Department of Science, Information Technology, Innovation and the Arts

Rainforests

Regrowth Benefits - Management Guideline

Prepared by

P. J. Peeters, D.W. Butler and M. J. Laidlaw
Queensland Herbarium
Science Division
Department of Science, Information Technology, Innovation and the Arts
PO Box 5078
Brisbane QLD 4001

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Contents

List of Tables

List of Figures

Summary

- In Queensland, rainforest includes wet rainforest and dry rainforest (some of which are also known as vine-thicket or softwood scrub).
- Temperature, moisture, soil fertility and drainage exert a strong influence on the carbon accumulation rates and standing carbon stocks in rainforest, but management can also have a large effect.
- Based on sites in Queensland, wet rainforest has the potential to store from 300 to more than 1700 tonnes of carbon dioxide equivalent (CO_2-e) per hectare, and dry rainforest has the potential to store from 170 to more than 800 tonnes CO_2-e per hectare.
- The maximum accumulation rate of wet rainforest can exceed fifteen tonnes/ha of CO_2-e per year, while the rate is likely to be slower for dry rainforest.
- Weeds, fire, vines, grazing pressure and seed limitation can all limit the establishment and growth of rainforest plants. Careful management of these threats is required in the early stages of restoration.
- Restoring rainforest will be of great benefit to biodiversity, as rainforests are diverse ecosystems and support a high number of plant and animal species.

Figure 1: Wet rainforest canopy, including kauri pines, *Agathis robusta* (Image: D. Butler, DSITIA)

Description

Various classification systems have been proposed for rainforests in Australia, each with their strengths and weaknesses (Lynch and Neldner 2000), and some with a high level of complexity and specific terminology (e.g. Webb 1959; Specht 1981). This guide uses two categories, 'Wet rainforest' and 'Dry rainforest' that reflect significant differences relevant to ecology and management. There is wide variation in the structure and species composition of vegetation within each of the two categories, but we use this simple approach because it is appropriate for the type of general advice about restoration and management that can be delivered through this guide. Wet rainforests and dry rainforests intergrade where average annual rainfall is between about 1000 mm and 1400 mm, and in many cases may not easily be distinguished. This is the complex reality of Australian rainforest classification. Land holders interested in drier types of Wet rainforest, or wetter types of Dry rainforest, should probably read both sections. The two types are presented in this guide because they share important ecological and evolutionary similarities that distinguish them from the more widespread and fire-prone eucalypt forests and woodlands that characterise much of Queensland's landscapes. Dry rainforest includes vine-thickets and 'softwood scrubs' that may occur in fire-protected situations where the average annual rainfall is as low as 600 mm per annum.

Wet Rainforest

Wet rainforest in this guide refers to vegetation with the following features (Fig. 2):

- The tree canopy is closed (>70% foliage projective cover) and is comprised of more than one tree species;
- Canopy tree species have the ability to regenerate in the absence of broad-scale disturbance;
- Trees are densely spaced, in contrast to more open, sclerophyllous forests;
- There can be up to three or more tree layers, with or without emergent trees;
- Characteristic life forms may be present, e.g. epiphytes, lianes, certain root and stem structures (e.g. buttresses), tree-ferns and palms;
- Annual herbs are absent from the forest floor.

(Webb and Tracey 1981; Busby and Brown 1994; Webb and Tracey 1994)

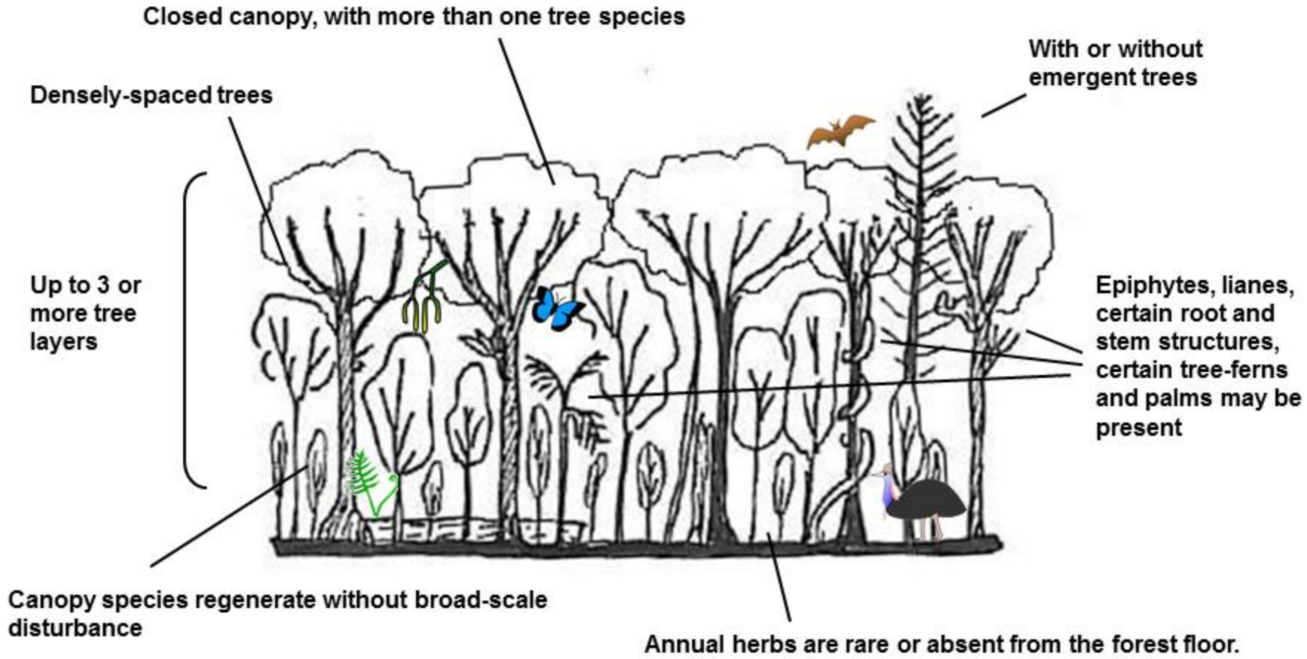

Figure 2: Structural features of wet rainforest

Figure 3: Wet rainforest (Image: D. Butler DSITIA)

Dry Rainforest

Dry rainforest in Queensland has the following features (Fig. 4):

- The tree canopy may be open or closed (greater or less than 70% foliage projective cover) and is comprised of more than one tree species[1];
- Canopy tree species have the ability to regenerate in the absence of broad-scale disturbance, and many plant species can regenerate vegetatively;
- The tree canopy is often uneven in height (typically 4-20 m), and a mixture of evergreen, semi-evergreen and deciduous tree species may be present;
- Vines, twining or scrambling plants are prominent;
- Trees with notophyll or microphyll sized leaves (2.5 – 7.5 cm long) are prominent;
- Emergent trees (9 -35 m tall) commonly occur above the main tree canopy (e.g. bottle trees, hoop pine, ooline);
- Prickly and thorny species are frequent in shrub understorey.

(Webb 1959; Webb and Tracey 1981; McDonald 2010)

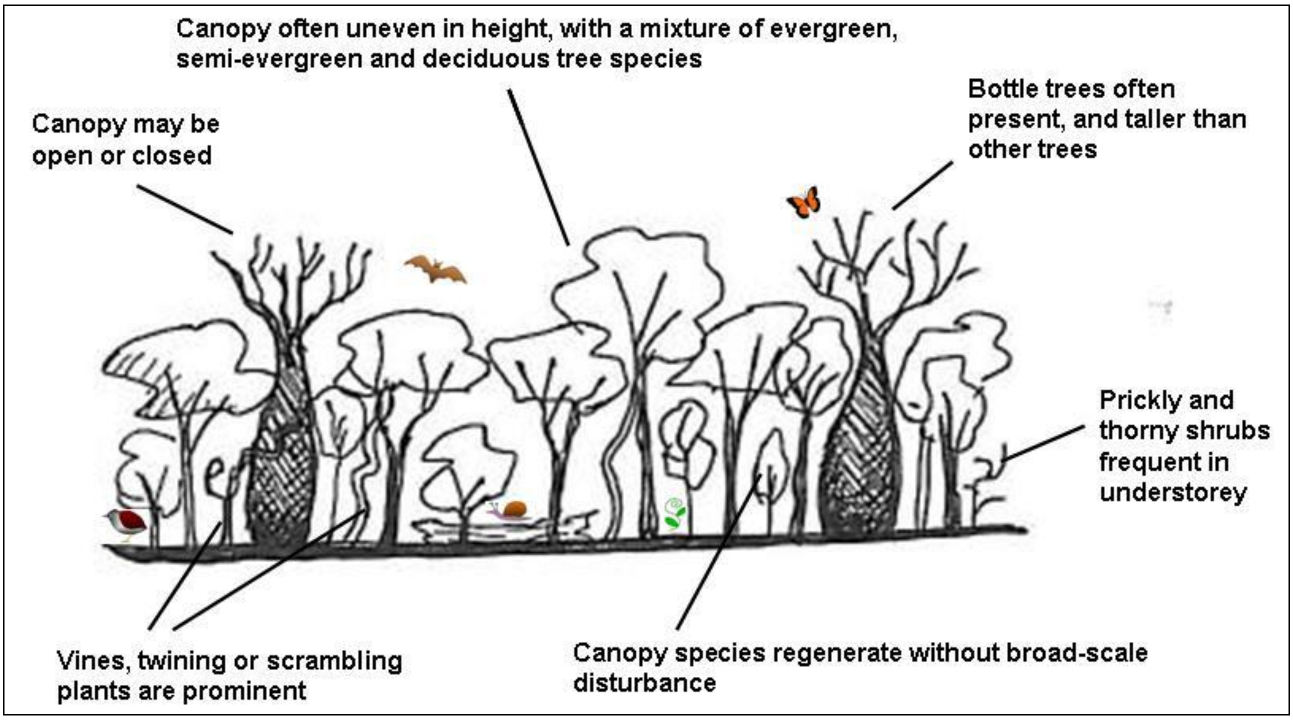

Figure 4: Structural features of dry rainforest

Management of reforestation projects may incorporate non-carbon income streams, such as cabinet timber or bush food production. The amount and type of uses that can be incorporated into carbon farming projects vary depending upon the methodology applied.

The target density, structure and composition for reforestation will depend upon the balance managers aim to strike between carbon, biodiversity and other values.

[1]Except where bonewood (*Macropteranthes leichhardtii*) forms a monospecific canopy

Figure 5: Dry rainforest (Image: B. McDonald)

Figure 6: The Queensland bottle tree *Brachychiton rupestris*, which occurs as an emergent canopy tree in some types of dry rainforest (Image: B. McDonald)

