Guidelines for managing fire in northern bettong (Bettongia tropica) habitat
These guidelines have been developed and produced by the Queensland Department of Environment and Heritage Protection (EHP) as part of the 'Bettongia tropica population status, viability and impacts of fire' project, in collaboration with the World Wide Fund for Nature Australia (WWF-Aus), Queensland Parks and Wildlife Service (Department of National Parks, Sport and Racing) and James Cook University. This project was funded through the Australian Government's Caring for Our Country grants program which was administered by WWF-Aus.


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Foreword

The endangered northern bettong (*Bettongia tropica*), a small truffle-eating kangaroo-like marsupial endemic to the Wet Tropics, is one of more than 150 species in Queensland that have suffered the effects of a changed fire regime.

As numbers of the northern bettong continue to decline across most of its range, the need to restore appropriate fire regimes becomes critical. As a conservation tool, fire is perhaps one of the most difficult to wield effectively and accurately. Fire management is a complex science. It requires careful planning and an intimate knowledge of the local conditions.

These guidelines provide the current best practice for managing fire in northern bettong habitat and are designed to be used by land managers.

It is hoped that this practical guide will assist the conservation of the northern bettong in the Wet Tropics. It also highlights the importance of fire as a tool in the conservation of Queensland’s vulnerable and unique species. Please consider it in your conservation endeavours to save one of Queensland’s rare and threatened species.

Dr Steven Miles MP

Minister for Environment and Heritage Protection and

Minister for National Parks and the Great Barrier Reef
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How to use these guidelines

Inappropriate fire regimes are partly, if not predominantly, responsible for the decline of the endangered northern bettong. Although there is limited empirical data to directly support this, the impacts of fire on northern bettongs are based on expert opinion and observation. Information contained in these guidelines is a summary of knowledge derived from expert elicitation, review of the literature and workshops held with experts, practitioners, indigenous groups and stakeholders.

These guidelines provide general principles for managing fire in northern bettong habitat and more specific recommendations for managing habitat features. It should be read in conjunction with the QPWS Planned Burn Guidelines for the Wet Tropics Bioregion of Queensland (http://www.npsr.qld.gov.au/managing/planned-burn-guidelines.html) which provide fire management recommendations for all fire vegetation groups and for the most common fire management issues. For information on how to assess when to burn to implement the recommendations, refer to the QPWS guideline: “How to assess if your planned burn is ready to go” (http://www.npsr.qld.gov.au/managing/planned-burn-guidelines.html). Where there are gaps in knowledge a risk management approach is recommended.

These guidelines will be incorporated into the Queensland Parks and Wildlife Service’s fire management system, FLAME, and into accompanying fire strategies within northern bettong habitat. Fire Reports entered into FLAME will record the parameters and conditions under which burning is implemented, and the scale and extent of burning undertaken.

These guidelines should be reviewed within two years (no later than 2019) and updated as more information becomes available.
Northern bettong habitat

Northern bettongs (*Bettongia tropica*) are found mostly in the eucalypt woodlands and forests located within 10km of rainforest but also occur in *Allocasuarina* spp. forest [2-4]. They prefer eucalypt woodland with a sparse, grassy ground cover [2,5] and are restricted to the wetter end of sclerophyll habitat that occurs to the west of rainforests in the Wet Tropics [6] (Figure 1). Habitat of the northern bettong has been impacted by disturbance associated with grazing and timber, within one of the core regional ecosystems (RE 7.12.22) that they occur in being considered endangered (biodiversity status) under the Vegetation Management Act 1999 [7]. See Appendix 1 for a full list of regional ecosystems in northern bettong habitat.

This habitat is where the northern bettongs' two critical food resources overlap: hypogeal sporocarps from ectomycorrhizal fungi (truffles which grow on the roots of trees) and cockatoo grass, *Allotheropsis semialata* [1]. Truffles, which grow in high rainfall areas, make up over 60% of the northern bettongs diet rendering the northern bettong less able to live in drier habitats utilised by the rufous bettong (*Aepyprymnus rufescens*) [3,8,9]. These truffles grow on large *Eucalyptus* spp. and *Allocasuarina* spp. trees [3,10]. Cockatoo grass (and the fleshy underground stem bases which the northern bettong eat) becomes especially critical in the dry season and during dry years when truffles are less prolific [8]. This dependence on a mix of spatially and temporally variable resources makes management of the northern bettong a delicate balance.
Figure 1 Map of northern bettong potential habitat
How fire impacts northern bettongs

Fire management has been identified as a key action necessary to recover populations of the northern bettong [1]. Estimates suggest northern bettongs have disappeared from 50-90% of their range [11,12] and as such they are considered endangered at the state, federal [13] and international level (IUCN Red List – International Union for the Conservation of Nature). Introduced predators e.g. feral pigs and grazing are thought to be moderate threats while inappropriate fire is considered a major threat to northern bettong populations [14].

It is hypothesised that a lack of fire has resulted in habitat loss/modification leading to the large range contractions observed in this species [15,16]. It is unclear how these habitat changes have caused population declines, however, presumably fire impacts the availability of critical resources such as truffles, cockatoo grass and shelter. As more information becomes available on the relationship between fire and northern bettong populations, recommended fire regimes may need to be tailored accordingly.

Previously it was thought that the primary impact on northern bettongs was the lack of fire resulting in open forest transitioning to closed forest (Figure 2 [1-3]) which in turns impacts on resource availability. However, the relationship between fire and northern bettong populations is complex. It may be that fire directly impacts on food resources (Figure 2 [4]) and/or directly impacts individual bettong (Figure 2 [5]). It is also likely that fire interacts in some way with other threats such as predation and grazing pressure to increase the impact on bettongs.

![Figure 2 Possible relationship pathways between fire and northern bettongs](image)

1) Lack of fire leads to thickening of northern bettong habitat
2) Shading from thickening impacts ground layer
3) Change in resources impact northern bettongs
4) Fire impacts cockatoo grass/grass diversity and truffles
5) Fire impacts northern bettong survival

Figure 2 Possible relationship pathways between fire and northern bettongs

Initial investigations indicate that the presence of fire alone does not cause mortality, loss of body condition, shifts in home range or changes to breeding success in northern bettongs [4,9,15,17,18].

Northern bettong habitat can shift from an open to closed structure in several ways. In the drier open woodlands where bettongs mostly occur, saplings of a number of sclerophyll species, for example Allocasuarina torulosa, can become over abundant in the mid-stratum and reduce the health of the ground layer through competition and shading. In the wetter parts of the northern bettongs range, the tall open forests can transition towards a closed forest structure when rainforest pioneer species, become dominant in the mid-stratum, also reducing the health of the understorey and shading out grasses and other understorey species and subsequently changing the composition and structure of the community.
Several studies have found evidence that tall open forests within the northern bettongs range have already transitioned to closed forest. Harrington and Saunderson (1994) estimate at least 70% of tall open forest has transitioned in the Wet Tropics. Thomas et al. (2015) found that in the wetter areas of northern bettong habitat, transitioning was as high as 99%. The prevailing hypothesis is that this transitioning is caused primarily by lack of fire [19]. There is a suggestion that rainforest has expanded in a response to climate change [20], however subsequent studies suggest change in community structure cannot be explained by climate and geology alone [19]. This is supported by a recent analysis which found that the areas of northern bettong habitat where fire was largely excluded had very high levels of transitioning and habitat where fire was used frequently there was less transitioning [21].

Habitat that has changed from open to closed can result in both the loss of truffles and cockatoo grass. In the tall open forest where rainforest pioneers have become dominant, the availability of truffles is reduced because rainforest species produce truffles with much smaller fruiting bodies [22]. There is also less cockatoo grass because the rainforest species form a dense layer shading out grasses which may be replaced by sedges [19]. Similarly, thickening in open woodlands changes the ground cover from grasses (including cockatoo grass) to sedges and other shade-tolerant species [8].

There are other threats that may add to and/or amplify the impacts of fire. Long term changes in rainfall and temperature could influence truffle availability [3, 8, 23]. Cockatoo grass can be impacted by weed invasion, over-grazing by cattle and rooting by feral pigs [24]. The northern bettong could be impacted from competition by the rufous bettong which is able to consume a greater variety of food and can live in drier habitats [25]. Although evidence for this competition is lacking, rufous bettongs now occur in localities where northern bettongs were frequently observed but are now thought to be absent (e.g. on the Australian Wildlife Conservancy property of Mt Zero-Taravale Nature Refuge and adjoining area of Paluma State Forest). Low level predation impacts could be exacerbated by fire if predators are more successful or northern bettongs more vulnerable immediately after a fire [26] although there is currently no evidence that this is the case.

Fire management has the potential to improve the future viability of northern bettong populations by reducing rates of transitioning and thickening thus potentially preventing future loss of truffle and cockatoo grass. If habitat has been altered through lack of fire then it follows that returning suitable/appropriate fire into a system may prevent further impacts. Unfortunately we currently have no certainty of what a suitable fire regime for northern bettongs is. There is little evidence available from the historical or paleontological records to reconstruct the regime prior to disturbance. In addition, the diversity of landscapes, topography, climate and soil across the northern bettong habitat compounded by the uncertainty with how vegetation responds to fire means it is not simply a question of returning fire to landscapes. There is however a growing body of knowledge around post fire response [27].

Clearly there is a long history of traditional burning practices and indigenous fire knowledge which can be used to inform and refine current fire regimes. While much of this knowledge has been lost, active fire management by current generations of traditional owners in these areas is increasing. A more recent understanding of what an appropriate regime may resemble, comes from land managers burning the landscape, and observing how vegetation responds. Advances in fire management in the long term should draw upon all this available information.

Of particular consideration in managing/restoring bettong habitat with fire is the degree of habitat change that can be realistically achieved given resources and timeframes. Maintenance of eucalypt woodlands and forests that are in good condition is most easily achieved (i.e. avoiding the transitioning and thickening), while recovering woodlands which have already transitioned to a closed structure, is far more difficult [16, 27], particularly in the case of dense Allocasuarina spp. forests (J. Kanowski pers. comm.). Getting a fire started in these transformed vegetation communities is difficult, therefore current efforts to manage northern bettong habitat with fire have concentrated on maintaining an open grassy structure, preventing thickening and further transitioning and where possible reversing transitioning and thickening where it is in the early stages [28]. Fire in this context is a preventative or maintenance tool, used primarily to maintain what exists in good condition, but used less commonly to recover open habitat that has become closed.

The following chapters outline general recommendations based on current best practice fire regimes in northern bettong habitat given what is feasible to achieve with fire. These general recommendations suggest the fire intensity, frequency, proportion to burn, and timing. Many other factors go into decision making about fire and these general recommendations should be interpreted in conjunction with individual fire strategies, local knowledge of the site and climatic conditions and checklists provided in the Planned Burn Guidelines [28], “How to assess if your burn is ready to go”[28].
Methods for implementing fire

While predicting the exact behaviour or impacts of a fire is difficult, managers can increase the likelihood of achieving the desired fire by choosing when to burn, under which conditions and how frequently. This will influence the behaviour of the fire through its intensity, the percentage area burnt and the impact of the fire on the vegetation. These guidelines provide recommendations for fire parameters where information is available (refer Table 1).

