Towards an appropriate fire regime for threatened regional ecosystem 7.12.22 in the Tumoulin Forest Reserve

A report prepared for the Tablelands National Park Volunteers Inc. by Donald C. Franklin

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Summary

Regional Ecosystem 7.12.22 is a tall open or semi-closed sclerophyll forest featuring stands of Red Mahogany (*Eucalyptus resinifera*) and other eucalypts. In the Tumoulin Forest Reserve, it supports a diversity of flora and fauna including the Vulnerable Yellow-bellied Glider (Wet Tropics) (*Petaurus australis* unnamed subspecies). This ecosystem is thought to be threatened by successional processes that could transform it into a closed-canopy forest, and by proliferation of the non-native shrub Lantana (*Lantana camara*). The proliferation and maturation of a natural component of the forest, Rose She-oak (*Allocasuarina torulosa*), to the point where it might be an agent of ecosystem transformation, appears to have been triggered by a history of heavy logging. The forest is fire-prone, fire-tolerant and fire-dependant, so excluding fire altogether is neither desirable nor practical, but an inappropriate fire regime also risks compromising its biodiversity and possibly even its existence. In this report, I briefly review relevant aspects of the history and ecology of this ecosystem at Tumoulin and explore options for maintenance of the ecosystem and its biodiversity. Low-severity (low-intensity) fires are unlikely to serve the purposes of ecosystem maintenance, and if too frequent or extensive are likely to reduce variation in the understorey and mid-storey and threaten some components of biodiversity. Extensive and especially crown-destructive fires are likely to threaten the existence of the Yellow-bellied Glider. Biodiversity in remnant forests is optimised by variation in vegetation (e.g. in understorey structure), and this can be enhanced by fires that are patchy and variable in interval and severity. Further, the Yellow-bellied Glider is dependent on a variety of resources extending well beyond sap and den trees. A mosaic of fire patches in which patch size is somewhat to considerably smaller than the home range of individual Glider groups is recommended as optimal, with a modal fire severity (from the range of Low-Moderate-High-Very High-Extreme) of High. Optimal fire frequency (the frequency with which any one patch is burnt) is uncertain and will vary with initial and intended final vegetation structure. A modal frequency of more than 10 years with considerable variation around the mode, is recommended as a starting point, longer intervals being preferable because fire is an additional (though necessary) stressor on an ecosystem that is already stressed. Because there is much uncertainty about the consequences of both single and repeated fires, monitoring and learning-by-doing is essential to the successful management of this forest. Particular emphases for monitoring include the survival of Yellow-bellied Gliders, the impact fires have on the resources gliders need, and on the risk that burning will promote rather than retard Lantana. Additionally, research collaborations have great potential to provide insights into the fire ecology of this forest.
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Introduction

Fire, and management of it, is a challenging issue in many parts of Australia. Australia is the land of fire (Bowman 2000; Bradstock 2010) in which major elements of the flora and fauna have evolved to cope with, and in some cases even to depend on and encourage fire (Bradstock et al. 2012). Other elements, such as native conifers of the genus *Callitris* (Trauernicht et al. 2012) and many rainforest communities (Bowman 2000), are relatively fire-sensitive. In a range of settings, vegetation structure and boundaries are set or fine-tuned by fire and can be sensitive to changes in fire regime (e.g. Petty & Douglas 2010; Russell-Smith et al. 2010; Trauernicht et al. 2012).

Nowhere are the challenges more evident than in the wet and moist sclerophyll (eucalypt) forests of eastern and south-western Australia where high fuel loads and volatile leaf oils combine with seasonal periods of great flammability to generate severe wildfires. These forests may well reflect the evolutionary origins of eucalypts more than 55 million years ago as competitors of rainforest (reviewed briefly by Wardell-Johnson et al. 1997). Eucalypts may have evolved as rainforest trees of mountain ridges where the soil was skeletal and the trees exposed to lightning strikes. Their success – and subsequent expansion as the continent dried out – lay not merely in coping with these conditions, but in exploiting them by evolving flammability and thus encouraging fire as a means of creating opportunities for the germination and establishment of light-dependent seedlings in the face of shade and competition from the rainforest. When ecologist Robert Mutch first proposed that plants could evolve to promote their own burning (Mutch 1970), the idea was treated with some scorn, Snyder (1984) famously entitling a paper "The role of fire: Mutch ado about nothing?". The theoretical difficulties with Mutch’s idea have since been overcome (Bond & Midgley 1995; Kerr et al. 1999; Schwilk & Kerr 2002) and the idea of evolved flammability is now widely accepted.

As detailed in the sub-section *Eucalypt forests and fire*, eucalypts have evolved two distinct methods of coping with and exploiting flammability, resprouting (in which the mature tree survives fire) and obligate seeding (in which it does not). The juxtaposition of these types in the one forests generates additional challenges for forest managers. Regional Ecosystem 7.12.22 in the Tumoulin Forest Reserve exemplifies these complications. Although characterised by fire-tolerant resprouting species such as Red Mahogany (*Eucalyptus resinifera*) and Pink Bloodwood (*Corymbia intermedia*), the forest also includes small stands and scattered individuals of Rose Gum (*Eucalyptus grandis*), a species whose regeneration strategy appears to be that of obligate seeding.

In this report, I explore ecological issues and information surrounding fire regimes in this Regional Ecosystem within the Tumoulin Forest Reserve, and provide some recommendations for management focused on maintenance of the ecosystem. This report was commissioned by the Tablelands National Parks Volunteers Inc. and funded by a grant from the Norman Wettenhall Foundation. Particular context for this appraisal is provided by the virtual restriction of the isolated and Vulnerable Wet Tropics population of the Yellow-bellied Glider (*Petaurus australis* unnamed subspecies) to this Regional Ecosystem, including stands of it in the Tumoulin Forest Reserve. DERMS (2011) rated “changed vegetation structure due to change in fire regime and other factors” as the major threat to the glider population. Further, key resources for the glider (Goldingay & Quin 2004) span the two forms of eucalypt regeneration strategy.