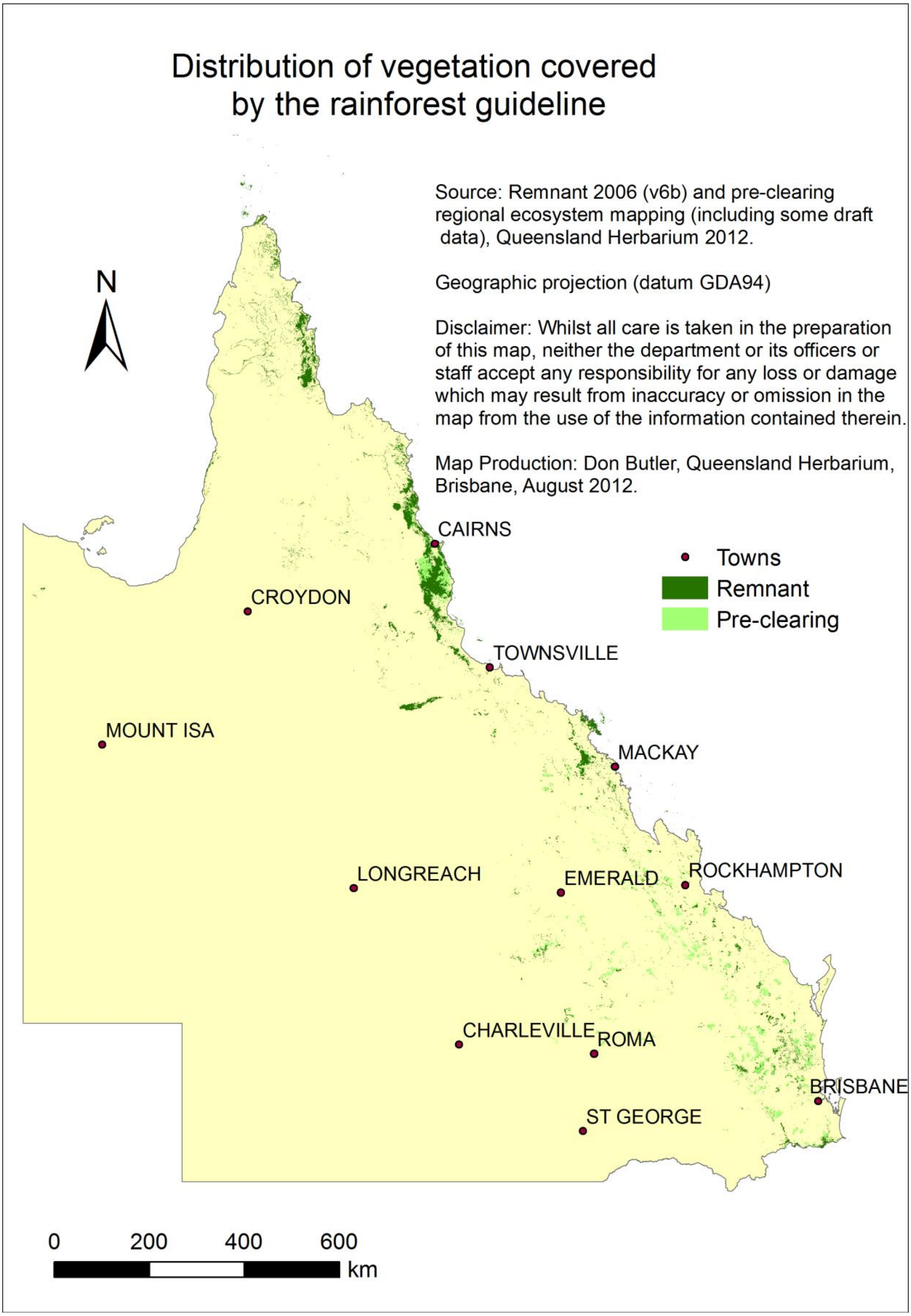

Figure 7: The distribution of pre-clearing and remnant rainforest in Queensland

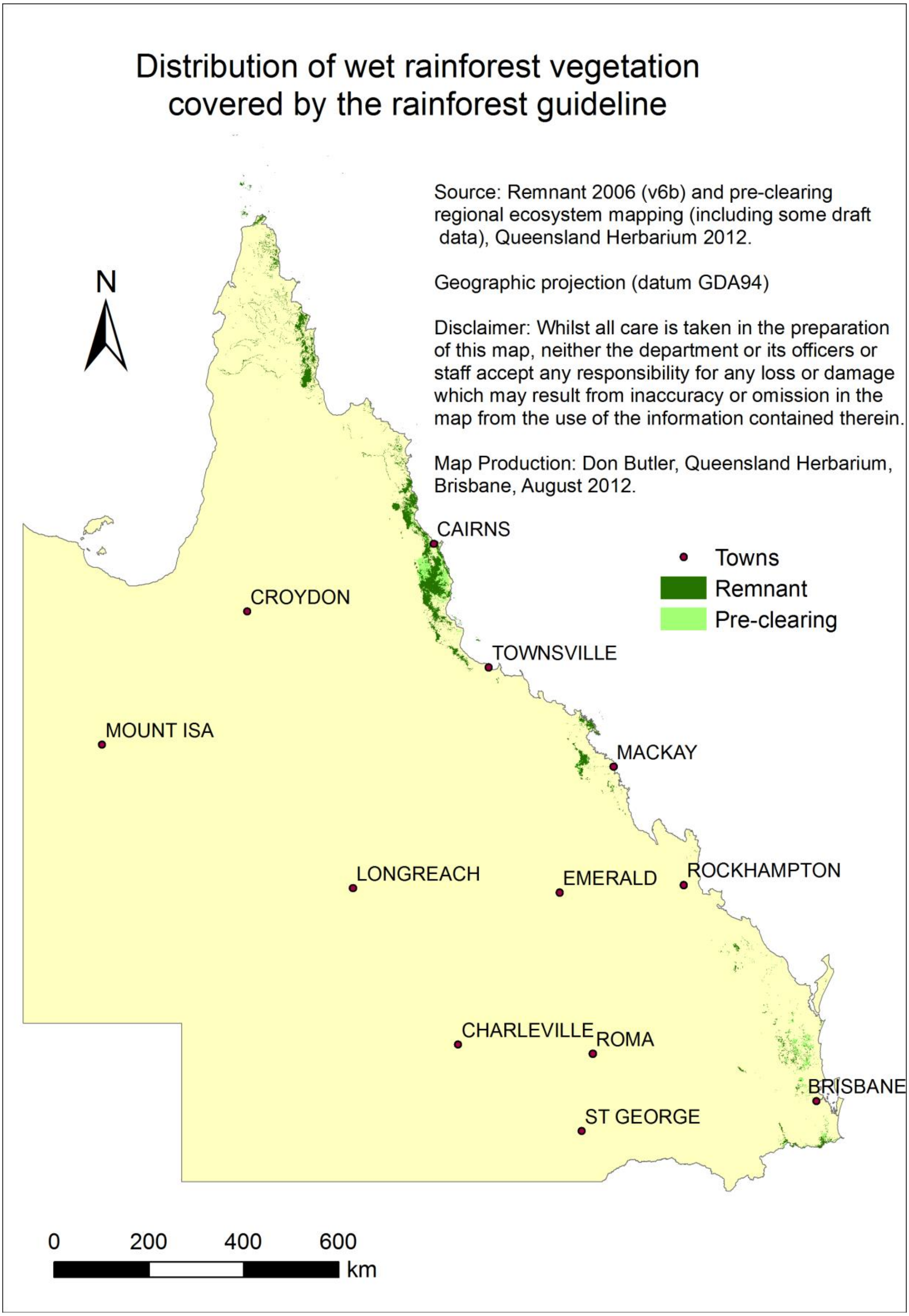

Figure 8: The distribution of pre-clearing and remnant wet rainforest in Queensland

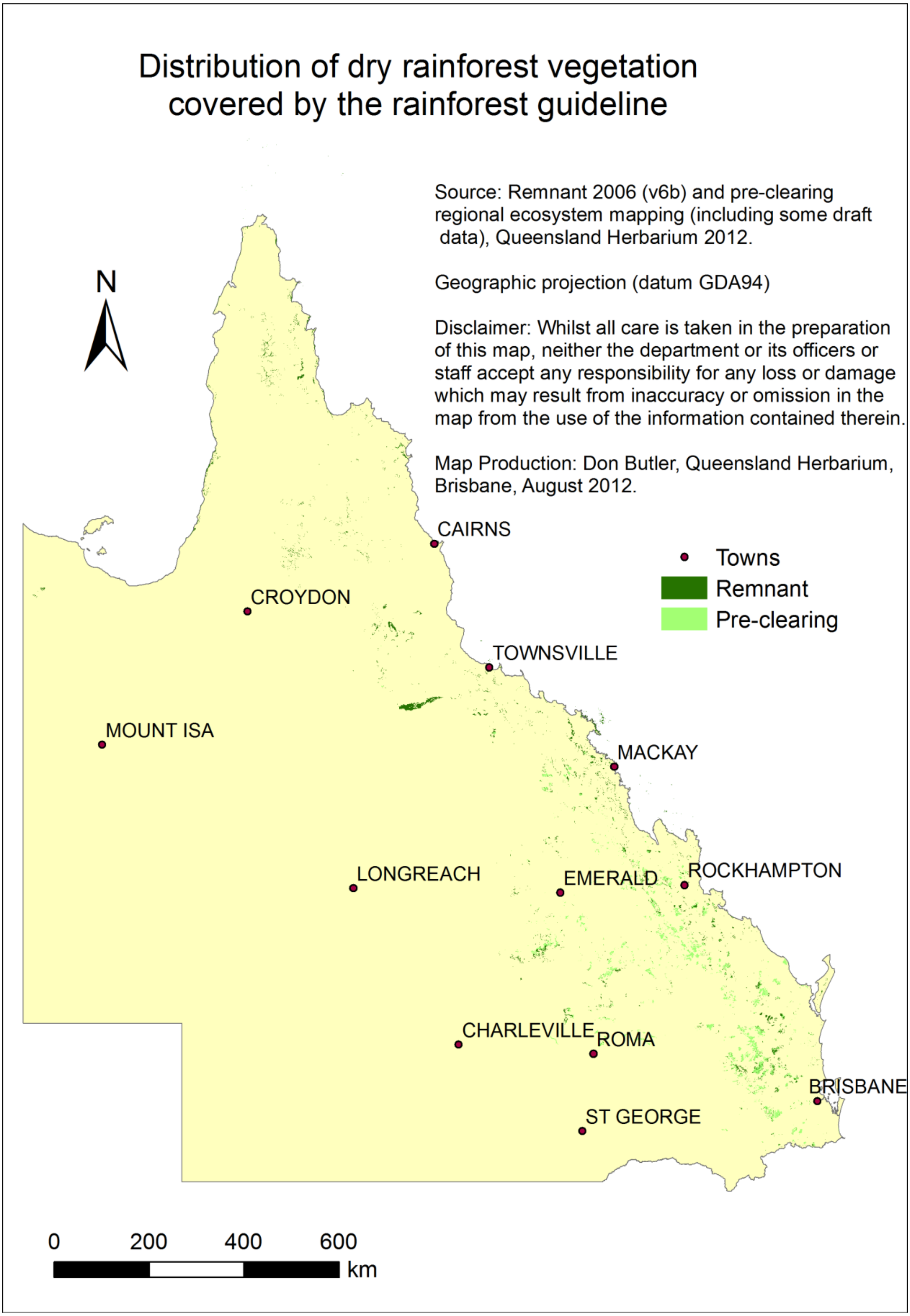

Figure 9: The distribution of pre-clearing and remnant dry rainforest in Queensland

Ecology

Rainforest has the ability to regenerate without major disturbance (Lynch and Neldner 2000), but disturbance (natural or human-induced) also plays an important role in dictating the type of rainforest that occupies any particular area (Hopkins 1981). Although rainforest can tolerate some forms of disturbance (e.g. individual tree death or storm damage), other forms of disturbance (such as clearing, grazing, weed invasion and fire) may hinder the regeneration of rainforest, and may cause the deflection of rainforest into other vegetation types (Hopkins 1981).

Temperature, moisture, soil and drainage

Within the broad descriptions of 'wet rainforest' and 'dry rainforest' outlined above, there is much variation in the types of rainforest encountered in Queensland. Rainforests vary in the height of the tallest canopy trees, the number and type of trees present, and in the proportion of trees that are deciduous.

Some rainforests are characterised by the presence of ferns and mosses, while palms are abundant in others. Trees with buttress roots are a feature of some rainforests, while emergent trees may also be present. This variation in rainforest type is related to gradients of temperature, rainfall, soil fertility and soil drainage (Webb 1968; Webb and Tracey 1981). The species composition and structure of rainforest are also shaped by disturbances such as tree fall, storms, fire, and clearing (Hopkins 1981; Webb and Tracey 1994). This variation in structure influences the carbon storage potential of rainforest.

Within the category 'wet rainforest', there are many different types of rainforest, reflecting the influence of temperature, moisture, soil fertility and drainage (Webb 1968; Webb and Tracey 1981). 'Dry rainforest' occurs in areas that experience more significant seasonal drought, and also includes a variety of rainforest types (e.g. semi-evergreen vine thickets and deciduous microphyll vine thickets).

Biology of rainforest trees

Mature wet rainforest has a closed upper tree canopy that maintains a dark and humid atmosphere within the forest. By blocking most of the sunlight, this closed canopy prevents the germination and growth of most weeds (which tend to be light-demanding). The moist microclimate beneath the canopy, combined with sparse fine-fuel in the ground layer, also suppresses the ignition and spread of fire within the rainforest (Bowman 2000, Fensham 1996; McDonald 2010). It follows that the development and maintenance of a closed tree canopy is a significant step in the restoration of wet rainforest.

The tree canopy of dry rainforest tends to be more open than that of wet rainforest, partly due to the seasonal deciduousness of some dry rainforest plants. As a result, undisturbed dry rainforest can be more vulnerable to weed invasion than undisturbed wet rainforest (Fensham 1996). However, the tree canopy still plays a major role in suppressing weeds and fire, so the restoration and maintenance of the tree canopy is also a major part of restoring dry rainforest.

The tree canopy of rainforest can quickly re-establish following some types of disturbance (e.g. individual tree death or cyclone damage), provided that the disturbance is not too large or intense (Hopkins *et al.* 1977). If a mature tree falls and creates a gap in the canopy, the different plants in the rainforest respond in a variety of ways to close the gap. The fallen tree itself, and other trees left standing, may produce coppice or basal shoots. The canopies of standing trees may also expand into the gap. Seedlings or saplings that survived the disturbance may grow rapidly to fill the gap. The seeds of 'pioneer' plant species that are intolerant of shade may germinate from the soil, triggered by increased light and heat. Pioneer species tend to be short-lived, so other tree species that are tolerant of shade ('climax' or 'mature phase' species) may eventually grow up under the pioneer species, and replace them as upper canopy trees (Adam 1994). These plant types have been further detailed, and defined into four groups for complex notophyll vine forest (Hopkins *et al.* 1977).

Other features of mature phase tree species that are relevant to rainforest restoration are their short-lived seeds and how they are dispersed away from the parent tree. Many mature phase tree species have fleshy fruits (Webb and Tracey 1981) and their seeds are dispersed by animals (Crome 1990). Also, the seed of many mature phase tree species tends to germinate immediately after dispersal and does not remain viable in the soil for very long (Hopkins and Graham 1987). For example, (Hopkins and Graham 1987) found on average that the seed of 90% of the mature phase species in their study was no longer viable after six months' burial.

Therefore, if mature phase tree species are removed from a site by clearing or fire, their replacement will depend on the dispersal of seed from another site by animals, or revegetation by land managers. Seed dispersal to the site by native animals (e.g. birds, bats) will be unlikely or less frequent if the site is remote from an adequate seed source, or the animal vectors are scarce or extinct in the local area. Rainforest plants with large seeds are particularly prone to dispersal limitation in and around rainforest fragments because the specialised animals they rely on are often restricted to large intact forests (Harrington *et al.* 1997; Moran *et al.* 2009).

