NATIONAL BURNING PROJECT

Australasian Fire and Emergency Service
Authorities Council (AFAC)
and Forest Fire Management Group (FFMG)

National Guidelines for Prescribed Burning Operations:
Case Study 3 – Low intensity burning in tall moist karri forests in Western Australia

National Burning Project: Sub-Project 4

An Australian Government Initiative

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This document is constructed by GHD from consultation and research between Forest Fire Management Group (FFMG) and AFAC, its member agencies and stakeholders. It is intended to address matters relevant to fire, land management and emergency services across Australia and New Zealand.

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1 Risk management overview

Karri (*Eucalyptus diversicolor*) forests are endemic to the south west of Western Australia. They are the tallest growing forests in WA, occupying higher rainfall areas, typically on deep loamy soils. Karri forests can accumulate deep litter beds and a tall, dense understorey in which suspended bark ribbons can collect. Hence long-unburnt karri forests, in adverse fire weather conditions, can support very intense and destructive bushfires. Due to its high canopy cover and tall, dense understorey layer, karri fuels are more heavily shaded and protected from drying winds and are thus slower to dry out after winter rains than other, more open, forest types. This means that relative to drier forest types in south west WA, windows of opportunity for safe karri burning are narrow, mostly during summer and early autumn, and have a high degree of technical difficulty.

In WA, prescribed burning is used throughout the forested south west area with the aim of reducing the likelihood of large scale, high intensity, high-consequence fires occurring which are detrimental to public safety, and which adversely affect economic and environmental values. A Royal Commission, following the Dwellingup fire tragedy in 1961, mandated an expanded prescribed burning program in south west forests as a means of reducing landscape fire risk. The findings of the Royal Commission remain relevant today, even more so due to the ever increasing numbers of people choosing to settle and live within the forested south west. As karri forests occupy a significant proportion of the forested landscape, particularly in the main karri belt between Manjimup and Denmark, karri forests are necessarily included in strategic burning programs.

One of the many complexities when prescribed burning is that by the time the karri is dry enough to burn, other forest types in surrounding areas are too dry and risky to safely burn. In pure karri stands and karri-marri mixed forests with tall dense understorey, fuel conditions under which low intensity fire can sustain spread typically don't occur until summer. In most cases, karri burning can only be effectively done in the December to early April period, so great care needs to be taken to prevent burns escaping from karri burning blocks into surrounding dry forest areas where they could develop into uncontrollable high intensity fires.

The least complex karri burns typically involve smaller blocks containing relatively homogenous karri stands. These can be burnt in a single day, or two day operation with edge-burning followed by core-burning.

However, most karri burns involve large blocks in which karri stands form part of a mosaic with other drier more open forest types (typically with jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*)), and in mixed stands with these species. Areas of heath vegetation may also form a component of the mosaic. After winter rains, these different vegetation types all dry out at different rates, with karri being one of the last, with only red tingle (*Eucalyptus jacksonii*) taking longer. Burning blocks containing these vegetation mosaics require multi-stage burning. This may involve five or more separate ignition days, potentially generating smoke over a period of days or weeks. This can be a cause of local landholder concern and potential conflict, such as in areas where karri forests are in close proximity to smoke-sensitive communities or crops (such as wine grapes).

Throughout this period aerial reconnaissance of burns is ongoing and a high level of local response capability through the burn period is maintained.

Low intensity burning in karri forest is underpinned by research undertaken by the WA Department of Parks and Wildlife (DPaW). It is one of the major fuel types covered in WA's 'Red Book' which provides forest fire behaviour tables for both bushfire and prescribed fire.

2 Fuel dynamics and fire behaviour issues

Research into karri forest fuels has identified:

- Karri can accumulate very high fuel loads exceeding 60 tonnes per hectare (t/ha) of surface litter in long-unburnt stands, plus a further 60 t/ha of trash and scrub fuel (near surface and elevated fuel made up of dead material) in long-unburnt, tall, dense stands. DPaW's preference is to burn karri stands well before they reach these fuel-extremes. Karri forest litter loads of around 25 t/ha, with an additional 25 t/ha of trash and scrub, are more characteristic of stands selected for burning;

- Karri forest stand and fuel characteristics are not uniform, thus karri forest is categorised into three broad categories:

    - *Karri dominant forests* with understorey taller than 5 metres, as typically found in wet and/or gully situations (known as 'Karri 1' and 'Karri 2' fuel types);

    - *Karri-marri dominant forest types* carrying a tall dense scrub layer up to 5 metres tall (known as 'Karri 4' and 'Karri 5' fuel types); and

    - *Jarrah-marri and karri-marri dominant forest types* carrying a low dense scrub layer up to 2 metres high (known as 'Karri 3' and 'Karri 6' fuel types).

