeon *et al.* 2008).

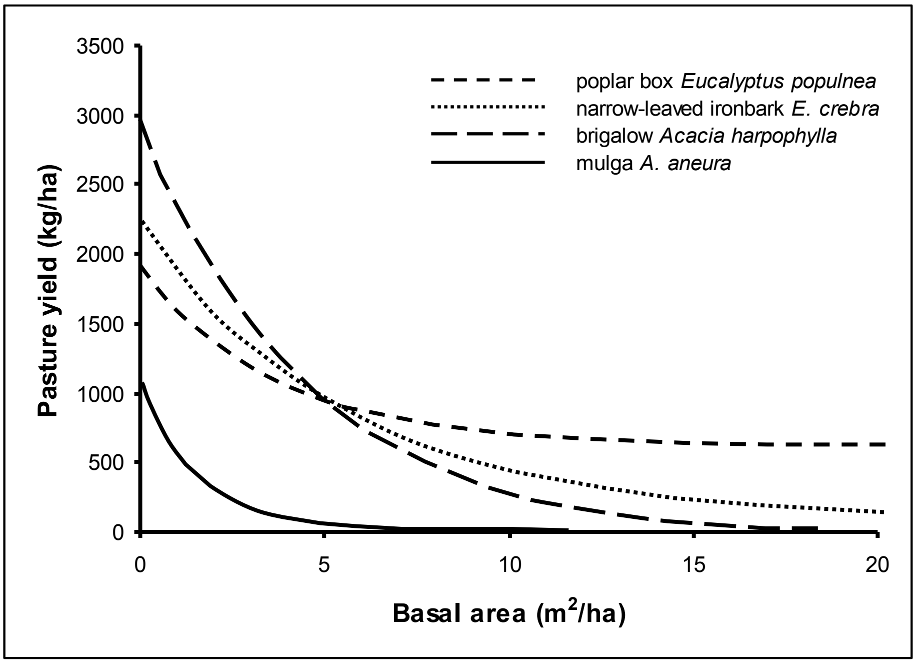


Figure 8: Relationships between tree basal area and pasture yield for a range of woodland tree species from sites in Queensland: redrawn from Burrows 2002; data originally derived from Beale 1973 (*A. aneura*); (Scanlan & Burrows 1990 (E. populnea and *E. crebra*); Scanlan 1991 (A. *harpophylla*)

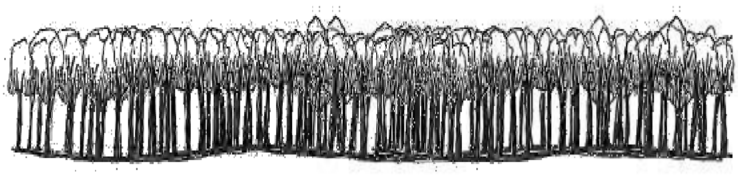
[3] This will depend on the details of the carbon farming or emissions reduction fund methodology being applied

Grow big trees to maximise carbon

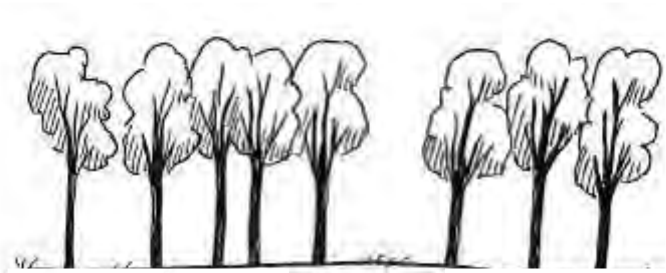
A few big trees can hold far more carbon than a large number of small or medium trees (Fig. 7). So it is in the interests of carbon farming to maximise the height and diameter of existing trees, which may be achieved by reducing tree density in dense regrowth. This may involve the selective thinning of smaller trees, or allowing drought and competition among trees to result in natural rates of tree dieback and thinning.

Pasture yield is still likely to be reduced by increasing tree basal area (Fig. 8), but a few large trees will hold far more carbon than a stand of smaller diameter trees with the same basal area (Fig. 9).

a)



b)



c)

Tree dbh (cm)	Number of trees	Basal area (m_2)	CO_2 equivalent (CO_2-e kg)
2	9549	3	14324
10	382	3	27235
20	96	3	35533

Figure 9: Potential variations in tree size, density and CO_2-e stored for the same basal area: high density of small trees (a) stores less CO_2-e than lower densities of larger trees (b and c); based on Scanlan 1991.

Limits to carbon accumulation

Biomass, and therefore carbon accumulation in brigalow vegetation is limited by rainfall, temperature, competition, clearing, fire and continuous high grazing pressure (Table 4). The total amount of carbon stored by brigalow, and the rate of carbon accumulation, can be maximised by removing these limits where possible.

Table 4: Summary of limits to carbon accumulation for brigalow

Site features	Effect on carbon		Management actions	Effect on carbon	
	Total carbon stored	Rate of carbon gain		Total carbon stored	Rate of carbon gain
 Annual rainfall	↑	↑	 Clearing	↓	↓
 Rainfall seasonality	↓	↓	 Fire	↓	↓
 Maximum summer temperature	↓	↓	 Continuous high grazing pressure	↓	↓
 Competition	↓	↓			

The limits to carbon accumulation in brigalow are:

Rainfall and temperature – Rainfall has a fundamental control on brigalow forest growth and biomass at maturity. Lower or more strongly seasonal rainfall and higher maximum summer temperatures have negative overall effects on biomass accumulation (Dwyer *et al.* 2010b).

