FIRE AND INTRODUCED PREDATOR MANAGEMENT PLANS FOR THE GREAT VICTORIA DESERT FAUNA MANAGEMENT AREA

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Prepared for the Great Victoria Desert Biodiversity Trust
January 2020

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Executive summary

Altered fire regimes and predation by introduced predators (feral cats and foxes) have been implicated in the post-European settlement decline of Australia's arid zone fauna, including in the Great Victoria Desert (GVD). Medium-size mammals and some bird and reptile species have been most severely affected. While predation by introduced predators is likely the primary cause of declines, this has been exacerbated by highly altered fire regimes. Today, intense spring and summer bushfires in the Great Victoria Desert kill countless numbers of animals and remove vegetation over very large areas, destroying habit and exposing surviving fauna to predation.

The Great Victoria Desert Biodiversity Trust's (GVDBT) mission is to, "*conserve and increase knowledge of biodiversity in the Great Victoria Desert*". The current project (Contract GVD-P-19-002) is one of a number of projects funded by the GVDBT to achieve this mission. Specifically, this project contributes to the GVDBT's mission by managing fire and reducing predation pressure by introduced predators. Fauna recovery will focus specifically on providing and protecting adequate sandhill dunnart (*Sminthopsis psammophila*) and malleefowl (*Leipoa ocellata*) habitat at appropriate temporal and spatial scales. These species are of special interest because they are threatened, extant in the project area, vulnerable to inappropriate fire regimes and predation, and are likely indicators of ecosystem health.

Two 'project areas', each ~100,000 ha, have been selected, in accordance with a set of criteria, in the south west GVD; one area will be an unmanaged reference area, the other, a managed area. Consistent with adaptive management, western science and Aboriginal knowledge was used to develop current best practice fire management and introduced predator control plans for the management area. The fire management plan aims to mitigate adverse impacts of bushfire by significantly reducing their size and intensity, and to create a fine-scale mosaic of seral stages / fuel ages ranging from recently burnt to long unburnt. This will be achieved by an annual program of aerial patch-burning under cool weather conditions in autumn - winter, supported by on-ground (hand) burning of roadside buffers. Suppression is usually not feasible in these remote landscapes so is not part of the fire management plan. The annual burning program – what areas and how much to burn – is guided by the current areal proportion of seral stages / fuel ages with the aim being to maintain about 44% of the area as non-flammable early seral stage (≤6 years old), 42% as intermediate seral stage (>6≤18 years old) and 14% as late seral stage >18 years old). Influenced by lighting pattern and 'natural' and burnt firebreaks, the distribution of seral stages will be scattered rather than clumped. Of the 100,000 ha management area, this will provide about 25,000 ha of sandhill dunnart habitat and about 14,000 ha of malleefowl habitat. Increasing the area of older (flammable) vegetation by decreasing the area of younger (non-flammable) vegetation will significantly increase the risk of large, damaging bushfires. Aerial burning will aim for at least 50% of the burnt patches to be <20 ha, with the mean and maximum burnt patch sizes being <200 ha and <6000 ha respectively. Large hot spring-summer bushfires leave few unburnt patches, but burning under mild autumn-winter conditions will increase the extent of unburnt patches within burnt patches.

In these landscapes, malleefowl habitat is primarily long unburnt associations of mallee-spinifex and mulga-spinifex that contain areas of deep leaf litter for nest-building and

foraging. With a lower cover of spinifex, these associations are less flammable than associations dominated by spinifex and low shrubs. While they burn under severe fire weather conditions in spring and summer, they are unlikely to burn under mild weather conditions in autumn and winter when aerial patch-burning will be carried out. This document provides detailed guidance on how to carry out the patch-burning based on an understanding of fire behaviour science.

Introduced predators (feral cats, foxes and wild dogs) are widespread throughout the arid zone. Feral cats are the most abundant and most difficult to control so represent the greatest threat to arid zone fauna, including malleefowl and sandhill dunnarts. Annual broadscale aerial baiting in winter with Eradicat® and in accordance with Western Shield protocols and procedures, is the recommended primary control strategy. Follow-up trapping using leg-hold traps may be necessary should baiting be ineffective. If resources are available, it is recommended that 12 months prior to aerial baiting, 20-30 feral cats be trapped and radio collared to better understand their home range, distances travelled and habitat usage. While not critical, this information will enable a more targeted baiting strategy to be planned and implemented. In order to interpret and measure management effectiveness, it will be necessary to monitor the density of introduced predators before and after baiting. This should be done using two proven techniques - i) counting tracks (footprints) along roads and tracks according to published protocols, and ii) using a carefully designed array of trail cameras to provide information about occupancy and abundance. For efficiency measures, it would be advantageous if the camera array was designed to provide information about both introduced predators and terrestrial native fauna, but this needs to be explored further.

In an adaptive management framework, this document provides detail on how to plan and implement fire management and introduced predator control programs to benefit arid zone fauna. It provides a schedule of major tasks but it does not provide specific tactical and operational detail about how to carry out the tasks, nor does it cost the implementation of the plans – these aspects are out of scope and are best dealt with by the operations service providers. Likewise, this document does not include details about how to monitor the 'target' species, including malleefowl and sandhill dunnarts.

1. Background

Altered fire regimes and predation by introduced predators (feral cats and foxes) have been implicated in the recent (post-European settlement) decline of arid zone fauna, with medium-size mammals and some bird and reptile species most severely affected[1,2,3] . While predation by introduced predators is most likely the primary cause of declines, this has been exacerbated by highly altered fire regimes. Today, intense spring and summer bushfires destroy habit structure and diversity and temporarily remove vegetation cover over very large areas, exposing fauna to predation[4,5,6,7].

This adaptive management project aims to improve the conservation status of fauna in an area of the Great Victoria Desert (GVD) by managing fire and reducing predation pressure by introduced predators. Fauna recovery will focus specifically on providing and protecting adequate sandhill dunnart (*Sminthopsis psammophila*) and malleefowl (*Leipoa ocellata*) habitat at appropriate temporal and spatial scales. These species are of special interest because they are threatened, extant in the project area, vulnerable to inappropriate fire regimes and predation, and are likely indicators of ecosystem health.

The Great Victoria Desert Biodiversity Trust's (GVDBT) mission is to, "*conserve and increase knowledge of biodiversity in the Great Victoria Desert*". The current contract (Contract GVD-P-19-002) is one of a number of projects funded by the GVDBT to achieve this mission. Specifically, this report will contribute to the GVDBT's mission by (as per contract scope of work):

1. Defining two areas (each ~100,000 ha) within the GVD (WA) with similar habitat and fire history, and containing known populations of sandhill dunnart and malleefowl. One area will be referred to as the 'management area', the other will be referred to as the unmanaged 'reference area'. Areas will not be part of the formal conservation estate, for which the Department of Biodiversity, Conservation and Attractions (DBCA) has management responsibility.
2. Designing a fire management plan for the management area that clearly defines;
    a) a goal of what the area should look like after 10 years of fire management (fire age distribution and mosaic scale),
    b) a target of what percentage of the study area should be burnt each year, within the 10-year time frame,
    c) the optimum mean size of the patch burns each year and the maximum burn size,
    d) detailed guidelines/methodology and an indicative annual schedule of how burns should be conducted, and the spatial arrangement of the patches, in order to achieve annual targets and reach the 10-year goal, and,
    e) detailed recommendations on how to maintain long unburnt areas as part of the mosaic, and how to protect culturally sensitive sites during prescribed burning or from bushfires.
3. Designing (in consultation with suitable technical expert/s on introduced predators in WA) an introduced predator baiting and monitoring plan for the management area which includes;
    a) an optimal baiting regime for the treatment area,
    b) detailed methodology on pre-burn / pre-baiting (baseline) monitoring and analyses that should be conducted for introduced predators, in consultation with suitable scientists, and,
    c) detailed methodology on what post-fire / post-baiting monitoring should be conducted for introduced predators.