Table 1 Definitions of fire parameters (see "How to assess if your burn is ready to go" for more information)

<table>
<thead>
<tr>
<th>Fire parameters</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggested conditions</td>
<td>Suggested conditions affecting fire intensity and patchiness including wind, relative humidity (%) and soil moisture (0-203 KBDI*).</td>
</tr>
<tr>
<td>Fire Danger Rating (FDR) / Fire Danger Index (FDI)</td>
<td>A relative number (0-100+) and rating denoting an evaluation of rate of spread (m/hr), or suppression difficulty for specific combinations of fuel moisture and wind speed.</td>
</tr>
<tr>
<td>Interval (min, max time between fire)</td>
<td>The number of years between fire events at the same point in the landscape, usually provided as a range reflecting the minimum and maximum intervals required for ecological function of the community.</td>
</tr>
<tr>
<td>Intensity</td>
<td>The amount of energy released per unit length of the fire front. Can be measured in units of kilowatts per metre of the fire line (kWm-1).</td>
</tr>
<tr>
<td>Season</td>
<td>Month or time of year (in general: dry = April to October, wet = November to March).</td>
</tr>
<tr>
<td>Patchiness</td>
<td>A percentage or proportion of the ground layer vegetation (grasses, herbs and trees/shrubs less than one metre) not affected by fire (i.e. 20% patchiness = 80% burnt).</td>
</tr>
<tr>
<td>Fire severity</td>
<td>A post-fire measure of the effect of fire on the vegetation and soil (e.g. vegetation consumption, vegetation mortality, soil alteration). Char height (burnt leaves) and scorch height (brown leaves) are surrogate measures for severity.</td>
</tr>
</tbody>
</table>

*KBDI: Keetch–Byram drought index*
Indigenous fire knowledge

For aboriginal people in the Wet Tropics, fire is an integral part of looking after country. Fire is used in a range of ways by traditional owners. Fire can be used in hunting, by encouraging kangaroos and wallabies to feed on the green grass that grows after a fire [30] or by catching animals as they escape a fire [31]. Fires can be used to ‘clean up’ country [32] and keep country open [31] and to prevent large wildfires [33]. While fire can be used to maintain a healthy country it can also be damaging if undertaken with adverse conditions. High intensity fires can also move into the rainforest and kill food plants and damage cultural sites [32]. Similarly fire management can avoid wildfires [33] that can damage resources and sites. There are a number of indigenous groups that overlap with the northern bettong habitat. Therefore the fire regimes for managing northern bettong habitat based on indigenous fire knowledge, are not site or group specific but rather a summary of broadly applicable principles and approaches.

Fire regimes in the general area where northern bettong habitat exists, according to many of the traditional owners of this region, should be “cool”, “slow” and “little”. While fires would be lit throughout the year, the majority of fire would be started early in the dry (season) [32], with low intensity ignition techniques such as spotlighting with matches [33]. Fires ignited later in the year during the drier and hotter months can be too hot and kill trees and animals and should be avoided [33, 34]. Fires should be small in size, ensuring fires do not escape to other people’s country [35] and that animals still have corridors to move through [33]. Fires should be implemented in a mosaic with a different patch burnt each year [39]. This will prevent large wildfires which in this country can be extensive >50km wide [33].

There are ecological indicators in the landscape that can signal when to start fires such as when certain plants are flowering or fruiting [33, 36, 37]. Lighting in low wind conditions should ensure the fire goes out and is not too fast or too big [33, 38]. Lighting a fire against the wind can be a good option too [34] and lighting fires on ridges or spurs will ensure the fire moves slowly downhill at a low intensity (not killing trees) [37]. Before a fire is lit the soil moisture should be checked. If the grass, for example, is too dry then fires should not be lit [30].

Traditionally each group had their own part of the landscape they were responsible for burning [33]. In some instances, only certain people can burn country [36] or elders have to give advice about when to burn [37]. Traditional owners prefer walking country, lighting matches, over aerial incendiaries. This is so people are on the ground when lighting fires to ‘talk to the story’ [32], talking with elders and passing on knowledge. It is also critical that the impact of burns is monitored. It is important that someone goes out to see how the country changes over time [39].
### Table 2 General indigenous approach to fire management (in and around northern bettong habitat)

<table>
<thead>
<tr>
<th>Fire parameters</th>
<th>Fire characteristics</th>
<th>Quotes from traditional owners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggested conditions</td>
<td>Low wind</td>
<td>“if the wind just blow up, it’ll burn everything” (38)</td>
</tr>
<tr>
<td></td>
<td>Grass not 100% cured</td>
<td>“they (senior custodian) pick up the grass, scrunch it up in their hand, and if it gets too powdery, well it’s no more lighting grass” (30, 33).</td>
</tr>
<tr>
<td>Interval</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Intensity</td>
<td>Low</td>
<td>“Slow, cool burns let animals crawl up the trees (i.e. ants) and other can move” (33)</td>
</tr>
<tr>
<td>Patchiness</td>
<td>Small, patchy fire</td>
<td>“100% black after a burn is bad” (33) “don’t light all the bush, light a little bit” (30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“they burn 2 or 4 acres” (35)</td>
</tr>
<tr>
<td>Season</td>
<td>Mostly early dry</td>
<td>“good to do little burns in April” (33)</td>
</tr>
<tr>
<td></td>
<td>Throughout year</td>
<td>“burn cool time, June or July” (36)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“when it gets to real hot time, they won’t light no more then” (30)</td>
</tr>
<tr>
<td>Fire severity</td>
<td>Low to moderate</td>
<td>“to burn grass, just a good fire, not destroy anything” (34)</td>
</tr>
</tbody>
</table>
Broad fire management principles

**Burn to avoid large, hot fires**
Fires that are large in extent and high intensity have high potential to cause damage, not only to northern bettongs, but to a range of flora and fauna species. Wildfires usually exhibit these characteristics.

**Burn for a diversity of fire intervals**
A diversity of fire intervals is good for biodiversity and northern bettongs, especially given we are unsure of what fire regimes bettongs prefer. There should be range of fire intervals. Some areas should be less frequently burnt (up to a maximum interval) and other areas should be more frequently burnt (down to a minimum interval).

**Burn to retain cover at the scale of home range**
Northern bettongs need cover within their home range during and post fire. When planning an individual planned burn, aim to retain some unburnt cover (i.e. 50-70% mosaic) across a broader area.
Managing northern bettong habitat with fire

The practice of fire management is a highly adaptive process, guided by the experience and skill of the practitioner and highly dependent on the conditions of the day. Accurately predicting outcomes of an individual fire is difficult. Therefore this guide is based on the objectives set by northern bettong experts and experienced land management practitioners. Each following chapter addresses an objective (see below), summarising the importance of the objective to northern bettong and its relationship to fire, outlining a fire approach with more detailed recommendations where information exists.

1. Maintaining healthy habitat
2. Providing home range scale refugia
3. Promoting truffle diversity
4. Maintaining cockatoo grass (as a food resource)
5. Improving grass diversity
6. Providing resource refugia
7. Providing seasonal refugia
8. Regaining connectivity
9. Improving habitat (reducing lantana)
10. Improving habitat (reducing thickening/early stages of transitioning)
11. Increasing habitat (reversing advanced thickening and transitioning)

Recommendations are provided for the two fire vegetation groups (FVG), open forest of the foothills and ranges and tall open forest, that occur in northern bettong habitat (see Appendix 1 for corresponding regional ecosystems and map of FVGs). Northern bettong are more often found in the open forest of foothills and ranges which contains open eucalypt and woodland communities with a grassy, shrubby understorey. Tall open forest is at the wetter end of their distribution and contains tall (>30m) open eucalypt forests and woodlands, typically dominated by one or more canopy species.

These guidelines will be updated as more information becomes available on the complex fire ecology of northern bettong habitat.
1. Maintaining healthy habitat

Northern bettongs and their habitat

Northern bettongs prefer open woodland and forest habitats with sparse yet diverse, grassy ground cover [2]. Their preference for an open habitat probably relates mostly to the associated grassy ground cover which they use for food and nesting/shelter. They may also prefer an open forest structure as it allows ease of movement for foraging [33].

Northern bettong habitat and fire

Regular low to moderate intensity mosaic burns maintain this open forest and woodland structure, promoting grass and managing the numbers of emerging saplings. Regular burns (within recommended interval range) also reduces the risk of large, damaging fires sweeping through long unburnt patches, promoting the overabundant recruitment of woody plants. The process of fire masking can identify these areas. The mapped fire history of a site highlights the areas outside the recommended fire interval (too infrequent fire) which can then be targeted for management (see Figure 3 for example). These planned burns should to be implemented at a scale of the home range of the northern bettong (see following chapter). Fire can further be used to restore habitats in the early stages of changing from open to closed structure (see Chapter 10).

Fire management approach

- Regular, low to moderate severity mosaic burns (late wet/early dry seasons).
- Burn at the scale of home range.
- An occasional moderate to high severity burn should manage emerging overabundant trees saplings and address thickening and transitioning (see Chapter 10 for details), however caution needs to be applied to ensure unburnt refugia and earlier burn scars are implemented to lower impact on northern bettong populations.

Where there has been an accumulation of fuel in longer unburnt habitat timing of burning should be brought forward (earlier than typical) and conducted over a number of years. This is because fire behaviour and intensity will be above the ‘normal’ range, meaning unburnt patches will be more difficult to achieve. Continue to burn where the fire can still self-extinguish overnight. Consider in this situation using more scattered spot ignition especially to carry fire on suspended fine fuels perched out of contact with soil moisture as these dry out earlier and faster (hydrophilic fuels).

Figure 3 Example of ‘fire masking’ where areas outside the recommended fire interval are highlighted red and used to prioritise management efforts
2. Providing home range scale refugia

Northern bettongs and their home range

Northern bettongs shelter in nests during the day which protect them from predator detection and provide shelter against environmental conditions. These nests are generally located in cover such as the skirts of grass trees, grass close to a log [4] or are simply constructed of grass and other vegetation [28].

The most recent published estimate for the average home range for males and females is 59ha [4]. This study was conducted in 1995–96 at Davies Creek. It is anticipated that updated estimates will be become available as new research emerges and this figure may need to be adjusted. Preliminary figures indicate that home ranges might be smaller than previously thought. Results from recent PhD research estimates male home range ~ 40ha, and female home range ~ 20ha (unpublished data, T. Whitehead). It is worth noting there is likely to be large variation in home range size between individuals. For example, Vernes and Pope (2001) observed a variation in home ranges from less than 20 ha to more than 130 ha.

Northern bettongs exhibit high site fidelity and are unlikely to move out of their home range even in the event of a significant disturbance [4, 40].