Competition – Efforts to control brigalow often result in stands with high stem densities such as ‘whipstick brigalow’ (Johnson 1964) and the apparently slow growth rates of these stands has led to concerns that carbon accumulation rates in brigalow vegetation will be slow when stem densities are high. Thinning has been suggested as a way to lessen the competition between stems and increase the growth rates of high density brigalow stands (Dwyer *et al.* 2009). An experimental study in southern Queensland tested the effect of four thinning treatments (1000, 2000, 4000, and 17,000 stems ha^{-1}) over two years, and then used these results to model brigalow growth over 50 years for seven different stem densities (1000, 2000, 4000, 6000, 8000, 10,000 and 17,000 stems ha^{-1}, Dwyer *et al.* 2010a). The modelled growth rates indicate that stem density does influence the initial rate of biomass accumulation, but the effect may diminish over time (Dwyer *et al.* 2010a). Furthermore, the gain in biomass accumulation from severe thinning treatments (1000 and 2000 stems ha^{-1}) is probably too little to offset losses associated with the thinning action (Dwyer *et al.* 2010a).

However, thinning can also accelerate the development of large trees and a ‘mature structure’ for brigalow, and increases woody plant species diversity, which is beneficial to wildlife conservation (Dwyer *et al.* 2010a).

However, further analysis of these results and other work suggests that lower densities of stems will increase the amount of carbon accumulated in brigalow (Dwyer *et al.* 2009). Dwyer *et al.* (2010b) used data from a landscape survey of 71 sites in central and southern Queensland to model brigalow biomass accumulation over time. The results predict an 81% probability of greater living above-ground biomass in low-density brigalow stands after 53 years. Another study in central Queensland provides some evidence that brigalow regrowth with higher initial stem densities accumulated less aboveground biomass than those with lower densities over a 45 year period (Ngugi *et al.* 2011).

So it is likely that lower stem densities, for example around 5 000 stems per hectare rather than 15 000, will improve the rate of carbon accumulation, or the total carbon stored by brigalow vegetation in the longer term, and there is also some evidence that thinning has benefits for wildlife conservation (this is discussed further in ***Wildlife conservation*** below). However, thinning stem density to less than 2000 stems per hectare is likely to hamper carbon gain. One of the difficulties of thinning brigalow is that the most rapid death of stems tends to produce the most vigorous suckering response (Johnson 1964). So the quickest and easiest methods of removing stems (e.g. by using loppers, a chainsaw, or small machinery, etc.) are likely to be the least effective in producing an overall reduction in stem density. To be effective, thinning has to utilise methods that cause slow stem death (e.g. ringbarking, selective herbicide application) and these are time- and labour-intensive.

However, increases in pasture productivity that can be created by thinning will generally also be an important factor (Scanlan 1991). For example, Bray and Golden (2009) show that retention of strips of regrowth brigalow can make substantial contributions to enterprise scale carbon balance with relatively small impacts on livestock production. But note that moderate to high densities of pasture grasses will probably also reduce the rate of forest carbon accumulation by competing with trees and shrubs for water and other resources.

Clearing – clearing brigalow 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 (moderate to high severity fires, see Department of National Parks, Recreation, Sport and Racing's *Bioregional planned burn guidelines*, http://www.nprsr.qld.gov.au/managing/planned-burn-guidelines.html, 2013) 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 brigalow and other fire-sensitive species. The risk of fire will depend on climate and fuel loads. More dense stands that prevent the development of dense grass swards are expected to reduce the risk of destructive fires. Low-severity burns and/or grazing may be used to reduce the risk of moderate- to high-severity fires where grass fuels are likely to accumulate.

Continuous high grazing pressure – grazing may reduce carbon gain and storage by disturbance to tree and shrub growth and establishment, and by trampling of woody debris and litter. However, grazing may also be helpful in managing fire risks by reducing fine fuels loads. Grazing may also reduce competition from grasses and increase the growth rates of brigalow (R. Johnson *pers. comm.*). Therefore grazing can be compatible with reforestation in brigalow, as long as grazing pressure is held at low to moderate levels, the trampling of litter and woody debris is minimised, and the mortality of mature trees is equal to the recruitment of new trees into the canopy.

Wildlife conservation

Figure 10: Some plant and animal species associated with brigalow; top: Painted honeyeater (Image: G. Chapman); bottom left to right; glossy black-cockatoo (*Calyptorhynchus lathami*) (Image: P. Bostock); brigalow scaly-foot (*Paradelma orientalis*) (Image: DSITIA); the ooline (*Cadellia pentastylis)*; the herb *Xerothamnella herbacea* (Image: D. Butler).

Brigalow vegetation in Queensland supports many different types of native plants and animals, including at least 32 threatened or priority species (Table 5, Figs. 10 & 11). The Brigalow Lands are a significant region for native land snails, containing at least 132 species, including 79 endemics (Stanisic 1998). At least 23 native species of land snail have been collected from brigalow vegetation (Stanisic 1998). Sixteen of Queensland's regional ecosystems, where brigalow is a dominant or co-dominant tree, have also been listed as an endangered ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Butler 2008) due to reduction in their extent caused by clearing (Department of Sustainability, Environment, Water, Population and Communities 2010).

Most management actions that will accumulate carbon in brigalow such as avoiding continuous high levels of grazing pressure, not clearing vegetation and excluding fire will also benefit wildlife. Habitat features that will help to conserve wildlife in brigalow include different types of shelter for wildlife, a good and varied supply of food, 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 11: The bridled nailtail wallaby once widespread throughout eastern Australia now persists in only two locations in central Queensland and appears to prefer the transitional vegetation between brigalow forest and grassy eucalypt woodland (Lundie-Jenkins & Lowry 2005)(Image:DSITIA).