This appraisal does not include an evaluation of fire risks to humans or infrastructure nor of practical issues in fire management, though these issues are acknowledged as important considerations for the management authority (currently Queensland Parks and Wildlife Service).
Background

Eucalypt forests and fire

There are two contrasting responses of eucalypts to crown fires, that of resprouter and obligate seeder (Gill 1997). Responses are mostly species-specific and most eucalypts are resprouters, obligate seeders being restricted to a few species of moist to wet sclerophyll forest (Tng et al. 2012a) and a suite of species from semi-arid portions of the south-west of Western Australia (Nicolle 2006). Though these responses are mediated by two apparently independent morphological traits – development of lignotubers and protection of stem bud strands (below), very few species display an intermediate or regionally variable mix of traits (O’Dowd & Gill 1984 cf Bowman & Kirkpatrick 1986; Nicolle 2006).

Resprouters are individually fire-resistant, regrowing from accessory buds in branchlets, epicormic bud strands in the stem and larger branches, or from the lignotuber below ground (Burrows 2013). Epicormic shoots arise from bud strands which in many eucalypts are unusual (almost unique) in occurring below the dead bark where they are protected from damage by intense fires (Burrows 2013). The development with age of a thick layer of dead bark by many eucalypt species (e.g. stringybarks, ironbarks) further enhances the survival of these strands (Lawes et al. 2011), though the living bark of smooth-barked eucalypts may also be thickened and protective of epicormic bud strands (McArthur 1968). Most eucalypt resprouter seedlings, which have yet to acquire the thick bark needed to protect above-ground shoots, rapidly develop a dense woody structure – the lignotuber – at the junction between the roots and above-ground stems. The lignotuber is a prolific source of regenerative buds and a combination of this density and its position below ground means that many eucalypt seedlings resprout readily and, if necessary, repeatedly following fires even though all living material above-ground has been destroyed.

Obligate seeders, in marked contrast, lack a lignotuber and the epicormic bud strands are not well-protected, so that they are killed by fire and depend on regeneration from seed for population recovery.

These two responses to crown-destroying fires yield starkly contrasting forest ecologies. For both forest types, mature forest trees suppress seedling establishment and growth, and eucalypt seed does not usually remain viable beyond 12 months (Boland et al. 1980). Most if not all eucalypt seedlings are intolerant of deep shade (Bell & Williams 1997). Though most eucalypts are prolific producers of seed, resprouters tend to produce less seed and at less consistent intervals than obligate seeders. The inconsistent interval arises because trees do not flower every year (Law et al. 2000) and because flowering is somewhat to highly synchronised among individuals (a phenomenon known as masting) so that entire stands may produce seed, or not produce seed, in a given year. Both because seed may thus not be available for germination following a fire and because of the suppression of seedlings by mature trees, seedling establishment in resprouter forests may be sporadic. A further feature of resprouters is that seedlings may remain in a suppressed state (the ‘dormant seedling bank’) for many years (Bell & Williams 1997), only developing into trees capable of resprouting from stems (and flowering and fruiting) when a gap in the forest is created by the death of an older tree.

In contrast, obligate seeders tend to produce seed prolifically and annually, hold the seed in capsules where they are protected from the heat of the fire, and shed them after a fire (Ashton 1975; O’Dowd & Gill 1984; Gill 1997). Forests of obligate seeders are re-initiated by each major fire event, the fire creating release from competition and thus the opportunity for prolific establishment and growth of seedlings. Forests of obligate seeders are thus mostly composed of individuals of the same age (Ashton 1976) and require a lengthy interval between crown-destroying fires for individuals to mature and produce seed; a second canopy-destructive fire before individuals have matured will eliminate the species.

Beyond qualitative documentation of the presence of lignotubers in seedlings and of the resprouting capacity of mature trees in some species, the regenerative “strategies” of eucalypts in moist tropical and sub-tropical forests have not been studied in detail. The nature of fire, particularly wildfire, in the moist
and wet tall eucalypt (“sclerophyll”) forests of the Australian tropics and sub-tropics is also not well documented. They are much less prone to severe crown fires than forests of similar structure and total rainfall in southern Australia. The difference is probably attributable to reduced levels of volatile oils in the leaves of eucalypts of tropical latitudes (Steinbauer 2010) combined with less severe fire weather. The eucalypt forests of south-eastern Australia in particular encounter severe fire weather because summers can be dry and because at those times strong dry winds can blow to them from the central Australian deserts. In contrast, those of north-eastern Australia are receive “summer” rains, and winds during the dry, warm period prior to the wet season are more likely to blow on-shore from the south-east.

**Regional Ecosystem 7.12.22 at Tumoulin**

Tumoulin Forest Reserve is c. 8 x 4 km, c. 2,700 ha in area, and centred at c. 17°34’S, 145°29’E. The southern edge of the forest c. 1 km north of the town of Ravenshoe in far north Queensland, Australia. The forest lies mostly between 920 and 1,100 m above sea level on the western portion of the Evelyn Tableland. Within the Reserve, Regional Ecosystem 7.12.22 (hereafter RE 7.12.22) occurs mostly in the higher, eastern part. It was set aside as part of the greater Tumoulin State Forest. Toohey (1991, page 48) wrote:

"A state forest was not set aside at Tumoulin until 1917. In that year an area of 596 acres north-east of Turulka was gazetted as state forest. Over the years this acreage was added to. As settlers moved out of the district, their land was resumed by the Forestry Department, one portion at a time. The present Tumoulin State Forest is 3,112 hectares in area."