Further details about the 'Scope of Work' for this consultancy are contained in Appendix 1.

2. Introduction

Consistent with the 'scope of work', this report develops plans to support and guide on-ground management to mitigate key threatening processes in the GVD, thereby enhancing biodiversity conservation. Adaptive management is systematically trying different actions to achieve a desired outcome. It is a process that recognises that knowledge is incomplete, bases actions on best available knowledge, makes explicit assumptions in the absence of knowledge and enables learning by doing. The adaptive management cycle involves the following steps:

1. Defining the problem / hypothesis: The combination of large, intense bushfires and predation by introduced predators threatens the survival of some fauna in the GVD, including sandhill dunnarts and malleefowl (the 'target' species).
2. Developing possible solutions: Reintroduce a patch-burn strategy to mitigate the adverse effects of large bushfires and to maintain critical habitat. Carry out baiting and trapping to control introduced predators.
3. Designing fire management and introduced predator control action plans and associated monitoring protocols.
4. Designing monitoring protocols for terrestrial native fauna (mammals and reptiles) with a focus on the sandhill dunnart and the malleefowl.
5. Implementing the threat mitigation plans and monitoring protocols.
6. Evaluating monitoring results and adjusting management actions in response to new knowledge.

Interactions between primary environmental factors and the condition of the target species are shown in the simplified conceptual systems model in Figure 1. This report addresses the adaptive management cycle steps 1, 2 and 3 above (in scope) but not steps 4, 5 and 6 (out of scope), and Primary Factors 2 (fire regime) and 3 (predation pressure) in Figure 1.

Sections 1 and 2 of this report address Milestones 3A.2 and 3A.3 – "provide a background and an introduction to the project".

Section 3 presents an overview of the fire environment in the south west GVD region to contextualise the fire management plan.

Section 4 summarises knowledge of arid zone fire ecology as a basis for developing an ecologically appropriate fire management plan of the GVD.

Section 5 addresses Milestone 3A.4 and 3A.5 – "the rationale for the selection of two areas of land on which to implement this adaptive management program – one being a management area, the other being an unmanaged reference area".

Section 6 addresses Milestone 3.6 – "including details of the fire management plan; recent fire histories of the region and the project areas; specific fire management objectives and targets including spatial and temporal metrics about the desired fire-induced mosaic; how the landscape should 'look' in terms of fire patterns; an indicative prescribed burn program; a prescription for achieving fire management objectives and targets; and a fire management monitoring protocol".

Section 7 presents an operations plan for aerial baiting and follow-up ground trapping to 'mop-up' feral cats. This section includes a protocol for pre- and post-baiting monitoring of introduced predator density to evaluate the effectiveness of control measures.

Section 8 presents a Schedule of Major Tasks associated with the fire management and introduced predator control plans.

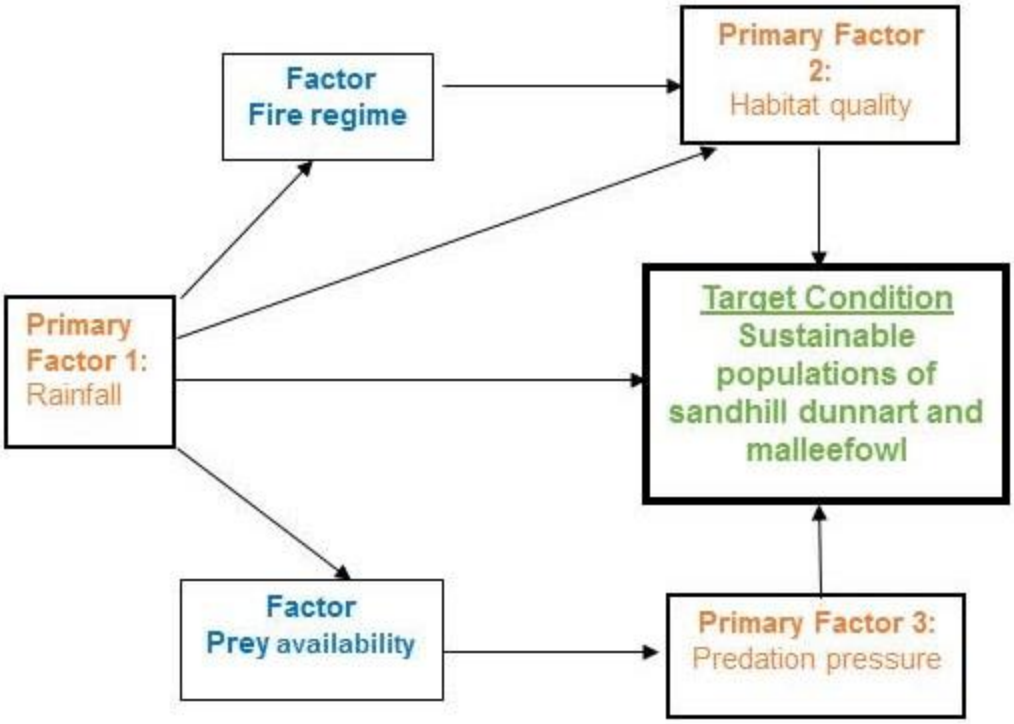


Figure 1: Simplified conceptual model of a management system showing interactions between the target condition (sandhill dunnart and malleefowl populations) and factors that influence the target condition, including fire regime and predation by introduced predators.

3. Regional fire environment

A summary of many of the biophysical attributes of the Shield and Central subregions of the GVD is provided elsewhere[8,9,10]. The current summary is in the context of the region's fire environment, which is not dealt with in the aforementioned references.

3.1 Climate and fire weather

The region's climate is arid with variable and unreliable rainfall[11]. There are no long-term weather stations in the GVD so weather, which is variable across the expanse of the GVD, is inferred from nearby stations. Generally, rainfall is lower in the southern GVD towards the Nullarbor Plain. The region experiences warm to hot summers, with maxima in the range 30-45ºC. Winters are mild with maxima in the range 15-25ºC and overnight temperatures often below 10ºC; frosts are not uncommon. Across the GVD, spatially averaged median rainfall is 162 mm and the study area lies between the 150 mm and 200 mm mean annual rainfall isohyets, making it one of Australia's driest regions (BoM). Rainfall is primarily from three weather patterns - winter rainfall associated with cold fronts, and summer rainfall associated with thunderstorms and rain bearing depressions (ex-tropical cyclones). Weather data in Figure 2a are from distant meteorological stations, but reflect the monthly / seasonal distribution of rainfall and temperature in the region. There is some evidence that in response to climate change / variability, rainfall in the interior has increased slightly, as has the incidence of summer thunderstorms and lightning-caused bushfires. This increases the 'fire-proneness' of the region by increasing fuel re-accumulation rates and ignition frequency. Figure 2b shows the

'bushfire season' in the south west GVD is generally from September to February, peaking in October and November.