- Up to age 10, karri regrowth fuels are normally discontinuous and insufficient to carry a ground fire except in very dry conditions with strong winds (> 25km/h). Karri is a relatively thin barked eucalypt species and susceptible to cambial damage from higher fire intensity. Young regrowth stands can tolerate low intensity fires (<500 kW/m) but are susceptible to cambial damage from moderate to high intensity fires. Therefore in young regrowth stands, care needs to be taken that burning is at low intensity to avoid cambial damage and degradation of future timber values;

- From around age 10 karri regrowth forests have accumulated sufficient fuel to carry ground fires;

Figure 1 Multi-layered fuel structure typical of 25 year old unburnt karri regrowth forest

Figure 2 Fuel structure in the second year after burning in 25 year old karri regrowth forest

Figure 3 Karri forest with low dense scrub layer

- Low intensity controlled burns can be, and are successfully conducted in karri forests, including karri 1 and 2 types and regrowth stands, but usually only when the Soil Dryness Index[1] (SDI) (Mount 1972) exceeds 800 for spring burning (rarely conducted) or in late summer or autumn when the SDI has fallen a minimum of 200 points from its peak summer value, and surface fuel moisture content (SMC) is in the range of 10 – 18%. (SMC is a measure of moisture content in the loose leaf, twig and bark litter on the surface of the litter bed to a depth of approximately 1 cm);

- There are some notable exceptions to the above in which fire spread can be sustained at lower SDI such as in karri stands with dense understorey of rushes, and in more open marri-karri types with open understorey conditions; and

- Karri forests have many fuel characteristics similarities with other tall moist eucalypt forest types which grow on higher-productivity sites in eastern Australia.

[1] The SDI scale used for Western Australia is in units of mm x 10 and ranges from zero to 2000. In most other places including the BoM website it is expressed in mm of precipitation on a scale from 0 to 200

3 Burn planning approach and process

There are two key phases of planning applied to all prescribed burning on DPaW managed lands across the south west forested area in WA. The first is burn program planning. Burn program planning is conducted in accordance with DPaW's *Prescribed Fire Manual Version 2.0* (chapter 2) (DPaW 2013) which establishes the rationale and process for developing a 3 year strategic burn program for a District/Region.

Once a burn is nominated within a prescribed burn program, it progresses into the second phase of planning which is the site-specific planning, for which a *Prescribed Fire Plan* is prepared. DPaW's *Prescribed Fire Manual Version 2.0* (chapter 3) (DPaW 2013) establishes the process, minimum requirements, and standard templates for preparation of a DPaW *Prescribed Fire Plan.*

This case study is focussed on the site-specific operational planning and burn implementation phases.

3.1 Karri burning – general operating context and technical challenges

Karri burning is among the most challenging types of prescribed burning undertaken in Australia. The key factors contributing to the high technical difficulty are:

- Karri forests mostly occur in a landscape mosaic with other vegetation types including drier Jarrah and marri types and heath. Fuels in the different vegetation types and different parts of the topography dry out at different rates, and cannot be practically and safely burnt at the same time under a single set of conditions. Therefore, in these situations technically complex, multi-stage burning is a necessity;

- Due to the heavy shading and low exposure of the forest floor to wind, karri is slower to dry out after winter rains than other eucalypt forest types that are more open. Taller, denser karri stands will generally not dry out sufficiently to accommodate low intensity burning until the summer months;

- For karri to be treated with prescribed burning, adjacent drier vegetation types within a burn block must have already been burnt because these dry vegetation types will burn too vigorously under the conditions suitable for low intensity burning in karri. Burning drier fuel types before burning karri areas means that potential sources of ignition will be present at karri margins in summer, with the potential to escalate to uncontrollable fire if adverse weather occurs;

- Over the typically dry summer period when karri is in a condition suitable for burning, local weather patterns, in particular the movement of west coast trough systems, can bring periods of severe fire weather conditions; and

- When burning of multiple fuel-type blocks containing karri starts in spring, it is not at that time possible to foresee what wildfire activity will be occurring (and what demands on local resources will be in place) when karri forest sections dry out and become suitable for burning.

Accordingly, burning in karri (particularly burning of larger sized blocks) comes with significant risks to manage. There are five critical actions for managing the risks:

- Spring burning of drier forest and heath sections must be sufficient to ensure fuels in these areas are reduced to levels unlikely to carry fire in summer, even in adverse conditions;
- Edge burns along containment lines must be continuous, and have sufficient depth to act as a barrier to fire escaping internal parts of the burn block;
- Monitoring for any internal smouldering/fire activity at the margins of karri areas within or at the edge of the burn block must be continuous and documented systematically so that visual signs of karri sections becoming dry enough to sustain fire spread can be detected as early as possible. A systematic aerial reconnaissance program for active karri burn blocks is therefore essential;
- The availability of local fire suppression resources (of adequate capacity) is required whenever karri burn blocks are active (this means keeping adequate suppression resources in reserve to respond to escalating karri fire activity even if summer wildfires are active and placing demands on local resources). Resources must include bulldozers with dedicated float capability available for immediate despatch; and
- Personnel nominated to conduct karri burning need to be highly competent and experienced at prescribed burning due to the high levels of technical difficulty.