In the Reserve, RE 7.12.22 is typically a tall-open forest of Red Mahogany (*Eucalyptus resinifera*; also known as Red Stringybark) with scattered Rose Gum (*E. grandis*; also known as Flooded Gum) and patchy co-occurrence of Turpentine (*Syncarpia glomulifera*), Pink Bloodwood (*Corymbia intermedia*) and Tindal’s Stringybark (*E. tindaliae*). The mid-storey is often dominated by Rose She-oak (*Allocasuarina torulosa*), with patchy dominance by *Acacia* spp. and rainforest species. The understorey is quite variably grassy, shrubby or ferny and is often dominated by the weed Lantana (*Lantana camara*). It occurs mostly on soils of granitic or rhyolitic origin and in areas with an mean annual rainfall of approximately 1,500 mm which includes frequent mists during the dry season. To the higher and moister east, RE 7.12.22 grades into pure stands of Rose Gum and upland rainforest, whilst to the west it grades into drier open forest featuring species such as Inland White Mahogany (*E. mediocris*) and Narrow-leaved Ironbark (*E. crebra*).

RE 7.12.22 is rated as threatened by the Queensland Government because of a history of logging, and because of invasion by rainforest and infestation by Lantana (http://www. ehp.qld.gov.au/ecosystems/biodiversity/re_introduction.html, downloaded 4 Sept. 2013). Substantial portions of RE 7.12.22 have been cleared for agriculture in the past.

Tall forest of Red Mahogany (*Eucalyptus resinifera*) with a mid-storey of Rose She-oak (*Allocasuarina torulosa*) in Tumoulin Forest Reserve.
Perceived issues

The statement of issues (Table 1) reflects discussion and perusal of the literature and is provided without prejudice or implied priority. It is intended as setting for subsequent exploration of the relevant ecology, from which an emergent perspective on management possibilities is presented in the Discussion.

Table 1. Issues in fire management of Regional Ecosystem 7.12.22 in the Tumoulin Forest Reserve.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Possible implications</th>
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| Closure of the mid-story by either rainforest species or Rose She-oak | • in the short- to medium-term, this may have negative implications for the gliding movements of the Yellow-bellied Glider.  
• in the longer-term, this may have negative implications for the regeneration of overstorey eucalypts and the persistence of other species  
• fire may have a key role in limiting the occurrence of Rose She-oak and development of rainforest |
| Weed control | • rampant Lantana may inhibit regeneration of key tree species and have negative implications for other components of biodiversity  
• rampant Lantana inhibits research and monitoring of Yellow-bellied Gliders  
• fire may contribute to the control of Lantana, and may be the only broad-acre management option available to this end  
• fire may also create opportunities for the expansion of Lantana populations |
| Biodiversity conservation | • Yellow-bellied Glider is a key concern  
• this ecosystem in Tumoulin is home for a range of other restricted range and/or rare taxa, e.g. Tropical Mountain Geebung (*Persoonia tropica*)  
• fire has varied and complex roles in the maintenance of biodiversity |
| Historical factors | • logging and fire in Tumoulin Forest Reserve may have created demographic gaps in the age profile of the Rose Gum population. This may have longer-term implications for habitat value for Yellow-bellied Gliders  
• logging may have created canopy gaps that have favoured the expansion of Rose She-oak  
• RE 7.12.22 and other ecosystems have been reduced and fragmented by European settlement, creating or increasing the isolation of RE 7.12.22 in the Tumoulin Forest Reserve. This may have serious implications for the future of the Yellow-bellied Glider population in the forest |
| Hazard reduction | • though beyond the scope of this study, the considerable practical and socio-political issues for managers with respect to the implementation of controlled burns, and the hazards arising from control burns and uncontrolled wildfire, are acknowledged.  
• an additional fundamental management conundrum is that exclusion of fire may in the short to medium term allow the accumulation of fuel hazards, but that fires may open the canopy and thus allow greater development of the ground- and shrub-layer vegetation that is a key source of fuels. |
Fire and Tumoulin: a brief review of relevant evidence

Pre-history

The pollen record from cores taken from Lynch’s Crater c. 10 km east of Malanda shows that eucalypts (Eucalyptus, Corymbia and/or Angophora) and casuarinas (Casuarina and/or Allocasuarina) were consistently present on the Atherton Tablelands from at least 190,000 years before present (Kershaw 1985; Moss & Kershaw 2000). Casuarina pollen was particularly abundant as an apparent component of Araucarian vine forest between c. 165,000 and 126,000 years ago. These records clearly and markedly pre-date the arrival of Aborigines. Charcoal particles were present but infrequent in the Lynch’s Crater core prior to the arrival of Aborigines, but another north Queensland core (ODP820, offshore from Cairns) shows a continuous and abundant charcoal record stretching back c. 200,000 years.

There is no way of confirming whether RE 7.12.22 existed as an identifiable entity at such times. However, the altitudinal, climatic and geological conditions for its existence – higher tablelands with rainforest to the east and a declining gradient in rainfall to the west, with granitic or rhyolitic soils just to the west of the rainforest, may well have existed continuously – but with some geographic shifts as rainfall ebbed and flowed – for the last several hundred thousand years or more.