Table 5: Species that frequently or primarily occur in the brigalow ecological community and are listed as endangered (E), vulnerable (V) or near threatened (NT) in Queensland or Australia, or as priority species for conservation work in Queensland under the *Back on Track Species Prioritisation Framework* (High or Critical BOT). 5a) Plants; Cook *et al.* 2006; Butler 2008; Eastwood *et al.* 2008; WildNet Database, Department of Science, Information Technology, Innovation and the Arts, Queensland

Scientific name	Common name	Status	Notes
Plants			
Aponogeton queenslandicus		E (QLD)	Aquatic plant that grows in Gilgai wetlands in brigalow.
Cadellia pentastylis	Ooline	V (AUST & QLD), Critical (BOT)	Large tree often associated with dry rainforest but also grows in brigalow.
Capparis humistrata		E (QLD)	Grows on the edges of brigalow forests near Rockhampton.
Dichanthium setosum		V (AUST), NT (QLD)	
Eucalyptus argophloia	Chinchilla white gum	V (AUST & QLD), Critical (BOT)	An emergent in brigalow and belah forests near Chinchilla.
Homopholis belsonii	Belson's panic	V (AUST), E (QLD)	A grass in brigalow and associated box woodlands on the Darling Downs and Moree plain.
Paspalidium scabrifolium		NT (QLD)	
Rutidosis lanata		E (QLD)	A daisy known between Jackson and Westmar on the Western Darling Downs.
Solanum adenophorum		E (QLD), High (BOT)	A "bush tomato" favouring brigalow country in the Dingo-Nebo-Clermont area.
Animals			
Acanthophis antarcticus	common death adder	NT (QLD)	

Scientific name	Common name	Status	Notes
Anomalopus brevicollis	short-necked worm-skink	High (BOT)	
Aspidites ramsayi	Woma	NT (QLD), High (BOT)	
Calyptorhynchus lathami lathami	glossy black-cockatoo (eastern)	V (QLD), High (BOT)	Feeds exclusively on *Casuarina / Allocasuarina* seeds (including belah and bull-oak), favours mature trees.
Chalinolobus picatus	little pied bat	NT (QLD)	Roosts in tree hollows, caves, rock shelters and disused mines by day. Forages in a variety of dry open forest and woodland types including brigalow.
Cyclorana verrucosa	rough frog	NT (QLD)	
Delma inornata		High (BOT)	
Delma torquata	collared delma	V (AUST&QLD), High (BOT)	A cryptic species with scattered populations in a variety of vegetation types in the Brigalow Belt.
Denisonia maculata	ornamental snake	V (AUST&QLD)	A specialist of low-lying, seasonally flooded areas, including brigalow-belah forests. Endemic to the Brigalow Belt, mainly in the Dawson and Fitzroy catchments.
Egernia rugosa	yakka skink	V (AUST&QLD)	Occurs in isolated populations from southern Cape York to southern Queensland.
Furina dunmalli	Dunmall's snake	V (AUST&QLD)	Uses fallen timber for habitat in brigalow and other woodland types. Distributed from Yeppoon to Inglewood in southern Qld.
Geophaps scripta scripta	squatter pigeon (southern)	V (AUST&QLD)	
Grantiella picta	painted honey-eater	V (QLD), High (BOT)	In Qld, brigalow/belah is used as nesting habitat during Oct-Dec, coinciding with flowering of mistletoes in the brigalow trees.
Hemiaspis damelii	grey snake	E (QLD)	Inhabits floodplains and low-lying areas on heavy soils, including brigalow-belah.
Jalmenus eubulus	pale imperial hairstreak butterfly	V (QLD)	Restricted to brigalow-dominated old-growth forests and woodlands.
Kerivoula papuensis	golden-tipped bat	NT (QLD)	More a specialist of eastern rainforests and wet forests, this species only creeps into the eastern edge of the Brigalow Belt via brigalow scrubs and more densely vegetated riparian zones.
Nyctophilus timoriensis	eastern long-eared bat	V (AUST & QLD)	Found in brigalow, but almost certainly requires eucalypts for at least part of its roosting.
Onychogalea fraenata	bridled nailtail wallaby	E (AUST&QLD), Critical (BOT)	Occurs in brigalow, open eucalypt forests and woodlands.
Paradelma orientalis	brigalow scaly-foot	V (AUST&QLD)	Also occurs in other vegetation types but relatively common in brigalow.
Strophurus taenicauda	golden-tailed gecko	NT (QLD)	
Turnix melanogaster	black-breasted button-quail	V (AUST&QLD), Critical (BOT)	Mainly an SEQ species that just spills over into the brigalow scrubs in the east of the Brigalow Belt bioregion.

Limits to wildlife conservation in brigalow

Table 6: Summary of limits to wildlife conservation in brigalow

Limits to wildlife conservation	Effect on wildlife: Total number of species	Effect on wildlife: Total number of individuals	Limits to wildlife conservation	Effect on wildlife: Total number of species	Effect on wildlife: Total number of individuals
Range of shelter options e.g. large trees, tree hollows, fallen timber, shrubs, rocks	↑	↑	 **Stem density**	⇕	⇕
Good supply of food e.g. insects, nectar, pollen, seeds, leaves, small animals	↑	↑	 **Clearing**	↓	↓
Landscape features Large patch size, small edge-to-area ratio, close to other patches	↑	↑	 **Fire**	↓	↓
Competitors and predators e.g. weeds, feral animals, aggressive native animals	↓	↓	 **Grazing pressure**	↓	↓

Shelter and food

Trees and shrubs

Trees and shrubs provide nesting, shelter and feeding sites for many animals, including brigalow bird species that forage mainly on the foliage of shrubs and trees (e.g. the glossy black-cockatoo that feeds on the seeds of belah which is often associated with brigalow; Butler 2008). 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 important nesting and foraging sites for small birds (Barrett 2000).