Attention to the above risk management actions will be vital in operational planning and during implementation.

3.2 Planning of burn area dimensions

Burn block dimensions are determined at the strategic phase during DPaW's *Master Burn Planning* process; as karri burns are part of a broader burn program aimed at reducing the risk of large damaging summer wildfires, burns need to be big enough that they can potentially affect wildfire spread patterns, but not so big that they carry unacceptably high risks for practical implementation. Karri burns typically range in size from small blocks immediately adjacent to at-risk communities, to blocks commonly around 1500 – 2500 hectares (although some burns incorporating significant tracts of karri may be up to 10,000 hectares).

At the operational planning stage, the location and condition of mineral earth trails for use as burn boundaries will be an important factor in determining burn block dimensions. The location of other fuel-reduced areas in the landscape will also be important.

In smoke-sensitive locations, such as in proximity to wine grape production areas, design of burn block size may also consider the volume and duration of smoke likely to be produced, with smaller than average burn block sizes considered where terrain features and vegetation condition can accommodate this.

For larger burns, a combination of ground operations for edge burning and aerial ignition for core burning is usually undertaken. For smaller burns, ground operations only are the norm. For larger burns, it is desirable to plan these adjacent to low fuel areas from previous burning in recent years (or from previous wildfires), in particular placing the downwind burn area edge (assuming adverse wind direction) adjacent to a low fuel area where possible.

3.3 Burning seasonal timing selection

The karri component of any multiple fuel-type burns will typically be done in summer (usually mid-December to mid-January) or early autumn when karri litter fuels have dried out sufficiently to carry a low intensity fire.

Within the karri burning season, selection of burn timing is dictated by seasonal conditions.

There are two main 'seasonal condition' scenarios that drive karri ignition timing selection:

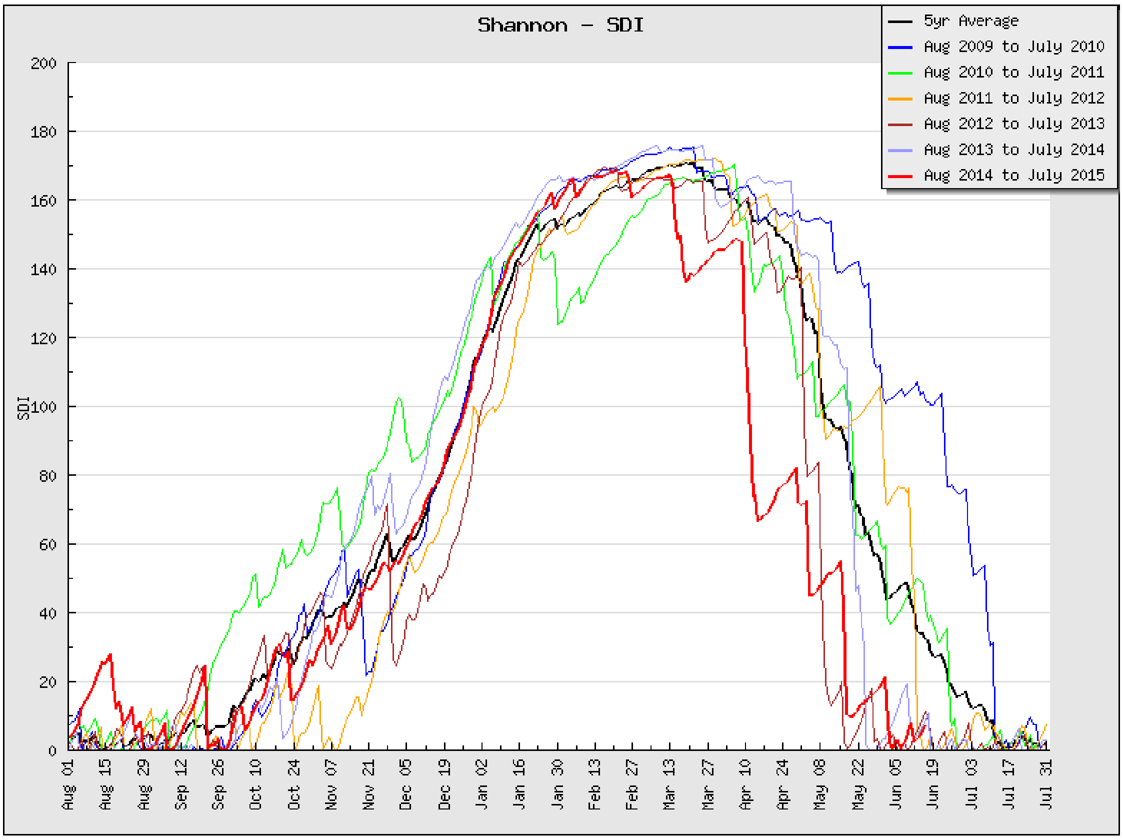
- ***Scenario 1 –*** Fire remains active with hotspots and smouldering within the burn block from previous edging and burning-out of dry vegetation types. In such circumstances, monitoring of karri sections is required to determine when karri fuels begin to burn and sustain fire spread (as indicated by increasing smoke and combustion activity at the margins of karri sections). In this scenario, ignition of active karri sections should be undertaken as soon as profile fuel moisture content and forecast weather conditions are suitable; and