Home range refugia and fire

It is likely northern bettongs survive low-moderate intensity fires [17]. It appears that individuals do not move their home range in the presence of fire [4]. Evidence indicates that northern bettongs can cope with a fire the size of their home range if there are other features such as boulder piles, fallen trees and non-burning patches of vegetation where they can take refuge [4]. Boulders in particular could play a critical role in post fire survival [4]. See below for recommended approach to fire management and more specific information in Table 4.

Fire management approach

- Planned burns should retain refuge features in the home range of an individual northern bettong (60ha).
- Refugia can take the form of larger areas of unburnt vegetation, for example, around gullies with an individual burn scar of no more than 60ha (clustered approach) or scattered patches of unburnt features across the home range (scattered approach) (see Figure 4).
- The area of unburnt refuge for the planned burn is recommended at 30–75% left unburnt.
- As a suggested technique, this can be achieved through multiple, scattered spot ignition to encourage low to moderate intensity fires, typically ignited from spurs and ridges, to reduce extent burnt in any one fire.
- Weather parameters, particularly average nightly temperature being below 17°C, low average wind speed (below 10 km/h), stable relative humidity above 45% and reliable dew point will provide favourable fire weather conditions for fire to self-extinguish; especially when finer fuels are not fully cured.
- Avoid moderate fire severity around boulders, by timing of burns to ensure that fire gradually lowers intensity as it burns in proximity to boulders and rock outcrops.
Options for achieving burns at home range scale – scattered vs clustered

Retaining refugia within the home range of northern bettongs can be achieved in at least two ways. The clustered approach allows for greater proportion burnt but in patches of 60ha or less, whereas the scattered approach assumes the planned burn will be larger than the home range in size (60ha) but will retain patchiness throughout the burn. These options are provided in a schematic in Figure 4. In this example the objective is 70% patchiness (burnt within the burn scar). Option 1 is to burn in home range scale patches (<60ha). This level of patchiness (the proportion of ground layer not burnt) can be low as long as the area outside the burn scars patches are largely unburnt. Preference should be towards fire scars that tend to be narrow, linear and elongate rather than circular, blobby and wide, to minimise the distance to reach unburnt refuges. Option 2 is to burn areas much larger than the home range but when doing so the patchiness within the burn scar must be high i.e. >30% unburnt. There may be several approaches to achieving these outcomes. One example for achieving the scattered approach is provided in Case study 1 and another for the clustered approach in Case study 2. To assess whether or not the planned burn has achieved the objective of burning at home range scale measure one of the objectives in Table 3.

Figure 4 Schematic of options for fire patterns at home range scale

Blue line is the burn scar. The red circle indicates the relative size of the northern bettong home range. Option 1 is to burn in home range scale patches (<60ha). Option 2 is to burn areas much larger than the home range but the patchiness within the burn scar must be high i.e. >30% unburnt).
<table>
<thead>
<tr>
<th>Option</th>
<th>Measurable objective</th>
<th>How to be assessed</th>
<th>How to be reported (in fire report)</th>
</tr>
</thead>
</table>
|        | **1** Largest individual burn areas no more than 60ha (widest patch no more than approx. 850m).                                                                                                                                                                               | **Choose one of these options:**  
  - Walk one or more transects across the narrowest section of the largest burn scar patch.  
  - Use an aerial assessment to map the boundaries of the burnt areas with a GPS, plot on map and thereby determine the size of the largest patch.                                                                                       | Achieved:  
  100% of the total number of individual burnt areas have burn scars no wider than 850m or no burn scar >60ha.  
  Partially achieved:  
  >75% of the total number of individual burnt areas have burn scars no wider than 850m or no burn scar >60ha.  
  Not achieved:  
  <75% of the total number of individual burnt areas have burn scars no wider than 850m or no burn scar >60ha.                                                                                                                  |
|        | **2** Patchiness (for example 70% burnt, 30% unburnt) is achieved throughout the burn scar.                                                                                                                                                                                   | **Walk one or more 850m transects (taking into account the variability of landform and likely fire intensity) and estimate the % ground layer unburnt.**  
  **Use an aerial assessment to map the boundaries of the burnt areas with a GPS, plot on map and thereby determine the size of the largest patch.**                                                                                           | Achieved: >30% unburnt  
  Partially achieved: 20–30% unburnt  
  Not achieved: <20% unburnt                                                                                                                                                                                                 |

Table 3 Measurable objectives for maintaining home range scale refugia
Table 4 Guidelines for fire management - parameter ranges for maintaining healthy habitat and home range scale refugia

<table>
<thead>
<tr>
<th>Fire parameters</th>
<th>Fire characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open forest of the foothills and ranges</strong></td>
<td><strong>Tall open forest</strong></td>
</tr>
</tbody>
</table>
| **Suggested conditions** (soil moisture) | <130 KBDI  
Thatch and long unburnt fuels will burn under lower KBDI of near 90  
Dew point (reliable, typically below 17°C) | <170  
When rain can reliably be expected or there is good return soil moisture  
Relative humidity 50–75% range |
| **Fire Danger Rating (FDR)** | <12 | <14* (*with an accompanying rising relative humidity) |
| **Interval** (min, max time between fire) | 2–5 years (moist grassy open forest and dry grassy open forest)  
6–10 years (grassy to shrubby) | 3–5 years (grassy understorey)  
6–10 years (shrubby understorey) |
| **Intensity** (fire height) | Low to moderate  
<0.5–1.5 m | Low to moderate  
<0.5–1.5 m |
| **Patchiness** (area unburnt) | 30–75%  
Grass curing: 60–80% | 20–40%  
Grass curing: 80–90% |
| **Season** | April-Jun (a longer wet winter may see burning extend beyond a typical end in early June, to carry into August) | In conjunction with first storm burst ~50–75mm (Nov-Jan, burning typically occurs within ~3 days of a rain event on clear, sunny weather) |
| **Severity** | Low to moderate | Low to moderate |
Case study 1 – home range burn: clustered

Burning mid-morning as heavier overnight dew starts to evaporate, using clustered spot ignition parallel to the prevailing terrain (i.e. along the top of a ridge or spur), will typically leave more continual areas of unburnt refuge lower and mid slope, and usually around the heads of gullies and moister areas. Known in a traditional owner sense as ‘circle fire’, this creates fire radiating out from a central point of ignition and under low wind strength, does not readily create a head fire where the fire will run in a prevailing direction. Rather, a more uniform, slower rate of spread around the whole perimeter will be generated as the fire expands out relatively evenly. Spot ignition is usually clustered to be approximately 100m or greater apart, though ignition may be in several locations at each loci to generate sufficient flame. This technique is very beneficial for long unburnt scenarios, where there is reasonable thatch and hydrophilic perched fuels, as fire will burn on those fuels but be slowed by greener, uncured grasses (~60-80%). The use of light breezes, ignition later in the afternoon (past 2pm), cloudy weather and stable relative humidity (above RH 45%) will also aid to generate ‘circle fire’, and help to self-extinguish the fire flanks more easily on greener or patchier fuels.

Photo 1: Gully mosaic – leaving 40% unburnt.
Mark Lawson, QPWS, Dinden National Park (2009)

Photo 2: Mild fire leaving duff with readily self-extinguishing fire behaviour against wetter substrates.
Mark Parsons, QPWS, Girringun National Park (2010)
Case study 2 – home range burn: scattered

Usually conducted in conjunction with colder, drier conditions than cluster burning as fine fuels start to rapidly cure, scattered ignition typically employs ignition along both the prevailing topography (i.e. following ridge and spurs), plus extending perpendicular to prevailing terrain features (i.e. down slope and across mid-slope). The intent is to generate small controlled head fronts that travel out perpendicular to a central ignition point, and as a continual line of fire to consume a higher rate of available fine fuels than cluster burning. Ignition spacing is usually much closer (typically <50m and generally 10m apart), with line ignition sometimes employed. It is more effectively employed in a mitigation sense, to lower fuel risk on slopes and drier forest fuels on spurs around rock outcrops, to lower the risk of late dry fire entering bettong habitat. Fine fuels are typically reasonably cured, and timing of burning is generally around a lower relative humidity of ~40%, ignition typically occurring during the warmer part of the day, and usually on a light to moderate breeze and low overcast day (3/8 or lower cloud cover). Scattered mosaics can also be achieved by staged burning, e.g. drier areas are burnt earlier in the season to minimise fire intensity and followed-up several weeks later to target some or most of the unburnt refuge areas, for fire to be able to move through those pockets.

Photo 3 Reducing potential intensity on fire-prone ridges around boulder outcrops
Mark Parsons, QPWS, Girringun National Park (2007)

Photo 4 Converging line ignition to reduce smothering blady grass cover (dry winter)
Mark Parsons, QPWS, Taravale (2007)
3. Promoting truffle diversity

Truffles and northern bettongs

Truffles make up approximately 60% of the northern bettong’s diet [3, 15]. Truffles grow on the root system of large Eucalyptus spp. and Allocasuarina spp. trees [3, 10]. Northern bettongs are known to consume a great number of different types of truffle (estimates range from 35-147 species) [4, 15, 40, 41]. There is mounting evidence that northern bettongs are essential to the life-cycle of many truffles and that the loss of northern bettongs could lead to a decline in truffle diversity (unpublished data S. Nuske).

Truffles and fire

There is no clear conclusion on whether fire promotes or supresses the growth of truffles [42-44]. It is likely that different truffle species respond to an individual fire and fire frequencies in differing ways [43-46].

It is possible that immediately post-fire northern bettongs have higher foraging success because the fire has cleared away the ground layer and other obstructions [18]. Truffles depend on their host tree so any destructive fire that killed large Allocasuarina spp. or Eucalyptus spp. could potentially cause an immediate decrease in the abundance of truffles. Later in the year or during dry years truffles may occur more abundantly in gullies and wetter areas (for example in stands of Allocasuarina littoralis). Stands dominated by Allocasuarina spp. or emerging Allocasuarina spp. are commonly targeted in fire management to reduce thickening. Allocasuarina littoralis is more likely to occur in stands in wetter areas supporting truffles and can be sensitive to high severity fires whereas other Allocasuarina spp., such as Allocasuarina torulosa exhibits recoppicing after fire and is more likely to result in mid-stratum thickening. A diversity of fire regimes (frequency, intensity, seasonality) should ensure some truffles are responding well at any one time within the wetter months.

Fire management approach

- Regular mosaic burning (temporal and spatial variation) [28].
- Avoid large scale fires with the potential to severely scorch Allocasuarina littoralis stands, and avoid deliberate ignition within denser Allocasuarina torulosa (she-oak) stands (encourage fire to trickle within, rather than advance steadily).
- Avoid high intensity, drier fires for tall open forests, instead utilise storm burst burning where prior immediate rain will have percolated through leaf litter and the top soil layer, likely to stimulate truffle production.
Photo 5 Damaging, high fire severity impact on fire killed stand of *Allocasuarina* spp. *Allocasuarina littoralis* can easily be prone to intense fire behaviour due to accumulation of the needle bed.

Mark Parsons, QPWS, Mt Halifax, Paluma Range National Park (2005)

Photo 6 Moderate fire severity targets gradual thickening of *Allocasuarina torulosa* (forest she-oak) saplings. *Allocasuarina torulosa* recoppices from fire so higher fire intensity which won’t kill this species, however low to moderate fires help to keep overall forest structure and diversity in balance.