It is important for woodlands to have a variety of tree/shrub size and age classes including dead standing and fallen, as these will provide different resources for wildlife. For example, the pale imperial hairstreak, the only species of butterfly endemic to the Brigalow Belt, needs both young and mature brigalow plants to complete its lifecycle. It breeds in old-growth brigalow, and its caterpillars only feed on small understorey plants of *A. harpophylla* (Eastwood *et al.* 2008). A study in the temperate eucalypt 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).

In southern Queensland, some bird species were associated more strongly with mature brigalow forest (e.g. the white-throated treecreeper), with others appearing to prefer old brigalow regrowth (e.g. the rufous whistler, grey fantail and yellow thornbill; Bowen *et al.* 2009). This suggests that more bird species will be supported if a range of vegetation growth types are represented in a given farmland area.

Brigalow vegetation is naturally dense relative to many other semi-arid vegetation types and provides important habitat for animals such as the black-striped wallaby (*Macropus dorsalis*) and brush turkey (*Alectura lathami*; Cook *et al.* 2006). Remnant brigalow and softwood scrubs are important stopovers for small migratory birds including the yellow robin, grey and rufous fantails, and varied trillers (Cook *et al.* 2006). Yellowwood (*Terminalia oblongata*), a common shrub in northern brigalow, is an important food source of the brown awl butterfly *Badamia exclamationis*, prior to its northward migration in late summer (Valentine 2004). Even though this species is not threatened with extinction, the number of butterflies making the migration has suffered a massive decline (Valentine 2004), and increasing the amount of vegetation containing yellowwood may see the return of mass migrations of this butterfly.

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). Brigalow and belah trees develop deep crevices and cracks, rather than hollows, but these are used in a similar way by animals. Eucalypts that form hollows like the poplar box may also be present in some stands of brigalow. Animals that use tree hollows in brigalow vegetation include bats such as the little pied bat, gliders like sugar and squirrel gliders, birds including the glossy black-cockatoo and owlet-nightjar, and reptiles such as the golden-tailed gecko (Drury 2001; Cook *et al.* 2006; Butler 2008; Richardson 2008). By retaining large, old and dead standing trees which are more likely to contain or form hollows you can provide valuable housing for wildlife. Nest boxes can be provided if hollows are absent or scarce.

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, and treecreepers and thornbills often collect insects from fallen timber or the ground nearby (MacNally *et al.* 2001). Many brigalow reptiles use fallen timber as shelter including Dunmall's snake, the short-necked worm-skink, yakka skink, golden-tailed gecko, brigalow scaly-foot, ornamental snake and the woma python (Drury 2001; Richardson 2008).

It can be tempting to collect fallen timber for firewood, or just to 'clean-up', but leaving it in place will help to retain water and nutrients in brigalow, and provide shelter 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). The abundance of mistletoe had a strong influence on the species richness and abundance of woodland birds in brigalow vegetation in southern Queensland, and was particularly important for the mistletoe bird and painted honeyeater (Bowen *et al.* 2009). A breeding population of the nomadic painted honeyeater was observed in brigalow vegetation in northern New South Wales, feeding on the flowers and fruit of pale-leaf mistletoes (*Amyema maidenii*) which were parasitic on brigalow and *Acacia oswaldii* (Oliver *et al.* 2003). The vegetation frequented by the honeyeaters contained significantly more mature trees, greater canopy cover, and more mistletoes than areas that were not visited (Oliver *et al.* 2003).

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). Many brigalow reptiles use rocks or rocky areas for shelter, including the collared delma, short-necked worm-skink, brigalow scaly-foot and yakka skink (Drury 2001; Richardson 2008). Some plant species may only be found in association with rocky areas.

Leaf litter

Litter like fallen leaves, bark and twigs provides shelter, nesting sites, and foraging sites for many invertebrates, birds, reptiles and small mammals. In brigalow vegetation, leaf litter is used as shelter by the common death adder, short-necked worm-skink and Dunmall's snake (Drury 2001; Richardson 2008).

Gilgais

Brigalow often occurs in landscapes with characteristic depressions known as gilgais or melonholes. These depressions become waterlogged after rain and attract many types of waterbirds. They provide a unique habitat for a range of plant species including the waterplant *Aponogeton queenslandicus* and the bush tomato *Solanum adenophorum*. Gilgais can also be prolific breeding sites for frogs, which are the diet of the threatened ornamental snake *Denisonia maculata,* which is endemic to central Queensland (Cook *et al.* 2006).

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, and 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 like truffles, and many fungi also have symbiotic relationships with native plants (Claridge & May 1994). It is not known how abundant or diverse such fungi are in brigalow vegetation, or how important they are as a food source to animals, or as symbionts of plants. Research is needed to better understand the importance of fungi for wildlife conservation in brigalow, and if significant, how to best manage this resource.

Landscape features

Large patch size

Small patches of habitat may be able to support populations of some plant and animal species (e.g. 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). Damage to the edges of habitat patches can lead to shrinkage in patch size over time, so it is important to protect edges from threats such as fire and pesticide spray drift (McAlpine *et al.* 2011).