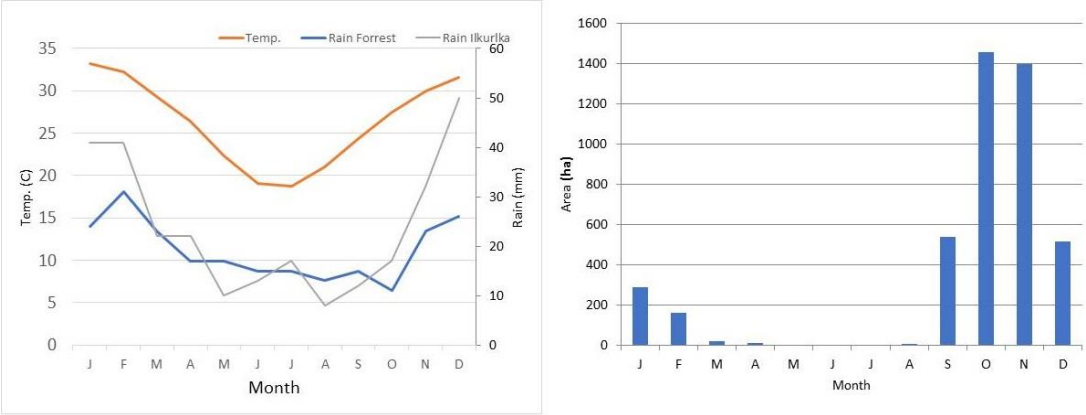


Figure 2a (L): Mean monthly maximum temperature and rainfall for Forrest (340 km SE of the project area) and rainfall for Ilkurlka (330 km NE of the project area) (source: BoM Climate Online). Figure 2b: Mean monthly area burnt by bushfire in the south and west GVD 2000-2019 (source NAFI).

Once spinifex fuels are sufficiently contiguous and dry enough to ignite, wind speed, temperature and relative humidity are the most important weather factors influencing fire danger rating and potential fire behaviour. There are no long term wind data for the project areas so the summary in Table 1 is from Giles. Based on combinations of mean temperatures, wind speeds and rainfall, the seasons of highest fire danger are, unsurprisingly, late spring and summer with late autumn and winter being the periods of lowest fire danger and most suited to prescribe patch-burning (Figure 2b).

Drn and speed	*Winter*	*Spring*	*Summer*	*Autumn*
Predominant direction	N (18%) E (18%) SE (15%)	N (20%) NW (18%) W (12%)	E (40%) SE (25%)	E (22%), SE (20%), N (15%)
<10 km/h	13%	11%	6%	18%
10-<20 km/h	48%	44%	39%	53%
20-<30 km/h	26%	30%	38%	24%
30<40 km/h	15%	16%	17%	5%

Table 1: Proportion of time (%) of 1500 hrs wind speed and direction for each season (Giles BoM weather station).

3.2 Vegetation and fuel

The project area is in the south west of the GVD characterised by sand plains, east-west trending dune fields and playa lakes. Vegetation cover is spinifex (predominantly *Triodia basedowii*) and a variety of low shrubs, often with an overstorey of scattered trees such as marble gum (*Eucalyptus gonglyocarpa*), callitris (*Callitris verrucose)* and mulga

/wanari (*Acacia aneura*), and mallees such as yarltarrpa (*E. youngiana*), and Kingsmill's mallee (*E. kingsmillii*)[8,9]. The Shield subregion is characterised by yellow sand plain and sand dune communities interspersed with low mallee 'woodlands' whereas the south-west portion of the adjoining Central subregion is characterised by red sand plains and dune fields interspersed with mulga / acacia 'woodlands'. Land tenure is mostly unallocated crown land, conservation reserves and Aboriginal land.

Spinifex communities of the GVD that regenerate from seed are reproductively mature (>50% of plants have flowered) at about 4-6 years post-fire (depending on rainfall). Up to this stage, ground / fuel cover is mostly <20%, which is too sparse to carry fire[12]. The spinifex / fuel cover threshold for fire spread varies depending on wind speed and fuel moisture content, but is about 25% for severe, high wind spring/summer weather conditions and about 35% for mild, low wind autumn/winter weather conditions[12]. As a guide, from a fire behaviour perspective, this equates to minimum possible fire return intervals of about 8-9 years (spring/summer fire) and about 10-12 years (autumn/winter fire). Meadows can re-burn at shorter intervals if they are invaded by annual grasses and herbs, which can occur on some sites following above average rainfall. By 12-15 years, cover has reached 40-45% and by about 25 years it is 45-50%, after which time it gradually decreases as plants senesce (Figure 3). It should be noted that these are mean values – the rate of post-fire regeneration is spatially and temporally variable, depending on rainfall and soil type. A method for mapping spinifex cover from satellite imagery has recently been developed, providing a cost-effective tool for fire management planning and vegetation cover monitoring[13].

The rate of post-fire recovery of fuel load, which comprises live vegetation ≤4 mm in diameter and dead vegetation <6 mm in diameter, is also variable, depending on rainfall and soil type. As with fuel cover, it tends to plateau after about 15-20 years (Figure 3). As spinifex meadows age, the proportion of dead material increases, which increases the flammability of the fuel complex. Fuel load has little influence on fire rate of spread, but influences flame dimensions, fireline intensity and the 'killing power' of the fire[12].

While Beard's[14] broad vegetation classification of spinifex-dominated GVD land systems could be further classified according to plant species assemblages and overstorey characteristics, their fire-proneness, flammability and fire behaviour characteristics (or 'pyro-botany'), are similar because of the dominance of spinifex. That is, fire interprets the landscape according to weather, topography and fuel characteristics rather than species composition *per se, s*o pyro-botanically, the spinifex-dominated land systems are similar notwithstanding variation associated with seral stage (fuel age) and site productivity (rainfall and soil type). The post-fire cover and fuel load dynamics presented here are for spinifex species that regenerate from seed following fire, which is mostly the case in the project area. Species that resprout are likely to recover more quickly. In the absence of better information, it is assumed that fire response patterns within these spinifex-dominated land systems are similar, despite some variability in plant species assemblages.

