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 8 – Burning of spinifex grasslands in the arid interior of 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 Context

Vast landscape areas of the arid interior of WA (as well as extensive areas of semi-arid and arid lands in Australia generally) are dominated by highly fire-prone spinifex grasslands. For thousands of years, lightning and human ignitions have ensured that fire is an environmental factor that has influenced their structure, function and biodiversity. Spinifex-dominated ecosystems are fire-maintained. Fire burns the above-ground biomass which accumulates in mature and over-mature spinifex grasslands and when rains arrive a regeneration response follows.

European colonisation resulted in a breakdown of traditional hunter-gatherer lifestyles and ended or greatly disrupted traditional burning practices. Prior to the impacts of colonisation, Aboriginal people used fire on a frequent basis, applying a patch burning regime in the spinifex landscapes they occupied[1]. Their use of fire maintained spinifex landscapes in a condition which contained a mosaic of seral stages (stages of recovery from fire), with abundant edges between growth stages, thereby providing an array of habitat niches which supported a variety of food sources that Aboriginal people accessed and depended on. Fire created the conditions which maintained sufficient availability of food sources, and fire was used, among many other purposes, as a tool to facilitate locating, hunting and gathering favoured foods (Burrows and Christensen 1990; Burrows, *et al.* 2006; Gammage 2011).

Figure 1 Burning in spinifex

(source: Burrows, Liddlelow and Ward 2015)

The removal of traditional Aboriginal burning practices from vast spinifex landscape areas reduced the frequency of fire (ignition being limited to lightning and much less frequent and differently-intentioned human caused fires), resulting in a substantial increase in fire size and severity, and

[1] *They still do in some areas, although now not at anywhere near the scale at which they did prior the breakdown of traditional hunter-gatherer lifestyles that followed the arrival of Europeans*

obliteration of the habitat heterogeneity associated with finely-scaled mosaics. The fire regime transitioned to a new state comprised of much fewer, but very much larger, hotter, high-impact fires. In some more remote desert areas, this transition occurred as recently as the 1960's (Burrows *et al*. 2006). Figure 2 shows fire scars across a land area west of Lake McKay in the Great Sandy Desert in WA. The light coloured strips and patches in the image are where fire has spread removing the flammable above-ground biomass. The most recent scars appear as lighter, and older scars (probably up to about 15 years old) are less bright, and dark areas represent the longest-unburnt sections of the landscape. It is apparent that a significant proportion of fire scars have their origins adjacent to dune ridges along which Aboriginal people walked and presumably set fires as they did.

Rainfall is a primary driver of the rate of spinifex fuel accumulation and subsequent flammability of spinifex grasslands. Large, extensive wildfires are usually preceded by seasons of above average rainfall. The response of species and communities to fire will be influenced by the scale and patchiness of fire (along with the rainfall that follows), which can drive systems towards a new transient state with respect to species composition and structure (DPaW 2013).

Figure 2 Aboriginal burning fire scars visible on a 1953 RAAF air photo

(source: RAAF, the Lake McKay area, from Burrows and Butler 2013)

Knowledge of the ways in which spinifex species and communities respond to fire, and of the temporal and spatial scales of fires in relation to life histories of organisms or communities, needs to underpin contemporary, proactive use of fire. Fire management needs to be both precautionary and adaptive, considering the requirements of both fire sensitive (habitat specific) and fire maintained communities and species in order to optimize biodiversity conservation outcomes (DPaW 2013).

In spinifex-dominated landscape areas where the current unplanned fire regime is comprised principally of very large, high-coverage fires that have burnt in adverse fire conditions, change to a more proactive use of fire is required for biodiversity conservation. In such areas, use of planned burns is the only viable method available to reduce the potential for very large adverse unplanned fires which can otherwise burn through and homogenise previously existing seral stage mosaics, with adverse consequences for biodiversity. Fire management may also be necessary to protect property, infrastructure and cultural values.

Very large scale, homogenising fires across spinifex landscapes are relatively infrequent, and mostly occur following sequences of 2 – 3 years or more of above average rainfall which result in rapid growth of spinifex with flammable soft grasses filling the space in between hummocks (thereby allowing broadscale fire spread). This renders the landscape much more conducive to large scale fires under a wider range of wind conditions than under more normal conditions when flammable soft grass is mostly absent from inter-hummock spaces. Strategically located low fuel buffers 50 – 100 metres wide may be required to restrict subsequent unplanned fire spread during large fire-conducive conditions (DPaW 2013).

Patch-burning can also be used to create seral stage mosaics. At the landscape scale, a fine grain mosaic of patches of vegetation representing a range of interlocking seral stages will provide diversity of habitats for organisms that are mobile and can move through the landscape. At the local scale, appropriate intervals between fires based on vital attributes of key species, are necessary to ensure the persistence of sessile (an organism fixed in one place) or less mobile organisms. The scale or grain size of the mosaic should (DPaW 2013):

- Enable natal dispersal (juveniles moving away from the place of birth);
- Optimize boundary habitat (boundary between two or more seral stages); and
- Optimize connectivity (ability of key species to migrate between seral stages).

In practice, before fine scaled burn mosaics can be successfully established (which takes many years and lots of fine-scaled burning effort), it is first necessary to break the cycle of very large scale fire recurrence. This typically requires the creation of a pattern of inter-connected burnt buffer strips that will impede the development of large fires. Once this has been achieved, further work to create finer-scaled burn mosaic patterns can be pursued.

Strategic planning for spinifex landscape fire management should be planned and implemented in an adaptive management framework. As part of an adaptive management framework, biodiversity monitoring should focus on:

- Threatened species and communities;
- Fire sensitive species and communities; and
- The remaining biota.