Coinciding at least loosely with the arrival of Aborigines in Australia c. 50,000 years ago, the frequency of charcoal in the Lynch’s Crater core increased markedly (Moss & Kershaw 2000). The Aborigines on the Tablelands experienced great fluctuations in climate associated with the last ‘Ice Age’, with a peak in aridity and coldness c. 18,000 years ago. Since then, rainfall has increased and, notwithstanding fire lit or started accidentally by humans, rainforest has expanded markedly across the Tablelands at the expense of eucalypt and casuarina forest (Hopkins et al. 1993; Haberle 2005; Hilbert et al. 2007). Haberle (2005) noted that a 23,000-year record of vegetation from Lake Euramoo on the Tablelands, an area now occupied by rainforest, changed progressively from “dry sclerophyll woodland” to “wet sclerophyll woodland” to rainforest, with casuarina pollen present throughout but very much more abundant during the two sclerophyll woodland phases.

Aboriginal use of the Tumoulin forests

Toohey (1991) provided an account of fire regimes in the Ravenshoe – Tumoulin area immediately prior to European settlement, apparently based on interviews with elderly Aboriginal women and the memoirs of the Swedish explorer, entomologist and anthropologist Eric Mjoberg who lived with the Jirrbal people close to the current site of Ravenshoe for several months in 1913 (Ferrier 2006). She wrote:

"Firing of the open forest was carried out towards the end of each dry season. The hunters burned patches of forest to encourage fresh growth after the storms and attract game to these small patches of green." (page 7)

Toohey also noted that the Jirrbal also foraged for plants in the "stands of stringybark, blue gum and bloodwood" (page 9). Wildfires occurred, Toohey reporting that:

"It was the enemy Pitcharu [spirits of the dead], for example, who started bushfires, ..." (page 6)
European settlement and the forest

Following the displacement of the Aborigines by European settlers, the Tumoulin forests were logged extensively, as indicated by the following quotes from Toohey (1991):

"In 1912, a year after the [railway] line opened, 2,759 tons of timber ... were freighted out of Tumoulin. .... In 1917, 4,360 tons of timber, 62 tons of firewood ... were consigned from Tumoulin ..." (page 36)

"Joe [Wolfe] had a contract to supply the Cairns Harbour Board with the turpentine piles which were cut from the scrub at Tumoulin." (page 38)

"The strong and durable timber from the stringybarks and bloodwoods was used for bridge decking, housing, construction materials and sleepers. From one huge stringybark one hundred and fifteen five foot sleepers were cut. Rose gum, yellow mahogany and oak provided strong building materials and the termite resistant mountain stringy made excellent fence posts. ... By 1917, 236,000 superficial feet of hardwood and 170,000 sleepers came through three sawmills on the Evelyn Tableland." (page 41)

"Quite a number of sawmills and sleeper mills were put in around Tumoulin." (page 44)

"During the depression the cutting of cordwood was a survival industry for many men. In 1932, 306 tons of cordwood were railed out of Tumoulin." [“cordwood” refers to a bundle of cut wood of specified size, and apparently not to a particular species.] (page 48)

Of relevance, Toohey also noted:

"On the forest floors where much timber-cutting had taken place, the timber left behind provided fuel for any bushfires that might occur. And bushfires there were, sometimes originating from the stacks of burning sawdust at the local mills or from the railway. At night, after a bushfire, the whole countryside would be aglow with the fires from burning timber residues." (page 41)

Ecology of key tree species

Many key tree species in RE 7.12.22 at Tumoulin have attributes that enable survival following even severe fire by most mature individuals through resprouting from stems and branches, and of most saplings by resprouting from below-ground (Table 2). However, a few do not. Rose Gum is vulnerable to crown fires, old hollow Rose Gum to fires that burn the trunk internally, and Rose Gum saplings to any fire, though taller saplings and vigorous mature individuals appear able to cope with fires that do not damage the crown. Fire may cause loss of above-ground parts in Brush Box (Lophostemon confertus) (Guinto et al. 1999) but it can resprout basally (personal observation). Sapling and smaller adult Turpentine may be quite vulnerable to fire, perhaps because the bark is not yet thick enough to protect the epicormic bud strands (see McArthur 1968 and Lawes et al. 2011 for exploration of issues in the bark thickness and fire resistance of Australian trees). Though it evidently has the capacity to resprout from stems and branches, Pink Bloodwood is perhaps less robust to fire than the Red Mahogany and Tindal’s Stringybark. Many upland rainforest trees of the region display a surprising ability to resprout basally, but not from stems, after fire (Williams 2000; Williams et al. 2012).
Table 2. Known and suspected attributes and responses to fire of key tree and shrub species in RE 7.12.22 at Tumoulin.