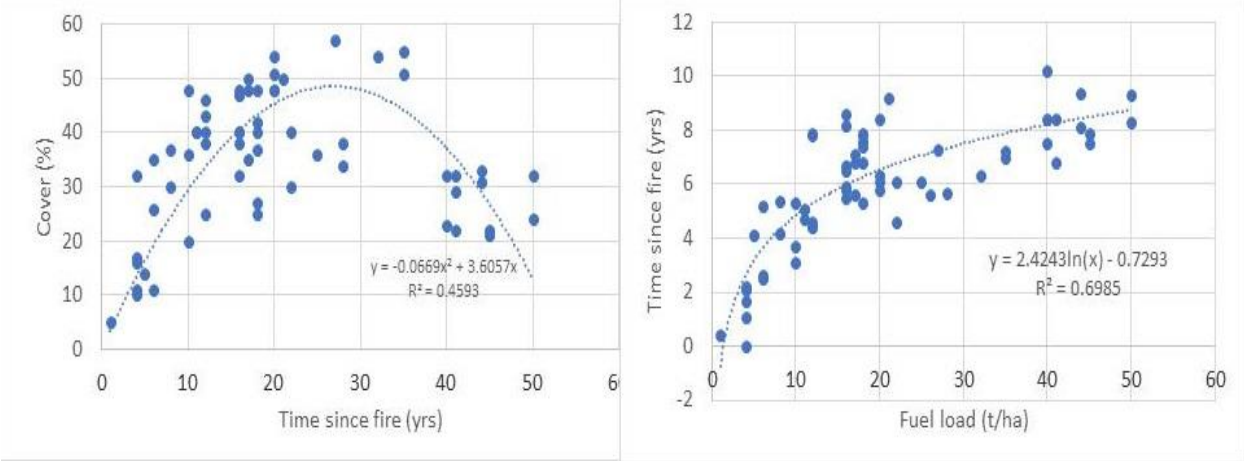


Figure 3: Post-fire recovery of fuel cover (spinifex and low shrubs <1.5m high) and fuel load in the GVD.

Descriptions of spinifex as a fuel are provided elsewhere[15,16]. Briefly, the spinifex plant is highly flammable due to its physical structure, and in the case of resinous species, chemical composition, and because dead fuel components are usually very dry.

Plate 1: Fire has shaped the biota of flammable GVD spinifex communities for millennia.

The perennial spinifex plant is able to survive under conditions of extreme moisture stress. When under moisture stress, spinifex gradually shuts down photosynthesis and growth, withdraws chlorophyll from its leaves, maintains cell structure and integrity (i.e. does not wilt) through a complex and poorly understood physiological pathway and 'suspends' metabolism. Under water stress, the plant is straw-coloured, and has the 'cured' appearance of an annual grass. The moisture content of 'living' parts of the plant (root, stem and leaf) can fall as low as 18% and plants can remain partly desiccated for at least 2 years, beyond which they will eventually die. During prolonged dry spells, some plants will actually shed foliage to conserve water, giving clumps a sparsely foliaged appearance. Within a short time after rain, the plant imbibes soil moisture, mobilises chlorophyll and commences metabolism - photosynthesis and growth - including production of new foliage, flowering and stolon growth. When the soil is 'moist'

the foliage is very green with the moisture content of live components reaching 70-80% and the moisture content of the whole plant profile, including live and dead components, reaching 40-45%.

After regeneration, usually from seed following fire and rain, the spinifex plant develops through a variety of structural or 'architectural' forms, starting as a small dome-shaped clump, and with age, taking on 'donut' or crescent-shaped structures as stolons grow more-or-less radially, and older parts towards the centre of the plant die. Dead spinifex (grey-black colour) can persist behind the 'active growing front' of the plant for several years. Not only does the structure of the plant change with age, but so does the proportion of dead material in the hummock, therefore its flammability. Dead spinifex makes a significant contribution to the plant's fuel properties mainly because it is very responsive to changes in relative humidity (RH) and rainfall events. Dead fuel can remain very dry for long periods on account of the low relative humidity normally experienced in arid and semi-arid environments[15,16].

Spinifex forms a dominant, often simplex, discontinuous fuel layer with flammable elements separated by bare ground patches of varying dimensions. Once the cover of ground fuel (spinifex and low shrubs) exceeds about 25%, it has the potential to sustain fire spread. Because of its patchiness, mature spinifex fuels have at least two fire spread thresholds - the first is fuel moisture content – when fully 'green', the plant may ignite, but fire spread will be difficult to sustain. However, the main threshold (for mature fuels) is wind speed. The wind speed threshold varies according to spinifex cover and moisture content, but is usually in the vicinity of 7-12 km hr^{-1} measured at eye level. Because it is patchy and has several spread thresholds, spinifex is often referred to as a 'go - no go' fuel. Ground fuel cover is usually lower beneath relatively dense stands of mallee and mulga due to edaphic and competition factors.

Fire in spinifex is capable of very high rates of spread - in excess of 15 km/h under conditions of high fuel cover, dry fuel and hot, strong wind (severe fire danger rating). Burn patchiness – the horizontal extent of vegetation removal – and combustion efficiency – the vertical extent of fuel removal – are dependent on the fuel structure, fuel moisture content and weather conditions (fire danger rating) during the fire. Burn patchiness decreases and combustion efficiency increases with increasing fire danger rating. Guides to fuel assessment and predicting spinifex spread are provided at Appendix 2.

3.3 Fire history of the south west GVD

3.3.1 1995-2018

A recent (1995-2018) fire history of a 6.893 million ha area of the south west GVD has been complied by van Dongen *et al*.[17] using a chronosequence of Landsat satellite imagery (Figure 4). Over that time, bushfires have burnt about 8 million ha, with large year-to-year variation (Figure 4). The annual area burnt ranged from about 20,000 ha to about 924,00 ha, or about 0.3% to 14.4% of the study area, averaging about 5.6% over 24 years. Figure 5a illustrates the annual variability and the somewhat cyclic nature of area burnt in response to trends in antecedent rainfall and historical fires. Usually 'big' fire years are preceded by above average rainfall and associated fuel / vegetation growth, and 'small' fire years usually follow a period of large fire years because there is less fuel available in the landscape to burn, until fuels re-accumulate. This cycle has been variously referred to as a "boom and bust bushfire cycle" or a "wildfire cycle" [18,19].

Lightning is the predominant cause of fires, although there has been limited anthropogenic burning in the region. Hundreds of fires occur in the south west region of the GVD each year[17]. Over the period 1995-2018 the average fire size was ~3,750 ha with the medium size ~253 ha[17]. While there have been many small fires, a few large fires accounted for most of the area burnt (Figure 5b). Fire size-class distribution is skewed to the left so mean and median values alone have limited meaning. The largest fire recorded over the period was 492,228 ha, which occurred in 1998; since 1995 there have been nine fires > 100,000 ha[17].