For this reason, the restoration of corridors to facilitate dispersal between remnant forests has been a prominent part of rainforest restoration in Australia over the past few decades (Kanowski *et al.* 2008b). Similarly, the provision of perches and fast-growing, early successional species to facilitate dispersal into restoration sites can be advantageous (Toh *et al.* 1999; Shiels and Walker 2003).

Many rainforest tree species are also thought to be 'non-gregarious', meaning that they do not grow well in monocultures (Hopkins *et al.* 1977), or in close proximity to the parent tree (W. McDonald *pers. comm.*). Attempts to grow rainforest species in monocultures have often failed because of unfavourable soil conditions and attacks by insects, fungi and rats (Webb 1968). Exceptions to this are the hoop pine *Araucaria cunninghamii* and bunya pine *A. bidwillii* which can be grown successfully in monoculture plantations. A variety of rainforest tree species used for cabinet timber can also be grown in mixed-species plantations.

Nutrient cycling

The bulk of the nutrient capital of a rainforest is stored in the above-ground biomass and topsoil (Webb and Tracey 1981) and most nutrients are tightly cycled within the ecosystem (Congdon and Lamb 1990; Gleason *et al.* 2010), especially on substrates of low fertility (e.g. granite). Clearing of rainforest, especially if accompanied by fire, can result in a loss of nutrients which may prevent the re-establishment of rainforest (Hopkins 1981; Webb and Tracey 1981), although rainforest on more fertile substrates (e.g. basalt) can regenerate more readily after disturbance. Nutrients may be lost either by the physical removal of biomass or by disrupting the nutrient retention mechanisms of the forest (e.g. by disturbing surface root mats, removing organic matter from the soil and so reducing cation exchange capacities, altering acidity and nutrient availability, and by burning) (Hopkins 1990; Hopkins *et al.* 1990). Successful restoration of rainforest relies on the appropriate soil conditions, including the availability of adequate amounts of nutrients (Big Scrub Rainforest Landcare Group 2005).

Figure 10: Regrowth dry rainforest, after clearing (Image: B. McDonald).

Clearing

The way in which a cleared rainforest is recolonised by plants will depend on the intensity of the initial (and any subsequent) disturbance (Hopkins 1990). A disturbance of low intensity that removes some individual canopy trees will create small gaps that will be rapidly filled by rainforest species (see **Biology of rainforest trees** above). Many rainforest trees can produce root suckers and coppice shoots (Stocker 1981; King and Chapman 1983) which will contribute to regeneration if fallen trees and tree stumps survive the disturbance. However, increasing intensities of disturbance that remove all canopy trees and also destroy established seedlings and saplings will increase the opportunities for weed invasion and retard ecosystem recovery. The highest intensity of disturbance that also removes soil seed stores and soil biota will provide the greatest opportunity for species change (Hopkins and Graham 1984; Hopkins 1990).

Large areas of rainforest have been cleared for agriculture, including the establishment of pasture grasses. When these areas are abandoned and protected from fire and other major disturbances, secondary forest may eventually replace the grassland (Kanowski *et al.* 2008b). Such secondary forests may contain a mixture of native and exotic tree species, and, in subtropical Australia, areas that once supported wet rainforest are often dominated by the exotic camphor laurel (*Cinnamomum camphora*) (Big Scrub Rainforest Landcare Group 2005); see section on **Weeds** below.

Seed rain

Seed availability is another factor that will determine if and how a rainforest will recolonise after clearing. If all rainforest plants and seeds have been removed from the site, revegetation will require either planting or direct seeding or must rely on the natural dispersal of seed into the site. The proximity, location and composition of other rainforest patches will determine which tree species are likely to reach the site by wind, water or animal dispersal. The presence and efficacy of animal dispersal agents will also have a large influence.

Seed rain will be concentrated around seed sources and around disperser attractions such as food trees or perches (Toh *et al.* 1999; Shiels and Walker 2003; Neilan *et al.* 2006; Crome 1990; Gosper *et al.* 2005).

Weeds

Many weeds invade disturbed rainforest; however this section considers only those weeds that compromise or facilitate the restoration and maintenance of rainforest. Weeds are unlikely to invade dense rainforest without some prior disturbance such as cyclones, clearing or burning, although some species can invade intact forest (e.g. Madeira vine *Anredera cordifolia* (Kooyman 1996). The more open canopy of some dry rainforests makes it easier for some weeds to invade (e.g. lantana, *Lantana camara*) and green panic (*Megathyrsus maximus* var. *pubiglumis*) (Fensham 1996; McDonald 2010) and become prolific (e.g. rubber vine (*Cryptostegia grandiflora*), Fensham 1995a; Fensham 1995b).

Grasses

The invasion of bulky pasture grasses, such as green panic, molasses grass (*Melinis minutiflora*) or buffel grass (*Cenchrus ciliaris*), can increase the likelihood and intensity of fires in or adjacent to rainforest (Hopkins 1981; McDonald 2010), and especially in restoration sites. The invasion of pasture grass species into dry rainforest can be facilitated by the trampling of cattle and the death of canopy trees by fire (McDonald 2010). Bulky pasture grasses can also suppress or prevent the regeneration of rainforest species by outcompeting them in the race for space, light and water.

Lantana

Lantana (*Lantana camara*) is a bird-dispersed shrub native to tropical America, and is a serious weed of most rainforest types. Several decades ago, lantana did not appear to establish vigorously above 700 m (Hopkins *et al.* 1977), but it is now found at altitudes up to 800 m in Lamington National Park (W. McDonald *pers. comm.*). Lantana is also absent from the drier forms of dry rainforest, and does not thrive in shade (Williams *et al.* 1969). Dense infestations of lantana increase the likelihood of fires (Fensham *et al.* 1994) probably by altering the distribution of fuel in the understorey (Berry *et al.* 2011); and can also block rainforest succession (Hopkins 1981). Lantana, however, can be more easily controlled than many other weeds; has some value as habitat for native species; and does not necessarily prevent regeneration of rainforest species (Fensham *et al.* 1994). The removal of lantana may also facilitate the establishment of grasses (which are more flammable than lantana) and other more serious weeds. In these situations it may be preferable to retain the lantana, and rely on the eventual closure of the rainforest canopy to over time for its eradication from the site.

Camphor laurel

Camphor laurel (*Cinnamomum camphora*) is a fast-growing, fleshy-fruited, relatively shade-intolerant evergreen tree from subtropical Asia (Kanowski *et al.* 2008a). Unlike many native rainforest trees, camphor laurel readily invades abandoned agricultural land to form secondary forests (Kanowski *et al.* 2008a). It often dominates the canopy in regrowth rainforest, and shades out and competes with other vegetation (Big Scrub Rainforest Landcare Group 2005). Camphor laurel can also invade and become established in the understorey of rainforest that often develops in wet sclerophyll forest (W. McDonald *pers. comm.*). However, stands of camphor laurel also provide habitat for rainforest birds (Neilan *et al.* 2006), can suppress the growth of pasture grasses and create conditions that are suitable for the recruitment of native rainforest trees (Neilan *et al.* 2006; Kanowski *et al.* 2008a).

The judicious management of camphor laurel regrowth can be a much cheaper method of restoring rainforest than clearing and planting seedlings ($0 - $10,000/ha vs. $30,000/ha, (Catterall and Kanowski

2010). Therefore it is important to determine whether camphor laurel is helping or hindering the establishment of rainforest on your site before embarking on a control program.

Other weeds

Weeds such as *Anredera* and *Tradescantia* can block the natural succession of rainforest after disturbance (Hopkins 1990; Hopkins *et al.* 1990). Weeds of concern in the Wet Tropics include miconia (*Miconia calvescens*), Hurangana *(Hurangana madagascarensis)* and Thunbergia *(Thunbergia grandiflora).*

Fire

Many rainforest tree species are sensitive to fire (in the sense that their capacity to resprout after fire is limited, and the seeds of many species are also killed by fire) (Hopkins and Graham 1984). Even though some rainforest plants can survive fire (e.g. Williams *et al.* 2011), repeated fires eventually extirpate most rainforest species, and weeds and/or non-rainforest native species are likely to take over the site (Hopkins 1981; Hopkins and Graham 1984; Fensham *et al.* 2003; McDonald 2010). As a result, rainforests generally occur in areas that are protected from frequent fires by topography, climate, or the low flammability of neighbouring vegetation (Webb and Tracey 1981; Fensham 1995a; Bowman 2000; McDonald 2010).

Fire is generally not a threat to undisturbed rainforests because of their low levels of ground fuel and relatively moist microclimate (Fensham 1995a; Adam 1994; Fensham 1995a). However, after prolonged drought, fires can burn into rainforest and cause the attrition of rainforest boundaries (Webb and Tracey 1981), and even spread through large areas (Adam 1994). Dry rainforest becomes more susceptible to fire following the invasion of exotic species that change fuel loads, such as lantana and exotic grasses (Fensham 1996; McDonald 2010). The establishment of eucalypts and grasses also increase the possibility of fires impacting on wet rainforest (Hopkins 1981).

Rainforest readily recolonises some areas if a seed source is available and if fire and other threats are excluded (e.g. Unwin *et al.* 1988; Fensham and Fairfax 1996).

Grazing

Grazing by livestock is generally detrimental to the restoration and conservation of both types of rainforest. Once established, rainforest can be degraded by very high densities of either cattle or macropods (McDonald 2010), especially where rainforest patches are surrounded by cleared land, and provide shelter for grazing animals. However, moderate levels of cattle grazing may be compatible with the conservation of dry rainforest in north Queensland (Fensham 1996).

Pigs

Fensham *et al.* (1994) suggested that the rooting of feral pigs led to tree death in a patch of dry rainforest in north Queensland, and the subsequent opening up of the tree canopy facilitated invasion of the site by lantana. Pig damage has also been linked to reduced seedling density, litter cover and soil macroinvertebrate density in wet rainforest (Taylor *et al.* 2011).

Ecological models

The ecological models for rainforests (Figs.11 & 12) summarise the dynamics of these vegetation types into condition states, and identify factors that cause transitions between states. Separate ecological models for wet rainforest and dry rainforest are proposed to reflect differences in the dynamics and management of these vegetation types.

Wet Rainforest

Mature wet rainforests are converted into other condition states in the following ways (Fig. 11):

- A major disturbance (e.g. tree clearing, cyclone damage) can reduce carbon stocks and create large canopy gaps that allow weed invasion to occur (States 1 to 3).
- Clearing followed by grazing can transform rainforest to a grassland or open woodland (State 5).
- Establishment of a canopy dominated by exotic trees (e.g. camphor laurel; State 4) or *Acacia* spp. (State 6) can block the succession of rainforest plants.
- When open areas are created alongside rainforest patches, this can lead to weed invasion of the rainforest edges (State 7).

Dry Rainforest

Mature dry rainforests are converted into other condition states in the following ways (Fig. 12):

- A major disturbance (e.g. tree clearing, cyclone damage) can reduce carbon stocks and create large canopy gaps (State 2).
- Weed invasion can occur with or without disturbance (State 3), as undisturbed dry rainforest tends to have a more open canopy than undisturbed wet rainforest (Fensham 1996; Fensham and Fairfax 1996).
- Invasion of flammable weed species (e.g. lantana) can increase the risk of fire (States 3 to 4).
- Clearing followed by grazing can transform rainforest to a grassland or open woodland (State 4).

For both rainforest types, the most rapid increase in carbon stocks for State 2 will be achieved by hastening its development into a mature rainforest (State 1). This transition will be accelerated if there is no further disturbance (including fire), grazing or weed invasion, and if native vines are prevented from smothering trees. Similar conditions facilitate increases in carbon stocks from the other states, but states without a rainforest tree seed source will require direct seeding or tubestock planting. Degraded states may also require weed control and soil rehabilitation. Carbon stocks in a mature rainforest (State 1) will be maintained close to their capacity if there are low levels of disturbance (e.g. periodic tree fall, minor storm damage), but no clearing, grazing and/or hot fires.