Mark Parsons, QPWS, Williams Creek, Paluma State Forest (2016)
4. Maintaining cockatoo grass

Cockatoo grass and northern bettongs

Northern bettongs eat the stem base of cockatoo grass, mostly during the dry season when truffles are less abundant [3, 8]. They make up a very important part of their diet [8].

Cockatoo grass and fire

In general, cockatoo grass responds well to fire [9, 47-50]. Its competitive advantage is that it uses the nutrients and carbohydrates stored in its stem base to persist through the dry and be ready to flower quickly after the first wet season rains [24]. This can make it sensitive to early wet season fires [24].

In general however, lack of fire can have a negative impact on cockatoo grass because: other perennials such as kangaroo grass can outcompete it [51], litter accumulation suppresses growth [49] or it can be impacted by shading from canopy species that can start to dominate in the absence of fire. Shading my disadvantage cockatoo grass more than other native perennial because it is a poor competitor [52, 53].

Fire management approach

- Regular mosaic burning (temporal and spatial variation) [28].
- Plan to burn when there is moisture in the ground to promote fast recovery.
- Avoid frequent or extensive fire in the early wet [8, 53].
5. Improving grass diversity

Grass diversity and northern bettongs

Apart from truffles, northern bettongs can eat a variety of lilies and grasses [3]. Although cockatoo grass seems to be a preferred food source it is possible they can/will eat a number of species. In addition, greater grass diversity leads to greater habitat complexity providing a more varied environment to find nest sites, shelter and other resources. For example, kangaroo grass and Xanthorrhoea spp. provide important refuges [28]. In addition, higher grass diversity may correlate with sparser ground cover which northern bettongs prefer over a denser ground cover [5]. This is supported by anecdotal evidence of northern bettongs rarely (if ever) being trapped in sites dominated by dense swathes of blady grass (pers. comm. J. Koleck).

Grass diversity and fire

Native perennial and annual grasses have different reproductive strategies and therefore respond differently to fire. For example, while cockatoo grass uses its underground stores to respond to conditions, it can regrow immediately after fire and seed with the first rains [53]. Other species, such as blady grass Imperata cylindrica, produce vast quantities of seeds that can survive the dry season and germinate with the first rains. Blady grass also has an advantage that it can reshoot from rhizomes (shallow root system) directly after fire, and can dominate particularly in dry conditions when other species struggle to recover. Kangaroo grass can become dominant, particularly in the absence of fire, when the thatch can exclude other ground cover as a continual blanket. As kangaroo grass thatch fuel accumulates, it may increase the likelihood that a larger extent of habitat is burnt in a single fire event, consequently reducing areas of unburnt refuge.

In general, appropriately scaled disturbance from fire creates an opportunity for shorter perennials such as cockatoo grass and annuals to gain a competitive advantage over taller perennials which can dominate through size and reproductive strategy in the absence of disturbance. Large, perennial grasses such as kangaroo grass also benefit from fire in the longer term, but under regular early burning will be less likely to dominate resulting in a more diverse ground cover and species.

The other factor which can influence grass diversity is when the ground cover is shaded through a closed canopy, thickening of an extended needle bed from Allocasuarina torulosa, or by a dominant leaf litter associated with rainforest pioneers as a result of the lack of fire. More shade tolerant species are favoured such as sedges [28], as the mid canopy becomes denser, and as the needle bed or leaf litter accumulates as a smothering, continual layer. By being densely compacted and typically thicker in diameter, she-oak needle beds and rainforest leaf litter tend to be less flammable, retain higher moisture, and are generally more fire resistant than the finer fuels associated with native grasses.

Over time grass diversity decreases as a result of shading. This is because fine, more flammable fuels disappear and fire becomes less frequent and less intense allowing larger species to dominate and reducing suitable fire conditions for other species.

Fire management approach

- Regular mosaic burning (temporal and spatial variation) – interval: 2–5 years [52, 54].
- Plan to burn when there is moisture in the ground to promote fast recovery.
- Avoid burning under very cold conditions (below 10°C) as grasses and bulb dependent species are placed under higher stress to reshoot, which may result in potential mortality or stunted growth.
- Target long unburnt areas for fire management (see Chapter 1 for suggested approaches).
- Where thickening and transitioning has resulted in a shaded ground cover, fire management to manage this issue can lead to an increase in grass diversity, usually gradually over several burn cycles rather than any one single burn.
- Monocultures/swathes of dense blady grass can be selectively burnt early in the year, where there is an accompanying level of accumulated thatch, to allow competition from other native species and to avoid higher intensity impacts from fire later in the year.
6. Providing resource refugia

How northern bettongs use resource refugia

Northern bettongs are particularly vulnerable to extended periods of low rainfall because truffles, their main food resource, are sensitive to water availability [8, 43, 55-57]. Truffle fruiting is delayed by at least several weeks after rain and they need a certain amount of rainfall to fruit [55].

Northern bettongs depend heavily on truffles as a resource during the wetter months [8]. While truffles occur throughout northern bettong habitat, they occur in greater abundance and biomass in the wetter parts of the habitat. Prolonged periods of low rainfall, especially during the wetter months, mean the areas that can support significant volumes of truffles and therefore bettongs is even narrower [3]. Degradation or loss of habitat in this narrow band, while not necessarily impacting bettongs during good years, can have significant impacts during drier years. It is hypothesised that the wetter parts of the habitat form a resource refuge when truffle abundance is reduced by persistent dry conditions.

The exact set of conditions that would cause truffles to contract/decline sufficiently to impact northern bettong densities is currently unknown. However, it is thought that these conditions might arise in a dry or failed wet season and be more likely after a series of years of below average rainfall. It is during the wetter months that these resource refugia might be a concern. Measurements that may assist in identifying these conditions include: below average seasonal rainfall (KBDI) and below average long term rainfall (rainfall deficiency ranking).

Resource refugia and fire

The long term management of resource refugia requires targeted effort to maintain open habitat in the eastern parts of the northern bettong habitat (see Increasing habitat and Improving habitat). The presence of a resource refuge might also be a consideration for overall population management. For example, reducing transitioning might not be a priority for a site that has plenty of open habitat in wetter areas, however a site where there has been significant transition in wetter areas might require targeted effort and progressive burning to maintain access to a resource refuge.

Planned burns in the wetter parts of northern bettong habitat can often have the objective of reducing or lowering rates of transitioning. The intention of these burns is to lower the density of rainforest saplings that shade native grasses to a tipping point of exclusion. They are usually late season/storm seasons burns of moderate to very high intensity with a large proportion of the ground cover burnt [28] and with a prolonged fire residence time (slow moving fire) to sufficiently scorch rainforest pioneers. These planned burns may need to be considered in the light of the possible impacts on a remnant population, and typically will rely on earlier burning in drier, open forest habitat, to ensure fire severity is contained to the area of transitioning without damaging adjoining areas of healthier habitat.

Fire management approach

Long term fire management of resource refugia outside these extended dry periods or where the risk to northern bettongs are low, would not involve particular consideration.

Fire management during extended dry periods may need a more cautious approach, especially where there is a remnant population. As the population may be more restricted to the refuge, the planned burn should first be assessed for the risk to the population.

- Refer to the Risk assessment for planned burns.
- During a failed wet season/extended dry period, fire severity can occur earlier than normally anticipated. Planned burns in adjoining habitat may need to be brought forward earlier in the year to lower the risk of unintended high severity fire that could escape into the resource refugia.
7. Providing seasonal refugia

How northern bettongs use seasonal refugia

Northern bettongs depend on a combination of truffles and the stem bases of cockatoo grass [3]. Each resource is available at different times of the year and northern bettongs forage predominantly on truffles when their abundance is high during the wetter months and on the stem bases of cockatoo grass when they are largest in the drier months [8].

Seasonal refugia and fire

Fire has the potential to both promote and impact these seasonally available resources. Current understanding on the impact of fire on truffles is that different species respond in different ways so that a diversity of fire during ‘truffle season’ should ensure continued availability to northern bettongs during this time (see Promoting truffle diversity).

Seasonal refugia should not be considered as being spatial as such (meaning that northern bettongs do not migrate or congregate according to the availability of resources in any geographic sense), but rather temporal (that is, within an area of habitat there are different food resources available at different times of the year and northern bettong depend heavily of the availability of each at different times).

‘Cockatoo grass season’ occurs in the dry season when truffles become less dependable as a food source. Cockatoo grass can be promoted by fire and is thought to be fire adapted [47-51, 58]. It competes well with other perennial grasses after fire as it uses the stores in its underground stem base to resprout after a fire [58]. For the purposes of managing seasonal availability for northern bettongs, promoting above ground growth and long term prevalence of cockatoo grass is different from promoting the food source i.e. the stem base. While it is possible that fire can support growth of the stem base by making more nutrients available it has also been suggested that fire can lead to a reduction in the size of the stem base as it reallocates biomass to above ground regrowth [58, 59].

Fire management approach

‘Truffle season’ (wetter months)

- See Promoting truffle diversity

‘Cockatoo grass season’ (drier months)

- As a precaution if burning later in the year ensure cockatoo grass can replenish stem base by burning with reliable, higher soil moisture (usually under extended and longer wet season or winter rainfall).
- Avoid extensive fire during cold, dry winter periods by burning with reliable dew point (amount of condensation overnight) and stable relative humidity.
- Avoid burning under persistently drier soil conditions because they will use their store to reshoot, lowering available nutrient and energy for northern bettongs.
- To ensure the planned burn does not impact seasonal refugia see Risk assessment for planned burns section.
- If a low risk, refer to Maintaining cockatoo grass
8. Regaining connectivity

Northern bettongs and connectivity

Northern bettongs have experienced a severe population decline \cite{11, 12}. An exacerbating factor of such a significant decline is the fragmentation and isolation of populations. Northern bettongs are likely to be particularly susceptible to the negative impacts of fragmentation. This is because northern bettongs tend to stay within their home range \cite{4} and genetic isolation has already occurred even in geographically connected populations \cite{40}. In addition, northern bettong habitat is extremely narrow \cite{2-4} and at risk of fragmentation from open woodland and forest becoming closed forest which further restricts access within the band of available habitat. Where populations are separated by new barriers such as unsuitable habitat, it is unlikely they would move through it or even travel larger distances to go around an expanse of unsuitable habitat given known fidelity to a home range, habitat resource partitioning and territorial behaviour.

Increasing connectivity with fire

Fire can be used as a tool to maintain and/or improve connectivity between populations. Potential barriers can be identified with expert knowledge and field verification (see example Figure 5). These areas can then be targeted with fire management to increase connectivity.

Figure 5. Example of a priority area for fire management (circled in blue) to maintain connectivity of northern bettong habitat in Mount Windsor National Park.
Fire management approach

- Where a planned burn is used to maintain/regain connectivity a follow up burn may be required if the burn has not extended far into the areas of thickening/transitioning. These burns should be a priority for assessing burn outcomes. To maintain connectivity the evaluation should focus on where and how far the fire reached.