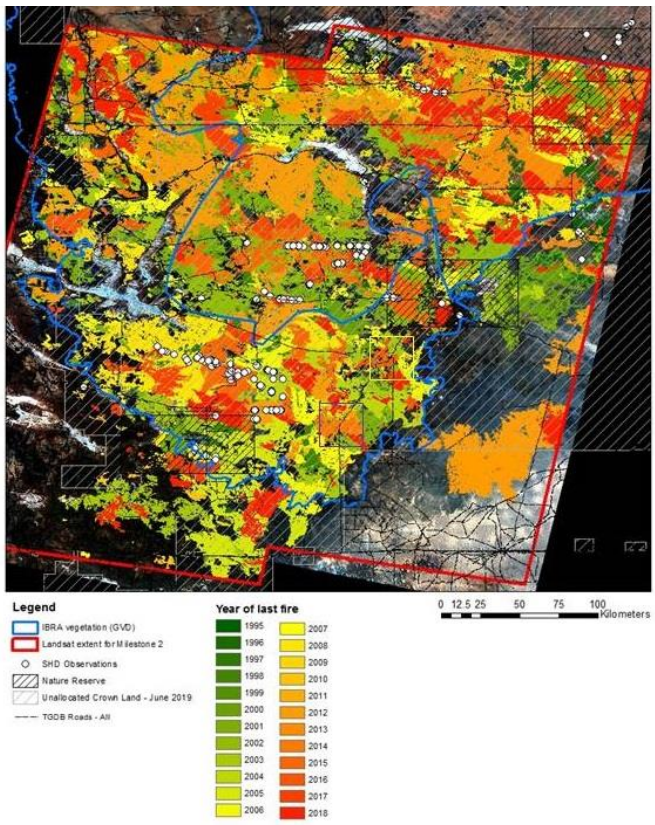
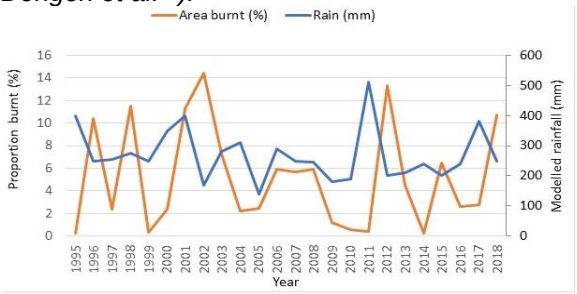


Figure 4: Fire history (1995-2018) of the south west Great Victoria Desert region (source: van Dongen et al.[17]).



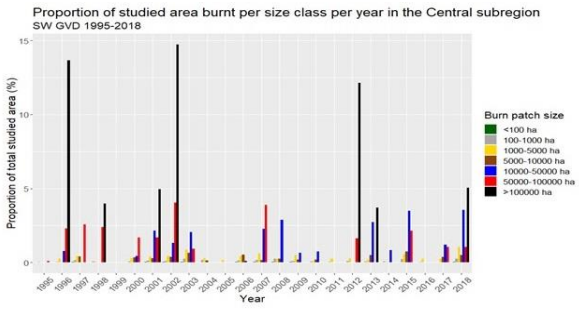


Figure 5a (L): Annual variation in area of the south west GVD burnt by bushfires (1995-2018) with modelled annual rainfall. Figure 5b (R): Proportion of the area burnt by fire size class. While there are many small fires, most of the area was burnt by a few large fires (source: van Dongen et al.[17]).

All fire-prone landscapes exist as mosaics of different post-fire seral stages (or fuel ages), as is evident in Figure 4. It is the spatial and temporal characteristics of the mosaic that determines how the biota respond, especially the fire interval, intensity, diversity of seral stages, burnt patch sizes and fire patchiness. The current distribution of fire intervals for the Central (IBRA GVD2) sub-region over the last 24 years is shown in Figure 6a. This distribution is similar for the Shield (IBRA GVD1) subregion[17]. Approximating a normal distribution, the mean and median fire intervals are similar at about 13 years. About 75% of the region burnt every 10-17 years, about 10% of the region burnt at intervals ≥18 years and about 3.5% of the region burnt at intervals ≤5 years, the latter were probably areas dominated by herbs and soft grasses. These data suggest most bushfires are occurring soon after the spinifex has recovered sufficient cover to re-burn (10-15 years).

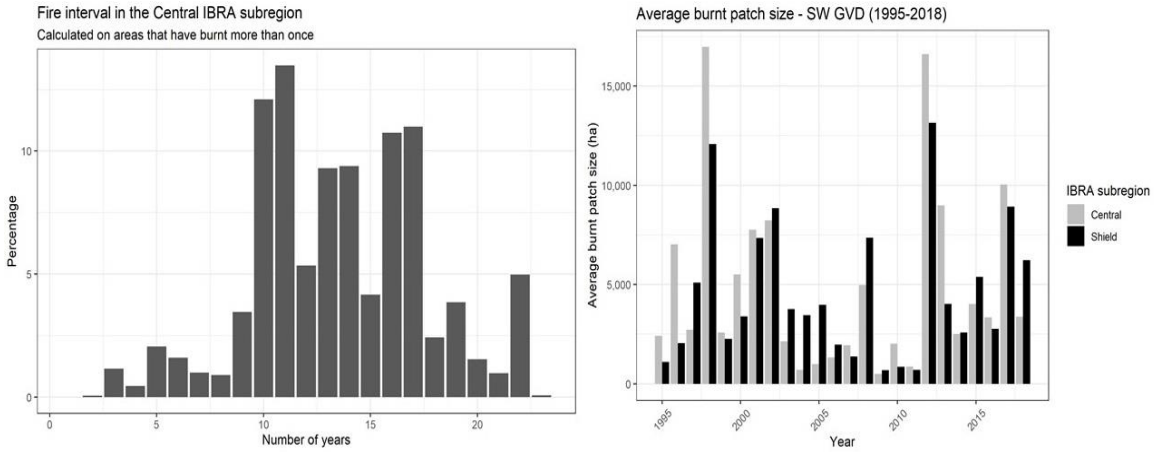


Figure 6a(L): Proportion of area burnt by fire interval for the south west GVD region. Figure 6b (R): Mean annual fire size for the south west Great Victoria Desert region (source: van Dongen et al. 2019)

In flammable ecosystems such as hummock grasslands, and in the absence of suppression action, the form of the relationship of the proportion of the landscape at various seral stages, or fuel age classes, will approximate a negative exponential[20,21,22,23]. That is, a greater proportion of the landscape will comprise early and intermediate seral stages, or younger fuels. This is the case for the south west GVD regional fuel age class distribution as at December 2018 (Figure 7a), where about 50% of the region comprises fuel ages ≤ 6 years and about 7% of the region carries fuels older than 18 years. Bushfires in summer 2019 have significantly increased the proportion of young fuels and decreased the proportion of older fuels (Figure 7b). The current (as at March 2019) regional fuel age class distribution is a result of the recent cyclical spike in large bushfires. In the absence of management, in time, the current large area of young fuels will age and become a large area of older, flammable fuels. Inevitably, these fuels will burn, once again converting the region to large areas of young fuel – perpetuating the bushfire cycle. Under the current unmanaged regime, the mean annual burnt patch size ranges from several thousand hectares to almost 17,000 ha, several orders of magnitude larger than traditional Aboriginal fire patterns (Section 4.1.1).