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). Long and thin patches of brigalow surrounded by bulky exotic grasses also face an increased risk of hot fires2, and this has already caused extensive degradation to some roadside brigalow remnants (Butler 2008).

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 brigalow vegetation like the koala, brush-tailed phascogale, yellow-bellied glider, squirrel glider, sugar glider, greater glider and feathertail glider are dependent on trees for food and shelter, and movement across open ground is very hazardous for these species (Cook *et al.* 2006). 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 remnant 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. The amount of brigalow forest in the landscape had an important positive influence on bird species richness in southern Queensland (Bowen *et al.* 2009).

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). Introduced pasture grasses, including buffel grass (*Cenchrus ciliaris*) and green panic (*Panicum maximum* var. *trichoglume*), are the most serious environmental weeds in brigalow vegetation, because they create high fuel loads and increase the risk of hot fires2. Even low densities of buffel grass were found to have a detectable negative association with native ground vegetation, birds and ants (Smyth *et al.* 2009). Plant species richness and diversity were lower in brigalow sites that had been cleared and sown with exotic pasture, primarily buffel grass (Fairfax & Fensham 2000). Buffel grass had a negative impact on the recruitment and growth of many native plant species in poplar box woodlands (Franks 2002; Butler 2008).

Other weeds of brigalow vegetation include mother of millions (*Bryophyllum delagoense*), velvet tree pear (*Opuntia tomentosa*), harrissa cactus (*Eriocereus bonplandii*) and parthenium (*Parthenium hysterophorus*)(Butler 2008) but these will only impact on wildlife if infestations are extreme (Cook *et al.* 2006). These weeds can be controlled by chemical and biological controls and grazing management in the case of parthenium (Cook *et al.* 2006).

The feral pig is probably the most serious animal pest in brigalow vegetation, although cats, foxes and goats also threaten native plants and animals (Butler 2008) through predation, competition and the spread of disease.

Aggressive native species

Noisy miners and yellow-throated miners are large, aggressive honeyeaters found throughout much of Queensland. The density or presence of miners has been consistently negatively correlated with the richness, abundance and assemblage composition of woodland birds in eastern Australia (Maron *et al.* 2011), and the noisy miner appears to be the only large-bodied bird species that depresses the occurrence of small-bodied bird species over a range of districts from Victoria to Queensland (MacNally *et al.* 2012). The abundance of noisy and yellow-throated miners had a strong negative influence on the species richness of canopy insect-eating birds, and on the abundance of the rufous whistler and singing honeyeater (Bowen *et al.* 2009). Miners are more abundant in highly fragmented patches of brigalow, and are rarely found in large intact patches of brigalow in good condition with naturally high densities of understorey shrubs (T. Eyre *pers. comm.*). This means that increasing the size and condition of brigalow patches will help to exclude miners, and provide a more suitable habitat for small birds (T. Eyre *pers. comm.*).

Stem density

Efforts to control brigalow often result in stands with high stem densities known as ‘whipstick brigalow’ (Johnson 1964) which have low plant species diversity, and a markedly different structure to mature brigalow. The apparently slow growth rates of these stands has led to concerns that large trees, and their associated features that are important to wildlife like hollows, mistletoe and large amounts of fallen timber and litter will take many years to develop, limiting the conservation value of these stands. Thinning has been suggested as a way to lessen the competition between stems and increase the conservation value of high density brigalow stands (Dwyer *et al.* 2009).

An experimental study of ‘restoration’ thinning of brigalow tested the effect of four thinning treatments (1000, 2000, 4000, and 17,000 stems ha^{-1}) over two years (Dwyer *et al.* 2010a). The study found that woody plant diversity and density was higher in the thinned treatments two years after thinning, and the growth rates of stems was also higher in the thinned treatments than the control (Dwyer *et al.* 2010a). This suggests that thinning accelerates the development of large trees and a ‘mature structure’ for brigalow, and increases woody plant species diversity, which is beneficial to wildlife conservation (Dwyer *et al.* 2010a).

One of the difficulties of thinning brigalow is that the most rapid death of stems tends to produce the most vigorous suckering response (Johnson 1964). So, the quickest and easiest methods of removing stems for example, by using loppers, a chainsaw, or small bulldozer, and so forth, are likely to be the least effective in producing an overall reduction in stem density. To be effective, thinning has to utilise methods that cause slow stem death such as ringbarking or selective herbicide application, and these are time and labour intensive. So, more evidence is needed to strengthen the case for the benefits of restoration thinning of brigalow, especially given the time and effort needed to do this effectively on a large scale.

Another complication is that some species like woodland birds benefit from high stem densities, because this type of habitat affords protection from aggressive noisy miners (see above). So having some patches of brigalow with dense stems may be important for the conservation of wildlife.

Grazing pressure

Grazing pressure by stock, feral and native animals can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of brigalow, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber (Butler 2008). Cattle often use patches of brigalow for shade, and while doing so also tend to selectively graze palatable plant species, facilitate the spread of buffel grass and increase soil compaction (Cook *et al.* 2006). Chandler *et al.* (2007) suggested that preferential grazing of belah (*Casuarina cristata* which is more palatable than *A. harpophylla*) may have resulted in lower densities of belah in a stand of regrowth brigalow in southern Queensland. Plant species that are dependent on gilgais are also particularly vulnerable to grazing (Cook *et al.* 2006). It has been suggested that grazing can also increase the wildlife values of brigalow if it is used strategically to control buffel grass (Butler & Fairfax 2003), and grazing can also increase the growth rate of brigalow by reducing competition from grasses (R. Johnson *pers. comm.*). However, there are concerns that the level of grazing required to control buffel grass may be just as destructive to wildlife as the buffel grass itself. More trials are needed to assess the effectiveness and any negative impacts of this method.