- ***Scenario 2 –*** There is no visual evidence of sustained fire activity within the burn block from previous edging and burning out of dry vegetation types. In such circumstances, timing selection for ignition of karri sections will follow rainfall events which results in the SDI dropping 200 points or more from its summer peak, and the profile fuel moisture and forecast weather conditions becoming suitable.

The critical decision point is to select conditions that are dry enough to burn around 80% of the litter bed profile (to minimise risk of subsequent re-ignition of remaining litter), but not so dry that erratic fire behaviour is generated. Burn timing selection is cued by hot-spot fire behaviour indicators (principally smoke activity) and/or the moisture content of the litter fuels (profile fuel moisture).

Optimal burning conditions are generally provided in years when a late summer rainfall event has significantly reduced the SDI from its summer peak (see SDI trace sample at Figure 4), and then a series of dry days have dried out the litter profile to suitable fuel moisture levels . The level of SDI drop is not rigidly prescribed. While the WA Red Book provides guidance in relation to desirable SDI levels and drops for karri burning, changes in rainfall patterns and timing across the karri belt over recent decades have necessitated the adoption of less restrictive limits. In summer, generally a drop of 200 points or more is favourable, however, a smaller drop may be acceptable if burn timing is being pushed into autumn (when shorter days, cooler conditions, and falling hazard prevail) due to sustained dry conditions over the summer months. When coincident with stable burning weather cycles in summer/early autumn, such conditions are typically optimal for karri burning.

Figure 4 SDI trace sample peaking through late Jan/Feb



Note: The SDI scale used for Western Australia is in units of mm x 10 and ranges from zero to 2000 rather than 0 to 200.

For karri burning, it is very important to closely monitor SDI trends in the forested area and profile fuel moisture content (PMC) in, and adjacent to, the burn block to establish when conditions are coming into burning windows. This is to enable full advantage to be taken of what may be short burning opportunity periods. In the south west, DPaW district offices maintain daily logs of rainfall and SDI from a network of weather observation locations in the forested area. PMC is a measure of fuel moisture through the profile of the duff layer, in between the surface litter and the mineral soil.

In early to mid-summer, on a drying out cycle (PMC trending down), a PMC in the range of 20 to 40 is desirable which ensures an adequate proportion of the fuel profile is burnt thus reducing re-ignition risk. In young regrowth and wetting-up cycles (PMC trending up) a PMC in the range of 40 to 60 is suitable, with optimal conditions being around the 40 – 45 range.

In Figure 5 the full profile of litter bed fuels in a karri forest can be seen.

Figure 5 Karri litter bed fuel profile

3.4 Burn staging and sequencing

Most karri burn blocks contain more than one karri fuel type, and often also contain areas with non-karri fuel types of drier, more open forest types and heath. Hence there can be significant differentials in the flammability of different areas within planned burning blocks. In most situations, staged burning will be required. When moister karri fuel types (such as karri 1 and 2 types which have tall dense understoreys and are associated with gullies and southern aspects) are in a condition to burn, drier more open types will be too dry to burn. Therefore, burning of drier parts of the block is undertaken first, when moister fuel types won't burn.

These differential drying rates often occur over a period of months, and therefore burns remain actively managed burns for the duration, often from early spring when heath and/or Jarrah sections are burnt, continuing through to summer or early autumn when the karri sections are burnt. This long burn duration period presents significant escape risks that need to be managed.

Most karri burning will involve at least two burning stages (edge burn and core ignition), and in more complex burns each stage may comprise multiple burning events. The first stage is to complete edge burns to achieve an edge-burn depth of at least 100 metres. If there is significant fuel moisture variability in fuels along the burn boundaries then two or more edge burning events may be required to complete edge-burning (burning each vegetation type in turn as they dry out sufficiently to carry fire). Once edge-burns have been satisfactorily completed, core ignition can be undertaken when conditions become suitable. Core ignition should be undertaken when fire behaviour on any ridges or exposed positions within the burn area can be kept within prescription. After initial core ignition, if large areas of fuel remain unburnt within the burn boundaries, further ignition events to ignite sheltered positions within the core may be necessary (noting that exposed positions must have already been burnt prior). Most core ignition is undertaken using aircraft even on relatively small burn jobs because of the difficulty and safety issues associated with lighting by ground crews, unless the shape of the burn block means that it can be effectively burnt out from the edge.