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

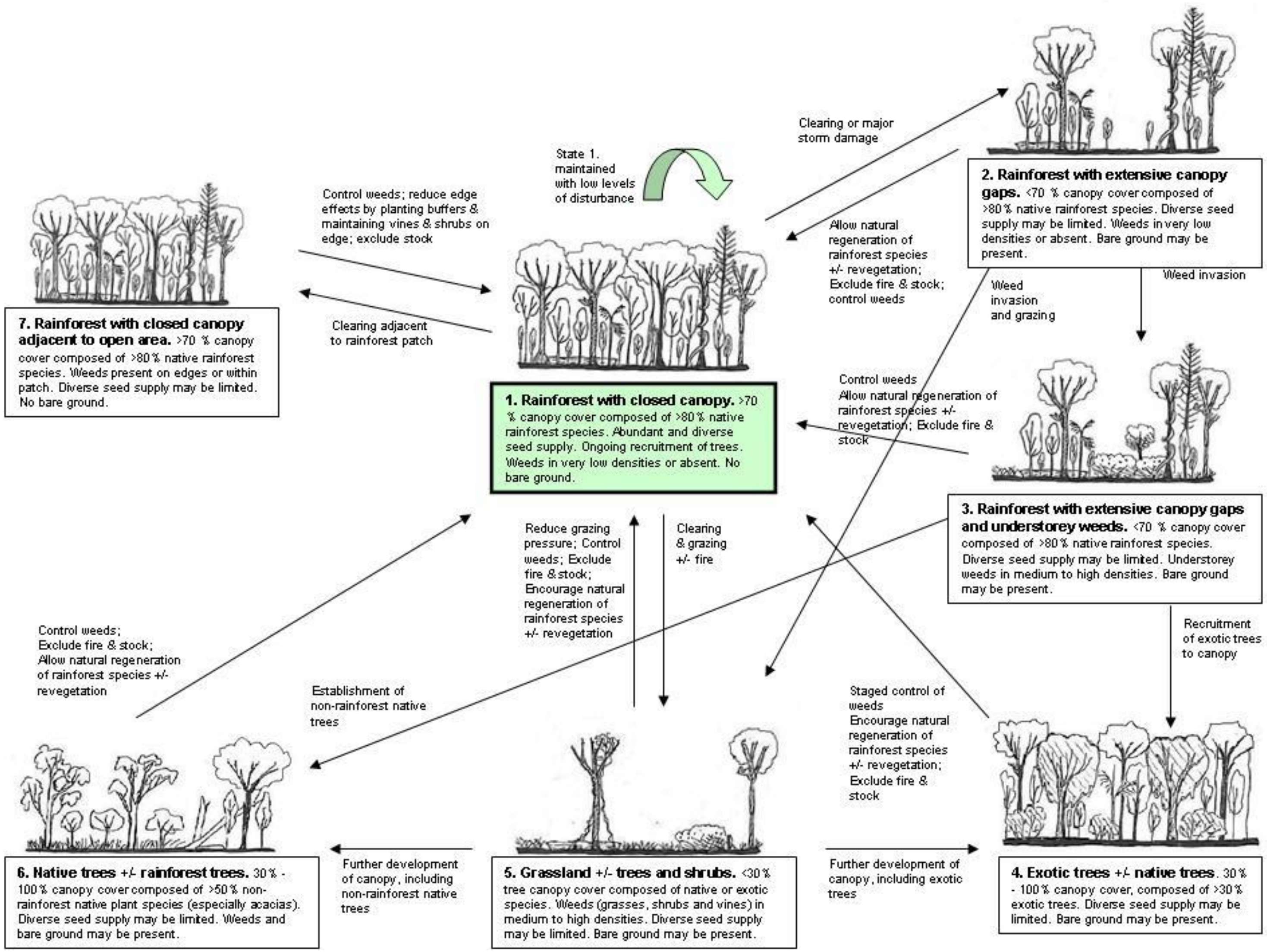

Figure 11: Ecological model for wet rainforest in Queensland

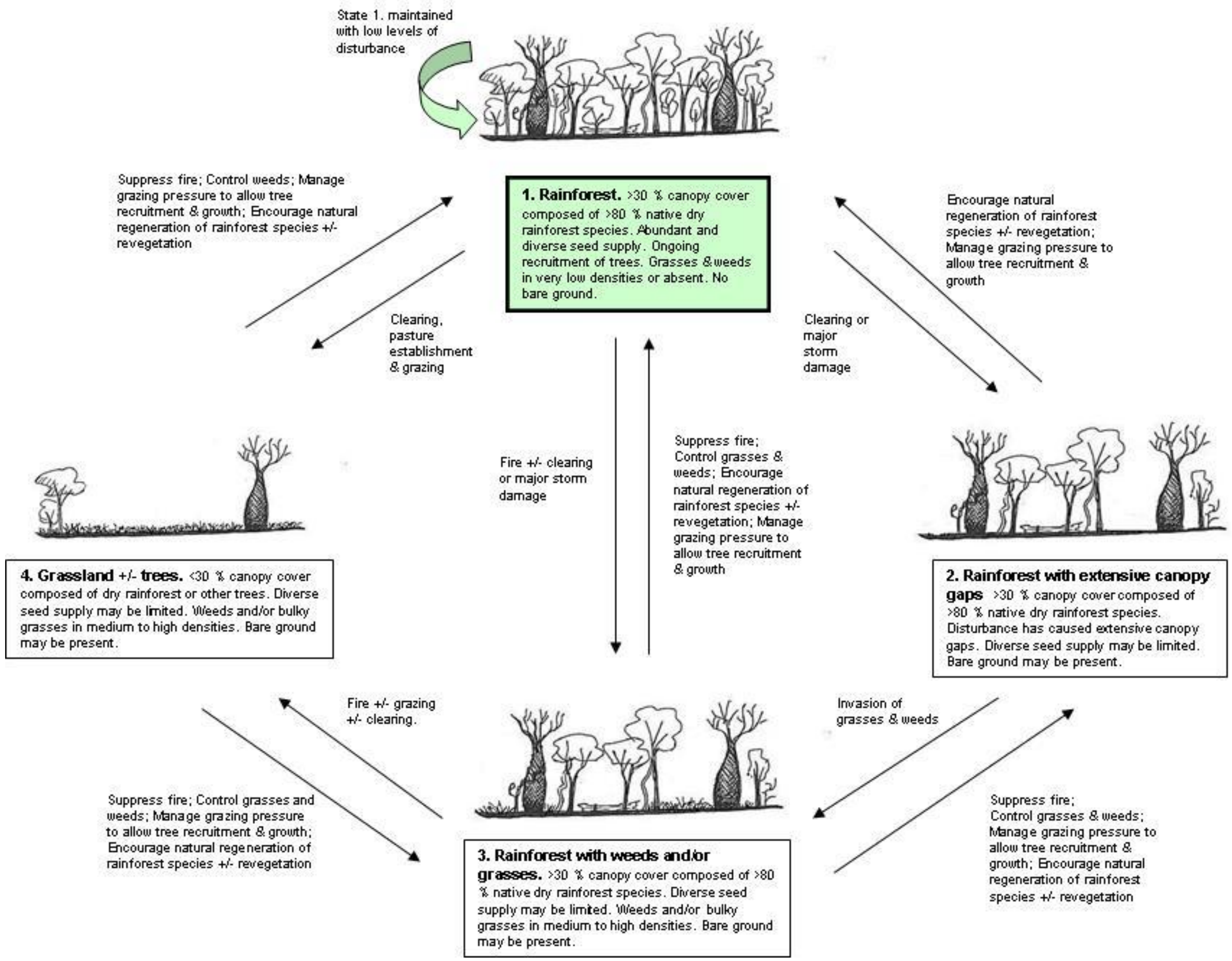

Figure 12: Ecological model for dry rainforest in Queensland

Farming carbon

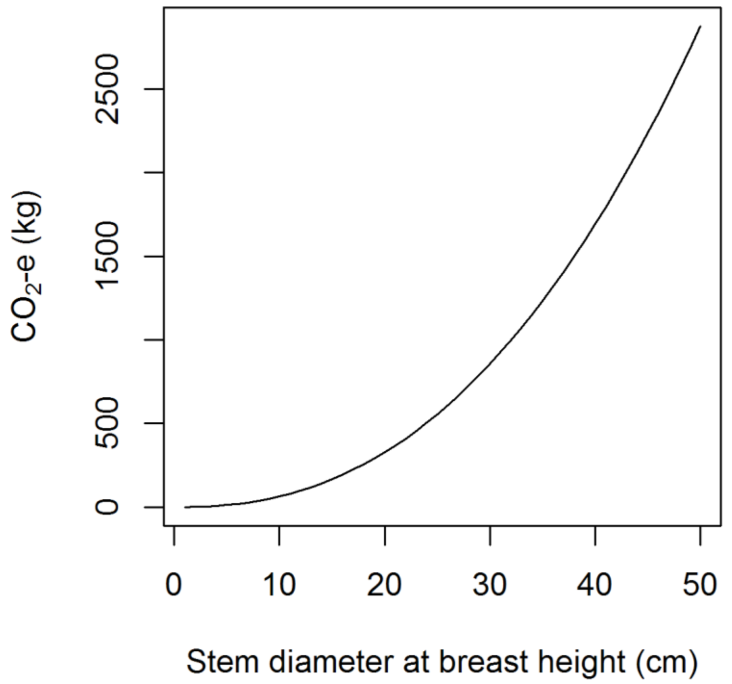

Figure 13: Relationship between carbon and stem diameter for a generic rainforest tree (based on Keith *et al*. 2000)

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 rainforest back to its full carbon capacity as soon as possible. Some carbon returns might be traded-off against other land-uses, such as selective logging, which may limit carbon accumulation rates.

Above-ground carbon in rainforest is stored in living trees, dead standing trees, fallen timber and litter. Based on sites in Queensland, wet rainforest has the potential to store from 300 to more than 1700 tonnes of carbon dioxide equivalent (CO_2-e) per hectare, and dry rainforest has the potential to store from 170 to more than 800 tonnes CO_2-e per hectare. The maximum accumulation rate of wet rainforest can exceed fifteen tonnes/ha of carbon dioxide equivalent per year, while the rate is likely to be slower for dry rainforest.

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. 13). For example, the carbon held in an average very large tree (~60 cm trunk diameter) is approximately equivalent to that held in nearly 369 smaller trees (~5 cm trunk diameters) (Fig. 14). Kanowski and Catterall 2010 found that small diameter trees (5–10 cm dbh) made up 46 % of stems in restoration plantings but contributed only 6 % of above-ground biomass.

In the Wet Tropics, plantings to restore wet rainforest (consisting of a diverse range of rainforest species) were found to store significantly more carbon in above-ground biomass than monoculture plantings of native conifers (on average, 106 t vs. 62 t carbon / ha), and tended to store more carbon than mixed species timber plantations (86 t carbon / ha) in about 15 years (Kanowski and Catterall 2010).

Table 1: Amounts of above-ground dry matter, carbon and CO_2 equivalent stored in generic rainforest trees of different diameters; based on Keith *et al.* 2000; note figures are approximate only

Tree dbh (cm)	Dry matter (kg)	Carbon (kg)	CO_2 equivalent (kg)
5	7	3	12
30	497	233	856
60	2567	1206	4423

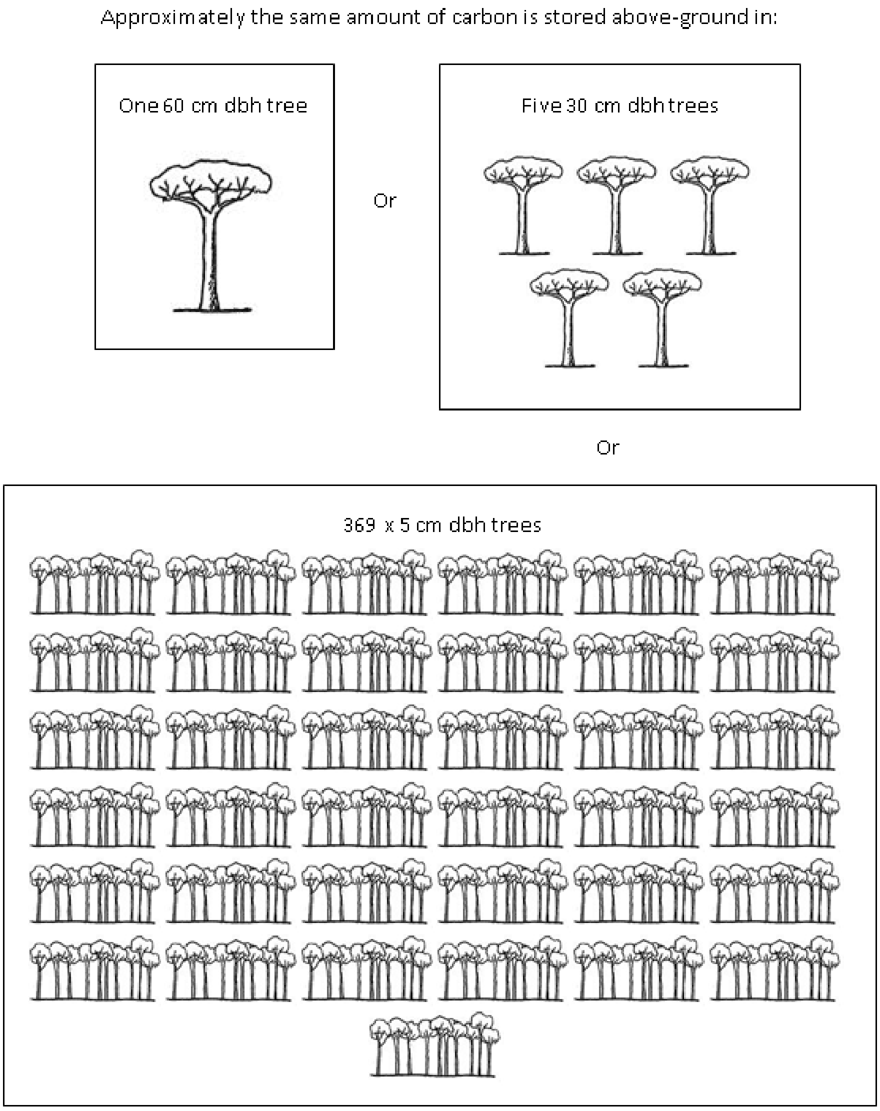

Figure 14: The relative amount of carbon stored in generic rainforest trees of different sizes; based on Keith *et al*. 2000;

dbh = main stem diameter at 1.3 m height

Limits to carbon accumulation

Biomass (and therefore carbon) accumulation in rainforest is limited by several factors including fire, grazing pressure and seed limitation (Table 2). While some of these factors are largely determined by the location of the site (e.g. temperature and moisture, and drainage) others can be influenced by management. The total amount of carbon stored by rainforest, and the rate of carbon accumulation, can be maximised by removing these limits where possible.