- Be aware that drainage lines and gullies are more vulnerable to thickening and this can create linear barriers in the landscape that left unmanaged, can expand out perpendicularly under a poorly managed fire regime and infrequent fire interval.

- Maintain connectivity – see Fire management approach for Maintaining healthy habitat.

- Regain lost connectivity – see Fire management approach for Increasing habitat.

- Regain reduced connectivity due to thickening– see Fire management approach for Improving habitat.

- Regain reduced connectivity due to lantana– see Fire management approach for Improving habitat (reducing lantana).
9. Improving habitat (reducing lantana)

Northern bettongs and lantana

Where *Lantana camara* occurs in dense and continually extensive infestations, it shades out native grasses, reducing food resources for the northern bettong. Typically, lantana contributes to thickening of understorey habitat and to a lesser degree, is found in association with rainforest pioneers expanding out on wetter gullies and margins. It is possible northern bettongs can use small patches of lantana for shelter and to move through (J Koleck pers. comm. 2016), but this is considered co-incidental.

Improving habitat with fire

Fire may be a sensible approach for managing lantana where dense ‘old mother’ thickets act as a barrier to the depth and coverage of fire. A series of burns can be effective to reduce the abundance and density of lantana, especially when lantana re-grows with returning, higher soil moisture.

Too frequent, cool intensity fire can adversely promote lantana under certain conditions; by removing available fuel to sufficiently scorch scattered lantana canes that then may form larger, denser infestations.

Fire management approach

- Repeated low to moderate severity fires might be sufficient to control lantana where some native grasses still remain as wicking fuel.
- For dense infestations a moderate to high severity fire may initially be required but need to ensure a high severity fire does not move into adjoining habitat.
- More serious infestations may require fire in combination with pre or post fire herbicide treatment (see Planned Burn Guidelines 2013, pp.227-33 for more information).
- Where lantana has been promoted, a low to moderate severity backing fire in moist soil conditions could kill the lantana by prolonging fire residence time.
- Leaf damage impact, reduced flowering/ seeding and density of lantana biocontrols should be assessed to determine whether further integrated control is required.
- Late, dry fire is ineffective for the control of lantana, as plants shut down and active, live parts of the plant are insulated under the soil.

Photo 7: Burning on fully cured leaf fuels but when soil moisture is high, promotes longer residence time for flames to boil sap within the base of lantana clumps. Avoid burning during dry times, as lantana will shut down and fire will be ineffective for control.

Mark Parsons, QPWS, Society Flats, Kirrama National Park (2015)
10. Improving habitat (reducing thickening/early stages of transitioning)

Northern bettongs and thickening/transitioning habitat

An overabundance of saplings recruiting to the mid-storey degrades northern bettong habitat by shading the ground cover that leads to a loss of grass cover and diversity, and potentially narrowing the food resource partitioning of northern bettongs.

A pulse of germination following higher intensity and severity late season fire such as the dense recruitment of hopbush *Dodonaea* spp. or longer wattle *Acacia* spp. will also contribute to thickening.

Improving habitat with fire

In the early stages of thickening fire can retard many of the saplings and impede the thickening process before it progresses to more advanced, entrenched stages. Where thickening is already advanced, fire will be a less effective tool (see *Increasing habitat*). More than one fire might be required to address the issue as many of these species resprout after fire, and are particularly stimulated by higher intensity, later season fire events.

See below for recommended approach to fire management, more specific information in Table 5 and an example in Case study 3.

Fire management approach

- Burn during approaching storm season.
- Burn with the aim of scorching the tip of mid-stratum saplings.
- Moderate severity with higher intensity burns, with slower rate of spread and longer residence time for sufficient sapling scorch.
- Consider a follow up burn if there is flush of the overabundant species; note the next, return burn should aim to occur prior to the flowering/seeding of ephemeral species (typically ~4 years since fire).
- Progressive burns conducted earlier in the year to reduce surrounding fuel loads, will enable targeting of the area of thickening, and assist fire containment (ensure sufficient regeneration for bettong refuge before implementing next burn).
Case study 3 – improving habitat (reduce thickening)

Reducing thickening typically requires drier conditions to promote a moderate to high fire severity, yet still with reasonable soil moisture (KBDI range ~130 to 160). The intent is to enable fire, both on the head and flank, to advance into thickened vegetation once fuels are either near fully cured or the duff layer is drier, that enables fire to move continually across that locality. Both running fire (burning with the breeze) and backing fire (burning into the breeze to prolong fire residence time when flames reach the needle bed layers) can be employed. Controlled, small converging ignition lines may be appropriate to ensure sufficient intensity for the fire to be drawn into a thickened pocket. Mechanical and manual thinning can be an effective means to enhance thickening treatment; however it is very site intensive and typically more appropriate at narrow connectivity corridors.

Photo 8 Using running fire on heavy fuel beds to suitably scorch she-oak and rainforest pioneers.

Mark Parsons, QPWS, Taravale (2007)

Photo 9 Backing fire trickling on deep needle fuel bed, to aid increasing native grass diversity.

Mark Parsons, QPWS, Mt Fox (2003)
Table 5 Fire guidelines - improving habitat by reducing thickening or reducing early stages of transitioning

<table>
<thead>
<tr>
<th>Fire measures</th>
<th>Fire characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open forest of the foothills and ranges</td>
</tr>
<tr>
<td>Suggested conditions (soil moisture)</td>
<td>&lt; 160 KBDI</td>
</tr>
<tr>
<td>Fire Danger Rating (FDR)</td>
<td>&lt; 14</td>
</tr>
<tr>
<td>Interval (min, max time between fire)</td>
<td>&lt; 5 years</td>
</tr>
<tr>
<td>Intensity (flame height)</td>
<td>Moderate 0.5-3.0 m</td>
</tr>
<tr>
<td>Patchiness (area unburnt)</td>
<td>20 % (&gt; 30% for high severity)</td>
</tr>
<tr>
<td>Season</td>
<td>Progressive (July to November)</td>
</tr>
<tr>
<td>Fire severity</td>
<td>Moderate to high</td>
</tr>
</tbody>
</table>
11. Increasing habitat (reversing advanced thickening and transitioning)

Northern bettongs and closed habitat

Loss of habitat from open forest transitioning towards closed forest has been identified as one of the primary drivers of northern bettong declines (1). The grass layer suitable for northern bettongs is lost through shading and competition (27) and this effectively reduces the availability of shelter and nest sites and food resources for the northern bettong.

Increasing habitat with fire

Recovery of open habitat that is close to transitioning to closed forest, using fire, can be extremely difficult (28). This is because once the canopy is closed, ground layer plants are shaded out and are cooler and wetter (16), thus typically less flammable. Therefore the conditions and opportunity to use fire to increase habitat by opening closed woodlands and forests are rare and need careful planning.

Fire may have a greater impact on advanced transitioning/thickening where some disturbance, such as a cyclone, has already opened up the canopy. Fires could be timed to take advantage of this state or alternatively by manual or mechanical clearing could simulate this disturbance prior to burning (J. Kanowski 2016 pers. comm.). This is a more costly approach but may be useful where the recovery of habitat is imperative.

Potential impacts on adjacent fire sensitive communities, with world heritage and high biodiversity value (usually restricted species) should also be carefully considered when burning areas in advanced stages of transition. See below for recommended approach to fire management and more specific information in Table 6.

Fire management approach

- Fire only (see Table 6 for fire parameters for tall open forest).
- Storm burns with high relative humidity and temperatures, impending rain and good, percolating soil moisture.
- Burn with the aim of scorching the tip of overabundant saplings.
- Utilise ignition tactics and timing that will encourage a slower rate of spread and prolonged fire residence time (see "How to assess if your burn is ready to go").
- Moderate to high severity – avoid very high severity fires with extensive scorching and very high ground cover loss – this will typically further entrench rather than retard transition, and create non target, fire sensitive damage.
- Will likely need a follow up burn to retard more saplings and if there is flush of the overabundant species.
- Progressive burns earlier in the year will reduce surrounding fuel loads and help contain and focus fire intensity within the transitioning habitat (ensure sufficient cover regeneration for refuge before implementing next burn).
- Avoid this approach in exceptional circumstances (such as the extremely dry, hot conditions that prevailed in 1990-91 and 2003) because there is a risk the fire could carry and impact sensitive rainforest communities, cloud zone microphyll rainforest, and other, wetter, restricted upper altitude vegetation types and associated species.
- Options for clearing plus fire for open forest of the foothills and ranges and tall open forest
- Tree felling plus herbicide, reapply herbicide where trees resprout, burn when possible, follow-up burns to kill resprout.
- Herbicide only, reapply herbicide where trees resprout, burn when possible, follow up burns to kill resprout.
Table 6 Guidelines for fire management – restoring communities in the advanced stages of transitioning

<table>
<thead>
<tr>
<th><strong>Fire parameters</strong></th>
<th><strong>Fire characteristics</strong></th>
</tr>
</thead>
</table>
| **Suggested conditions** (soil moisture/rainfall) | Must burn in conjunction with a returning soil moisture gradient (> 50 mm rain event in or around following 3 days, on clear sunny weather)  
Burn under higher and returning relative humidity values (> 50 % ) |
| **Fire Danger Rating (FDR)**                     | < 16                                                                                     |
| **Interval** (min, max time between fire)        | Aim to return interval to less than 5 years                                               |
| **Intensity (fire height)**                      | Low to high  
0.5-3.0 m                                                                                      |
| **Season**                                       | Potentially Nov-Jan  
(in conjunction with first storm burst)                                                    |
| **Patchiness** (area unburnt)                    | > 30 %                                                                                     |
| **Fire severity**                                | Moderate to high                                                                           |
Risk assessment for planned burns

Although northern bettongs are generally thought to be fire-adapted [4], an individual fire has the potential to have a negative impact on sub-populations. The significance of this has increased now that populations have been severely reduced in size and are highly fragmented [1]. Remaining populations neither have the choice of refuges they once did nor the capacity to rebuild from adjoining populations after a disturbance. Therefore it is important to manage the risk that planned burns could have on northern bettongs. A simple risk management approach will aid in avoiding any potential catastrophes.

The first step in the risk assessment process is for a land manager to identify whether the site is low, medium or high risk (see Table 7) and hence whether a Fire Risk Assessment is required. Where required, a Fire Risk Assessment (see Table 8) will be conducted during fire planning to ensure appropriate measures are considered and the proposed burn will not negatively impact on northern bettongs.

This risk assessment aims to ensure that planned burns that may pose a risk to a northern bettong population are identified and considered well before implementation. When a planned burn is assessed as being a risk the recommendation is to review that burn. That means exploring alternative options to reduce this risk. This can be achieved by further consulting the relevant sections of these guidelines, seeking advice from peers or colleagues or approaching professional networks (such as the fire referral group for Queensland Parks and Wildlife Service (QPWS)). It is important to realise this risk assessment is not to discourage early season burning, in fact early season burning is strongly encouraged.