Clearing

Clearing destroys many plant species and also removes the food and shelter of animals that depend on trees and shrubs (Collard *et al.* 2009). Animals which have little or no capacity for dispersal, such as the many species of land snails which occur in brigalow, are severely impacted by land clearing (Stanisic 1998).

Plant species richness and diversity was substantially higher on uncleared brigalow sites compared to cleared sites with exotic pasture (Fairfax & Fensham 2000). The species richness of herbaceous plants was also found to be higher in brigalow remnants than in grassland or cultivated land from which brigalow had been cleared (Collard *et al.* 2011). If the vegetation is allowed to regrow, the species richness of woody plants increases with time following clearing (Bradley *et al.* 2010). The cover of trees, herbs and litter in brigalow was also found to increase with years since clearing (Bradley *et al.* 2010). There is some evidence that more effort is required to restore brigalow to its 'remnant' or 'mature' structure and species composition if it has been 'pulled' once or repeatedly than if it has been cleared by less severe means such as ringbarking (Chandler *et al.* 2007).

Fire

Many brigalow plant species have limited capacity to resprout after hot fires2, and, as discussed above, fire destroys features such as litter, fallen timber and hollows which are important for many animal species (Butler 2008). Fire is a major threat to the many species of land snails which are associated with brigalow (Stanisic 1998). High densities of grass, such as buffel grass, can increase the frequency and intensity of fire in acacia woodlands by increasing ground fuel loads (Butler & Fairfax 2003; Franks 2002), and this can have negative impacts on birds. Many bird species rely on long-unburnt vegetation, therefore the protection of long-unburnt areas is recommended for bird conservation in acacia woodlands including brigalow (Woinarski 1999). Therefore the most appropriate fire regime for brigalow stands is fire-exclusion (Butler 2008). However, if fine fuels (e.g. grasses) are present in a regenerating brigalow stand, low severity fires may also be used to reduce fine fuels, and in this way reduce the incidence and severity of wildfires (Department of National Parks, Recreation, Sport and Racing 2013).

General fire guidelines for maintaining the overall biodiversity of regional ecosystems are provided in the Regional Ecosystem Description Database (REDD; Queensland Herbarium 2011). The Department of National Parks, Recreation, Sport and Racing's bioregional planned burn guidelines also provide advice on managing fire in native vegetation (http://www.nprsr.qld.gov.au/managing/planned-burn-guidelines.html, 2013).

Table 7: Habitat values for selected brigalow species

		Tree hollows, cracks & crevices	Fallen timber	Trees & shrubs	Gilgais	Litter	Mistletoe	Rocks	Insects
Mammals									
little pied bat	*Chalinolobus picatus*	✓		✓					✓
sugar glider	*Petaurus breviceps*	✓		✓					✓
bridled nailtail wallaby	*Onychogalea fraenata*		✓	✓					
Birds									
painted honey eater	*Grantiella picta*			✓			✓		✓

		Tree hollows, cracks & crevices	Fallen timber	Trees & shrubs	Gilgais	Litter	Mistletoe	Rocks	Insects
glossy black-cockatoo (eastern)	*Calyptorhynchus lathami lathami*	✓		✓					
white-throated treecreeper	*Cormobates leucophaea*	✓		✓					✓
rufous whistler	*Pachycephala rufiventris*			✓					✓
grey fantail	*Rhipidura albiscapa*		✓	✓					✓
Reptiles									
short-necked worm-skink	*Anomalopus brevicollis*		✓			✓		✓	
common death adder	*Acanthophis antarcticus*					✓			
ornamental snake	*Denisonia maculata*		✓		✓				
yakka skink	*Egernia rugosa*		✓					✓	
Dunmall's snake	*Furina dunmalli*		✓			✓			
brigalow scaly-foot	*Paradelma orientalis*		✓					✓	
golden-tailed gecko	*Strophurus taenicauda*	✓	✓	✓					
Frogs			✓	✓	✓	✓			✓
Insects		✓	✓	✓	✓	✓	✓	✓	✓
Pale imperial hairstreak butterfly	*Jalmenus eubulus*			✓					✓
Brown awl butterfly	*Badamia exclamationis*			✓					