Table 2: Summary of limits to carbon accumulation for rainforest.

Limits to carbon accumulation	Effect on carbon	
	Total carbon stored	Rate of carbon gain
Weeds	↓	↓
Fire	↓	↓
Vines	↓	↓
Temperature & moisture	↑	↑
Soil fertility	↑	↑
Drainage	↑	↑
Clearing	↓	↓
Grazing pressure	↓	↓
Seed limitation	↓	↓

The limits to carbon accumulation in rainforest are:

Weeds – competition from weeds and other plants will generally be the most important, manageable limiting factor in the rate of carbon gain for rainforest restoration. Weeds retard the recruitment and growth of rainforest species, and many also increase the risk of fire.

Fire – large and intense fires result in carbon loss by consuming the carbon stored in all parts of rainforest (trees, dead wood and litter). Repeated small fires reduce the rate of carbon gain by removing small trees and shrubs, reducing the size of rainforest patches, and decrease the capacity of the vegetation to store carbon by limiting the recruitment of rainforest species.

Vines - Native vines are an important and characteristic life form in established rainforests, but can be a major problem during early stages of forest restoration. Competition and smothering by vines decreases the rate of carbon accumulation by slowing the early stages of tree growth. Heavy vine infestations can limit the amount of carbon stored by causing tree death and limiting the recruitment of tree species.

Temperature and moisture – Rates of carbon accumulation may be slower at sites that are colder or drier.

Soil fertility – plant establishment and growth will generally be better on sites with more fertile soils, and this will increase carbon accumulation if other limiting factors are managed. However, fertiliser application should be avoided in most circumstances because additional nutrients will encourage weeds.

Drainage –rates of carbon accumulation by rainforest will generally be impeded on sites that are poorly drained.

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

Grazing pressure – grazing pressure can remove rainforest trees, and prevent their recruitment, which will reduce the rate of carbon gain, and the capacity of the vegetation to store carbon. Moderate levels of grazing may be compatible with the conservation of existing patches of dry rainforest.

Seed limitation – availability of propagules can limit the amount and diversity of plant establishment in rainforest restoration. Sites in close proximity to seed sources, with resources that attract seed-dispersing animals (such as feed trees and perches) will show less limitation and may therefore achieve faster carbon accumulation.

Wildlife conservation

Rainforest are diverse ecosystems. This diversity is apparent both in the number of plant and animal families and species supported, as well as the diversity of life forms represented. The biodiversity of Queensland's rainforests includes numerous rare species and many listed as threatened with extinction (e.g. the Nangur skink *Nangura spinosa* which is found in dry rainforest, Horsup *et al.* 1993). Some types of Queensland rainforests are also listed as threatened ecological communities or endangered regional ecosystems.

Mammals associated with dry and wet rainforest include the fawn-footed melomys *Melomys cervinipes,* bush rat *Rattus fuscipes,* red-necked pademelon *Thylogale thetis* and red-legged pademelon *T. stigmatica* (Horsup *et al.* 1993; Bower and Kanowski 2005; Kahn and Lawrie 1987). Arboreal mammals found in tropical wet rainforest include the lemuroid ringtail possum *Hemibelideus lemuroides*, green ringtail possum *Pseudocheirus archeri* and Lumholtz's tree kangaroo *Dendrolagus lumholtzi* (Pahl *et al.* 1988). Many birds are associated with wet rainforest including the rose-crowned fruit-dove *Ptilinopus regina* and wompoo fruit-dove *Ptilinopus magnificus*, catbirds *Ailuroedus spp.*, regent bowerbird *Sericulus chrysocephalus*, riflebirds *Ptiloris spp.* and the black-breasted button-quail *Turnix melanogaster* (Catterall *et al.* 2004; Bower and Kanowski 2005). Bird species frequently recorded from dry rainforest include Lewin's honeyeater *Meliphaga lewinii*, grey and rufous fantails *Rhipidura spp.*, the fairy gerygone *Gerygone palpebrosa* and Australian brush-turkey *Alectura lathami* (note that another name for dry rainforest is 'turkey scrub')(Kahn and Lawrie 1987; Horsup *et al.* 1993; Coughlan and Pearson 2004). Reptiles associated with wet rainforest include the skinks *Eulamprus murrayi, E. tigrinus* and *Gnypetoscincus queenslandiae*, and the southern angle-headed dragon *Hypsilurus spinipes* (Catterall *et al.* 2004; Bower and Kanowski 2005). Australian rainforests (wet and dry) are also particularly rich in land snails (Stanisic and Ponder 2004).

Rainforests support ancient plant lineages such as the Kauri, Bunya and Hoop Pines (*Agathis* and *Araucaria* spp.), *Bowenia* spp., *Austrobaileya scandens* and *Eupomatia* spp. A typical hectare of rainforest will support more than 30 tree species, even in some drier rainforest types. Vines and epiphytes, including orchids, bryophytes and ferns, are also more common in rainforest ecosystems than any other vegetation type.

Most management actions that will accumulate carbon in rainforest will also benefit wildlife, in particular the re-establishment of a closed canopy (e.g. Grimbacher and Catterall 2007) and the development of a mid-canopy and understorey (Catterall and Kanowski 2010; Bower and Kanowski 2005). Habitat features that will help to conserve wildlife in rainforest 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.

Figure 15: Animal species associated with rainforest in Queensland; clockwise from top left: wompoo fruit-dove (Image: Graeme Chapman); red-necked pademelon (Image: DSITIA); southern angle-headed dragon (Image: L. Hogan, DSITIA); Herbert river ringtail possum (Image: DSITIA)

Figure 16: Plant species associated with rainforest in Queensland; left: *Austrobaileya scandens* (Image: Queensland Herbarium, DSITIA); centre: Bunya pines *Araucaria bidwillii* (Image: W. Harris, DSITIA); right: small bolwarra *Eupomatia bennettii*

Limits to wildlife conservation in rainforest

Table 3: Summary of limits to wildlife conservation in rainforest

Limits to wildlife conservation	Effect on wildlife: Total number of species	Effect on wildlife: Total number of individuals
A large variety of plant species Including trees, vines, shrubs and other plants	↑	↑
Range of shelter options e.g. tree hollows, large old trees, fallen timber, rocks, leaf litter	↑	↑
Good supply of food e.g. fruit, insects, nectar, pollen, seeds, leaves, fungi, 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	↓	↓
Clearing	↓	↓
Fire	↓	↓
Grazing pressure	↓	↓

A large variety of plant species

There is great potential to boost wildlife conservation in a rainforest patch by encouraging the growth and survival of a large range of plant species (Catterall and Kanowski 2010). Not only will many plant species be preserved in this way, but trees, vines, shrubs, epiphytes and other plants also provide nesting, shelter, feeding and courtship sites for many animals (Bower and Kanowski 2005). A diversity of plant species that flower and fruit at different times will provide food including fruit, seed, nectar, pollen and insects throughout the year for birds, bats and other animals.

A large proportion of rainforest birds and bats include fruit in their diet (Jones and Crome 1990), and some species eat rainforest fruit and nothing else (e.g. the rose-crowned and wompoo fruit doves, Catterall *et al.* 2004). Figs are perhaps the most important and prolific fruit-producing species in subtropical rainforests (Kooyman 1996) and were observed to be a significant food source for frugivorous birds in dry rainforest (Coughlan and Pearson 2004).

Of the leaf-eating rainforest animals, some species specialise on only one plant species (e.g. the Richmond birdwing butterfly), while others feed on a small group of plants (e.g. the lemuroid ringtail possum feeds mostly on mature-phase rainforest trees, Laurance 1997) and others feed on a wide range of plant species (e.g. the green ringtail possum, Pahl *et al.* 1988). Prickly vines (e.g. lawyer cane) and shrubs provide important shelter, nesting and roosting sites for a wide range of animals (Bower and Kanowski 2005). Lists of subtropical rainforest plant species that are particularly attractive to animals can be found in Kooyman 1996 and in the Big Scrub Rainforest Landcare Group 2005.

Other shelter and food resources

Tree hollows

Many native animals use tree hollows for shelter and nesting, and some also feed on prey found in hollows (Gibbons and Lindenmayer 2002). Animals that use tree hollows in rainforest include birds, reptiles, frogs and small mammals (e.g. the brown antechinus *Antechinus stuartii*). 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.

Large old trees and fallen timber

Large old standing trees don’t just provide tree hollows, they also provide ‘mature timber’ which is an important food and housing resource to a great diversity of insects, as well as fungi, mosses, liverworts and lichens (Grove 2002). In fact, most insects that live in the rainforest are in some way dependent on mature timber (Grove 2002). Fallen timber is also a significant part of the ‘mature timber’ habitat of rainforest, and provides shelter for many animals (e.g. the skink *Gnypetoscincus queenslandiae* (Catterall *et al.* 2004) and land snails (Stanisic and Ponder 2004). Large old trees can be retained in remnants, and logs added to revegetated sites, to attract and conserve native species which are dependent on mature timber (Grove and Tucker 2000).

Rocks

Surface rocks and piles of boulders are important habitats for animals (e.g. reptiles), and rocks embedded in the soil may provide animals protection from predators and fires (Lindenmayer *et al.* 2003). Some plant species may only be found in association with rocky areas. Numerous species of lizard (Kahn and Lawrie 1987) and land snails (Stanisic and Ponder 2004) are found in dry rainforest on rock outcrops.

Leaf litter

Leaf litter provides habitat for many rainforest animals including lizards and land snails (Kahn and Lawrie 1987; Stanisic and Ponder 2004), ground-feeding birds such as logrunners, whipbirds and pittas, and even insects that are usually aquatic such as dragonfly larvae and water beetles (Kikkawa 1990).

Invertebrates

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

For example, the flowers of plants such as *Brachychiton australis, Capparis* spp. and *Lysiphyllum hookeri* were observed to attract insects that were fed on by birds in dry rainforest (Coughlan and Pearson 2004).

Fungi

Many Australian mammals eat fungi, especially those that produce fruiting bodies underground (e.g. truffles), and these fungi also enter into symbiotic relationships with native plants (Claridge and May 1994). Fungi make up part of the diet of the musky rat-kangaroo *Hypsiprymnodon moschatus* in tropical wet rainforest (Dennis 2002) and are also eaten by invertebrates (e.g. the giant panda snail *Hedleyella falconeri*).

Figure 17: Habitat features for examples of rainforest wildlife

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). In general, the greater the area of rainforest the more likely it will contain a diversity of species, habitats and resources (Howe *et al.* 1981; Goosem and Tucker 1995; Bentley *et al.* 2000; Bower and Kanowski 2005; Catterall and Kanowski 2010). Some rainforest species rarely occur in small remnants (e.g. the brown antechinus *Antechinus stuartii* (Catterall *et al.* 2004) and larger predators such as the spotted-tailed quoll and rufous owl (Laurance 1997). However, small areas may also contain and conserve wildlife (Pahl *et al.* 1988; Goosem and Tucker 1995; Catterall *et al.* 2004). Restoration adjacent to forest edges can provide valuable buffers for small remnant patches.

Small edge-to-area ratio

Rainforest 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). This is particularly relevant for rainforest-dependent species, which often require a moist, humid microclimate (e.g. land snails, Stanisic and Ponder 2004) and prefer forest interiors to forest edges (Goosem and Tucker 1995).

Close to other patches

Many animals (e.g. land snails, reptiles) are unable to move large distances between suitable patches of habitat (Saunders *et al.* 1991; Stanisic and Ponder 2004), or face increased risk of predation if they attempt to do so (Cogger *et al.* 2003). Plant dispersal into new patches, and pollination between existing plant populations, can also be restricted by the distance between habitat patches. Species diversity tends to be greater in rainforest patches that are close to, or connected to other patches by corridors, than in more isolated patches (Goosem and Tucker 1995; Bentley *et al.* 2000).

How much of the landscape is cleared

The amount of suitable habitat remaining in a landscape has a large influence on the survival of wildife (Boulter *et al.* 2000; Smith *et al.* 2012). Small patch size and large distances between patches will have stronger negative impacts on birds and mammals if more than 70% of the landscape has been cleared of suitable habitat (Andren 1994). Also, a rainforest patch surrounded by intensive agriculture is likely to support fewer forest-dependent animals than one surrounded by a modified landscape that includes forest patches (e.g. a mosaic of crops and managed forests) (Laurance 1997).

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 and Fensham 2000) and this increases trampling and the opportunistic grazing of understorey plants.

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 and West 2000; Natural Resource Management Ministerial Council 2010). Since rainforests are scattered over a large area of Queensland they are subject to a variety of weeds and feral animals. The impact of these species on wildlife will vary considerably between sites, so the type and urgency of management actions should be determined on a site-by-site basis.