Threats such as introduced plants and animals, and abiotic processes including weather (rainfall) and fire history, must be monitored/recorded in order to help interpret changes in biodiversity. Where spinifex grasslands have been invaded by flammable weed species such as buffel grass (which is capable of adversely altering the frequency and intensity of fire) prescribed fire should be used conservatively and strategically to break up the run of major wildfires.

Consultation and partnerships with neighbours, including traditional owners, is an effective way of managing fire for mutual benefit.

2 Fuel dynamics and characteristics

Spinifex grasslands form a discontinuous fuel, comprised of grass hummocks with inter-hummock spaces in between. The size of the hummocks and the inter-hummock spaces varies as a function of the cumulative growth of the spinifex grassland (time and cumulative rainfall since last fire), with sparse cover in young spinifex grasslands (small, low regenerating hummocks comprised almost exclusively of live biomass), to a high level of cover of large senescent hummocks (up to 45cm in height and with a substantial dead biomass component) in grassland 20 years or older.

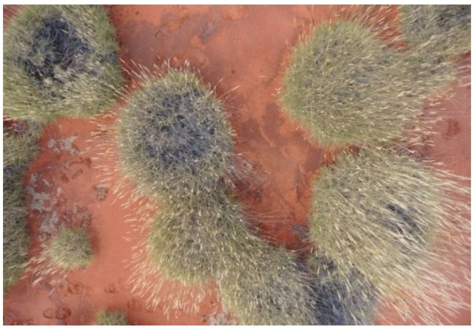
The fuel discontinuity brought about by the characteristic bare gaps between hummocks is a key limiting factor in fire spread. Accordingly, there are three key thresholds to fire spread that are factored in to first determining whether threshold conditions are met for sustained fire spread: fuel cover, wind speed and moisture content. For fires that will sustain spread, and additional fuel input value required to predict rate of spread and behaviour is the fuel load. For estimating the relevant fuel values (cover and load), the most recent spinifex fire behaviour guide developed for WA (Burrows, Liddlelow and Ward 2015) uses a 5 category fuel classification system (see Figure 3).

In years of above average rainfall, soft ephemeral grasses may germinate in pulse-events occupying inter-hummock spaces and increasing fuel continuity. Many of the largest spinifex fire events have occurred in such circumstances. Even younger age classes of spinifex which in most weather conditions may normally be too discontinuous to sustain fire spread, may carry fires in such circumstances. Invasion of spinifex grassland by fire-prone introduced grass species such as buffel grass can also substantially alter fuel and fire behaviour characteristics.

In addition to considering fuel cover and load, fuel moisture content needs to be determined or estimated for fire behaviour prediction. Direct measurement can be undertaken by collecting and bagging samples for oven drying, although this is often used as a means of post-burn validation of FMC estimations. Recently, Wiltronics fuel moisture meters have also been used with success – it is estimated that fuel moisture values were within 2% of actual values (DPaW 2013).

Direct measurement of fuel moisture is not always feasible, and methods for spinifex FMC estimation have been developed. The use of the Australian Water Availability Project (AWAP) data (http://www.csiro.au/awap) for off-site estimation of the profile moisture content of live spinifex clumps has had limited testing, but shows promise. The methodology for PMC estimation using AWAP data is provided in the WA Spinifex Fire Behaviour Guide (Burrows, Liddlelow and Ward 2015). Remote sensing (satellite imagery) to estimate ‘curing’ and cover is also under development. However, in the field, the principal method of estimating fuel moisture content is using visual field estimation guides. Burn crews make a visual assessment of the colour of the live spinifex leaves and use a field guide to estimate the moisture content associated with the observed colour (see Figure 4).

Figure 3 Spinifex fuel categories and characteristics

Fuel class 1 (<6 years old)  Spinifex seedlings mostly <15cm tall and <15cm wide. Plants are discrete, mostly separated. No dead leaves or stolons in centre of plant.	Key fuel characteristics  Fuel Cover (total): 20 – 40% Bare ground: (60 – 80%) Fuel Height (cm): <15 Fuel Load (t/ha): <3.5
Fuel class 2 (6 to 10 years old)  Mostly discrete, compact hummocks, some joined. No or few dead (black/grey) leaves or stems evident in hummocks. Spinifex flower/stalks present. Most plants 20 – 30cm tall and 20 – 30cm wide.	Key fuel characteristics  Fuel Cover (total): 40 – 50% Bare ground: (50 – 60%) Fuel Height (cm): High: 25 – 30, Low: 20 – 25 Fuel Load (t/ha): High: 6.5, Low: 4.5
Fuel class 3 (11 to 15 years old) 	Key fuel characteristics  Fuel Cover (total): 45 – 55%

Plants are roughly circular, dome-shaped clumps 20 – 35cm high, 20 – 50cm wide. Many discrete, but many are joined. Most have dead (black/grey) leaves and stems forming in the centre of the hummock and in the growing front. Spinifex flower/stalks present.	Bare ground: (45 – 55%) Fuel Height (cm): High: 30 – 35, Low: 25 – 30 Fuel Load (t/ha): High: 8.5, Low: 6.5
Fuel class 4 (16 to 20 years old)  Oldest plants have formed ‘donuts’ up to 3m diameter with bare ground or sparse dead stems in the centre and usually a band of dead stems behind the live front. Sometimes the growing front is fragmented. These meadows can be mixed age, with some younger plants	Key fuel characteristics  Fuel Cover (total): 50 – 60% Bare ground: (40 – 50%) Fuel Height (cm): High: 35 – 40, Low: 25 – 35 Fuel Load (t/ha): High: 10.5, Low: 8.5
Fuel class 5 (21 to 25+ years old)  Oldest plants have formed ‘donuts’ and semi-circles up to 3m diameter with a dense mat of dead (black) leaves and stems behind the growing front. There are similar proportions of live and dead material. Sometimes the growing front is fragmented. These meadows can be mixed age, with some younger plants.	Key fuel characteristics  Fuel Cover (total): 60 – 70% Bare ground: (30 – 40%) Fuel Height (cm): High: 40 – 45, Low: 35 – 40 Fuel Load (t/ha): High: 16.5, Low: 14.5