Management actions

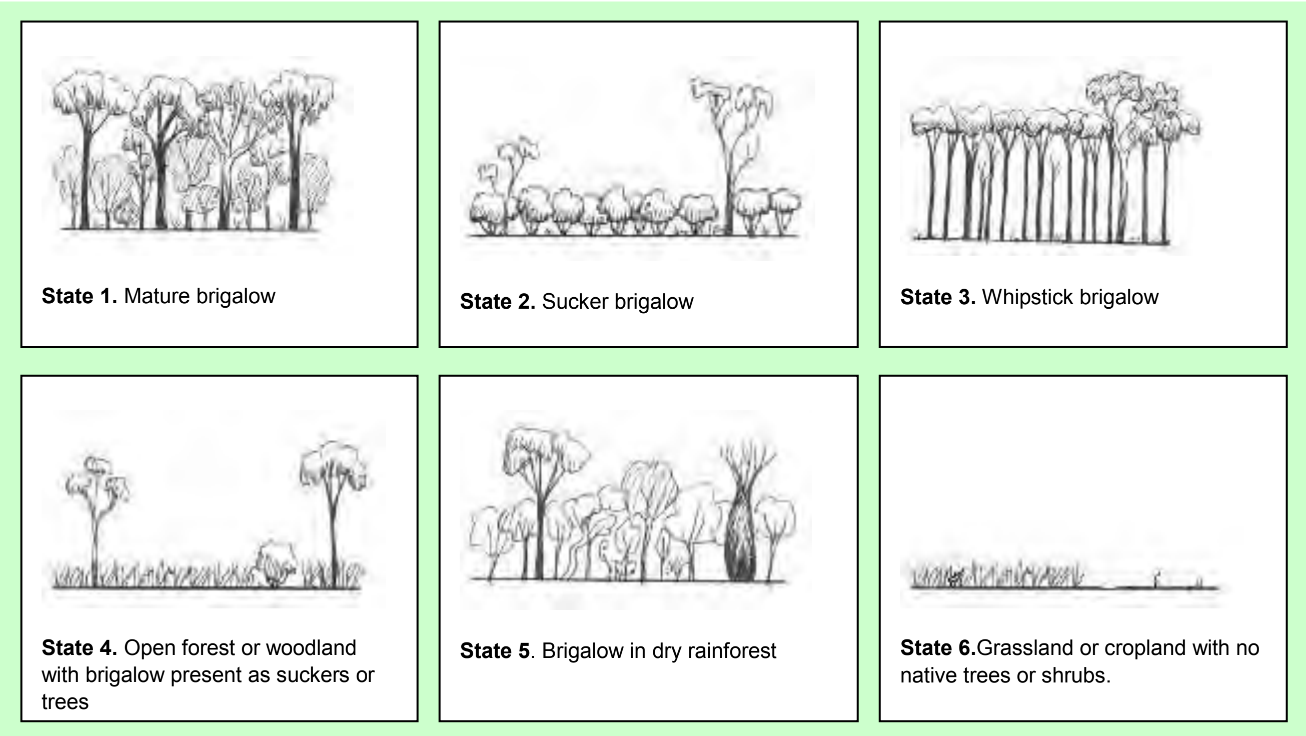


Figure 12: Brigalow condition states which feature in the brigalow ecological model (Fig. 5)

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. Brigalow landscapes are currently found in one of six conditions or states (Fig. 12), and the main management issues vary among some states (Table 8).

To **maximise carbon** by restoring the site to State 1, the management aims for all states are:

- Maximise the height and diameter of existing trees within the productivity constraints of the site, e.g. brigalow communities in the east are notably taller and have larger diameters than those in the west.
- Increase the density of large trees including brigalow, belah, eucalypts and other species to reach the typical tree density for the vegetation type. Alternatively, managers can choose a lower target tree density, but this will prevent the site reaching its maximum carbon state.
- Ensure that the recruitment of new trees into the canopy is adequate to replace losses from mortality of large trees, by allowing seedlings, suckers and saplings to develop into trees.

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

- Avoid actions that kill or injure wildlife such as clearing and fire
- Provide a range of shelter options and food resources for wildlife
- Manage fire and grazing to allow ongoing recruitment of all plant species
- Protect and restore landscape features that support wildlife

- Control competitors and predators that threaten wildlife like feral animals, weeds, and aggressive honeyeaters.

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

To determine which actions apply to your site:

1. Identify the condition state of your site by referring to Fig. 12.
2. Select whether your goal is farming carbon, conserving wildlife, or both.
3. Compile a list of actions from Table 9 (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 Department of National Parks, Recreation, Sport and Racing’s bioregional planned burn guidelines (2013).

Table 8: The main management issues for each condition state for brigalow. Condition states 1, 2, 3 and 5 have been grouped because their management actions are the same

Condition state	Description	Main management issue
1, 2, 3 & 5	Native trees and shrubs present, dense pasture grass absent	Areas in these states should require little intervention to sustain or increase their carbon stocks.
4	Native trees and shrubs, and dense pasture grass present.	Management of pasture grasses and fire will be needed to maintain and increase carbon stocks.
6	Native trees and shrubs absent; dense pasture grass may be present or absent.	Seed sources for trees and shrubs (and perhaps suckers for brigalow) will be critical to restoration of carbon stocks from the grassland or cropland state.

Table 9: Management actions for restoring and maintaining brigalow 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; condition states 1, 2, 3 and 5 have been grouped because their management actions are the same

Action	Benefits	Carbon	Wildlife	Condition state/s		
				1,2,3,5	4	6
Clearing and thinning						
1. No clearing of live trees and shrubs**.**	• Clearing brigalow 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, such as the many species of land snails which occur in brigalow, are severely impacted by land clearing.	↑	↑	✓	✓	
2. Retain dead standing trees and shrubs, and fallen timber. Minimise or avoid collection for firewood or 'cleaning-up'**.**	• Dead trees and fallen timber contribute to the amount of carbon stored. • Dead trees (especially those with hollows) and fallen timber are important shelter and foraging sites for wildlife.	↑	↑	✓	✓	✓
3. Encourage the growth and survival of large trees**.**	• Healthy, large trees make a substantial contribution to the amount of carbon stored. • Large trees are more likely to contain and form hollows, provide shelter and foraging sites for wildlife, and they can take a very long time to replace.	↑	↑	✓	✓	✓
4. Selectively thin brigalow when stem densities are very high (e.g.	• It is likely that thinning will improve the rate of carbon accumulation in dense stands, though it may	↑	↑	✓		