Weed species (e.g. lantana, camphor laurel) may provide food resources for animals, but often this is for a limited number of species and for short periods of time. Encouraging a diverse range of plant species is better for wildlife conservation as this will provide a wider range of food resources to more species over the whole year (Bower and Kanowski 2005). If weedy species are currently providing habitat for fauna, it is important to remove the weeds in stages (Kooyman 1996) and/or create new native plant habitat for these animals before the removal of the weedy habitat (Bower and Kanowski 2005). Also, excessive weed removal may create canopy and understorey gaps that will encourage open habitat generalist species (e.g. the pied currawong, noisy miner, pied and grey butcherbirds) at the expense of rainforest-dependent species (Bower and Kanowski 2005).

Pigs damage and remove the ground vegetation of wet and dry rainforest and facilitate weed invasion, which degrades the habitat of small mammals, reptiles, amphibians (Horsup *et al.* 1993) and ground-dwelling rainforest birds such as the Australian brush turkey (Coughlan and Pearson 2004).

Grazing pressure

Grazing pressure by stock, feral and native animals can reduce housing and food for wildlife by slowing and preventing the recruitment and growth of plants. Cattle can reduce the ground vegetation and leaf litter of rainforest and facilitate weed invasion, which degrades the habitat of small mammals, reptiles, amphibians (Horsup *et al.* 1993) and ground-dwelling rainforest birds such as the Australian brush turkey (Coughlan and Pearson 2004), eastern whipbird and yellow-throated scrubwren (Howe *et al.* 1981). But note that grazing can also be an important management tool for controlling pasture grass around the edges of rainforest patches to protect against fires.

Table 4: Habitat values for selected wet rainforest species

		Tree hollows /cracks	Fallen Timber	Trees & Vines	Fruit	Leaves	Fungi	Litter	Rocks	Mammals & birds	Invertebrates
Mammals											
Golden-tipped bat	*Kerivoula papuensis*			✓							✓
Lumholtz's tree-kangaroo	*Dendrolagus Lumholtzi*			✓	✓	✓					
Red-legged pademelon	*Thylogale stigmatica*			✓	✓	✓	✓				
Musky rat-kangaroo	*Hysiprymnodon moschatus*		✓	✓	✓		✓				✓
Spectacled flying-fox	*Pteropus conspicillatus*			✓	✓						
Herbert River ringtail possum	*Pseudochirulus herbertensis*	✓		✓	✓	✓					
Brown antechinus	*Antechinus stuartii*	✓	✓		✓		✓	✓			✓
Birds											
Southern cassowary	*Casuarius Casuarius johnsonii*			✓	✓						✓
Australian longrunner	*Orthonyx temminckii*		✓	✓				✓			✓
Albert's lyrebird	*Menura alberti*		✓	✓				✓			✓
Green catbird	*Ailuroedus crassirostris*			✓	✓						✓
Paradise riflebird	*Ptiloris paradiseus*			✓	✓						✓
Wompoo fruit-dove	*Ptilinopus magnificus*			✓	✓						
Reptiles											
Land mullet	*Bellatorias major*		✓		✓		✓	✓	✓		✓
Amethystine python	*Morelia king horni*		✓	✓					✓	✓	

		Tree hollows /cracks	Fallen Timber	Trees & Vines	Fruit	Leaves	Fungi	Litter	Rocks	Mammals & birds	Invertebrates
Boyd’s forest dragon	*Hypsilurus boydii*	✓	✓	✓	✓			✓	✓		✓
Chameleon gecko	*Carphodactylus laevis*		✓	✓				✓	✓		✓
Frogs											
Cascade treefrog	*Litoria pearsoniana*		✓					✓	✓		✓
Pouched Frog	*Assa darlingtoni*		✓					✓	✓		✓
Orange eyed treefrog	*Litoria chloris*		✓	✓				✓	✓		✓
Fleay’s barred frog	*Mixophyyes fleayi*							✓	✓		✓
Plants			✓	✓				✓	✓		

Management actions

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

To **maximise carbon** (by restoring the site to State 1 in Figs. 11 or 12), the management aims for all states are:

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

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

- Avoid actions that kill or injure wildlife (e.g. clearing, fire);
- Provide a range of shelter options and food resources for wildlife;
- Manage threats (e.g. fire, grazing) to allow ongoing recruitment of all plant species;
- Protect and restore landscape features that support wildlife;
- Control competitors and predators that threaten wildlife (e.g. feral animals, weeds).

Temperature, rainfall and drainage will have a large influence on the potential for reforestation and carbon accumulation on your site. However, other factors, such as weeds, grazing and fire, 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:

- Identify the condition state of your site. States can be identified by referring to Fig. 19 for wet forest, or Fig. 20 for dry rainforest.
- Select whether your goal is farming carbon, conserving wildlife, or both.
- Compile a list of actions from Table 7 (below) that apply to the vegetation type (wet or dry rainforest), the condition state, and goal of your site (either ‘carbon’, ‘wildlife’, or both).

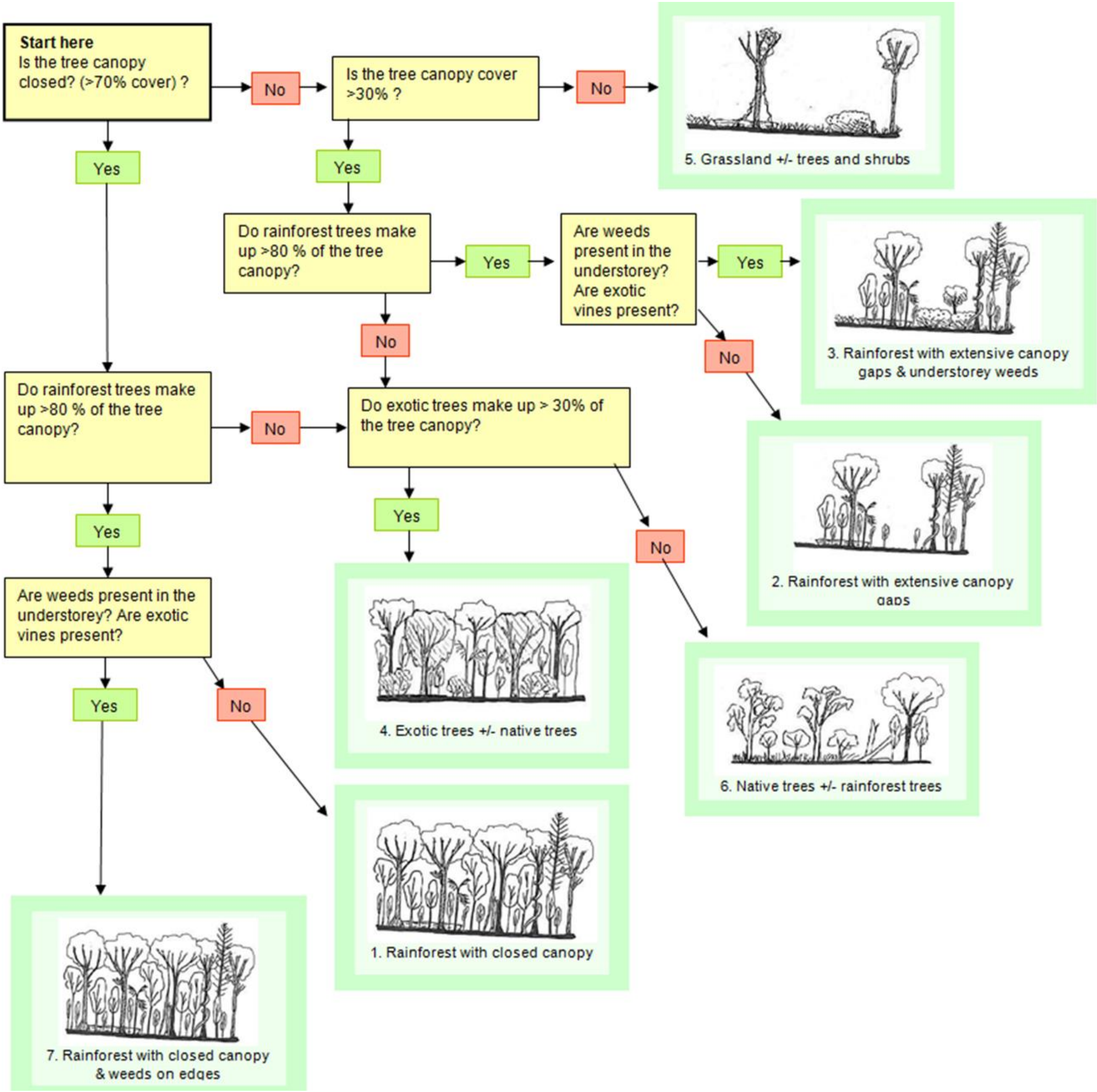

Figure 18: Key to condition states for wet rainforest

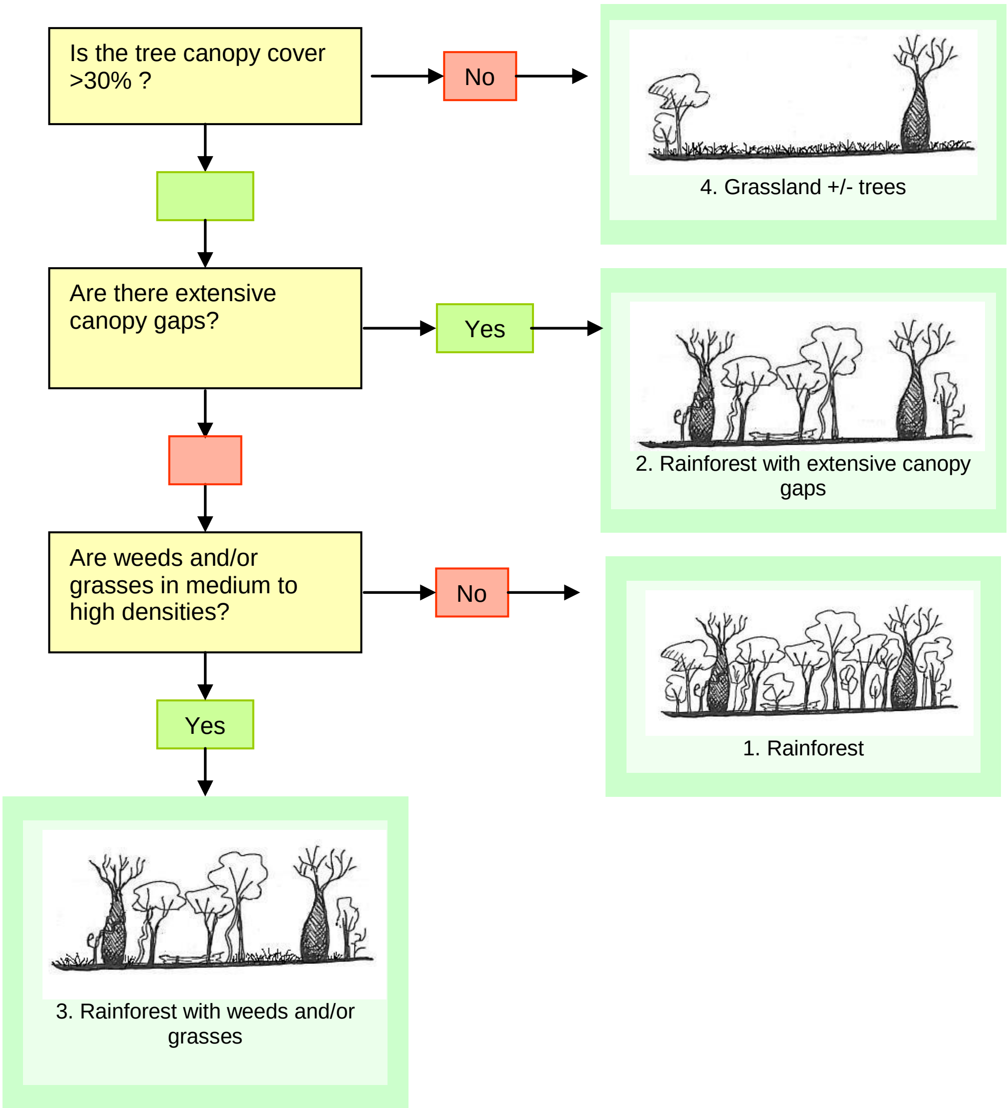

Figure 19: Key to condition states for dry rainforest

Table 5: The main management issues for each condition state for wet rainforest

Condition state	Description	Main management issue
1	Canopy closed; native rainforest trees present and dominating the canopy; weeds absent.	Areas in this state should require little intervention to sustain or increase their carbon stocks, although vigilance should be used to detect and eradicate any weeds that appear.
2	Canopy with extensive gaps; native rainforest trees present and dominating the canopy; weeds absent.	Areas in this state will require vigilance to detect and eradicate any weeds that appear, and may need minor supplementary planting.
3,7	Canopy closed or with extensive gaps; native rainforest trees dominate the canopy; understorey weeds and/or exotic vines present in patch, and/or weeds present on edges.	Weed management will be needed to maintain and increase carbon stocks.
4	Canopy closed; exotic trees > 30 % of canopy.	Staged removal of exotic trees will be needed to maintain and increase carbon stocks through the restoration of wet rainforest.
5	Grassland; native rainforest trees may be present.	Seed sources for rainforest trees, and weed control during establishment, will be critical to restoration of carbon stocks from the grassland state.
6	Canopy open or closed; native non-rainforest trees > 50 % of canopy.	Fire exclusion and the establishment of rainforest trees will be needed to maintain and increase carbon stocks through the restoration of wet rainforest

Table 6: The main management issues for each condition state for dry rainforest

Condition state	Description	Main management issue
1	Canopy > 30 % or with extensive gaps; native rainforest trees present and dominating the canopy; weeds in low densities or absent.	Areas in this state should require little intervention to sustain or increase their carbon stocks, although vigilance should be used to detect and eradicate any weeds that appear and/or begin to suppress establishment and growth of rainforest species.
2	Canopy with extensive gaps; native rainforest trees present and dominating the canopy; weeds in low densities or absent.	Areas in this state may need minor supplementary planting, and will require vigilance to detect and eradicate any weeds that appear and/or begin to suppress establishment and growth of rainforest species.
3	Canopy > 30 % or with extensive gaps; native rainforest trees present and dominating the canopy; weeds and/or bulky grasses in medium to high densities.	Weed management and fire suppression will be needed to maintain and increase carbon stocks.
4	Grassland; native rainforest trees may be present; weeds and/or bulky grasses in medium to high densities.	Seed sources for rainforest trees, weed control, fire suppression, and watering during seedling establishment, will be critical to the restoration of carbon stocks from the grassland state.