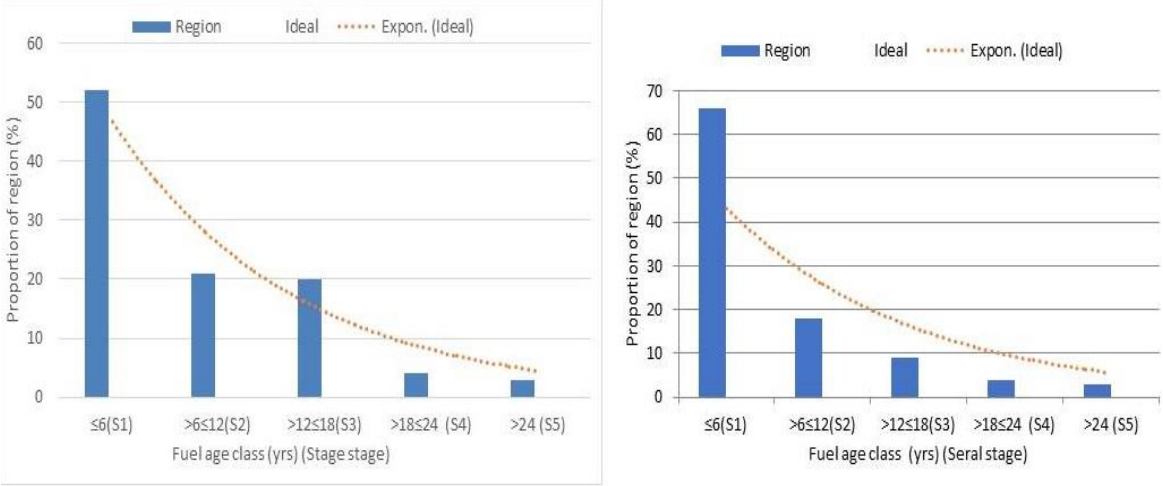


Figure 7a (L): Fuel age class /seral stage (S) (areal proportion) distribution of the south west Great Victoria Desert region as at December 2018 (source van Dongen et al.). Figure 7b: Fuel age class distribution as at March 2019. Almost 1 million ha of older fuel ages (15-24 years) were burnt by intense summer bushfires in 2019 (source: NARFI). The theoretical 'ideal' fuel age class distribution is shown.

3.3.2 Bushfires in summer / autumn 2019

The fire history complied by Van Dongen *et al*. covered the period 1995-2018. However, large areas of the south west GVD were subsequently burnt by bushfires in summer / autumn 2019 (Figures 8b and 9). From an analysis of MODIS imagery accessed via the Northern Australia and Rangelands Fire Information (NARFI) website, bushfires in the south west GVD in January, February and March 2019 burnt ~905,770 ha, or about 13% of the region; the largest fire was about 324,000 ha and severely burnt about 60% of the Queen Victoria Spring Nature Reserve. While these fires are not included in the van Dongen *et al*. analysis, they have impacted the project by further restricting areas available to undertake the project.

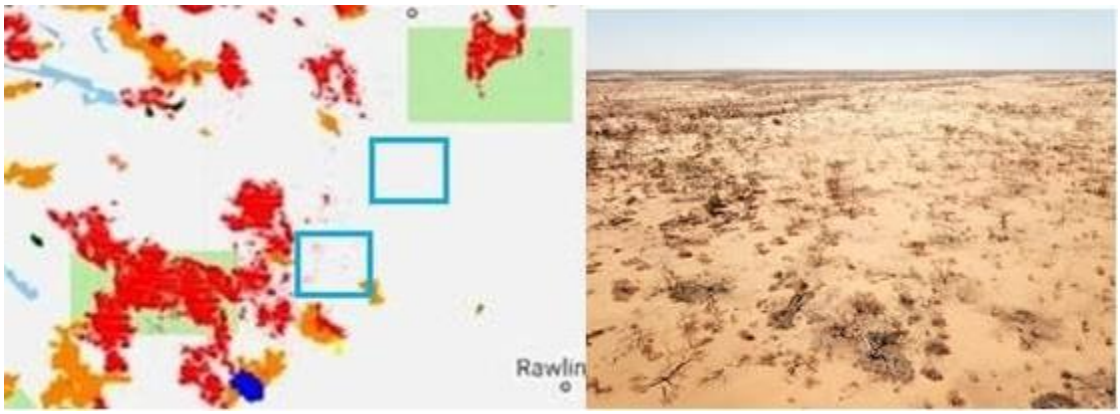


Figure 8: February-March 2019 bushfires in the south west GVD. Almost 1 million ha was completed de-vegetated by the high intensity fires (low to nil patchiness and high combustion efficiency). Proposed project areas shown (blue squares). At time of writing (November 2019), a large bushfire was burning south of the Queen Victoria Spring NR.

4. Fire in spinifex grasslands

The combination of accumulations of flammable vegetation, the physical structure of the spinifex hummocks and the often extreme fire weather make spinifex grasslands highly flammable[15,18,24]. Historically, lightning and deliberate burning by Aboriginal people were the main causes of fire, with the latter being the dominant ignition source[25]. Today, most fires are started by lightning, although human-caused ignitions are significant near settlements, along vehicle travel routes and in association with land management practices on Aboriginal and conservation lands. While most *Triodia* species are fire sensitive (readily killed by fire), spinifex grassland communities are fire maintained; fires at appropriate temporal and spatial scales are essential for their persistence and health[18,26,27].

Under traditional law and custom, Aboriginal people inherit, exercise and bequeath customary responsibilities to manage their traditional country. The relatively recent displacement of Aboriginal people from parts of central Australia, including the GVD[28,29], has coincided with an alarming decline in some native mammal and bird species, and a contraction of some fire sensitive plant communities. Proposed causes of these changes include an altered fire regime resulting from the departure of traditional Aboriginal burning practices, predation by introduced predators and competition with feral herbivores[2,30,31,32,33]. While knowledge of fire effects in hummock grasslands is incomplete, there is strong evidence of dramatically changed fire regimes in parts of the Gibson, Great Sandy and Great Victoria Deserts since the displacement of Aboriginal people and the associated decline of traditional burning. In general, there has been a reduction in diversity of fire regimes (frequency, season, intensity and scale), and an increase in the intensity and scale of hot spring and summer bushfires. This has resulted in a shift from a pyrogenic fine-grained habitat mosaic to pyrogenic homogenization of habitat over most of the spinifex grasslands[18,25,35,36].

4.1 Background information and supporting science

4.1.1 Evidence of altered fire regimes

The most compelling and quantifiable evidence of recently altered fire regimes in the Western Desert comes from studies linking oral evidence from Traditional Owners with early black and white aerial photography taken over a remote area of the Gibson Desert in 1953 and over parts of the Great Victoria Desert in 1960/61.

At the time of the 1953 photography, Pintupi Aboriginal people were living a ‘traditional lifestyle’, more than a decade before European contact[25,29]. The last of the bush people, the so called ‘Pintupi Nine’, walked in to the Kiwirrikurra community in 1984. As well as making a field trip with one of the Pintupi Nine in 1989, the author and colleagues[25,34] studied the 1953 aerial photography covering about 2,500 km^2 west and south of Lake McKay where the last Pintupi bush people were living and it revealed a mosaic of numerous small burnt patches. The mean burnt patch size was about 60 ha, with most (75%) of the burnt patches being less than 32 ha and 50% less than 5 ha[25,34]. About 20% of the area was burnt by fires < 100 ha and ~36% by fires > 1000 ha; the largest fire was about 6,000 ha. Based on fire shape and on information provided by Martu and Pintupi people, most of the burnt patches were consistent with having been lit by people, who burnt the spinifex for a myriad of reasons but primarily for acquiring food[25,34].