Where one or more risk criteria cannot be adequately lowered, a case by case evaluation will need to be considered on acceptable risk; particularly around a threat posed by a late season fire event to that local population. Specifically designed monitoring and evaluation programs will often be valuable in this situation, as these are often very illustrative of how resilient northern bettongs are to fire within their habitat and aid the refinement of knowledge around seasonality of burning.

This risk assessment should be incorporated into the fire management framework of QPWS as an added component of the burn proposal (within the FLAME fire system) and the burn plan approval process of the Fire Referral Group, for all burn proposals in protected area estate involving northern bettong habitat.

Table 7 Risk assessment for planned burns at sites with northern bettongs

<table>
<thead>
<tr>
<th>Population Status*</th>
<th>Risk that a planned burn could impact northern bettong population</th>
<th>Fire risk assessment required</th>
</tr>
</thead>
<tbody>
<tr>
<td>No population</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Stable population</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Possible/remnant population</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Declining population</td>
<td>Medium</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Population status is based on current best available knowledge. Where no data is available use precautionary principle (i.e. if historically there was a small population and it may still be there, consider it ‘possible / remnant’).
Table 8 Recommended fire risk assessment

<table>
<thead>
<tr>
<th>POTENTIAL BURN IMPACTS</th>
<th>FIRE RISK ASSESSMENT</th>
<th>Circle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will the planned burn...</td>
<td>Yes – consult and review (see suggestions on previous page to reduce burn risk)</td>
<td></td>
</tr>
<tr>
<td>Will the planned burn...</td>
<td>Yes – consult and review (see suggestions on previous page to reduce burn risk)</td>
<td></td>
</tr>
<tr>
<td>Will the planned burn...</td>
<td>Yes – consult and review (see suggestions on previous page to reduce burn risk)</td>
<td></td>
</tr>
<tr>
<td>...remove seasonal refugia? (see Objective 7)</td>
<td>Northern bettongs rely on the nutrients found in the shoot base of cockatoo grass in the dry season when truffle availability is low. When cockatoo grass sprouts post fire it is possible it uses it’s below ground stores in the process.</td>
<td>No / Yes</td>
</tr>
<tr>
<td>...remove resource refugia? (see Objective 6)</td>
<td>Northern bettongs are particularly vulnerable to extended dry periods when truffle availability is limited and populations may be restricted to the wetter areas during these years. If during an extended drier period will the planned burn during the wet season remove &gt;50% grass cover or small scale refugia on the wetter margin of habitat?</td>
<td>No / Yes</td>
</tr>
<tr>
<td>...remove home-range scale refugia? (see Objective 2)</td>
<td>The home range of the northern bettong is 60 ha. During a fire they are may find refuge in non-burning areas within the burn scar. Are fire/weather conditions conducive to removing &gt;70% of grass cover within the home range? OR are the conditions conducive to burning patches larger than home range?</td>
<td>No / Yes</td>
</tr>
<tr>
<td>...remove seasonal refugia? (see Objective 7)</td>
<td>Northern bettongs rely on the nutrients found in the shoot base of cockatoo grass in the dry season when truffle availability is low. When cockatoo grass sprouts post fire it is possible it uses it’s below ground stores in the process.</td>
<td>No / Yes</td>
</tr>
<tr>
<td>...remove resource refugia? (see Objective 6)</td>
<td>Northern bettongs are particularly vulnerable to extended dry periods when truffle availability is limited and populations may be restricted to the wetter areas during these years. If during an extended drier period will the planned burn during the wet season remove &gt;50% grass cover or small scale refugia on the wetter margin of habitat?</td>
<td>No / Yes</td>
</tr>
</tbody>
</table>

1 Current published home range estimate ~ 60ha. See Chapter ‘Providing home range scale refugia’ for more information on home range size estimate.

2 See Chapter ‘Providing resource refugia’ for more information on when and where resource refugia occur.
# FIRE RISK ASSESSMENT – additional considerations

<table>
<thead>
<tr>
<th>Circle</th>
</tr>
</thead>
<tbody>
<tr>
<td>No – proceed</td>
</tr>
<tr>
<td>Maybe – proceed with monitoring</td>
</tr>
<tr>
<td>Yes – proceed with mitigation</td>
</tr>
</tbody>
</table>

## POTENTIAL POST BURN IMPACTS

<table>
<thead>
<tr>
<th>Will the planned burn amplify the impact of other threats?</th>
</tr>
</thead>
<tbody>
<tr>
<td>While fire alone may not impact northern bettongs, it is often the case that fire in combination with a threat can have the unintended consequences.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Does the planned burn increase the impact of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predation-------------------------------------</td>
</tr>
<tr>
<td>Grazing pressure-------------------------------</td>
</tr>
<tr>
<td>Feral pigs------------------------------------</td>
</tr>
<tr>
<td>Other threat----------------------------------</td>
</tr>
</tbody>
</table>

No / maybe / yes
Managing co-occurring threatened species

Developing best practice guidelines for northern bettong habitat inevitably leads to the question, what impacts will there be on other threatened species in the habitat? This is a valid question, especially for the Wet Tropics, where high densities of threatened species co-occur. The potential impacts on other species can be either complementary (the fire regime that suits the northern bettong suits other species) or competing (the fire regimes that suit the northern bettong are different from the fire needs of the other species (Table ).

Yellow-bellied glider (northern subspecies)

Species that depend on the same or similar ecotonal habitat of the Wet Tropics are likely to have the same habitat management needs as the northern bettong—maintaining an open, grassy eucalypt forest. This is likely to be the case with the yellow-bellied glider (unnamed northern subspecies). Changed vegetation structure as a result of changed fire regimes are a major threat to this species [60]. Thickening and restrict their ability to move around their habitat [60]. The fire regimes recommended in this guide to manage thickening, will benefit both the glider and the northern bettong, especially progressive, seasonal and storm burning.

Birds

A number of threatened bird species that co-occur with the northern bettong, require open habitat and can be threatened by thickening of vegetation caused by the lack of fire. For example, the red goshawk forages in open woodlands and could be impacted by thickening that restricts their ability to capture prey. The little understood buff-breasted button quail is also potentially threatened by fire regimes that promote thickening [61, 62]. Some observations indicate that they have a preference for storm burnt areas [62], most likely due to the availability of new seed grasses. However other fire recommendations for the species suggest avoiding fire in the breeding season which appears to be the wet season [61, 62]. Large, late season fires are thought to be a threat and reducing this risk is aligned with the fire recommendations for northern bettong. More information is needed on this species.

Quolls

Northern quoll are thought to be impacted by inappropriate fire regimes that result in the loss of habitat and food [63, 64]. Although this relationship is not fully understood [63] too frequent fire and too infrequent fire are thought to potentially affect northern quoll [63]. High severity fires could potentially impact den sites or young survivorship although there is currently no evidence to suggest this is the case. Northern quolls have an annual breeding season around May with young born in June–September. Nesting and territorial latrine localities are typically found around rock outcrops and boulders, where lower intensity burning is recommended in these guidelines. It is thought that the greatest threat to northern quolls is from predation post-fire in the absence of cover [65]. Therefore the fire regime recommended in these guidelines applying a diversity of fire intervals, reducing the prevalence of wildfires and retaining cover post-fire would be compatible with the requirements of the northern quoll.

Spotted-tailed quolls can also be impacted by fire. While they prefer wetter habitats such as rainforest they also use more open woodland habitats. The most likely impact on this species is thought to be from fires during the breeding season [66] The spotted quoll breed between June and September and make dens in tree hollows, logs and rock crevices. The fire regimes in these guidelines do not make specific planned burn recommendations for this time period, however caution should be taken to avoid higher severity burns in their breeding season.

Sharman’s rock-wallaby

The Sharman’s rock wallaby has a very restricted distribution, inhabiting rocky outcrops and boulder piles in woodland habitat on the lower edge of the northern bettong habitat [67]. Due to its restricted distribution Sharman’s rock wallaby would be vulnerable to disturbance including uncontrolled fire. Sharman’s rock wallaby would probably benefit from a mosaic of low intensity burns providing them with a diversity of food resources at different times [68] with too frequent fire and too infrequent fire likely to negatively impact the species [68]. Therefore the fire regime recommended for the northern bettong with a diversity of fire intervals and reducing the prevalence of wildfires would be compatible with the requirements of Sharman’s rock wallaby.

Bats

While several species of co-occurring bats could be impacted by inappropriate fire regimes it seems to be a minor potential threat rather than a significant concern. For example there is little evidence to suggest there is a direct impact on the greater large-eared horseshoe bat other than a potential impact on prey abundance and habitat suitability [68]. For the ghost bat while inappropriate fire regimes are suspected to be a threat [69] there is little supporting evidence [68]. The tube-nosed insectivorous bat is the most likely bat species to be impacted given it may use the ecotonal habitat. However the consequences of thickening and transitioning habitat and the recommended fire management to mitigate this, on this bat are also unknown [68].
Table 9. Potential impacts of fire regime for northern bettong on co-occurring species

<table>
<thead>
<tr>
<th>Common name</th>
<th>Species</th>
<th>BoT Status</th>
<th>NCA Listing</th>
<th>EPBC Status</th>
<th>Percentage overlap</th>
<th>Complementary fire needs</th>
<th>Competing fire needs</th>
<th>Unknown fire needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>yellow-bellied glider (northern subspecies)</td>
<td>Petaurus australis unnamed subsp.</td>
<td>Critical</td>
<td>V</td>
<td>V</td>
<td>94</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>northern quoll</td>
<td>Dasyurus hallucatus</td>
<td>Medium</td>
<td>LC</td>
<td>E</td>
<td>30</td>
<td>likely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>buff-breasted button-quail</td>
<td>Turnix olivii</td>
<td>Data deficient</td>
<td>E</td>
<td>E</td>
<td>62</td>
<td>potentially</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sharman’s rock-wallaby</td>
<td>Petrogale sharmani</td>
<td>Low</td>
<td>V</td>
<td></td>
<td>72</td>
<td>potentially</td>
<td></td>
<td></td>
</tr>
<tr>
<td>red goshawk</td>
<td>Erythrotiorchis radiatus</td>
<td>High</td>
<td>E</td>
<td>V</td>
<td>33</td>
<td>potentially</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tube-nosed insectivorous bat</td>
<td>Murina florium</td>
<td>High</td>
<td>V</td>
<td></td>
<td>76</td>
<td>unlikely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>greater large-eared horseshoe bat</td>
<td>Rhinolophus philippinensis</td>
<td>High</td>
<td>E</td>
<td>E</td>
<td>43</td>
<td>unlikely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ghost bat</td>
<td>Macroderma gigas</td>
<td>Critical</td>
<td>V</td>
<td></td>
<td>37</td>
<td>unlikely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spotted-tailed quoll (northern subspecies)</td>
<td>Dasyurus maculatus gracilis</td>
<td>Critical</td>
<td>E</td>
<td>E</td>
<td>74</td>
<td>potentially</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semon’s leaf-nosed bat</td>
<td>Hipposideros semoni</td>
<td>Medium</td>
<td>E</td>
<td>E</td>
<td>32</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macleay’s fig-parrot</td>
<td>Cyclopsitta diophthalma macleayana</td>
<td>Low</td>
<td>V</td>
<td></td>
<td>88</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spectacled flying-fox</td>
<td>Pteropus conspicillatus</td>
<td>High</td>
<td>V</td>
<td>V</td>
<td>80</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delma mitella</td>
<td></td>
<td>Low</td>
<td>NT</td>
<td>V</td>
<td>58</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a* Back on Track (Queensland Government species prioritisation process)

*b* Nature Conservation Act 1992

*c* Environmental Protection and Biodiversity Conservation Act 1999
Knowledge gaps

Critical gaps

There are still many things that are not well understood in the relationship between fire and northern bettong populations. There are gaps in knowledge at every step of the relationship between fire and northern bettong populations (Figure 6). The list of questions is long (see Table 10) however there are a few that are critical to the appropriate management of northern bettongs with fire, including:

- **How much COVER is enough cover for northern bettongs to survive a moderate-high severity fire?** (4, 3, Figure 6)

  Most of the recommendations in these guidelines are based on the assumption that northern bettongs can survive fire with sufficient cover. While there is research to say that low-moderate severity fires have negligible impact in the Lamb Range there is no data from other places or other severity fires. Knowing how much cover is enough under different fire scenarios will greatly improve the appropriateness of planned burns.