Action	Benefits	Carbon	Wildlife	Condition state/s		
				1,2,3,5	4	6
>10 000 stems per hectare).	not increase the total carbon stored by brigalow vegetation in the longer term. • Effective, thinning of brigalow requires methods that are time and labour intensive. • Thinning brigalow appears to benefit wildlife by hastening the growth of large trees, and increasing the species diversity of woody plants.					
Fire						
5. Prevent and suppress moderate- to high-severity fire in the brigalow area to be restored.	• 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 grass fuel loads are likely to build up in the brigalow area 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 brigalow and other fire-sensitive species. 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**). • May have negative impacts on small relatively immobile species such as insects and land snails, but these are preferable to the larger impacts of more extensive and severe hot fires on wildlife.	↑	↑	✓	✓	✓
7. Conduct low severity burns, when soil moisture is high, in the	• Reduces the risk of fire in the area to be restored (see **5**).	↑	↑	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s		
				1,2,3,5	4	6
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.						
8. Use grazing management to reduce high fuel loads in the brigalow area to be restored. 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**).	↑	↑	✓	✓	✓
9. 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 **5**).	↑	↑	✓	✓	✓
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. Manage grazing to allow tree recruitment to reach or maintain the tree density required. For example, to maintain tree density, the mortality of mature trees needs to be equal to the	• 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	↑	↑	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s		
				1,2,3,5	4	6
recruitment of new trees into the canopy.).	recruitment and growth of brigalow, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.					
12. 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 brigalow, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓
Site preparation and plant establishment						
13. Use slashing or low severity fire to reduce the cover of herbaceous plants before direct seeding or tube stock / sucker planting.	• Improves the establishment and growth of woody plants by reducing competition.	↑	↑		✓	✓
14. Revegetate treeless areas with native trees and shrubs especially brigalow, eucalypts and belah using direct seeding or tube stock. If brigalow seed or tube stock is scarce, try transplanting small suckers.	• 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.	↑	↑		✓	✓
15. 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.		↑		✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s		
				1,2,3,5	4	6
16. If new brigalow plants are slow to establish via natural regeneration use shallow mechanical disturbance of soil like disc ploughing or abrupt mechanical disturbance of trunks, when soil moisture is low, to promote brigalow suckering.	• 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.	↑	↑		✓	
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.	• 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, approximately April), and then applying herbicide when it resprouts. Hand-pulling or grubbing is also an effective (but highly labour intensive) method of control. Aim to get canopy shading by trees and shrubs for long-term buffel grass control.	• 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/s		
				1,2,3,5	4	6
19. Encourage dense growth of native trees and shrubs on site edges to suppress the growth of grasses. Mechanical disturbance of soil around brigalow plants such as disc ploughing or abrupt mechanical disturbance to standing brigalow trunks when soil moisture is low may promote suckering and high densities of brigalow stems.	• 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	• 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 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 brigalow where these are having a negative impact on wildlife and plant regeneration.	• The feral pig is probably the most serious animal pest in brigalow vegetation, although cats, foxes and goats also threaten native plants and animals through predation, competition and spreading disease. • Management actions that have adverse effects on		🡑	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s		
				1,2,3,5	4	6
	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.		↑	✓	✓	✓
23. Reduce numbers of aggressive honeyeaters like noisy miners and yellow-throated miners where these are having a negative impact on wildlife by modifying habitat.	• Miners can have a strong negative influence on the abundance and species richness of other native birds. • Direct control of miners is not recommended. • Increasing the size of brigalow patches, and the density of understorey shrubs, will help to exclude miners, 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. Provide nest boxes if hollows are scarce	• Tree hollows provide important shelter and foraging sites for wildlife.		↑	✓	✓	✓
26. Encourage the establishment and growth of yellowwood (*Terminalia oblongata*) north from about Springsure to Biloela.	• Increasing the amount of vegetation containing yellowwood is likely to increase populations of the brown awl butterfly *Badamia exclamationis.*		↑	✓	✓	✓
27. Retain and protect mistletoe on brigalow and other woody plant species.	• Mistletoe provides nectar, berries and nesting sites for many animal species, including the threatened painted honeyeater.		↑	✓	✓	
28. Retain and protect rocks and rock outcrops.	• Many threatened brigalow reptiles use rocks or rocky areas for shelter, including the collared		↑	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s		
				1,2,3,5	4	6
	delma, short-necked worm-skink, brigalow scaly-foot and yakka skink. • Some plant species may only be found in association with rocky areas. • Rocky areas provide habitat for invertebrates.					
29. Retain and protect leaf litter (including fallen leaves, bark and twigs).	• In brigalow vegetation, leaf litter is used as shelter by several threatened reptile species like the common death adder, short-necked worm-skink and Dunmall's snake and provides habitat for invertebrates.		↑	✓	✓	✓
30. Retain and protect gilgais (melon holes).	• Gilgais in brigalow vegetation attract waterbirds, and provide a unique habitat for a range of plant species including the waterplant *Aponogeton queenslandicus* and the bush tomato *Solanum adenophorum*. • Gilgais can also be prolific breeding sites for frogs, which are the diet of the threatened ornamental snake *Denisonia maculata,* which is endemic to central Queensland.		↑	✓	✓	✓
31. Minimise or avoid the use of insecticides in brigalow areas to be restored, and prevent spray drift from adjacent areas.	• Invertebrates deserve protection in their own right, but also provide food for other animals, and ecosystem services such as pollination and seed dispersal.		↑	✓	✓	✓
Other considerations						
32. Rainfall will have a large bearing on the success of management actions.	• Lower or more strongly seasonal rainfall and higher maximum summer temperatures have negative overall effects on biomass accumulation. • Extended dry periods may cause the death of mature trees.					

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