(Source: Adapted from Burrows, Liddlelow and Ward 2015)

Figure 4 Field Guide – Spinifex Clump Profile Fuel Moisture Content for a Class 2 (standard) fuel (<5% dead leaves)

1. Leaves bright green with few / no yellow leaves: Class 2 PMC ~30-40%

2. Leaves pale green with some yellow leaves: Class 2 PMC ~20-30%

3. Leaves yellow-green with many yellow leaves: Class 2 PMC ~15-20%

4. Leaves yellow / straw, no green leaves. Class 2 PMC ~10-15%

PMC correction for older fuels with a higher proportion of dead leaves and stems

Class 3 PMC = Class 2 PMC - (1/(0.03 x RH)) x 1.5;
Class 4 PMC = Class 2 PMC - (1/(0.03 x RH)) x 2.5;
Class 5 PMC = Class 2 PMC - (1/(0.03 x RH)) x 3.5;
Use Class 2 PMC mid-point

(Source: Burrows, Liddlelow and Ward 2015)

The ‘Class 2 PMC’ indicated under each spinifex colour class needs to be corrected using the PMC correction factors to correct for spinifex classes older than Class 2 and the relative humidity at the burn site. The PMC correction calculation is identified above and explained with examples in the WA Spinifex Fire Behaviour Guide (Burrows, Liddlelow and Ward 2015).

The rate at which spinifex grows and increases biomass/fuel following fire is largely dependent on rainfall, which is highly variable from year-to-year. This makes predicting post-fire response and fuel accumulation imprecise and indicative only. On average, spinifex fuel in the arid interior west re-accumulates at around 0.6 t/ha/year for about 18 years before stabilising at around 11-12 t/ha. This equates to around 400mm of accumulated rain being needed to produce 1 t/ha of fuel. Generally, periods of above average rainfall are followed by extensive fires due to the build-up of flammable fuel and inter-hummock gaps being filled by herbaceous ephemerals.

2.1 Other issues, opportunities and constraints

In a high proportion of landscape areas where spinifex burning is considered, roads and tracks suitable for use as fire breaks may be in limited supply. On former pastoral properties a network of roads and tracks that can be used may be available but in areas without these, areas to work fire from may be limited to natural features such as fuel discontinuities associated with dune ridges, stony country, clay pans salt lakes/scalds and recent fire scars. In any case, burns will typically be unbounded along at least one edge, and thus it is necessary to select favourable fuel conditions and diurnal weather patterns in which periods conducive to sustained fire spread will be limited, and fire will self-extinguish overnight.

Due to the remote location of many areas where ongoing spinifex burning programs are pursued, significant operational and logistics management issues arise. Travel by vehicle from routine office/work locations to selected burn sites may take a whole day (or more in some cases), via remote roads and tracks. To optimise program delivery efficiencies, multiple works may need to be programmed (not just fire management works) and conducted over a minimum period of at least a few days to a week. This means that operational and logistics organisation needs to be sound, and able to achieve burn crew and operating camp self-sufficiency, with prudent contingency arrangements in order, for what can be extended operating periods in very remote arid locations. This includes allowing for sufficient logistical supplies/support for equipment used for burning and operational management for the duration of the operation. Such operating circumstances require good leadership, management systems, and operating discipline to be in place, with systems in place for teams to self-sustain and manage any safety, operations, work group-dynamics/discipline or health/medical issues that may arise.

A second key issue is that there is very limited capacity for response to any fire-escape or unanticipated fire behaviour events that may arise. Response actions may be limited to consequence management and getting out warnings to communities/travellers in the area. Prior preparation and planning for contingencies, focussed on consequence management, is particularly vital in remote operations because typically there is little, if any, assistance that can be mobilised locally for response.

A third key issue is that operational planning and implementation of burning operations will often require, and in many cases be reliant on, cooperation and assistance from traditional owner groups. Planning, work systems, and culturally aware inter-personal communication approaches which engage with, and provide for participation of traditional owner groups, and which can accommodate cultural requirements that may arise will be needed. Traditional owner groups may have a number of other priorities to factor in to their availability over an extended remote operation. Therefore operational planning will need to have sufficient flexibility to allow for traditional owner needs and the possibility that other competing priorities may arise. Operational management systems will also need to accommodate the integration of traditional owners into agency work health and safety and operational delivery systems.

A fourth key issue is that in some areas where spinifex burning is being conducted in conjunction with feral animal control and endangered native fauna reintroduction programs, careful consideration needs to be given to fire interactions with these programs. Burning may be strategically positioned to provide protection of acclimatisation compounds (predator proof areas designed for threatened species recovery) from unplanned wildfire incursion, or to manipulate habitat to suit the requirements of particular species. In addition to considering ecological requirements, protection of any monitoring or research equipment that may be deployed will need to be implemented.

3 Burn planning approach and process

Remote area burning operations in spinifex landscapes typically involve the implementation of a program of burns over a number of days. Pre-planning a fixed sequence of burns is not always possible or prudent. Even though weather conditions at particular times of the year, such as in the favoured May to August burning period, are relatively consistent and predictable, there is still a significant degree of variability which occurs from day to day.

Two key weather related factors affecting spinifex burning operations are wind (direction and strength), and fuel moisture content (which is affected by preceding rainfall, relative humidity, and also the degree of cloud cover).