<table>
<thead>
<tr>
<th>Species</th>
<th>Attributes</th>
<th>Response to fire</th>
<th>Sources of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Mahogany (Eucalyptus resinifera)</td>
<td>has a lignotuber, thick protective bark and deeply embedded epicormic bud strands</td>
<td>vigorous resprouter as adult from trunk, presumably also as sapling from base; repeat fire may kill saplings</td>
<td>Guinto et al. (1999) CPBR (2006) DCF (personal observation)</td>
</tr>
<tr>
<td>Tindal’s Stringybark (Eucalyptus tindaliae)</td>
<td>has a lignotuber, thick protective bark and deeply embedded epicormic bud strands</td>
<td>vigorous resprouter as adult from trunk, presumably also as sapling from base</td>
<td>CPBR (2006) DCF (personal observation)</td>
</tr>
<tr>
<td>Rose Gum (Eucalyptus grandis)</td>
<td>no lignotuber; lacks a protective layer of dead bark except at base but may have thick protective layer of living bark; epicormic bud strands apparently not deeply embedded</td>
<td>saplings c. 0.5 – 8 m killed by fire; taller sapling and mature trees resistant to damage of internal stem organs but unable to re-sprout following canopy loss</td>
<td>Burgess &amp; Bell (1983) CPBR (2006) Nicolle (2006) Mark Parsons (personal communication)</td>
</tr>
<tr>
<td>Pink Bloodwood (Corymbia intermedia)</td>
<td>has a lignotuber, thick protective bark and deeply embedded epicormic bud strands</td>
<td>vigorous resprouter as adult from trunk, presumably also as sapling from base, though even low-intensity fires can cause some mortality</td>
<td>Guinto et al. (1999) CPBR (2006) DCF (personal observation)</td>
</tr>
<tr>
<td>Turpentine (Syncarpia glomulifera)</td>
<td>has deeply embedded epicormic bud strands</td>
<td>fuel reduction burns caused considerable mortality of plants &lt; 15 cm diameter</td>
<td>Burrows (2013) Guinto et al. (1999)</td>
</tr>
<tr>
<td>Brush Box (Lophostemon confertus)</td>
<td>thin smooth bark except at base; epicormic bud strands not deeply embedded</td>
<td>fuel reduction burns caused considerable stem mortality across all but the largest individuals, but some resprout basally</td>
<td>Guinto et al. (1999) Burrows (2002) DCF (personal observation)</td>
</tr>
<tr>
<td>Rose She-oak (Allocasuarina torulosa)</td>
<td>mature plants have thick protective bark</td>
<td>severe fire causes some mortality of mature plants; moderate fire doesn’t usually kill mature plants; saplings resprout from base; seedlings are fire-sensitive</td>
<td>Crowley (1986) Russell &amp; Roberts (1996) Morrison &amp; Renwick (2000) Williams (2000) DCF (personal observation)</td>
</tr>
<tr>
<td>Northern Forest Banksia (Banksia aquilonia)</td>
<td>has protected epicormic bud strands</td>
<td>re-sprouts after fire</td>
<td>George (1999)</td>
</tr>
<tr>
<td>upland rainforest trees (many species)</td>
<td>most lack thick protective bark; few or none have deeply-protected epicormic bud strands</td>
<td>in most species, stems readily killed by fire but many resprout basally; fire triggers germination and seedling recruitment in some</td>
<td>Williams (2000) Williams et al. (2012)</td>
</tr>
</tbody>
</table>
Responses of trees to fire other than survival are also relevant. For example, complex positive and negative diameter growth responses to fire can occur depending on the frequency and perhaps also the intensity of fire (e.g. Guinto et al. 1999). Even low-intensity fires trigger loss of flower buds in some eucalypts, but didn’t in Red Mahogany and Turpentine; in contrast, crown scorch delayed flowering in eucalypts including Red Mahogany, though by no more than 3 years (Law et al. 2000). Fire facilitates germination in many eucalypts (see Discussion), but represses it in Turpentine (Guinto et al. 1999).

Ecology of the Yellow-bellied Glider

The Yellow-bellied Glider (YBG) utilises a suite of resources of which sap from Red Mahogany and hollows in Rose Gum for denning are the most obvious (Goldingay & Quin 2004). Others documented are nectar, pollen, honeydew and arthropods (insects, spiders etc.) as food (Smith & Russell 1982; Quin et al. 1996). Nectar and pollen is obtained from Northern Forest Banksia and eucalypts in particular, and pollen is obtained also from a number of rainforest plants. Fairly frequent foraging among the loose bark on the lower trunks of Rose Gum is believed to be in search of arthropods (Quin et al. 1996).

The spatial scale of resource availability is influenced by the home range and gliding capacity of glider groups (Table 3). YBG can glide up to 150 m, the lesser distances in Table 3 reflecting an absence of need to glide further (QEC 1991). Landing heights of considerably less than 5 m have been recorded in Tumoulin (Alan Winlaw, personal communication). Gliders make repeat glides during the course of a night. The sum of nightly glide distances has not been documented for YBG though DERM (2011) report movements of up to 1 km. The mean nightly foraging distance of the smaller Mahogany Glider (Petaurus gracilis) was 1506 m with a range from 590 to 3420 m (Jackson 2000).

Table 3. Metrics of habitat use in the Yellow-bellied Glider, summarised from data collected to the south-east of Ravenshoe (QEC 1991).

<table>
<thead>
<tr>
<th>Metric</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>group home range (ha)</td>
<td>52.6</td>
<td>29.0 – 119.5</td>
</tr>
<tr>
<td>glide distance (m)</td>
<td>34.9</td>
<td>7.0 – 90.8</td>
</tr>
<tr>
<td>glide launch height (m)</td>
<td>30.8</td>
<td>15.0 – 45.0</td>
</tr>
<tr>
<td>glide land height (m)</td>
<td>11.0</td>
<td>5.5 – 22.8</td>
</tr>
<tr>
<td>glide angle (°)</td>
<td>31</td>
<td>20 – 46</td>
</tr>
</tbody>
</table>
**Lantana**

The relationship between Lantana (*Lantana camara*) and fire is complex and site-dependent. Lantana can be suppressed by shading and promoted by the increased light that is available following fire (Fensham *et al.* 1994; Gentle & Duggin 1997a; Duggin & Gentle 1998; Prasad 2012). However, many of these reports relate to dry rainforest and similar closed-canopy habitats and their application to the somewhat more open canopies of eucalypt forest may be limited. Indeed, St Clair (2010) reported that an intense fire in eucalypt forest reduced the cover of Lantana from 80% to c. 2.5%, though cover doubled in the following year. Similarly, in a moist eucalypt forest Russell & Roberts (1996) found that burning kept Lantana small and Lantana invaded unburnt areas. A prescribed fire reduced Lantana’s seed production but encouraged the growth of young plants (Osunkoya *et al.* 2013a). High-intensity fire had a greater impact on Lantana vital rates than did the prescribed burn, but neither controlled Lantana (i.e. caused population reduction) unless repeated at least every second year, with outcomes also somewhat contingent on site (Osunkoya *et al.* 2013a). Complex germination responses to fire have also been reported, Raizada & Raghubanshi (2010) finding that smoke enhanced the speed of germination, the proportion of seeds that germinated and the survival of seedlings, whereas Osunkoya *et al.* (2013b) found that fire reduced the seedbank and didn’t alter the proportion that germinated. Sundaram *et al.* (2012) reported that fire promotes Lantana when Lantana density is high but suppresses it when density is low.