Where karri burns are not large and fuel types within the burn area are dominated by a small number of fuel types, single stage burning is possible (but rare), but will require well organised and expedient execution and favourable wind conditions in order to get edge burns and core burns ignited and substantially burnt-out in the one day.

3.5 Limiting conditions

The key to successful burning in karri forests is achieving a rate of spread sufficient to get the block burnt across the burnable area within the allocated timeframe, whilst keeping fire intensity within acceptable limits (flames in litter to around 1 metre high, and extending to 2 metres in trash fuels). This generally entails achieving a rate of spread less than 60 metres per hour. To achieve these rates of spread, ideally the daily minimum SMC should be between 8 and 14%. Burning can be done at higher SMC up to 18% (except for edging where SMC should be less than 14%), however at the higher end of the SMC range, burn results may be marginal and lighting patterns used will generally need to be more intensive to achieve an acceptable result. Burning should be avoided in conditions where the SMC will fall below 8%.

Wind speed is another important variable governing rate of fire spread and intensity. In karri forests, wind penetration to surface level varies according to stand characteristics, in particular the density of overstorey canopy cover and understorey vegetation density.

Research into wind penetration in karri forests indicates:

- In karri types 1 and 2 and well-stocked karri regrowth, wind at 1.2 metres is around 1/9th of wind speed above the canopy;

- In karri types 4 and 5, wind at 1.2 metres is around 1/7th of wind speed above the canopy; and

- In karri types 3 and 6, wind at 1.2 metres is around 1/6th of wind speed above the canopy.

The above wind reduction ratios are built into the *Karri Rate of Spread Table* in the 'Red Book'.

As a general rule, burning should not be planned for days when the forecast wind speed in the open will exceed 25 km/h[2]. Accordingly, the influence of wind on a low intensity fire burning in surface and near-surface fuels in dense karri stands will be relatively low.

[2] *In some parts of the Karri range, particularly close to the south coast, winds are consistently stronger than 25 km/h. Consideration of the exposure of the site to the prevailing wind, and of the ignition pattern employed is important in these situations to ensure that that good burning opportunities are not otherwise forfeited.*

3.6 Developing prescriptions for the burn

Prescriptions used for karri burning usually fall within the parameters identified in Table 1:

Table 1 Karri burning prescriptions

Weather variable/ fire behaviour attribute	Prescribed Range	Comments
Drought Index (using SDI) *Note: SDI used in WA is based on 0.1mm increments and is therefore 10 times the equivalent SDI used in some eastern states.*	All seasons: less than 1500 with a recent drop of 200 from the seasonal peak required to commence burning in the autumn season. Final core ignitions may be required at an SDI >1500 for reasons of burn security	For broad area burning of larger blocks all weather and fire behaviour variable should be within prescription. For burning of smaller blocks, burning at temperatures up to 30^{o}C OR relative humidity falling to 30% may be undertaken but only if FFDI and forward rate of spread remain within prescription.
Wind speed	Less than 25 km/h at 10m (or less than 4 km/h in the forest at 1.5 m)	Wind speed is average speed – gust speeds may exceed prescriptions.
WA Red Book FFBT FDI	15 – 40 without special approval Approval (from DPaW Fire Management Services) required above 40	
Surface Fuel Moisture Content (SMC)	8 to 16%	
Forward rate of spread	Less than 60 metres per hour	Rate of spread prescription is for fuel and weather conditions on exposed aspects.
Profile Fuel Moisture Content (PMC)	30% – 60%	

Subject to SDI levels being within desired limits, the principal fuel factor used to determine appropriate conditions for burning in karri is the proportion of litter fuel that is available to burn which is a function of daily PMC. In WA, this is known as the Available Fuel Factor (AFF). The methodology for calculating the AFF is published in the ‘Red Book’. The ‘Red Book’ recommended AFF limits for burning are when 30% to 70% of the litter fuel is available to burn. In landscape conditions with widespread heavy fuels, it is necessary to burn at the top end of the AFF range, extending this up to 80%.

3.7 Burn timeframe and duration

Due to the potential for adverse windy days to occur in summer and early autumn period when the bulk of karri burning is conducted, planning for fire to burn-out target fuels within normal weather forecasting timeframes of 3-4 days is paramount. On the days selected for ignition, stable conditions when wind direction will be relatively consistent (preferably from south west to east) throughout the day is generally desirable, and unstable days are to be avoided (north-east to north west winds).

The time period during the day available for burning in karri fuel types will vary according to what the minimum predicted SMC for the day will be. The 'Red Book' contains a table for estimating hours of burning time available on days with different minimum SMC predictions.

Table 2 Hours of burning time available (reproduced from the 'Red Book').