Due to the characteristic fuel array discontinuity associated with spinifex, wind is a vital enabler of sustained fire spread, tilting flames from burning hummocks across inter-hummock gaps to ignite the next hummocks. Younger spinifex fuels will typically require stronger wind strengths to sustain fire spread than older spinifex in which inter-hummock gaps are relatively fewer and smaller. Therefore the wind strength on any particular day, or even time of day, will influence which spinifex can and can't be burnt successfully. Wind direction is also very important, because sustained fire spread in prescribed burning conditions is generally only in the direction of the wind, except in particularly old fuels which support a greater degree of flank and even backfire spread than younger fuels. Hence if executing a particular burn (say from or towards a particular track or asset) is reliant on wind coming from a particular direction, then winds from an unfavourable direction may preclude burn implementation.

In spinifex fuels, a high proportion of the fuel profile is live (especially so in younger fuel classes) and therefore recent rainfall has the most significant bearing on fuel moisture content through moisture uptake and retention in live plant tissues. Changes in relative humidity have a proportionately smaller influence on the fuel moisture content of higher FMC fuels (changes in RH have less impact on greener spinifex than on yellow – straw coloured spinifex). It is noteworthy also that the degree of cloud cover is commonly observed to have a discernible effect on spinifex fire behaviour, although the physical mechanisms of how this effect operates is not well understood. If wind conditions are marginal, then the presence of a high degree of cloud cover will typically render conditions unsuitable for achieving good fire spread and coverage. Cloud cover in favourable wind conditions will typically moderate fire behaviour, and can also serve to shorten the period during the day in which fire spread is sustained.

Accordingly, for fire planning in remote spinifex areas, burn programs will need to be implemented with a degree of intuition applied to selecting which burns are best suited to implementation in the conditions prevailing on any particular day. Consideration of how the forecast weather is expected to vary over the course of the field operations period is also important so that some planning ahead of burn order can be undertaken.

The key point is that for remote spinifex burning operations, planning an inter-dependent sequence of burns with little flexibility for sequence alteration is a sub-optimal approach. A better approach is to have a range of burns planned, which while the majority may assume occurrence of seasonally prevailing winds, there are a sufficient range of potential alternatives that can be implemented in weather conditions other than the typical seasonal patterns. A degree of nuancing that takes advantage of diurnal variability is also advisable. Such an approach is necessary to ensure that to the extent possible, burn program delivery efficiency is maximised in the event that atypical weather conditions arise for significant time periods during the remote operations.

3.1 Burning season selection

From an operational risk perspective, the lower risk season for spinifex burning in the arid interior west is in the May to August period. Relatively mild temperatures at this time of year, and reasonable expectations that fires will self-extinguish with falling wind speed, falling temperature and rising relative humidity overnight make this period the most suitable for unbounded burning and buffer strip burning. Burning later in the spring/early summer period from September to December has higher risks because this is at the tail end of the driest seasonal period, it is typically the windiest time of year, and daily temperature and relative humidity associated hazard is on an increasing trend.

However, from an ecological point of view, burning in the September to December period is preferable. A key reason is that good rainfall soon after fire occurrence is optimal for post-fire recovery, promoting good regeneration. A long delay (several months) between fire and favourable rain is best to avoid if possible. Although rainfall in the arid interior west is unreliable and highly variable, statistically, the highest probability of receiving good rain before the onset of the very hot summer period is in the spring. This is also thought to be the most active period of traditional owner burning in spinifex country, coinciding with when reptiles were becoming increasingly active (Burrows and Butler, 2013).

Therefore, in practice, a spread of burn timing is preferable. For unbounded burns and buffer strip burns, in higher risk situations, it is considered preferable to undertake these burns in the May to August period. However, for burns within reliable boundaries, such as those being undertaken within previous established and reliable burnt buffers, patch burning in the September to December period may be considered. During this period, the occurrence of winds sufficient to attain good fire spread may occur more reliably, and the likelihood that rain events favourable for regeneration and post-burn recovery will follow within a few months of the burn is increased. The downside is the increasingly hot conditions and longer day length which typically results in low fuel moisture content, and the increased potential for windy conditions to arise. Hence burning during this period is typically focussed on small scale ecological patch burns within areas bounded by reliable burnt buffers.

3.2 Burn timeframe and duration

Optimally, spinifex burns are generally planned to have a single day burn-out timeframe (although some smouldering combustion may persist in woody shrub components such as mulga beyond this timeframe). A general aim is for burns to self-extinguish overnight as wind speeds and temperatures fall and relative humidity rises.

The time period during the day available for burning in spinifex largely depends on the onset of rising and declining wind speeds, and also on relative humidity and cloud cover. Burns undertaken in the May to August period are during the coolest time of year, and shortest daytime periods. Typically, lighting is not commenced until late morning (seldom before 11 AM) when temperatures have risen sufficiently from the cool overnight lows, and when any diurnal wind development has begun to take effect. During these months day length is relatively short, with sunset occurring between 5 and 5:30 PM. Other than on atypically warm, dry or windy days, fire behaviour tends to decline substantially and often quite abruptly in the sunset/twilight period. The presence of cloud cover typically tends to retard fuel moisture adsorption processes during the morning delaying the onset of favourable fire spread conditions to the early afternoon, and advances fuel moisture absorption processes bringing forward the period when fire behaviour declines (an hour or so before sunset), and can shorten the period of active fire spread. On days of heavy cloud cover it can be difficult to attain good fire spread at all. On most wintertime burning days seasonal conditions are such that free-running fire will generally only occur for around 3 to 4 hours during the afternoon.