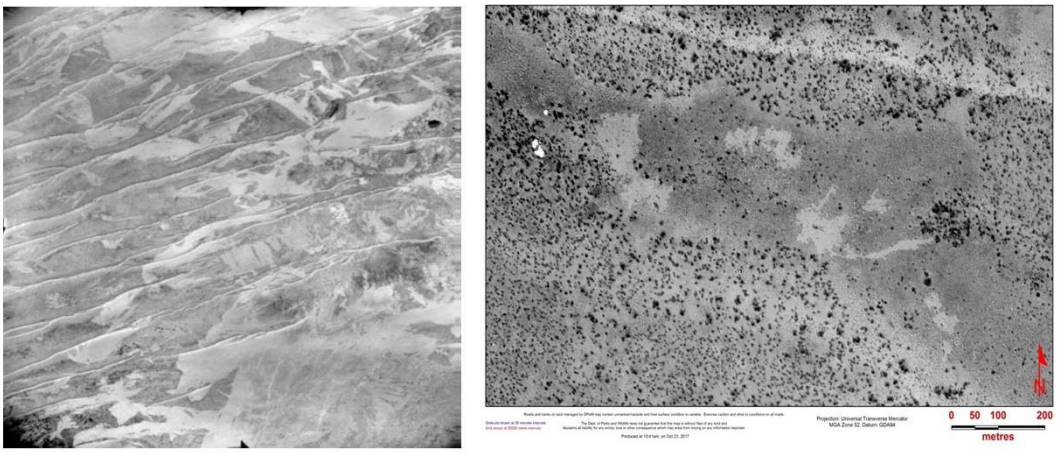


Plate 2: Early aerial photography over the Gibson Desert (1953) (L) and GVD (1960) (R) revealing fine-scale Aboriginal burning patterns (light areas).

The fire patterns resulting from a fire regime dominated by Aboriginal burning contrasts sharply with the more recent fire regime following the displacement of people and the cessation of traditional burning from much of these lands. By the mid-1970s, some 15-20 years after displacement, the fire regime in the Great Sandy and Gibson Deserts had changed. Satellite imagery revealed that the mosaic of small, low intensity (cool) fires evident on the 1953 photography had been replaced by large, intense (hot) bushfires primarily ignited by lightning – the average fire size today is several orders of magnitude greater than the fires set under traditional Aboriginal management[25,34].

A recent study[36] compared and contrasted the current fire pattern in a part the Great Victoria Desert (GVD) with that likely created by traditional (pre-contact) Aboriginal (Pila Nguru – Anangu tjuta pila nguru) burning. A chronosequence of Landsat satellite imagery from 2000-2016 was used to reconstruct and quantify the contemporary fire pattern over an area of almost 13 million ha, and the earliest black and white aerial photography, taken in 1960 and covering more than 1 million ha, to reconstruct and quantify traditional Anangu burning patterns. Depopulation and displacement of Anangu began in the GVD as early as the late 1940s so by the time of the aerial photography, there were relatively few groups extant. The study also included a literature review and a discussion about fire with elders from the Tjuntjunjara community[36].

As with most other spinifex-dominated Australian deserts, the contemporary fire pattern in the GVD is characterised by cycles of very large areas burnt by hot fires in spring / summer followed by periods of lower fire activity, a cycle largely driven by rainfall. On a 13 million ha GVD study area, the mean and maximum fire sizes were 3,699 ha and 1,033,121 ha respectively over the period 2000-2016[36]. This contrasted sharply with the size of fires attributed to Anangu burning, visible on the 1960 aerial photgraphy. While the photography is a 'snapshot' in time and space, the mean and maximum fire sizes were 11.2 ha and 3,953 ha respectively, similar to the scale of Pintupi fires in the Gibson Desert prior to European contact. However, compared with the Gibson Desert study, the extent of recent Aboriginal burning evident on the early GVD aerial photographs was limited, with only about 3% of the study area showing visible signs of having been recently burnt. This reflects the sparse Aboriginal population at the time of photography and relatively large areas of low flammability vegetation in this region of the GVD[36].

In summary, there is scientific and oral evidence that the fire regime in spinifex-dominated deserts, including much of the GVD, has changed significantly as a result of the displacement of Aboriginal people and their traditional burning practices. It has changed from a stable pattern of numerous small, cool fires to an unstable pattern of large, hot spring / summer bushfires followed by intervening periods of few fires because of lack of vegetation to burn, culminating in large hot bushfires once the fuel has re-accumulated – a 'megabushfire' cycle. This 'boom and bust' fire regime is now largely driven by rainfall, which drives the rate of fuel accumulation with lightning as the dominant ignition source, whereas for thousands of years, burning by people was a dominant influence on the fire regime over much of the region. There is some evidence that since the 1990s, rainfall has increased in parts of central Australia, as has the incidence of lightning-caused summer bushfires, exacerbating the bushfire cycle. Because of the lack of long term weather data for the GVD, this is difficult to confirm.

4.1.2 Desert fire regimes and fire ecology – a summary

Scientific knowledge of the ways in which spinifex ecosystems and species respond to fire is incomplete. Consistent with an adaptive management approach, this plan draws on best available science, indigenous knowledge, and experience to provide best possible fire management practices aligned with the objectives of this GVD adaptive management program.

In arid and semi-arid ecosystems there are key feed-back loops involving fire, vegetation, biome productivity and rainfall (Figure 1). Antecedent rainfall drives vegetation growth, which results in increased fuel levels and increased potential for large and intense fires[18,26,37,68]. Generally, periods of above average rainfall are followed by extensive fires due to the build-up of flammable fuel. Primarily through its influence on vegetation, rainfall also determines habitat quality, including cover, food and moisture resources, and nesting / breeding sites.

Because of the flammability of spinifex and the climate of Australian deserts, all spinifex communities are in a cyclic state of dynamic change from fire to fire[38]; there are communities that have recently burnt and those that are about to burn. This fire-driven dynamic equilibrium is inevitable and has persisted for millennia. However, the fire regime – or the spatial and temporal scales of fire, can vary depending on rainfall and the frequency of ignitions, and it is the fire regime that can be beneficial or harmful to the biota. Generally, fire severity (intensity and extent) increases with increased rainfall and reduced ignition frequency, and decreases with reduced rainfall and increased ignition frequency.