Table 7: Management actions for restoring and maintaining rainforest; 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 3 and 7 for wet rainforest have been grouped because their management actions are the same.

Action	Rationale	Carbon	Wildlife	Condition/State									
				Wet rainforest						Dry rainforest			
				1	2	3, 7	4	5	6	1	2	3	4
Clearing													
1. No clearing of live rainforest trees.	Clearing rainforest 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 fallen timber (minimise or avoid collection for firewood, or 'cleaning-up').	Dead trees and fallen timber contribute to the amount of carbon stored. Dead trees (especially those with hollows) and fallen timber are important shelter and foraging sites for wildlife.	↑	↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3. Encourage the growth and survival of large trees.	Healthy, large trees make a substantial contribution to the amount of carbon stored. Large trees are more likely to contain and form hollows, provide shelter and foraging sites for wildlife, and they can take a very long time to replace.	↑	↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fire													
4. Prevent and suppress moderate- to high-severity fire in the rainforest area to be restored.	Moderate- to high-severity fires result in net carbon loss by consuming the carbon stored in trees, dead wood and litter. Trees, dead wood and litter that would be damaged or destroyed by fire all provide shelter and foraging sites for wildlife.	↑	↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Action	Rationale	Carbon	Wildlife	Condition/State									
				Wet rainforest						Dry rainforest			
				1	2	3, 7	4	5	6	1	2	3	4
5. If grass fuel loads are likely to build up in the rainforest 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 rainforest 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 #4). 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 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 rainforest 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 surrounding vegetation, if the surrounding vegetation includes pasture.	Reduces the risk of fire in the area to be restored (see #4).	↑	↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
8. 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	Rationale	Carbon	Wildlife	Condition/State									
				Wet rainforest						Dry rainforest			
				1	2	3, 7	4	5	6	1	2	3	4
Grazing													
9. Exclude livestock to allow the establishment and growth of rainforest plants.	Grazing by livestock can reduce carbon gain and storage by disturbance to tree growth and establishment, and by trampling of woody debris and litter. Grazing by livestock, can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of rainforest plants, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓	✓	✓	✓		✓	✓	✓
10. Reduce the grazing pressure of livestock if current levels of grazing and trampling are damaging rainforest plants and preventing their establishment.	Some grazing of mature dry rainforest by livestock may be compatible with carbon farming.	↑								✓			
11. Control macropods and feral herbivores (e.g. goats) if they are in sufficient densities to prevent the recruitment of rainforest plants.	Uncontrolled grazing may reduce carbon gain and storage by disturbance to tree 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 rainforest plants, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Site preparation and plant establishment													
12. If large areas of bare ground are present, cover with mulch (if feasible) to restore soil health.	Plant establishment may be impeded on areas of bare, degraded soil.	↑	↑		✓	✓	✓	✓	✓		✓	✓	✓
13. Use slashing or low severity fire to reduce the cover of herbaceous plants before direct seeding or tubestock/sucker planting.	Improves the establishment and growth of woody plants by reducing competition.	↑	↑		✓			✓	✓		✓	✓	✓

Action	Rationale	Carbon	Wildlife	Condition/State									
				Wet rainforest						Dry rainforest			
				1	2	3, 7	4	5	6	1	2	3	4
14. If native tree seedlings are absent or very rare, revegetate using Maximum diversity method and direct seeding.	Establishment and growth of rainforest plants increases the rate and amount of carbon stored, and provides food and habitat for wildlife.	↑	↑		✓	✓	✓	✓	✓		✓	✓	✓
15. If native tree seedlings and saplings are apparent use natural regeneration, and consider supplementary planting of large-fruited tree species, or other plants species unlikely to be dispersed into the area by birds and bats (e.g. wind-dispersed species).	Establishment and growth of rainforest plants increases the rate and amount of carbon stored, and provides food and habitat for wildlife.	↑	↑		✓	✓	✓	✓	✓		✓	✓	✓
16. Establish a diversity of rainforest plant species.	A diversity of rainforest plant species of different sizes and ages provides food and habitat for wildlife.		↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
17. Consider provision of perches for seed dispersing animals, or planting of hardy and fast-growing tree species which will attract birds and bats.	Birds and bats can disperse the seeds of native rainforest plants into the site.	↑	↑					✓					✓
18. Control native vines at revegetation sites until trees are well established. Cut vine stems close to the ground using loppers or a machete, and avoid the use of herbicide, so that growth is slowed, but the vine is not killed. Repeat at intervals until the other rainforest plants are large and sturdy enough to support vines.	Native vines can suppress the growth of rainforest trees.	↑	↑		✓	✓	✓	✓	✓		✓	✓	✓
Competitors and predators													
19. Control understorey weeds if present, especially shade tolerant ones	Weeds may reduce carbon gain and storage by reducing tree growth and establishment, and increasing the risk of fire.	↑	↑		✓	✓	✓	✓	✓		✓	✓	✓

Action	Rationale	Carbon	Wildlife	Condition/State									
				Wet rainforest						Dry rainforest			
				1	2	3, 7	4	5	6	1	2	3	4
20. Prevent the introduction and spread of lantana, exotic vines and grasses, and other serious weeds.	Weeds may reduce carbon gain and storage by reducing tree growth and establishment, and increasing the risk of fire.	↑	↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
21. Remove exotic trees (e.g. camphor laurel) by using staged canopy conversion	Exotic trees can reduce the establishment and growth of native rainforest trees.	↑	↑				✓						
22. Remove non-rainforest native trees (by using staged canopy conversion) if these are blocking rainforest regeneration.	Non-rainforest native trees can reduce the establishment and growth of native rainforest trees.	↑	↑					✓					
23. 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 rainforest plant 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.	↑	↑									✓	✓
24. Establish and maintain vines and shrubs on the edges of rainforest to block weed invasion, reduce the risk of fire and reduce edge effects.	Weeds, fire and edge effects can reduce the establishment and growth of native rainforest plants.	↑	↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
25. Control feral animal species in rainforest where these are having a negative impact on wildlife and plant regeneration.	The feral pig is probably the most serious animal pest in rainforest, although cats and foxes also 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.		↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Action	Rationale	Carbon	Wildlife	Condition/State									
				Wet rainforest						Dry rainforest			
				1	2	3, 7	4	5	6	1	2	3	4
26. 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.		↑		✓	✓	✓	✓	✓		✓	✓	✓
Other actions for wildlife													
27. Provide nest boxes if hollows are scarce	Tree hollows provide important shelter and foraging sites for wildlife.		↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
28. Retain and protect rocks and rock outcrops.	Rocky areas provide habitat for many animal species.		↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
29. Retain and protect leaf litter (including fallen leaves, bark and twigs).	Leaf litter provides habitat for many animal species.		↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
30. Minimise or avoid the use of insecticides in rainforest areas to be restored, and prevent spray drift from adjacent areas.	Invertebrates deserve protection in their own right, but also provide food for other animals, and ecosystem services such as pollination and seed dispersal.		↑	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other Considerations													
Rainfall will have a large bearing on the success of management actions.	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.												

Wet rainforest – restoration principles and techniques

There are large differences in the costs of different restoration approaches (Catterall and Kanowski 2010) for wet rainforest, and much has been learnt about the effectiveness of different techniques over the last 20 years (Kanowski 2010). So it is worth spending some time determining what is likely to work best for your site and situation, and developing a systematic work plan for your site (Joseph 1999).

Excluding fire

The risk of fire to a rainforest restoration site can be reduced by controlling weeds such as lantana and grasses within and adjacent to the site (Berry *et al.* 2011), and maintaining firebreaks. Closing the canopy and edges of rainforest (as much as possible – depending on the type of rainforest) will also create a moist microclimate within the patch which will protect against fire. A dense shady canopy will also help control weeds in rainforest restoration. A range of plant species have been suggested for creating buffers along wet rainforest edges (e.g. Joseph 1999; Big Scrub Rainforest Landcare Group 2005) and these can serve the dual purpose of blocking weed invasion and reducing the risk of fire.

Managing grazing pressure

Fencing around degraded remnant rainforest patches may be all that is required to promote natural regeneration in the Wet Tropics (Goosem and Tucker 1995). Temporary or moveable fencing (e.g. electric) is worth considering if restoration is to be undertaken in stages, and wallaby-proof fencing may be desirable if wallaby damage is a problem (Big Scrub Rainforest Landcare Group 2005).

Vines

Native vines are an important and characteristic life form in established rainforests, but can be a major problem during early stages of forest restoration. Control of vines is recommended for most wet rainforest restoration sites, at least until trees are well established. It is preferable to cut vine stems close to the ground using loppers or a machete, and avoid the use of herbicide. In this way the growth of the vine is slowed, but the vine is not killed. This treatment can be repeated at intervals until the other rainforest plants are large and sturdy enough to support vines. Vines may also be added to established plantings once the tree canopy is tall and well developed, and may be particularly useful around site edges to provide some protection from weed invasion, moisture loss, light penetration and temperature extremes.

Controlling weeds

Many weeds invade regenerating rainforest or plantings, but the impact of some weeds is worse than others. Therefore it is important to plan and prioritise weed control, based on the state and condition of the site, the availability of labour and resources, the level of weed infestation, the type and scale of restoration (e.g. *are you restoring a remnant versus replanting a paddock? Is your site large or small?*) and the best time and methods to control the weeds present (Joseph 1999; Big Scrub Rainforest Landcare Group 2005).

General principles

When using herbicide, it is best to spray before or at the onset of weed flowering to ensure good translocation of the herbicide and to prevent seeding (Goosem and Tucker 1995). It is preferable to use non-residual herbicides such as glyphosate (e.g. *Roundup,* Goosem and Tucker 1995) to reduce long-term impacts. However, some species are very susceptible to glyshosate so spray drift should be minimised (Big Scrub Rainforest Landcare Group 2005). Weed spraying should be done by someone who can identify the target weeds and native species, or in tandem with an expert who tags the plants to be treated before spraying is commenced (Big Scrub Rainforest Landcare Group 2005).

Remnants

(Joseph 1999) suggests that controlling weed in rainforest remnants should exploit the natural resilience of the native vegetation, so that weeds are replaced by native species. To follow this strategy, weed control should be done in stages, with the weeds of one section of the site being removed and replaced with natives before the next section is tackled. This approach differs from the 'target' weed control strategy which focuses on the control of one species across the whole patch, and can be far less effective. However, the 'target' approach may be appropriate for the eradication of small weed outbreaks ((Joseph 1999).

Margins of remnants can be 'closed off' with native vines and shrubs to discourage further invasion of weeds (for a list of suggested species refer to (Goosem and Tucker 1995; Joseph 1999; Big Scrub Rainforest Landcare Group 2005). Spraying margins of remnants infested with lantana or exotic brambles (*Rubus* spp.[2]) can be helpful as this encourages the growth of native seeds and seedlings below these weeds (but note that wetting agents should not be used in these situations) (Goosem and Tucker 1995). However, the control of lantana is not recommended if it is likely that more flammable weeds may take its place (e.g. grasses).

Planted sites

Weed control is an important part of site preparation prior to planting, and this can be achieved by chemical or physical means. Blanket spraying with herbicide to kill all grasses and woody weeds is an effective way to remove competing plants and also allows dead material to act as mulch (Goosem and Tucker 1995). The depth of the resultant mulch layer can be increased by slashing the area two to three times before spraying which also promotes new growth on the weeds thereby providing a better target for the herbicide (Goosem and Tucker 1995). The final spraying can be completed one to two days before planting (Goosem and Tucker 1995). Alternately, weeds should be removed within 500 mm of where each seedling is to be planted. Retaining soft weeds around the plant may be beneficial in frost-prone areas (Big Scrub Rainforest Landcare Group 2005).

If herbicides are not acceptable, physical removal can be an effective option for some weeds such as lantana, and in planting sites regular and heavy applications of mulch (following ripping, slashing, or other manual control) can also be used to control weeds (Goosem and Tucker 1995). Hay bales, cardboard and sugar cane trash can all be used as mulch (Goosem and Tucker 1995). Mowing or brushcutting may be useful in some circumstances but is not generally recommended because this encourages the growth and development of grasses, and because of the risk of cutting or damaging desirable plants (Goosem and Tucker 1995).