Patch burning in the September to December period is generally done after the afternoon temperature peak has passed and relative humidity is rising. The extending day length in spring typically accommodates a 2 to 3 hour burning period in the late afternoon before sunset, and fire activity may continue beyond sunset in dry conditions. Care is taken to avoid burning on days when the weather pattern will result in above average temperatures or unsuitable wind.

3.3 Planning of burn area dimensions

In the case of buffer strip burns adjacent to roads or tracks, a degree of precision can be applied over the size, shape and dimensions of a burn. In general a buffer strip width of around 50 metres wide is the objective in clear spinifex grassland situations, and this is increased to 100 metres wide where scattered or open patches of mulga are present. A degree of active control along the unbounded windward lit edge may be applied if necessary to achieve this.

In the case of patch burning, there is much less control over the shape, size, number and distribution of burnt patches. Lighting pattern (particularly ignition location selection in relation to wind direction and low fuel areas planned to restrict head fire spread) can be used to exert some influence over patch size and shape, however with mostly unbounded sections and weather variability the patch size and shape cannot be precisely defined or controlled.

The arrangement of buffer strips and patches in the landscape is designed with the aim of restricting bushfires to an upper size limit – in the case of Lorna Glen/Earaheedy ex-pastoral leases[2] where DPaW is developing and testing spinifex burning strategies and techniques, the aim is to restrict bushfires to less than 6,000 hectares[3]. In achieving this aim, the general approach to prescribed burn application is to keep the mean burnt patch size (of all fires, planned and unplanned) to less than 100ha with the median patch size less than 10 ha, accepting that larger fires will inadvertently occur. These are considered reasonable and practical patch size objectives noting that under traditional Aboriginal burning, some 70% of the landscape was burnt by patches >100ha (Burrows *et al*. 2006).

Burnt patch size distributions in the following range are the aim:

- 35% of landscape: patches <250 ha;
- 35% of landscape: patches 250 – 700 ha; and
- 30% of landscape: patches 700 – 1,000 ha.

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[2] *Lorna Glen/Earaheedy ex-pastoral lease covers approximately 600,000 hectares of semi-arid rangelands on former pastoral lease land in the northern WA goldfields region. It is the centrepiece of Operation Rangelands Restoration, which through an integrated and sustained fox, cat and wild dog baiting, camel control, cattle exclusion, fire management and infrastructure work program aims to restore the land to a condition which will support the successful reintroduction of rare and threatened native mammal populations. It contains extensive tracts of spinifex grasslands mulga/spinifex communities.*

[3] *This upper bound is based on research by Burrows et al. (2006) into the maximum patch size determined from analysis of fire scars from aerial imagery from 1953 of a spinifex landscape area still under the influence of Aboriginal burning.*

3.4 Planning of seral state patch mosaics and burning frequencies

In spinifex dominated landscapes where inter-annual rainfall is highly variable and unreliable, a system of seral state classifications (loosely based on spinifex developmental stages) is preferred to a time-since-fire only centred system. At Lorna Glen/Earaheedy, a five category spinifex seral state classification system is being applied (see Table 1). Fire management at Lorna Glen/Earaheedy aims to establish and maintain a heterogeneous mosaic distribution of seral states to increase spinifex habitat diversity from recent historical levels, improving faunal habitat diversity and increasing resilience to unplanned bushfires.

Within each fire management unit (FMU – landscape area bounded by strip/buffer burns) the aim is to achieve a scattered (avoiding clumped) distribution of seral states, with each FMU to contain at least three of the five seral states and in general to optimise habitat boundary.

Table 1 Spinifex seral states used for fire management planning

Spinifex seral state [Martu term]	Accumulated rainfall	Indicative time-since-fire	Landscape proportion in seral stage
Very early seral state [waru waru]	750 mm	<=3 years	20%
Early seral state [nyukara]	750 – 1,500 mm	3 – 6 years	20%
Intermediate seral state [manguu]	1,500 – 3,000 mm	6 to 12 years	25%
Late seral state [kunarka]	3,000 – 4,500 mm	12 – 18 years	20%
Very late seral state [wuurlpala]	>4,500 mm	>18 years	15%

(Source: Adapted from Burrows, Liddlelow and Ward 2015)

4 Fire behaviour prediction

Spinifex fire behaviour prediction is undertaken using the WA Spinifex Grassland Model – Mk 2 (Burrows, Liddlelow and Ward 2015).

The model can be applied to spinifex-dominated grasslands of Western Australia that are:

- 6 – 25 years old;
- Fuel load 3.5 – 16 t/ha; fuel cover 20-70%; spinifex clump height 20 – 50 cm;
- Spinifex clump profile moisture content 10 – 35%; and
- Winds at eye level <40 km/h (~<48 km/h at 10 m).

The model incorporates a two-step prediction process.

Step 1

The first step is to determine whether or not sustained fire spread is likely to be achieved. This requires input value estimates for wind speed at eye level, percentage of spinifex cover, and clump profile fuel moisture content. A spread index is calculated upon which 7 categories of spread likelihood are based (Very Low, Low, Moderate, High, Very High, Extreme and Very Extreme).

Likelihood of fire spread and potential ROS (m/h) is tabulated in Table 2.

Table 2 Spinifex fire spread likelihood categories

Spread Index (SI)	Spread likelihood	Indicative rate of spread (ROS in m/hr)
SI <-2	Very Low	Fire highly unlikely to spread (ROS = 0)
-2 <SI <0	Low	Fire could spread (ROS <500)
0 <SI <2	Moderate	Fire should spread (ROS: 500 –1000)
2 <SI <4	High	Fire will spread (ROS: 1000 – 1500)
4 <SI <6	Very High	Fire will spread (ROS: 1500 – 2000)
6 <SI <10	Extreme	Fire will spread (ROS: 2000 – 3000)
SI >10	Very Extreme	Fire will spread (ROS >3000)

(Source: Adapted from Burrows, Liddlelow and Ward 2015)

Step 2

The second step is to estimate rate of spread and flame height. These can be calculated using the mathematical formulas provided in the model Guidelines (reproduced below) or from simple look-up tables provided in the model Guide. Input values for the calculation of rate of spread and flame height are wind speed at eye level, percentage of spinifex cover, average spinifex clump height, and clump profile fuel moisture content.