A proportion of Lantana seeds retain viability for a number of years (Osunkoya *et al.* 2013b). Lantana suppresses seedlings of other species by allelopathic effects (Gentle & Duggin 1997b) and perhaps also by direct competition. Lantana enhances soil fertility, thus promoting its own growth (Osunkoya & Perrett 2011).

**Discussion**

*Dynamics of a changing forest*

Vegetation types and boundaries between them change over long time scales and in some cases are unstable even in the short term. Short-term instability may be created or stemmed by management, but equally may be driven by factors largely beyond management control. It is informative that rainforest has expanded with increased rainfall on the Atherton Tablelands since the last “Ice Age” notwithstanding the presence of Aboriginal burning. It is also informative that the expansion of rainforest at the expense of eucalypt forest during the last c. 50 years on the Tablelands and associated ranges (Ash 1988; Unwin 1989; Harrington & Sanderson 1994; Tng *et al.* 2012b) has occurred notwithstanding a possible decline in rainfall during this time (Smith 2004; Luffman *et al.* 2010; but see Suppiah *et al.* 2009 for a contrary perspective on rainfall trends). This has been attributed to changes to fire regimes (e.g. Ash 1988) and in particular the cessation of Aboriginal burning practices (e.g. Russell-Smith *et al.* 2004). However, Murphy & Bowman (2012) point out that recent expansion of tropical rainforest at the expense of savanna or open forest is a global phenomenon which may best be explained by the “carbon fertilization” effect – in which elevated levels of atmospheric CO₂ favour the growth of trees over grasses. For the Australian seasonal tropics, Bowman *et al.* (2010) argued that the carbon fertilization effect can overwhelm the effects of fire.

Moist and especially wet eucalypts forests in general sit rather precariously between more arid-adapted ecosystems and rainforest, with rainforest able to shade the forest floor and prevent the regeneration of light- and disturbance-dependent eucalypts (Goosem *et al.* 1999). Warman & Moles (2009) argued that wet sclerophyll forest in Queensland’s Wet Tropics is no more than a semi-stable state. The suggestion that wet sclerophyll forest may ultimately expand into drier forest areas, thus compensating for losses at the rainforest fringe, is strongly contingent on rainfall being the key driver of the process (Warman & Moles 2009). This is very likely to have been the case since the last “Ice Age” but not in recent decades – even if rainfall hasn’t declined in recent decades, it clearly hasn’t increased – so it seems unlikely that this process
is continuing. There is no evidence that compensation has occurred, though the proposition has not been formally evaluated.

Harrington & Sanderson (1994) showed that rainforest expansion in north Queensland’s Wet Tropics is most severe in pure stands of Rose Gum but also occurs in mixed eucalypt forests such as RE 7.12.22. Tng et al. (2012b) showed that this expansion is largely constrained to the immediate proximity of rainforest, occurring at a mean rate of 0.6 m per decade, which suggests that much of RE 7.12.22 is not under immediate threat of rainforest invasion. This is consistent with observed patterns of vegetation in the Tumoulin Forest Reserve.

However, an alternate model of vegetation change may be of greater concern for RE 7.12.22 in Tumoulin Forest Reserve. Rose She-oak may have been released from competition with eucalypts by logging, developing a dense mid-stratum that retards fire, reduces or prevents the establishment of eucalypt seedlings, and facilitates the establishment of rainforest species (Crowley 1986; Mark Parsons personal communication). Observation in Tumoulin indeed suggests that Rose She-oak has thrived in many areas where the density of eucalypts has been reduced by logging.

_Rose Gum: the odd one out_

Some evidence suggests that Rose Gum is an obligate seeder and thus has a very different mode of coping with fire to other eucalypts at Tumoulin. In spite of its extensive use as a forestry tree internationally and an extensive scientific literature to match (e.g. Campeoe et al. 2013), ecological data about Rose Gum in the wild is very limited beyond observations of rainforest invasion. One trait typical of obligate seeders – absence of a lignotuber – is a defining character of the species, distinguishing it, for instance, from the closely-related Sydney Blue Gum (E. saligna) (CPBR 2006). Also typically of obligate seeders, growth from seed is exceptionally fast, Myers et al. (1996) reporting average heights of more than 12 m in three years in irrigated and fertilised plantations. However, an inability to resprout epicormically after a crown fire is not well documented and could also reflect the rarity of such events in the environments in which it occurs. Tng et al. (2012a) reported it to be an obligate seeder based on citation of Nicolle (2006), but Nicolle actually stated that its regeneration strategy is “unknown”. The statement that it is unable to resprout following a crown fire (Table 2) is based on observations by Mark Parsons, the generality of which is uncertain.

Though individuals may perish in crown fires, the ultimate ecological question is whether populations persist in the face of fire. Though Rose Gum might be eliminated by crown fires repeated at relatively short intervals (perhaps < 100 years), such fires are likely to be infrequent in this ecosystem. The persistence of Rose Gum within RE 7.12.22 with its demonstrable history of Aboriginal burning and wildfire is confirmation that Rose Gum is not fire sensitive at a population level; it seems likely that regeneration from seed is triggered by fire.