Predicted min SMC (%)	Start time	Jarrah burning hours		Karri burning hours	
		Spring	Autumn	Spring	Autumn
20	14:30	0	1	0	1
18	14:00	1	2	1	2
16	12:30	4	5	2	3
14	11:00	6	7	5	6
12	10:00	8	9	7	8
10	09:00	10	12	9	10
8	08:30	12	14	11	12

As can be seen from the table above, the burning time for SMC in the middle the desired range (14%) is 6 hours. However, if SMC conditions are toward the moister end of the suitable spectrum (18%) available burning time falls to just 2 hours. Conversely at the drier end of the SMC spectrum (10%) burning time extends to 10 hours. Planning of ignition patterns needs to take this significant SMC-burn time variability into account. Typically, late in the day between 4 pm and 10 pm is when optimal burning and spread will occur. Karri will continue to burn all night with fire behaviour moderating in morning hours.

To keep fire intensity low, wide head fires and junction zones need to be minimised during peak afternoon conditions, therefore spot ignition patterns that join up after fuel moisture conditions have bottomed and are on a rising trend are usually optimal. Planning of burn timing and lighting patterns should take this into account. Spots joining at around 8:00 pm are usually optimal.

3.8 Pre-planning of lighting patterns for the burn

Field assessment of proposed burn sites is vital for all burns, in order to factor in, among other things, stand characteristics and fuel type variability into planning of lighting sequences and patterns.

It is particularly important during field inspection to identify:

- Areas with different karri fuel types – fuel quantity and arrangement will vary as will fuel moisture conditions on any given day, therefore the time of day when fuels will be in the recommended range for burning will vary (mapped using aerial photograph interpretation). In State forest it is common for karri type burns to include stands of young regrowth (both jarrah and karri), some of which may have been thinned commercially. Burn areas may also include recently harvested and regenerated areas;

- In areas with steep slopes > 15^{o} on north aspects, it will be near-impossible to keep uphill head fires in these areas within fire behaviour prescription, and therefore such areas may need to be considered for downslope burning;

- The adequacy of perimeter trails for fire containment should also be checked and potential weak areas identified for preparatory works and noted in the burn plan;

- Hazardous trees – where previous fires and/or decay have weakened trees generating substantial risks that trees may fall on to roads or trails during or following the burn; and

- Areas needing scrub rolling to achieve satisfactory edge burn.

While all burn blocks should have a lighting plan customised to the specific features of the block, in general the following lighting sequence and pattern considerations are applied for larger sized burn blocks. Each vegetation community has its own prescription and resources allocated according to that burning phase:

- Heath sections are generally lit first, and have to be lit with the wind to achieve sustained forward spread (Note: SMC in downwind forest areas needs to be high enough to halt fire spread when it emerges from heath sections);

- Dry forest types are next to be burnt, starting with drier, more open types and progressing to those with denser stand structure and more sheltered surface fuels. Lighting patterns will vary principally according to fuel load but also other factors including surface fuel moisture. Long-unburnt areas with high fuel loads will generally need a less intensive spot lighting pattern, whereas more recently burnt areas with light fuels may need to be burnt with a more intensive spot or line pattern to achieve a suitably high burn coverage, which is particularly important for edge-burns;

- Karri sections are last to be ignited, being lit once other fuel types within a burn block have already been burnt. A spot lighting pattern is generally used with spacing determined by fire behaviour prediction results, and the desired timing for spots to join up;

- Lighting patterns in young regrowth stands and higher fire-sensitivity areas usually need a less intensive spot-lighting pattern, relative to other areas, to keep fire intensity suitably low;

- In areas with significant topographic variation, steeply sloping areas on northerly to westerly aspects will usually need a less intensive spot-lighting pattern using a downslope-burning direction to keep fire intensity low, whereas more sheltered aspects may need a more intensive ignition pattern; and

- All lighting patterns need to take account of wind direction and strength – lighting into the wind (generating a backing fire) will help to moderate fire behaviour to counter other fire behaviour escalation factors such as fuel dryness and/or quantity. Lighting with the wind will escalate fire behaviour and assist forward spread promotion if other factors are inhibiting desirable fire behaviour.

3.9 Weather cycle selection for burn days

For karri burning, burn-timing aims to select a sequence of stable days. This entails picking the beginning of a sustained stable period when a high pressure ridge will dominate the weather pattern for the duration of the burn. Four day weather forecasts, supplemented by longer range projections from trained meteorologists are relied upon for selecting such burning opportunities. Four day forecast periods when a west coast trough is predicted to move across the burn area require specific evaluation and consideration in relation to the risk of escape during the west coast trough change.

The other key factor in burn day selection are fuel drying patterns, in particular whether fuels are within the appropriate fuel moisture range for burning.

Monitoring of surface and near-surface fuel moisture trends is necessary to identify when the desired PMC is approaching suitable conditions for burning. PMC is a key fuel moisture indicator used to determine when conditions are suitable.