In field practice, either the indicative spread rates from step 1 are used give a rate of spread range, or the look-up tables in the Guidelines can be used to give a more precise rate of spread prediction and also a flame height prediction (sample table for Fuel Class 3 from Guide reproduced at Figure 5).

Figure 5 Sample fire behaviour prediction table from WA spinifex fire behaviour guide

Cover spinifex live(%)	Cover spinifex dead(%)	Cover Other (%)	Cover fuel total (%)	Bare ground (%)	Spinifex ht (cm)	Fuel load (t/ha)
35-45	5-10	3-6	45-55	45-55	**Hi**: 30-35 **Lo**: 25-30	8.5 6.5

	Wind speed eye level (km/h) Rate of Spread (m/h) (~flame height m)							
PMC (%)	**>7**	**10**	**15**	**20**	**25**	**30**	**35**	**<40**
35 Hi Lo	0 0	0 0	0 0	0 0	0 0	0 0	625 2.0 536	1309 2.6 1221
30 Hi Lo	0 0	0 0	0 0	0 0	289 1.3 0	974 2.5 886	1658 3.1 1571	2344 3.4 2256
25 Hi Lo	0 0	0 0	0 0	639 2.0 551	1325 2.6 1236	2009 3.3 1921	2694 3.6 2606	3379 4.0 3291
20 Hi Lo	0 0	304 1.5 216	989 2.5 901	1674 3.1 1586	2359 3.4 2271	3044 3.7 2916	3729 4.1 3641	4414 4.5 4326
15 Hi Lo	645 2.0 566	1339 2.6 1251	2024 3.3 1936	2709 3.6 2621	3394 4.0 3306	4079 4.3 3991	4764 4.5 4676	5494 4.6 5361
10 Hi Lo	1689 3.1 1601	2374 3.4 2286	3059 3.7 2971	3744 4.1 3656	4429 4.5 4341	5114 4.6 5026	5799 4.8 5711	6484 5.2 6396

(Source: Adapted from Burrows, Liddlelow and Ward 2015)

Figure 6 Mild fire behaviour in spinifex

(Source: DPAW 2013)

Figure 6 shows mild fire behaviour in spinifex grassland (Class 3). Favourable weather conditions were prevailing but cloud cover was moderating fire behaviour. Weather conditions for this burn were:

Time	Temp (°C)	DP (°C)	RH (%)	Wind (km/h)
1500	28	-12	6	WNW@17

In these conditions fire spread was assessed to be good in spinifex fuels older than 12 (or in the mid-range of Class 3 fuels or higher) but patchier than desired with suboptimal spread in younger fuels.

4.1 Burn Program and Operational Planning

Landscape-scale strategic fire management plans should guide the operational fire management planning process. The operational burn planning process needs to be undertaken annually to take account of burns successfully undertaken in the previous burn season, as well as any unplanned fires that may have occurred. In spinifex landscapes unplanned fires, especially those in areas with large expanses of old spinifex, can attain very large sizes and therefore greatly impact previously planned strategies and programs.

Accordingly the burn planning process typically involves taking a landscape view of:

- Recent fire history, particularly fire occurrence patterns over the last 6 to 10 years, and most importantly the arrangement of recent mosaics created from recent years burning;
- Predicting how unplanned fires burning in adverse conditions would be likely to burn in the landscape;
- Where road and track networks are located that can be of strategic value for implementing prescribed burns;
- Considering which parts of the landscape it is ecologically appropriate to apply prescribed burning in (e.g. spinifex grassland areas) and which it is appropriate to avoid if possible with prescribed burning (e.g. mulga groves);
- Considering where the highest priorities for biodiversity conservation are located; and
- Having considered the above matters, deciding where best to place prescribed burns in the landscape to maximise the potential for low fuel areas to impede unplanned fire spread, and what sequence of burns to pursue to maximise effectiveness with the available resources.

Once an annual program of individual burns has been planned, the finer detail of burn timing, identification of preferred conditions and burning technique, preparations and resourcing for burn execution can be planned.

4.2 Site-specific planning: operational burn site analysis

In identifying areas to be patch-burnt during a burning operation there is a range of factors to be considered, with some of the more critical factors being:

- How will the planned patch-burn area link up with other recently burnt areas in the landscape to form effective buffers against unplanned fire spread?
- Where to physically restrict the burn patch, and what physical advantages (such as exiting tracks and recently burnt patches), and constraints (such mulga presence which could sustain overnight smouldering) are there to achieving successful containment?
- What features and lighting tactics can be used to achieve this?
- What preparatory ground works may be required to facilitate successful containment or to protect specific assets (within or near the planned patch-burn area) from fire impact?

- Under what fuel and weather conditions will the burn need to be conducted to keep the burn to the desired area?[4]

- What ignition methods, lighting patterns and burn-out period will be required to achieve this?

- What resources will be required to light and monitor the burn, including consideration of which traditional owners will need to be involved? and

- If the patch burn spreads beyond the planned containment features (such as burnt buffer boundaries), under adverse burn-season conditions where is it likely to go, what is it likely to impact and where is it likely to become contained?