However, some evidence suggests that Rose Gum does not completely fit the characterisation of obligate seeding eucalypts outlined in the section _Eucalypt forests and fire_. Though Rose Gum can and often does occur in mono-dominant stands, its presence as small stands and scattered individuals within RE 7.12.22 (which is dominated by resprouter eucalypts) at Tumoulin suggests a capacity to regenerate from seed in the presence of competition. Further, at least some stands of Rose Gum at Tumoulin are of mixed age, with saplings, young (pre-reproductive) and mature trees growing together, further indicating a capacity to regenerate in the presence of competition.
**Fire and Tumoulin**

All dominant trees and perhaps all plants in RE 7.12.22 within the Tumoulin Forest Reserve can cope with one-off fires including crown-destructive fires. Varying combinations of fire frequency and severity may influence relative abundance and forest structure. Seasonal timing of fire may also influence subsequent patterns of regeneration, but in this ecosystem there is limited possibilities for variation in timing. The natural source of ignition is lightning which is most likely to occur and trigger a forest fire in October and November. Aborigines burnt late in the dry season, though this hasn’t been defined. Low-severity management burns might occur in drier patches from the mid-dry season on, but in general this forest system is likely to be flammable only late in the dry season.

RE 7.12.22 is a fire-dependant ecosystem at at least two temporal scales. The first is that the environment immediately following a fire is favourable for establishment of eucalypts seedlings, and they and some other tree species may not regenerate from seed under any other naturally-occurring circumstances. The second is that fire exclusion for long periods is likely to lead to at least portions of the forest becoming more or less permanently non-flammable due to the establishment of fire-suppressive Rose She-oak and rainforest trees, thus permanently precluding regeneration from seed by eucalypts.

Fire is not the only factor influencing the many variations in structure and understorey composition that exist in the Tumoulin Forest Reserve and even within RE 7.12.22. Logging history has doubtless played a role by creating canopy gaps that would otherwise occur infrequently, and this is likely to have promoted the growth of suppressed mid-storey species, notably Rose She-oak, and invasion by Lantana. Local variation in soils is likely and doubtless contributes to heterogeneity. Rainfall and evaporation varies strongly with altitudinal variation within this forest system. Moisture availability for plants will also be influenced by landscape position (run-on, run-off; also aspect) and the moisture-holding capacity of the soil. These underlying sources of variation in vegetation interact with fire by contributing variation to fuel loads, drying rates and flammability.

Though the forest would cope with an extensive crown fire, the Yellow-bellied Glider would most likely not do so with mortality occurring within dens high in Rose Gum occurring during fires, and subsequent to fires due to loss of foraging potential (e.g. flowering of eucalypt crowns). Populations of YBG in the Wet Tropics region may have occasionally been eliminated by such fires but, prior to European land clearing, sites were more likely to eventually be recolonised. Recolonisation by YBG is constrained by their gliding capacity, requiring connectivity in the form of trees spaced less than c. 150 m apart and optimally considerably less. Such connectivity between Tumoulin and forests to the north and south remains but has been greatly reduced and, within habitat that YBG may recognise as suitable, effectively eliminated. The ability of YBG to survive non-crown fires of higher severity is unknown but plausible, and clearing of vegetation around den trees to save the trees may also serve to save the gliders within them. The impact of non-crown fires on the resources needed by YBG, and their response to such impacts, has not been documented. Northern Forest Banksia is a key nectar source which resprouts after fire but is likely to delay flowering in consequence. YBG forage among loose bark on the lower trunk of Rose Gum, and this option may be unavailable for some time after fire – bark is shed annually in many eucalypts. YBG also make use of resources provided by rainforest trees, and these are likely to be affected by fire. Even fires that don’t destroy tree crowns cannot be assumed to have negligible consequences for the availability of resource for YBG.

Occasional low-severity fires are unlikely to cause significant harm to the forest or any of its components, particularly if individual fires are not of great extent. The scant record suggests that Aborigines used small-scale low-severity fire to facilitate hunting of game. However, such fires will not achieve the key management objective of maintaining this ecosystem in the long term face of succession towards mid-storey dominance by Rose She-oak and rainforest elements; indeed, they may have the opposite effect by triggering germination of rainforest elements and not subsequently curtailing their growth (Williams 2000).
Notwithstanding populist generalisations from other environments, there is no evidence that Aborigines burnt most of this forest ecosystem frequently. Frequent low-severity fires may prevent the maturation of rainforest elements but are unlikely to prevent or remove dominance by established rainforest elements and by Rose She-oak. They elevate mortality rates of eucalypt saplings (Guinto et al. 1999) and may prevent eucalypt seedlings from developing to maturity. There may also be negative implications of such a fire regime for other elements of biodiversity (e.g. ground-dwelling small mammals, shrub-dwelling birds and some plants), and for soil processes.

In attempting to curtail the growth of seedling and saplings of Rose She-oak and rainforest elements, there is likely to be some trade-offs between severity and frequency. In other words, a more severe fire may have greater impact and thus require less frequent repetition.

**Suggestions for management**

The key to juggling these many somewhat contradictory demands outlined in Table 1 lies, I believe, in variability of fire regimes so as to yield a heterogenous (varied) landscape. This is an argument for variation in fire severity and inter-fire interval applied in a mosaic of unevenly-sized patches. It stands in stark contrast to notions that there is an optimal fire prescription that should be applied repeatedly and throughout. Fixed fire prescriptions typically have a single objective (e.g. maximising wood production or fuel reduction) and aim (at least implicitly) to reduce variation in order to generate conformity to the defined end.