Emerging opportunities for karri burning (based on SDI and PMC trends) generally begin to firm-up around 5 days ahead of when the burn day is scheduled. This provides a lead time of around 4 days to organise burn resources, complete pre-burn preparations, finalise approvals, and mobilise resources. Leading up to burning both the FMC in the duff fuels and the surface fuels are measured separately, using primarily oven drying. Fuel moisture is calculated on a daily basis for at least 4 – 5 days prior to the burning date. This includes the fuels within the burning block and those within adjoining compartments.

Subject to resources being available, days when fuel moisture and forecast weather cycles are both suitable and no adverse fire weather is foreseeable in the seven day forecast are selected for burning. Additionally, DPaW's ability to resource any ongoing wildfire response commitments whilst attending to the burn must be considered.

3.10 Burn plan preparation

DPaW has in place a structured burn plan preparation process and standards for burn planning are set out in DPaW's *Prescribed Fire Manual Version 2.0* (2013).

For the summer/early autumn burning season when most karri burning is done, burn planning is conducted as part of the spring burn season planning routine. The general *Prescribed Fire Plan* preparation routines are as follows:

- DPaW regions prepare their proposed spring burn programs (including karri burns scheduled for summer/early autumn) by the third week of July after the completion of stakeholder consultation processes that occur earlier in July;

- Prescribed Fire Plan development for spring/summer scheduled burns commences in late July to develop prescriptions and resolve identified issues;

- Spring/summer season *Prescribed Fire Plans* are fully developed by end of September for approval;

- Spring/summer program public notification consultation maps are published on DPaW website in mid-September; and

- Final *Prescribed Fire Plan* is signed-off by the end of September for implementation thereafter.

Any required preparatory works need to be planned and completed prior to the scheduled burn day, if not already completed earlier.

In common with DPaW burns in other fuel types *Prescribed Fire Plans* for karri burns are compiled using a range of standard templates for plan components, containing the following prescriptions:

- The area to be burnt;

- Conditions under which the burn can proceed;

- The manner in which the burn is to be conducted including preparations;

- Related measures to protect DPaW staff, the public and things of value;

- Contingency arrangements for burn escape or other unintended events;

- Any factors that are to be the subject of ongoing monitoring or review during the course of the burn including those intended to detect the onset of contingencies; and

- The briefing to be provided to those involved in the burn (for finalisation on the day of the burn).

The *Prescribed Fire Plan* contains:

- A register of risks[3] associated with the burn and a record of the associated risk assessment;

- The overall level of risk associated with the burn[4];

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[3] A risk management context statement and register of risks is documented (as per DPaW Prescribed Fire Manual Appendices 14 and 15), considering PESTLE;

[4] The overall risk for the burn is assessed using DPaW's Risk Matrix which combines consequence and likelihood ratings (consequence and likelihood criteria are tailored specifically for prescribed burning – see DPaW Prescribed Fire Manual Appendices 16 and 17). Assessed risk levels trigger different levels of approval; and

- The priority of the burn;
- Success criteria;
- An analysis of the burn complexity[5];
- A single page Summary of the Burn;
- An Operations Map;
- A Context Map that encompasses the burn area and the surrounding landscape;
- An Aerial Burn Map (where relevant);
- The approvals of any external agencies or persons that are either obliged or entitled to approve particular aspects of the plan;
- The signatures of persons authorised to endorse the plan on behalf of those DPaW programs with a legitimate interest in the plan;
- The signature of the duly authorised person who has approved the plan; and
- The information to be recorded following the burn.

4 Burning operations implementation

4.1 Obtain approval to conduct burn

DPaW has a structured process for seeking approval for burn ignition. For all burns this entails the proposing District completing a *Day of Burn Ignition* request form. A regional and State review process occurs on a daily basis during the burning season to authorise burns.

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[5] *The complexity of the burn is assessed using a three category scale (High, Medium, Low), with complexity rated across the following risk factors:*

- *Burn objectives and success criteria;*
- *Internal values requiring special treatment;*
- *Constraints to burning;*
- *Ignition methods and procedures;*
- *Fire behaviour;*
- *Safety;*
- *Public information;*
- *Smoke management;*
- *Burn logistics;*
- *Interagency coordination; and*
- *Organisational structure and management.*

4.2 Obtain weather forecasts for the burn area and verify with on-site conditions

Spot weather forecasts for the planned burn site should be obtained from the Bureau of Meteorology, relevant for the location(s) where burning will be carried out. PMC is verified from the most recently collected, and oven-dried and weighed litter bed profile samples. SMC measurements are sampled on the scheduled burn day using Wiltronics fuel moisture meters. Upon arrival at the burn site during the morning, field weather readings should be checked for alignment with or variance from forecast conditions, and fuel moisture readings taken in surface and near-surface fuels.