The outcomes and decisions from these analyses essentially form the basis of the burn plan. These operational issues and risks are considered in a structured way in accordance with DPaW's Prescribed Fire Manual (DPaW 2013), and a Prescribed Fire Plan prepared using DPaW's Prescribed Fire Plan Template.

4.3 Burning operations implementation

The following general burn process is implemented.

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

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. Burn site field weather readings should be checked for alignment/variance with forecast conditions, and fuel moisture readings taken or estimated and predictions made for expected afternoon peak weather conditions.

In general, stronger wind conditions (but within prescription) are more suitable for burning younger spinifex fuel classes and lighter winds more suitable for burning older spinifex fuel classes.

Operational preparations and briefings

Routine procedures for staff and traditional owners assisting with operations, equipment checks and preparedness are undertaken. Planning information is communicated/distributed to burn crews. A routine pre-burn operations briefing is conducted and crews dispersed to take up planned roles as per the burn plan and briefing (the briefing follows a standard SMEAC format). Checks that the necessary burn intention notifications have been made are undertaken and preparations completed ready for ignition. Authorisation to proceed with ignition is requested and obtained from the appropriate burn manager.

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[4] *Use of Spread Index calculations is instructive. Older aged fuels with high cover (fuel classes 4 and 5) will require less wind strength to achieve desirable spread, whereas younger fuel classes will require higher wind strengths to attain satisfactory sustained spread. Control risks can be expected if burning is undertaken in older aged fuels if winds strengthen unexpectedly.*

Conduct fire behaviour prediction and test fire

Once weather parameters and fuels are within the desired moisture range (as predicted, measured or both), a test fire location is selected with fuels representative of those to be burnt, and a test burn is conducted.

Based on the test burn results and any fire behaviour predictions for later in the day, (if necessary) refinements may be made to the pre-planned lighting schedule and pattern to achieve the burn objectives and desired fire behaviour.

Implement burning operations

The focus of burning programs in arid zone spinifex-dominated landscapes is on achieving a desirable degree of seral stage heterogeneity within the landscape. There are essentially two key types of burn that are undertaken.

The first burn type can be characterised as buffer, edge or strip-burns, typically taking advantage of existing roads or tracks and implemented to develop burnt buffers which impede the spread of unplanned fires and provide areas to work from for subsequently implementing patch burns.

The second burn type can be characterised as ecological patch-burns. These are wholly or partially unbounded burn patches implemented within larger cells (fire management units) which have buffer, edge or strip-burns to reduce the likelihood of patch-burn escape, and to limit incursion of unplanned fires from outside the cell.

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 and any lighting pattern modifications arising from the test burn.

- Buffer / edge / strip-burns;

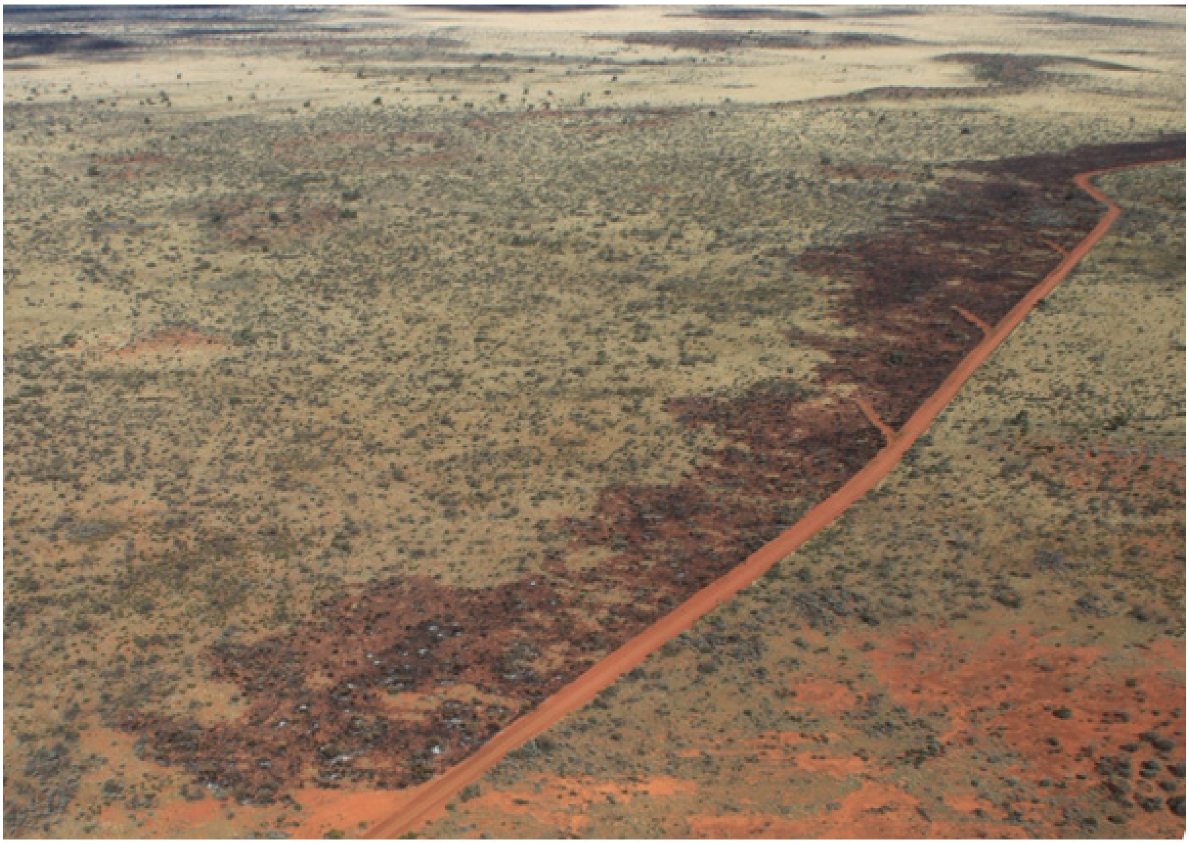
  An effective buffer strip/edging technique is to use drip torches to set a continuous line of fire upwind of a mineral earth break (>3m road or track). With the wind blowing from the burn area toward the road/track, light an initial line of manageable length (depending on resources on hand) about 2 to 3m in from the road/track and let it spread with the wind towards the road. Then move back another 10 metres from the initial line and light the second line parallel to the first. These initial edge burning steps are often implemented using an echelon lighting method (see Figures 8 and 9). Once the burnt edge has attained a width of around 15 metres, drop back another 20 metres and light a third ignition line and let it spread back towards the road. This technique should produce a burnt edge/buffer about 30 to 40 metres wide alongside the road edge. Depending on conditions, an echelon lighting method with up to three lines may be used successfully, with 20 to 30 metre gaps between ignition lines, achieving a greater edge burn depth. Put out any backfire with water or rake to contain the unbounded edge. When spinifex cover is greater than 35% and fuel moisture content less than 20%, backfires can be expected to spread. Extinguishing backfire along the unbounded edge is prudent if there is the possibility of a substantial shift in wind direction later in the day.