The edges of restoration sites often provide the most weed problems, but these can be managed by maintaining a 3 m buffer by slashing or spraying (which also provides a firebreak) (Goosem and Tucker 1995). Once planting has reached its full extent, margins can be 'closed off' with vines and

[2] Take care not to confuse the exotic and native *Rubus spp.* when undertaking weed control.

shrubs (for a list of suggested species refer to (Goosem and Tucker 1995; Joseph 1999; Big Scrub Rainforest Landcare Group 2005).

Weeds as wildlife habitat

Some weed species which are a threat to rainforest (e.g. camphor laurel *Cinnamomum camphora*, lantana *Lantana camara* and privet *Ligustrum* spp.) also provide important habitat (including food resources) for native animals. So any removal of these weed species should be done in stages, and the weeds immediately replaced with native rainforest species that provide similar resources to wildlife (Kooyman 1996) .

Control of camphor laurel

Stands of camphor laurel can function as ‘nurse’ trees for native rainforest trees, and facilitate the conversion of pasture to rainforest (Big Scrub Rainforest Landcare Group 2005), and this can be a relatively economic method of restoring rainforest (Catterall and Kanowski 2010)(see **Encouraging natural regeneration** section below). However it is not known whether stands of camphor laurel will eventually revert to native rainforest without intervention (Kanowski *et al.* 2008a) and this is probably unlikely if most seed rain is composed of exotic species (Kanowski *et al.* 2008b). Instead, a strategy of selective, progressive culling of camphor laurel trees is recommended, where trees are poisoned but left *in situ* to provide perches for seed dispersers, some shade for seedlings, and extra carbon for the soil (Big Scrub Rainforest Landcare Group 2005). Removal of trees can be staged, or in patches, as both methods have been found to successfully convert stands of camphor laurel to regenerating rainforest (Kanowski *et al.* 2008a). Both methods require intensive control of camphor laurel recruits and ongoing maintenance (Kanowski *et al.* 2008a). For landholder accounts of converting camphor laurel stands to rainforest see (Woodford 2000) and (Lymburner *et al.* 2006). Detailed methods for camphor laurel control and chemical application rates can be found in (Big Scrub Rainforest Landcare Group 2005).

Other weed control guidelines for individual species

The Big Scrub Rainforest Landcare Group has compiled specific weed control information for many weed species that occur in wet rainforest in southern Queensland and northern New South Wales (Big Scrub Rainforest Landcare Group 2005). Detailed weed control information is also available on the following Weeds of National Significant (WONS) from the websites below:

Lantana

Weeds Australia website http://www.weeds.gov.au/publications/guidelines/wons/l-camara.html

Parthenium

Weeds Australia website http://www.weeds.gov.au/publications/guidelines/wons/p-hysterophorus.html

Rubber vine

Weeds Australia website http://www.weeds.gov.au/publications/guidelines/wons/c-grandiflora.html

Controlling non-rainforest trees

Acacia species can establish as canopy dominants in areas that once supported rainforest, and delay the recruitment of rainforest trees. The lifespan of these acacias can be 50-70 years (W. McDonald *pers. comm.*), and during this time the conversion of the stand to rainforest may be delayed. To restore rainforest in these situations, we suggest that the staged removal method is used (as described for camphor laurel above), by poisoning trees and leaving them *in situ.* But note that the effectiveness of this approach is uncertain and needs to be tested. In theory, rainforest seedlings should grow through the gaps and eventually shade out neighbouring acacias. Care should be taken that tree removal does not facilitate the invasion of grasses and other weed species, and follow-up monitoring and control of weeds (including acacias) may be necessary.

Encouraging natural regeneration

Natural regeneration of rainforest uses seed dispersal by animals and wind to re-establish native plants on a site. Therefore the success of this method relies on an abundant and diverse source of rainforest plant seeds on-site or nearby, and this method is most suited to expanding remnant rainforest patches or stimulating regeneration close to existing rainforest stands (Goosem and Tucker 1995; McDonald 1999). As with other rainforest restoration techniques, natural regeneration requires the ongoing management of threats such as grazing, fire and weeds to be successful (Kanowski 2010).

Seed-dispersing birds can be attracted to the site by providing perches (Crome 1990; Kooyman 1996), temporarily retaining fleshy-fruited exotics (e.g. camphor laurel Neilan *et al.* 2006) or planting bird-attracting native species (Kooyman 1996). It may be worth encouraging a wide range of seed-dispersers (e.g. including birds that are primarily insectivorous and nectivorous, but occasionally eat fruit), as specialist frugivores may not be the best seed dispersers (Kooyman 1996). Lists of bird- and bat- attracting species and perch trees for subtropical Queensland / northern NSW are included in (Kooyman 1996).

Staged removal of camphor laurel

Encouraging natural regeneration using existing camphor laurel stands can be a much cheaper method of restoring rainforest than clearing and planting seedlings ($0 - $10,000/ha vs. $30,000/ha, (Catterall and Kanowski 2010). Camphor laurel trees are progressively culled from a site by poisoning, and dead are trees left *in situ* (Big Scrub Rainforest Landcare Group 2005). These provide perches for seed dispersers, some shade for seedlings, and extra carbon for the soil (Big Scrub Rainforest Landcare Group 2005). Removal of trees can be staged, or in patches, as both methods have been found to successfully convert stands of camphor laurel to regenerating rainforest (Kanowski *et al.* 2008a). Both methods require intensive control of camphor laurel recruits and ongoing maintenance (Kanowski *et al.* 2008a). For landholder accounts of converting camphor laurel stands to rainforest see (Woodford 2000) and (Lymburner *et al.* 2006).

Because natural regeneration relies on the seed rain brought to the site by natural dispersal, problems can arise through the overabundance of weeds in the seed rain, or lack of certain native seeds (Gosper *et al.* 2005; Moran *et al.* 2009). These issues can be addressed by ongoing and vigilant weed control, and the supplementary planting, or direct seeding of native species that do not arrive naturally (McDonald 1999).

Revegetation

A number of methods have been proposed for revegetating rainforest, and these can be grouped into two main categories. The ‘Pioneer’ and ‘Early succession’ models (Kooyman 1996) and the ‘Framework species’ model (Goosem and Tucker 1995) all use hardy pioneer and early to mid-successional tree species to create a canopy and ‘bait crop’ for birds, and rely on natural dispersal for the recruitment of mature phase (or ‘climax’) tree species.

The ‘Late succession’ (Kooyman 1996) , ‘Maximum diversity’ (Goosem and Tucker 1995) and ‘Mixed species’ models include mostly secondary and mature phase species, and aim to rapidly establish a multi-layered canopy with low light conditions in the understorey (Kooyman 1996) and the original (pre-clearing) diversity of trees (Goosem and Tucker 1995).

These early revegetation methods were based on observations of intact rainforest and did not address all factors influencing the success of restored sites (Kanowski *et al.* 2008b). After two decades of rainforest revegetation it has now become clear that the ‘Maximum diversity’ or ‘mixed species’ models generally perform better than the ‘Framework species’ and similar models (Freebody 2007; Kanowski 2010). This is because the ‘diverse’ planting models can rapidly achieve canopy closure and suppress grasses and weeds (Kanowski 2010), whereas the more open-canopied ‘early succession’ models are more vulnerable to weed invasion as planted pioneers senesce (Freebody 2007) and therefore require much more maintenance. In addition, mature phase species may fail to recruit even if there is an adequate seed source nearby. As a result, ‘mixed species’ models are now recommended for wet rainforest revegetation in almost all situations.

Good site preparation before planting is important as it can equate to three to six months extra growth (Goosem and Tucker 1995). Mechanical site preparation such as deep ripping may be necessary on cleared sites with compacted or poorly drained soils (Kooyman 1996), or if the area has been heavily grazed by stock over a long period, or mowed weekly with a ride-on mower (Goosem and Tucker 1995). Mulching is a good way of suppressing weed growth and improving the soil but can be expensive (Big Scrub Rainforest Landcare Group 2005). For more information on controlling weeds see **Controlling weeds – *Planted sites*** above.

Plant species should suit the site conditions (including soil type, aspect, exposure) and be native to the local area. ((Big Scrub Rainforest Landcare Group 2005) provides genetic guidelines for selecting species, and extensive plant lists are included in (Goosem and Tucker 1995; Big Scrub Rainforest Landcare Group 2005) and (Kooyman 1996). Contact your local rainforest plant expert for advice about which species to plant at your site, and where to get them.

In the Wet Tropics, all site preparation should ideally take place in winter or early spring so that planting may begin when summer rain arrives (Goosem and Tucker 1995). For south-east Queensland, the best time to plant is after the wet season begins (late Feb – late April). Earlier planting may be desirable in frost-prone areas, but avoid the long hot days between November and January (Big Scrub Rainforest Landcare Group 2005). Close spacing of trees (1.5 – 1.8 m apart) are likely to result in taller canopy tree heights (Goosem and Tucker 1995), which may have significant implications for carbon storage. However, an assessment of planting models in the Wet Tropics recommended a planting density of 1.8 m, as planting at higher densities was more costly and did not achieve better results (Freebody 2007). For more detailed information about planting, refer to (Goosem and Tucker 1995; Big Scrub Rainforest Landcare Group 2005) and (Kooyman 1996).

Ongoing maintenance (especially weed control) is very important to ensure that the planted site develops into a rainforest and not a weed-dominated stand (Kanowski 2010). For more information see **Controlling weeds – *Planted sites*** above.

Direct seeding can also be used to revegetate rainforest and is most successful under a canopy where there is little or no weed competition (Big Scrub Rainforest Landcare Group 2005). Seed should be buried at a depth equal to the diameter of the seed, and the site protected from indiscriminate trampling or weeding (Big Scrub Rainforest Landcare Group 2005). Soil can also be disturbed in cleared areas adjacent or downwind of remnants as seed ripens nearby, and large seeds (e.g. black bean or bangalow palm) can be cast directly into dense weedy areas with some success (Big Scrub Rainforest Landcare Group 2005).

Improving soil conditions

If your site includes badly eroded areas where the humus layer has been lost and the mineral soil is exposed, it may benefit from heavy mulching, and the planting of pioneer species to rebuild soil structure and microbe levels (Kooyman 1996). However, many rainforest tree species are tolerant of mineral soil exposure and site conditions caused by erosion (Kooyman 1996). Areas of severe soil compaction may benefit from deep ripping and/or cultivation, but this should be done at least six months prior to planting (preferably earlier) to allow the soil to settle and reconsolidate (Big Scrub Rainforest Landcare Group 2005).

Cloud forests

The revegetation of cloud forests may call for special techniques as up to 40 % of the water used by the vegetation comes from cloud harvesting. When establishing rainforest plants on open areas that once supported cloud forests, it may be useful to first establish species that are cold tolerant, and have lower moisture requirements (e.g. in south east Queensland these might include hoop pine *Araucaria cunninghamii*, crow's ash *Flindersia australis,* brush box *Lophostemon confertus* and even scattered blackwood *Acacia melanoxylon*)(W. McDonald *pers. comm.*). Once a canopy is formed, other species more characteristic of cloud forests can be added. This proposed method is theoretical only, and more information on the effectiveness of this technique is needed.

Dry rainforest – restoration principles and techniques

The restoration of dry rainforest is problematic. Natural regeneration after clearing seldom occurs, as dry rainforest species are usually eradicated by post-clearing fire. Revegetation of completely cleared sites is rarely feasible because of slow plant growth rates and the ongoing management costs of weed, fire and grazing control.

However, the restoration potential of some dry rainforest types is greater than others, and these differences are outlined below. There is also far less known about the restoration of dry rainforest than wet rainforest, as most rainforest restoration has focussed on the latter. It is hoped that ongoing attempts to restore dry rainforest will yield more specific and detailed information about the restoration of this vegetation type.

Dry rainforest on rocky substrates, or on better soils where annual rainfall < 900mm

This type of dry rainforest is the most difficult to restore because of slow plant growth rates. If a cleared site was replanted with dry rainforest species, it is estimated that about 50 years would be required to develop a closed canopy (R. Fensham *pers. comm.*). This is due to the typically slow growth rates of these dry rainforest plant species. Until canopy closure is achieved, ongoing management of grazing, fire and weeds would be required, demanding substantial cost and effort.

For these reasons, broadscale restoration of this type of rainforest is unlikely to be feasible. But there may be situations where small areas can be restored more easily. For example, a small area could be protected from fire if surrounded by a buffer of fire-retarding vegetation (e.g. brigalow forest without exotic grasses). If fencing or weed eradication of the revegetation site is required there would be high initial costs, but ongoing costs may be lower if the surrounding buffer vegetation is weed free. There may also be some natural dispersal of rainforest plants into the site if they are present in the surrounding brigalow vegetation.

Dry rainforest on better soils where annual rainfall is 900 – 1400 mm

Restoration of this type of dry rainforest is possible, but it requires intensive planting, weed control, fire management, and watering in establishment phase. Hoop pine (*Araucaria cunninghamii*) is a common species of this vegetation type and is a relatively hardy, and fire-resistant species.

Species mixes with a substantial proportion of hoop pine may have a better chance of success than those consisting of more delicate species.

Revegetation

Techniques for the planting and maintenance of dry rainforest species are largely consistent with those recommended for wet rainforest, although the plant species will vary (Kooyman 1996). But as dry rainforest occurs in more seasonally dry conditions, more water and mulch may be required to assist the survival of planted trees (Kooyman 1996).

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