- **How much do CATS/foxes prey on northern bettongs immediately post-fire?** (6, Figure 6)

  Cats predate significantly on other species of bettongs and similar, critical weight range (CWR) fauna in other places especially in the presence of late, dry fire. There is insufficient evidence to establish whether this is the case or not with the northern bettong, or more likely, the level at which it may occur and threat posed (at a population level). Feral cats are known to occur within northern bettong habitat, while foxes appear still well outside the range of northern bettongs. It is critical that this possibility is eliminated or clarified because it could fundamentally change the way populations are managed. It will be equally important to know if cats do have a significant impact, to determine what degree management intervention becomes necessary.

- **Is there a FIRE REGIME (intensity, interval, severity, size, season) that is preferred by northern bettongs?** (1, 2, 3, 4, 5, Figure 6)

  These guidelines provide recommendations for fire regimes in northern bettong habitat based on best available knowledge and current understanding. However impacts of varying fire parameters on northern bettongs is not well understood or documented. Addressing this question and determining how fire affects northern bettong persistence, is central to the recovery of this species.

Figure 6 Interactions between fire and northern bettongs - including the interactive effects of predation, grazing and pigs 6) and the potential impacts upon co-occurring threatened species 7).
Finding answers

Managers face a range of perplexing questions, e.g. why are there no northern bettongs at Mount Windsor where there is minimal transitioning and plenty of seemingly suitable habitat? How high a priority investing in resolving these uncertainties depends on two factors: 1. how important is this gap to the management of the species, and 2. how resource intensive will it be to answer this question? Options for addressing these questions vary in rigor and resources requirements from low to high and include: learning by doing (LBD), data analysis (DA), monitoring (M) and targeted research (TR) (Table 10).

Learning by doing

Learning by doing is where a manager observes what works and what doesn’t and adjusts their approach according to experience. This is arguably the most widely applied approach to addressing uncertainty in fire impacts. Feedback from managers in northern bettong habitat suggests that their learning can be vastly increased through access to other managers’ experience in learning by doing. To implement this, a template has been designed for managers to record observations and outcomes in the field. They will then present the information recorded at a regular forum of fire practitioners within northern bettong habitat.

Data analysis

Data analysis is an option where the appropriate data exists and if analysed in the correct way could be very valuable in shedding light on specific questions. This is a relatively low cost option (if no additional data collection is required) and should be investigated before large scale monitoring is attempted. This could help address questions around quantifying the relationship between northern bettong presence and different fire regimes. For example, analysing the correlation between northern bettong trapping data and the fire regime data from the Lamb Range could potentially uncover a quantifiable relationship.

Monitoring

Additional monitoring data is required to answer many of the questions around northern bettongs and fire. However, such monitoring needs to be carefully considered as it is far more resource intensive than a simple desk top analysis. For example such monitoring could include: vegetation plots, camera traps, truffle and cockatoo grass surveys. Monitoring can be used to address some relatively simple questions, e.g. do late season fires deplete cockatoo grass stems? (Table 10). This would require going out after late season fires and measuring cockatoo grass stems in burn sites and outside burn sites in the same community (control). Where possible a monitoring program could be used to efficiently collect data to eliminate issues outlined in Table 10 and increase the confidence of management.

Targeted research

Targeted research is the most thorough and resource intensive approach but may be essential to their successful conservation where the outcome of the research greatly influences management and other approaches are unlikely to provide adequate answers. Interactive effects, for example how cat predation or pressure from grazing interact with fire to impact northern bettongs, are particularly difficult to measure. This is because there are many factors involved, increasing the difficulty of identifying the factor that is having the greatest impact on the northern bettongs. Equally, understanding the impact of particular fire regimes on northern bettong populations is critical but involves investigating a large number of variables. Untangling these influences requires a robust statistical design that measures all variables to an extent sufficient to eliminate them as factors that determine what is causing the declines. This is particularly challenging where these impacts (such as fire) could be occurring over large geographical areas and topographical variation. The lack of data on northern bettong populations exacerbates these issues. However, there are opportunities amongst these challenges. A good statistical design over a number of sites and scenarios can provide information about how those sites might have changed without having to wait for those sites to change. In addition, there is a high level of co-ordination between managers over the northern bettongs range so getting access to these sites would be possible.
Table 10. Gap analysis - remaining knowledge gaps in the relationship between northern bettong populations and fire (learning by doing (LBD), data analysis (DA), monitoring (M) and targeted research (TR)).

<table>
<thead>
<tr>
<th># in fig 6</th>
<th>Interaction</th>
<th>Unknowns/uncertainties</th>
<th>Potential response</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lack of fire leads to thickening of northern bettong habitat</td>
<td>What fire regime and conditions cause a ‘flush’ of saplings – i.e. when does fire promote thickening</td>
<td>LBD</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>Shading from thickening impacts grass layer</td>
<td>Do northern bettongs use tall open forest when it’s in good condition?</td>
<td>TR</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>Change in resources impact northern bettongs</td>
<td>How does habitat/resource use change in drier years?</td>
<td>TR</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What post-fire conditions (time since fire) do northern bettongs prefer?</td>
<td>DA</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How does fragmentation through thickening impact northern bettong populations?</td>
<td>TR</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>Fire impacts cockatoo grass/grass diversity and truffles</td>
<td>What fire regime increases/maintains the availability of the truffles preferred by northern bettong?</td>
<td>TR</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do late season fires deplete food resource of cockatoo grass stem bases?</td>
<td>M</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How does the loss of northern bettongs affect the diversity and abundance of truffles?</td>
<td>TR</td>
<td>Medium</td>
</tr>
<tr>
<td>5</td>
<td>Fire impacts northern bettong</td>
<td>How do northern bettongs respond to moderate/high intensity fire?</td>
<td>DA/TR</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How much cover is enough cover to survive a moderate-high severity fire?</td>
<td>DA/TR</td>
<td>High</td>
</tr>
<tr>
<td>6</td>
<td>Other threats interact with fire to impact northern bettongs, for example, predation increases after fire, grazing changes fire.</td>
<td>How much do cats/foxes prey on northern bettongs immediately post-fire?</td>
<td>TR</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How does grazing influence the impact of fire on northern bettong habitat?</td>
<td>TR</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How will climate change impact fire and northern bettongs?</td>
<td>TR</td>
<td>Medium</td>
</tr>
<tr>
<td>7</td>
<td>Potential impacts of fire regimes on co-occurring species</td>
<td>Are there any positive or negative impacts on other species from fire management focused on northern bettong habitat?</td>
<td>TR</td>
<td>Low (see previous chapter)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact of northern bettong fire regime on northern quoll?</td>
<td>TR</td>
<td>Medium</td>
</tr>
<tr>
<td>1-3</td>
<td>Impact of fire on habitat change, resource availability and northern bettong populations</td>
<td>Is there a fire regime (intensity, interval, severity, size and season) that is preferred by the northern bettong?</td>
<td>DA/TR</td>
<td>High</td>
</tr>
<tr>
<td>Terminology</td>
<td>Definition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Burn scar</strong></td>
<td>Burn scar is the mapped burn perimeter or burn extent, as in what is shown on NAFI. The term, fire scar, may be used inter-changeably.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dew point temperature</strong></td>
<td>This is a measure of the moisture content of the air and is the temperature to which air must be cooled in order for dew to form. The dew-point is generally derived theoretically from dry and wet-bulb temperatures, with a correction for the site’s elevation (BOM). Reliable dew point means a high likelihood that dew will form overnight. This is used to ensure fires self-extinguish or to protect areas such as gullies where the dew will settle.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire behaviour</strong></td>
<td>The manner in which a fire reacts to variables of fuel, weather and topography.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire coverage</strong></td>
<td>The internal burnt area of the burn scar expressed as a percentage of the total area mapped.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire Danger Index (FDI)</strong></td>
<td>A relative number (0-100+) and rating denoting an evaluation of rate of spread (m/hr), or suppression difficulty for specific combinations of fuel moisture and wind speed.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire frequency</strong></td>
<td>The frequency of successive fires for a vegetation community in the same point of the landscape (refer to fire interval).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire intensity</strong></td>
<td>The amount of energy released per unit length of fire front, in units of kilowatts per metre of the fireline (also known as the Byram fire-line intensity).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire interval</strong></td>
<td>The interval between successive fires for a vegetation community in the same point of the landscape. Often expressed as a range indicating a minimum and maximum number of years that an area should be left between fire events.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire parameters</strong></td>
<td>Characteristics that can influence the planned burn including descriptions of the desired fire, when and how to burn to increase the likelihood of achieving burn objectives.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire regime</strong></td>
<td>The recommended use of fire for a particular vegetation type or area including the frequency, intensity, extent, severity, type and season of burning.</td>
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<tr>
<td><strong>Fire regime group (FRG)</strong></td>
<td>A group of related ecosystems that share a common fire management regime including season, severity, recommended mosaic etc. These are a sub-grouping of the fire vegetation groups to provide more detail about specific fire management requirements. Fire regime groups are provided as a more detailed alternative for use with fire strategies or in mapping.</td>
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<tr>
<td><strong>Fire season</strong></td>
<td>The period(s) of the year during which fires are likely to occur, spread and cause sufficient damage to warrant organised fire control.</td>
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<tr>
<td><strong>Fire severity</strong></td>
<td>A post-fire measure of the effect of fire on the vegetation and soil (e.g. vegetation consumption, vegetation mortality, soil alteration). Char height (burnt leaves) and scorch height (brown leaves) are surrogate measures for severity.</td>
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<tr>
<td><strong>Fire vegetation group (FVG)</strong></td>
<td>A group of related ecosystems that share common fire management requirements. For the purpose of practical fire management, these ecosystems are treated as a group.</td>
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<tr>
<td><strong>Flame height</strong></td>
<td>The vertical distance between the average tip of the flame and ground level, excluding higher flares.</td>
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<tr>
<td><strong>Fuel</strong></td>
<td>Any material such as grass, leaf litter and live vegetation, which can be ignited and sustains a fire. Fuel is usually measured in tonnes per hectare.</td>
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<tr>
<td><strong>Fuel load</strong></td>
<td>The dry weight of combustible materials per area, usually expressed as tonnes per hectare. A quantification of fuel load does not describe how the fuel is arranged, nor its state or structure.</td>
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<tr>
<td><strong>Fuel moisture content</strong></td>
<td>The water content of a fuel particle expressed as a percentage of the oven dry weight (ODW) of the fuel particle.</td>
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<tr>
<td><strong>Grass curing</strong></td>
<td>The proportion of dead material in grasslands – usually increases over summer as tillers die off and dry out, increasing the risk of grassland fire.</td>
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<tr>
<td><strong>Intensity</strong></td>
<td>The amount of energy of the fire front. Can be measured in units of kilowatts per metre of the fire line (kWm⁻¹). Flame height (m) is a surrogate measure for intensity.</td>
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<tr>
<td><strong>Measurable objective</strong></td>
<td>Indicators that reflect the degree to which the fire has achieved desired objectives.</td>
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<tr>
<td><strong>Mosaic burns</strong></td>
<td>An approach which aims to create spatial and/or temporal variation in fire regimes. This can occur within an individual burn and at a landscape level by altering the interval, seasonality, intensity and scale of area ignited to ensure variability in time since fire, and in fire severity (ideally kept within the fire regime tolerance).</td>
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</tbody>
</table>
| **Patchiness**            | In fire management patchiness can refer to:  
  - The percentage of unburnt ground layer vegetation and/or  
  - The behaviour and intensity of the fire and/or  
  - The pattern and size of burnt areas.  