  Strip burns may also be undertaken within FMUs in locations where there are no road or track edges to work from, using the wind alone to achieve a burnt strip. A consistent breeze is required to push a narrow running head fire (typically a 50 metre wide line ignition strip is used) from the ignition location toward a burnt buffer area (or other low fuel feature) where the head fire runs out of fuel. This technique relies on the flanks becoming benign and self-extinguishing as fire conditions decline in the early evening and overnight. Strip burning is more reliably achieved in younger, lower cover fuel classes than in older, heavier fuel classes.

Preferably, buffer burning should be done in the lower-risk May to August period, after significant rainfall (>10 mm) when fuel moisture content (hummock profile) is >20%. Under such conditions an eye level wind speed threshold of around 10 – 15 km/h will be required to achieve sustained fire spread in Class 3 fuels, however if fuels are dry (FMC <20%) the wind speed threshold for sustained fire spread may reduce to around 6 – 7 km/h and backfire can be expected to spread, particularly in older fuels (Class 4 and 5).

Figure 7 shows the results of an edge burn along the main road. Figure 8 and Figure 9 shows implementation of echelon edge-burning methods parallel to a road. Burning is undertaken with wind pushing fire toward the road.

Figure 7 Edge burn result beside a road at Lorna Glen



(Source: DPaW)

Figure 8 Close echelon lighting pattern being implemented

(Source: DPaW)

Figure 9 Wider echelon lighting pattern being implemented

(Source: DPaW)

- Ecological patch burns.

  Where the planned system of FMU edge-burnt buffers and internal and external buffers are in place to contain and restrain fire, implement ecological patch-burning within designated FMUs that aims to meet the patch size specifications planned in the annual burning program.

  This can be undertaken in the April to late September period, and in certain circumstances may extend to December (depending on fuels being in a favourable condition) and will require burning under conditions such that fires self-extinguish either due to diurnal fire weather conditions (sub-threshold wind speed, temperature and RH) or by running into low fuel areas (previous burns, buffers and/or naturally sparse fuel areas). Patch burning may be planned using aerial ignition, although this may be costly. Due to the discontinuous nature of spinifex fuels, ignition by aerial drip torch will normally be more suitable than aerial incendiary capsules. If capsule are used, a poor take can be expected in younger fuels, particularly if winds are less than

15 km/h. The application of capsules in spinifex is better suited to older classes of spinifex with higher cover, and in conditions when winds are favourable for sustained fire spread (Spread Index >2). Patch burning is also undertaken using ground crews lighting using a pre-planned ignition pattern based on predicted rate of spread and anticipated spread direction such that the desired patch size is achieved.

Good, sustained operational discipline needs to be applied throughout lighting to ensure that burn crews stick to planned lighting patterns and spacing.

Once a successful ignition has been established, monitoring of the fire direction and rate of spread is undertaken. 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 augmented or backed-off (or ceased in the event of substantial unexpected wind changes) if required to achieve desired outcomes. Any significant changes to planned lighting patterns require approval from the burn manager.

Burn security requires continuous monitoring during the burn, particularly focussed on the weather and on potential weak-points such as patchy or shallow edge burn sections. If coarse woody fuels are present, as can occur where mulga or other woodland species are present with spinifex, these can smoulder through the night and be a potential source of fire re-ignition and escape the following day if weather deteriorates. Therefore it is important to monitor the next morning for signs of smouldering, particularly in sections where scattered mulga (or other woody shrub/tree species) is present or where fire has burn to the edge of mulga groves. If aircraft are available these are particularly useful for observing for signs of active/smouldering fire.

Burning implementation activity/timing, observed fuels, weather and fire behaviour information and observations about burn results or noteworthy incidents/observations are recorded on the DPaW prescribed burn report form.

5 Appraisal

After each burn a post-burn assessment is undertaken to determine if the burn objectives have been met, and the extent to which any follow-up works may be required.

When a helicopter is available burnt area assessment is usually undertaken by an air observer, with burnt areas mapped. Satellite imagery can also be used to map burn scars.

Results of burning, including analysis of methods that went well, not so well or unexpected, and general observations and thoughts for future improvement are documented in Annual Prescribed Burning Results reports. The knowledge captured through these is of high value for continuous improvement processes. The accurate mapping of treated areas is also very important, and is particularly useful when unexpected fire spread occurs on subsequent burns, to inform considerations about options for containing unplanned fire spread.

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