Patchiness of fires enhances variation in the understorey and mid-storey and maximises the length of edges between micro-environments. The Aborigines well understood the value of such edges, for instance between dense shrubbery and grassy understoreys, to facilitate the abundance of prey as well as the practicality of hunting. Patchiness maximises possibilities for recolonisation by small fauna and plants. It should also maximise foraging options for the Yellow-bellied Glider. Such patchiness could and should proactively include retention of some patches of mature Rose She-oak and rainforest trees, though it may be highly desirable that the proportion covered by these formations be reduced. It should also include extensive areas of sclerophyllous shrubby understorey as well as grassy and sedge-dominated understoreys.

The scale of patchiness is both a practical and conceptual issue. To ensure a continuous diversity of foraging options for each YBG group, fire patches should ideally be considerably smaller than group home ranges which are c. 30 to 120 ha. Individual fires of variably between 1 to 10 ha would seem ideal, but would require an intensity of management that is likely to stretch the available resources. I must, however, express concerns about plans for a single 300 ha fire (or 300 ha patch resulting from a series of contiguous burns in one year or consecutive years or even near-consecutive years) notwithstanding that some heterogeneity within such an area is inevitable due to local variation in flammable fuel loads, wind speeds and slope angles.

Throughout this Discussion, I have employed the term severity as defined by QPWS (2012) in lieu of the widely used but less appropriate term intensity. For open forests, QPWS (2012, page 14) define five classes of severity: Low, Moderate, High, Very High and Extreme. High severity fires have some inherent patchiness. They will scorch some canopies up to 20 m but not generally taller trees such as are typical of RE 7.12.22. High severity fires appear to offer the best compromise of possibilities for manageable fires with potential to curtail Rose She-oak and rainforest elements whilst avoiding extensive crown scorch and minimising the risk to gliders. However, in the interests of heterogeneity not all fires should be of this intensity – and low severity fires will be useful as firebreaks for high severity fires (Mark Lawson, personal communication). A hypothetical scheme is shown in Fig. 1.
As with fire severity and patch size, variation in the interval between fires contributes to environmental heterogeneity. I recommend against fixation on a particular interval or narrow band of intervals. Some constraints on maximum interval may be set by the need to burn before rainforest elements grow sufficiently as to preclude further fire, but this will vary between sites and I see no reason to preclude this successional pathway from all forest patches. There is little data available about the consequences of fire interval in the ecosystem, but much can be learnt by experience and observation of growth after known fires. Considerable knowledge to this end has already been acquired by QPWS staff (Mark Lawson personal communication).

An important additional consideration in appraising the desirability inter-fire intervals is to acknowledge that fire itself is a stressor on the ecosystem. This is particularly relevant to the enhancement of fragments where populations and the entire ecosystem may already be stressed (as they are at Tumoulin). The immediate consequence of fire for many small animals such as those that require cover is to reduce the carrying capacity of the environment both by reducing habitat (e.g. cover) and its productivity. Plants that need to resprout must divert resources away from flowering and fruiting, so that the availability the flowers and fruit on which many species of fauna depend are depleted following fire (e.g. Law et al. 2000 for eucalypts and Osunkoya et al. 2013a for Lantana, though in the latter case a reduction in fruiting may be desirable). It is for this reason that I believe that inter-fire intervals should be considered conservatively but also re-evaluated in the light of evidence and actual outcomes. I suggest that a modal inter-fire interval for any given patch of more than 10 years would be an appropriate starting point for adaptive management.

A reduction in the cover of Lantana is desirable to promote natural regeneration and facilitate access to the forest for research and management. Fire has potential to contribute to that objective by reducing the cover of individual plants, but there appears to be no potential for eradication or even major population reduction using any fire regime that is acceptable in Tumoulin. The management of fire in Lantana is tricky because it dries late in the season but generates high fuel loads when dry (Mark Lawson, personal communication). Further, there is a real risk that fire could promote Lantana by enabling it to colonise or thicken in areas where it is not yet dominant.

Fire is not the only management tool available, and on its own will not be sufficient to achieve all objectives. Manual cutting of Rose She-oak might be a practical additional control measure. This could involve commercial or private cutting for firewood provided the practice is undertaken in a manner designed to optimise conservation outcomes. For example, concentration of the activity in patches until
the resource is locally depleted may yield much better conservation outcomes than allowing it to occur sporadically throughout the forest. Conversely, logging of eucalypts is very likely to have negative implications for Yellow-bellied Gliders both through depletion of key food resources and facilitation of dominance by Rose She-oak.

Much remains to be learnt about both the practicalities and impacts of management in Tumoulin for conservation of the ecosystem, of the Yellow-bellied Glider population, and of other elements of biodiversity. Further, in a time of changing climate, impacts and outcomes have an additional element of unpredictability such that even the “known” may prove incorrect. Monitoring and learning-by-doing rather than by prescription is key and I strongly endorse the concept of management as an experiment – adaptive management (Walters & Holling 1990). Three questions stand out among many possibilities for active monitoring:

- under what circumstances do Yellow-bellied Glider survive, or not survive fire?
- what is the impact of fires of various severity on the resources gliders use? and
- what is the impact of varying fire severity on the cover and population of Lantana both in areas where it currently dominant in the understorey and in areas where it is not?

Tumoulin Forest Reserve has already proven ideal in many ways for research as shown by the current Yellow-bellied Glider project. There is great potential to expand this by collaboration with research institutions with the aim of improving our understanding of the fire ecology and biodiversity of this ecosystem. For example, and these are but a few of many possibilities, the following projects would seem eminently suitable for research by Honours and/or PhD students and address key questions with long-term practical application to forest management and the conservation of biodiversity:

- what is the impact of shading, litter and competition from Rose She-oak on the germination and establishment of seedlings of eucalypts and rainforest trees?
- what can stand structure tell us about the history and regeneration of Rose Gum?
- how often and in what circumstances do resprouting eucalypts produce seed and do their seedlings become established?

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