4.3 Operational preparations and briefings

Routine procedures for staff and equipment checks and preparedness are undertaken and planning information distributed to burn crews. A routine pre-burn operations briefing is conducted and crews dispersed to take up planned sectors and roles as per the burn plan and briefing which follows a standard SMEACS format. Authorisation to proceed with ignition is requested and obtained.

4.4 Conduct fire behaviour prediction and test fire

Once fuels are within the desired surface fuel moisture range (8 – 18%) fire behaviour predictions are calculated using the 'Red Book' to predict rate of fire spread in metres per hour. Select an exposed aspect location for fuel moisture and wind speed measurement.

Inputs:

- Karri fuel type;
- Wind speed (either tower or in-forest); and
- SMC (%).

For areas where fuel quantity differs from the standard fuel quantity assumed for each karri fuel type, a fuel quantity-rate of spread correction table is used to correct for the variance.

Scorch height is predicted using Table 6.14.2 in the Red Book.

Two sets of fire behaviour predictions should be calculated:

1. Current – using measured fuel moisture and wind conditions at the current time; and
2. Mid-afternoon predicted – using forecast afternoon wind speed, and expected afternoon surface fuel moisture content.

A test fire may be then conducted using a strip ignition to observe rate of spread and flame height and compare with calculated fire behaviour predictions, to confirm fire behaviour is within prescription.

Consideration should be given to the time of day the test fire is lit, the results of the test fire, and how fuel moisture and weather conditions are predicted to develop during the afternoon.

5 Conduct of burning operations

Subject to successful conduct of the test burn (if unsuccessful the test burn is put out), lighting operations are executed in accordance with the burn plan.

While the *Prescribed Fire Plan* typically provides a general level of information about burn stages and sequence, ignition methods (e.g. ground or aerial), and lighting direction, the more precise detail of lighting patterns (i.e. selection of line or spot ignition techniques, spacing of lines or spot ignitions, orientation of ignition direction to terrain features/wind direction etc.) is left to the burn supervisor to determine, based on fire behaviour predictions and test fire results.

Selection of lighting patterns appropriate to the local terrain, fuel and weather conditions will be based on:

- Where fire behaviour predictions and test fire results fit within the acceptable range of prescribed conditions. For example, if SMC is toward the lower end of the acceptable range and weather conditions toward the upper end of the acceptable range, a conservative spot ignition pattern may be adopted to start with. On the other hand, if SMC is toward the high end and weather variable readings toward the low end of the acceptable range, a more closely spaced spot or line ignition lighting pattern may be selected;

- The degree of fuel moisture variability within the burn block. Where compatible with burn security and risk management objectives, lighting may commence in drier areas and progress to moister areas as SMC reduces to satisfactory levels during the afternoon. Lighting pattern selection must take into account fuel moisture and wind variability within a burn site; and

- Resources available to control the burn. It is generally desirable to conduct burning operations as efficiently as possible so that operational costs are contained to reasonable levels. Burn supervisors will need to select a lighting pattern that can be effectively delivered with the available resources with burn security able to be maintained throughout the burn.

As a general principle, it is best to start with a conservative lighting pattern and progress up to higher intensity patterns as required, rather than starting with a higher intensity pattern and subsequently having to back it off.

Fire behaviour and on-site weather need to be monitored throughout the burn with results recorded at least hourly, to ensure conditions remain within prescription and that where necessary, lighting patterns can be modified as conditions change.

Burn security and mop-up requires continuous monitoring throughout the burn, to identify and address potential escape points. The extent of active mop-up required will depend on weather conditions and the location and extent of fuels that could cause fire to escape boundaries through spotting or burning material or trees falling across control lines. Large trees alight in the crown pose a particular issue in karri burning. Some heavy duty tankers have been equipped with a hydraulic ‘snorkel’ that allows a water canon to be elevated to a height where it can spray water directly into the burning limbs and branch hollows.

Once lighting operations are completed and mop-up activity winds down, the burn supervisor will need to assess the extent of unburnt fuels remaining, and assess overnight fire behaviour potential, to make a decision on patrol requirements, in particular if and when resources can safely depart the burn site overnight and the timing of patrol checks the following day. These decisions need to be made based on forecast weather (overnight and days following the burn).

Assessment also needs to be made of likely smoke transport and settling locations to inform placement of smoke hazard signs on public roads and any other prudent smoke management actions.

Figure 6 Low intensity backing fire in karri forest with shrub understorey

Figure 7 Mature karri forest burnt at low to moderate intensity under dry summer conditions with minimal scorch to overstorey trees

6 Evaluate results of burning operation

Upon completion of the burn, evaluation of burn results is undertaken.

DPaW has a structured process for burn closure and results evaluation and recording which is done by completing standard templates included as part of the Prescribed Fire Plan.

- Evaluation of whether the burn objectives and success criteria have been met; and
- Completion of a post-burn checklist which checks off that appropriate post-burn mapping and results records have been completed and burn closure actions implemented.

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8 References and further reading

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