In the context of this guide, patchiness predominantly means the percentage of unburnt ground layer vegetation (grasses, herbs and trees/shrubs less than one metre) not affected by fire and left available as refugia for ground dependent fauna. For example 20% patchiness = 80% burnt. |
| **Planned burn**          | The controlled application of fire under specified environmental conditions to a predetermined area and at the time, intensity, and rate of spread required to attain planned resource management objectives. In the context of QPWS operations: a fire that is deliberately and legally lit for the purposes of managing the natural and/or cultural and/or production resources of the area (e.g. reducing fire hazard, ecological manipulation), and protecting life and property. |
| **Progressive burning**   | Progressive burning is an approach to planned burning where ignition is carried out throughout much of the year as conditions allow. In northern Queensland, ignition can begin early in the year after heavy seasonal rain, with numerous smaller ignition points creating a finer scale mosaic. These burnt areas can provide opportunistic barriers to fire for burning later in the year. They also provide fauna refuge areas.  

Progressive burning helps create a rich mosaic of intensities, burnt/unburnt areas, and seasonal variability. Depending on local climatic conditions, there can be up to four seasons in the wet tropics (this will vary from moister to drier climatic areas):  

- The early burn period following seasonal heavy rain where fire self-extinguishes overnight and will not burn through areas burnt the year before.  

- Secondary burn season is when fires will continue to burn throughout the night and will extinguish within areas burnt the year before.  

- Falling leaf season, where a blanket of leaves often crosses natural water features. This is the dry season and fires will not go out. Fires in dry conditions, also known as the fire risk period or bushfire season will often favour woody species over grasses.  

- Storm burning, where climatic conditions allow, from December through to January, is a useful way to achieve intense, wind supported fire where rain can be reliably expected to follow; providing good conditions for regeneration (Mick Blackman pers. comm., 10 September 2011). |
| **Refugia/refuge**        | An area of habitat that remains suitable for a species when surrounding areas have become unfavourable. |
| **Rainfall Deficiency Ranking** | A measure of if the rainfall in a given period is lower than the historical average (using records since 1900). http://www.bom.gov.au/climate/ada/ |
| **Relative humidity (RH)** | The amount of water vapour in a given volume of air, expressed as a percentage of the maximum amount of water vapour the air can hold at that temperature. In a fire behaviour context, rising relative humidity will slow a fire’s rate of spread, retard ignition, and can buffer |
fire intensity, whereas falling relative humidity, typically below 30%, increases fire severity and leads to wildfire type fire behaviour such as spotting and live ember generation.

<table>
<thead>
<tr>
<th><strong>Residence time</strong></th>
<th>The amount of time heat (not necessarily just flame) is retained at any point along the ground at the front, flank or edge of an active fire. Ensuring a longer residence time is typically an objective of burning for rainforest pioneers or lantana, to ensure sufficient heat is generated to boil sap at the base of the plant (rather than just scorch the tip). Tactics such as backing fire are utilised to promote a longer residence time, while burning under a higher soil moisture gradient or storm burning ensures the plant is actively growing, and hasn't shut down as occurs during the late, dry season.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scorch height</strong></td>
<td>The height at which former green leaves still suspended on plants are turned brown by the heat of a fire. Scorch height often extends well above flame height. For measuring burn objectives, scorch height should not be relied upon alone, as many rainforest pioneers may show full scorch height, yet recoppice strongly if burnt in the late dry season.</td>
</tr>
<tr>
<td><strong>Seasons</strong></td>
<td>Month of the year or time of year (approximately dry=April–October, wet=November–March).</td>
</tr>
<tr>
<td><strong>Staged burning</strong></td>
<td>Interchangeable with progressive burning. Staged burning usually refers to each individual burn undertaken, whereas progressive burning identifies the combination and sequence of separate burns required, to achieve the overall intended burn objective.</td>
</tr>
<tr>
<td><strong>Thickening</strong></td>
<td>The process where sclerophyll saplings become over abundant in a woodland community mid-stratum and in the long term would result in a more closed woodland structure.</td>
</tr>
<tr>
<td><strong>Transitioning</strong></td>
<td>Transitioning in the context of this document refers to the process of open forest changing to a closed structure as a result of rainforest pioneer species becoming dominant in the mid-stratum.</td>
</tr>
</tbody>
</table>
## APPENDIX 1

### Table 11 Fire vegetation groups (within northern bettong habitat) and corresponding regional ecosystems

<table>
<thead>
<tr>
<th>Fire vegetation group</th>
<th>Fire regime group</th>
<th>Regional ecosystems (^{[70, 71]})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open forests of the foothills and ranges</td>
<td>Open forest – moist grassy</td>
<td>7.11.16, 7.11.16a, 7.11.16b, 7.11.19, 7.11.19a, 7.11.20, 7.11.31, 7.11.31a, 7.11.31e, 7.11.32e, 7.11.32f, 7.11.33, 7.11.33b, 7.11.33c, 7.11.45, 7.11.46, 7.11.47, 7.11.50, 7.11.50a, 7.11.50b, 7.11.50c, 7.11.51a, 7.11.51b, 7.12.24, 7.12.24a, 7.12.24b, 7.12.25, 7.12.25a, 7.12.25b, 7.12.27, 7.12.27a, 7.12.27b, 7.12.28, 7.12.28a, 7.12.29a, 7.12.29b, 7.12.29d, 7.12.33, 7.12.33a, 7.12.33b, 7.12.24, 7.12.52, 7.12.53, 7.12.53a, 7.12.53d, 7.12.56, 7.12.56a, 7.12.61b, 7.3.13, 7.3.16, 7.3.16a, 7.3.16b, 7.3.19, 7.3.19a, 7.3.20, 7.3.21, 7.3.21a, 7.3.39, 7.3.39a, 7.3.45b, 7.5.2, 7.5.2a, 7.5.2b, 7.5.2c, 7.5.4, 7.5.4a, 7.5.4c, 7.5.4d, 7.5.4e, 7.5.4f, 7.11.16d, 7.11.19b, 7.11.33a, 7.11.5, 7.11.5a, 7.11.5b, 7.11.5c, 7.11.5d, 7.11.5e, 7.11.5f, 7.11.5g, 7.3.19, 7.3.43, 7.8.17a, 7.8.17b, 7.8.17c, 7.8.19, 7.8.7a, 7.8.8, 7.8.8a, 7.8.8b.</td>
</tr>
<tr>
<td></td>
<td>Open forest – dry grassy</td>
<td>7.11.16c, 7.11.21, 7.11.21a, 7.11.3, 7.11.35, 7.11.35a, 7.11.35b, 7.11.35c, 7.11.35d, 7.11.37, 7.11.37a, 7.11.37b, 7.11.49, 7.11.51b, 7.12.24c, 7.12.25c, 7.12.25d, 7.12.30, 7.12.30a, 7.12.30b, 7.12.30c, 7.12.34, 7.12.35, 7.12.51b, 7.12.53e, 7.12.55, 7.12.59, 7.12.61c, 7.12.62, 7.12.62a, 7.12.62b, 7.12.63, 7.12.65d, 7.12.69, 7.12.69a, 7.12.69b, 7.3.14, 7.3.14a, 7.3.14b, 7.3.19f, 7.3.19g, 7.3.21b, 7.3.44, 7.3.48, 7.3.48a, 7.3.48b, 7.5.2, 7.5.3, 7.5.3a, 7.5.3b, 7.5.4b, 7.3.19g, 7.5.1b, 7.5.2e, 7.5.2f, 7.5.2g, 7.5.3a, 7.8.10, 7.8.10a, 7.8.10b, 7.8.18, 7.8.18a, 7.8.18b, 7.8.18c, 7.8.18d.</td>
</tr>
<tr>
<td></td>
<td>Open forest – shrubby</td>
<td>7.11.32g, 7.11.36, 7.11.38, 7.11.38a, 7.11.42, 7.12.12c, 7.12.26c, 7.12.26d, 7.12.26e, 7.12.26f, 7.12.37h, 7.12.51, 7.12.51a, 7.12.58, 7.12.5f, 7.12.65c, 7.12.66, 7.12.66a, 7.12.66c, 7.12.66d, 7.11.38b, 7.11.41b, 7.11.41c, 7.12.4, 7.12.5g, 7.8.16, 7.8.16a, 7.8.16b, 7.8.16c.</td>
</tr>
<tr>
<td></td>
<td>Tall open forest</td>
<td>7.11.31c, 7.11.31d, 7.11.44, 7.12.61, 7.12.61a, 7.3.40, 7.3.43a, 7.3.43b, 7.5.1a, 7.5.1c, 7.5.1d, 7.11.31b, 7.11.6, 7.11.14, 7.11.14a, 7.11.14b, 7.11.14c, 7.11.14d, 7.11.32, 7.12.21, 7.12.21a, 7.12.21b, 7.12.21c, 7.12.21d, 7.12.22, 7.12.22a, 7.12.22b, 7.12.22c, 7.12.22d, 7.12.22e, 7.3.42, 7.3.42a, 7.3.42b, 7.8.15, 7.8.15a, 7.8.15b.</td>
</tr>
</tbody>
</table>
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