The biomass (fuel load) and surface vegetation cover dynamics of spinifex communities in the GVD, developed from space-for-time studies by the author, are shown in Figures 3 and 4. There is considerable spatial and temporal variability associated with variability in rainfall and soil. On average, spinifex fuel (live and dead material <6 mm diameter) re-accumulates at ~0.4 t/ha/annum for ~18-20 years before stabilising at around 6-8 t/ha. This rate of fuel accumulation is about two thirds that of higher rainfall deserts further north. Similarly, the cover of spinifex peaks about 15-20 years after fire, then declines as plants begin to senesce. The fuel cover threshold for sustained fire spread (under extreme summer conditions) for spinifex meadows is about 25%[16]. For 'average' rainfall conditions, this equates to a minimum possible (summer conditions) fire return interval of about 8-9 years. For moist fuel and cool weather conditions in winter and early spring,

the threshold increase to about 35% cover, equating to a minimum 'cool fire' return interval of about 10-12 years.

Season of fire and post-fire rainfall will influence the composition, structure, biomass and rate of recovery of the vegetation (habitat) and its associated fauna. For example, in spinifex communities near Alice Springs, winter fires favoured forbes and caused less physical damage to woody shrubs and trees than summer fires, which favoured grasses and stimulated better regeneration of some woody species[28,33].

Unlike sclerophyllous vegetation that dominates much of southern Australia, spinifex-dominated ecosystems tend to follow a *pseudo-classical* succession post-fire[37,68]. In the early post-fire period, annual and biennial herbs and soft grasses often dominate cover and biomass, with spinifex and woody shrubs present as either small seedlings or as re-sprouts. With time, and depending on rainfall, the herbfield gives way to spinifex and a scattering of woody trees and shrubs, with spinifex eventually dominating the ground cover. The rate at which these ecosystems develop following fire is largely dependent on rainfall, which is variable from year-to-year. This makes predicting post-fire response and fuel accumulation imprecise and indicative only.

At various stages of post-fire development (seral stages), the floristic composition and structure of the vegetation provides different habitat opportunities for a variety of fauna. Published studies show a consistent pattern – that there is no specific or optimal seral stage, or time after fire, that suits *all* fauna. Some taxonomic groups prefer the early seral stages (recently burnt), some the later seral stages (long unburnt), while others occur in many seral stages. Many species prefer a mosaic of seral stages - sheltering or breeding in older spinifex, but foraging in younger spinifex. This fundamental ecological principle of niche partitioning associated with diverse fire-induced habitats, coupled with fire stability, is the ecological basis for the fine-scale mosaic or patch-burning strategy presented in this plan. This concept is summarised by Pianka[39] writing about the richness of lizards in the GVD:

"*One of the most important factors contributing to this is fire, which generates a patchwork of habitats at different stages of recover, each of which favours a different subset of lizard species. Habitat specialised species can go locally extinct within a given habitat patch (fire scar) but persist in the overall system by periodic reinvasions from adjacent or nearby patches of suitable habitat of a different age. Such spatial-temporal regional processes facilitate local diversity".*

In the Tanami Desert, hare-wallabies preferred fine-grain mosaics of vegetation at different seral stages, or post-fire regenerative states, which provide a diversity of feeding and sheltering habitats[4,43]. Large summer bushfires destroyed their habitat but cool season patch-burning by Aborigines acted as firebreaks, reducing the impacts of large hot fires[4]. Small scale patchy fires in spinifex grasslands to create a diversity of seral stages has been shown to benefit a variety of small mammals by ensuring that suitable successional stages were always present. Typically, small mammals shelter in long unburnt patches and foraged in a range of other seral stages[44,45,46]. A long-term study in the Queen Victoria Springs Nature Reserve (GVD) by David Pearson (unpublished) showed that cool, patchy fires did not cause extirpation of small mammals or reptiles and in fact led to a minor increase in species diversity (D. Pearson pers. com.). In contrast, summer fires that virtually completely removed spinifex cover resulted in the temporary loss of many species of legless lizard, small mammals, skink

and gecko although over time, these species reinvaded from surrounding unburnt vegetation (D. Pearson pers. com). Where the distance between unburnt vegetation is large, as is often the case following spring - summer bushfires, then fauna may not be able to recolonize the burnt area before the next fire. Pearson suggested that patch size and boundaries need to take into account the reinvasion / dispersal capabilities of the fauna (which are difficult to determine). The distance between unburnt patches should be less than 3 km to enable sandhill dunnart dispersal (Moseby pers. com.). Maximising the perimeter-to-area ratio of burnt patches and having patches of unburnt habitat within burnt patches enhances reinvasion potential.

Interactions between fire and predation by introduced predators are poorly understood, and can lead to erroneous conclusions about habitat preference. For example, it was thought that mulgara habitat was restricted to dense, long unburnt spinifex because that was where they were mostly trapped. However, monitoring at Lorna Glen (Matuwa) ex pastoral lease north east of Wiluna has shown that this species will inhabit recently burnt spinifex with low cover if introduced predators (feral cats, foxes, wild dogs) are reduced or eliminated, suggesting that the cover provided by longer unburnt spinifex is very important in the presence of predators[47].

4.1.3 Sandhill dunnart: a summary of fire ecology

A summary of the known ecology of sandhill dunnarts is provided by Churchill[48]. From the few studies of the species' fire ecology and habitat requirements, it appears that it prefers to dig burrows beneath or between 'large' spinifex clumps on sandy substrates[48,49] (dunes and swales). In the GVD, these are often associated with marble gum (*Eucalyptus gonglyocarpa*), mallees and *Callitris verrucose* and a variety of low shrubs[48,50]. As spinifex plants regenerate and age, they progress through structural stages peculiar to their radial (stolon) growth habit with the rate of development dependent on site conditions (rainfall and soil), and species. On the Eyre Peninsula, sandhill dunnarts commonly nested in 'large' clumps that formed an intact mound or 'large' clumps that were starting to die in the centre, referred to as development States 2 and 3[51] or fuel /seral structural stages 2 and 3[52] (Figure 9). On the Eyre Peninsula, sandhill dunnarts were only trapped in areas that had been burnt 10 years earlier – they did not use an adjacent long unburnt area (30 years since fire) because the spinifex structure had 'broken down'[48]. This observation is consistent with the spinifex cover dynamics in Figure 3 above for the GVD, where clumps senesce and cover declines after about 25-30 years post-fire. In the lower rainfall environment of the GVD, spinifex clumps begin to die in the clump centre at about age 12-15 years and by 15-18 years, 'donuts' have formed[52] (see Figure 9). On the Eyre Peninsula, there was no strong relationship between time since fire and sandhill dunnart occurrence, but the presence of 'large' spinifex clumps, 8-20 years old, was found to be critical for food, and shelter from predators[48,53].

Other studies have reported that cover >25%, and clump height, are also important[54]. On average, spinifex and low shrub cover in the GVD reaches 25% at about age 10 years. In many spinifex communities, cover and height have been reported to decline some 20-25 years after fire[52,54] (Figures 3). Figure 10 shows a significant but weak relationship between clump height and time since fire for spinifex in the GVD, with maximum clump heights ranging from 20-30 cm. Variability can be explained by variability in soil and vegetation types across the sites sampled, and temporal variation in rainfall. Generally, spinifex communities growing on yellow sands (Shield subregion) are lower and provided lower cover than those growing on red sand (Central subregion).

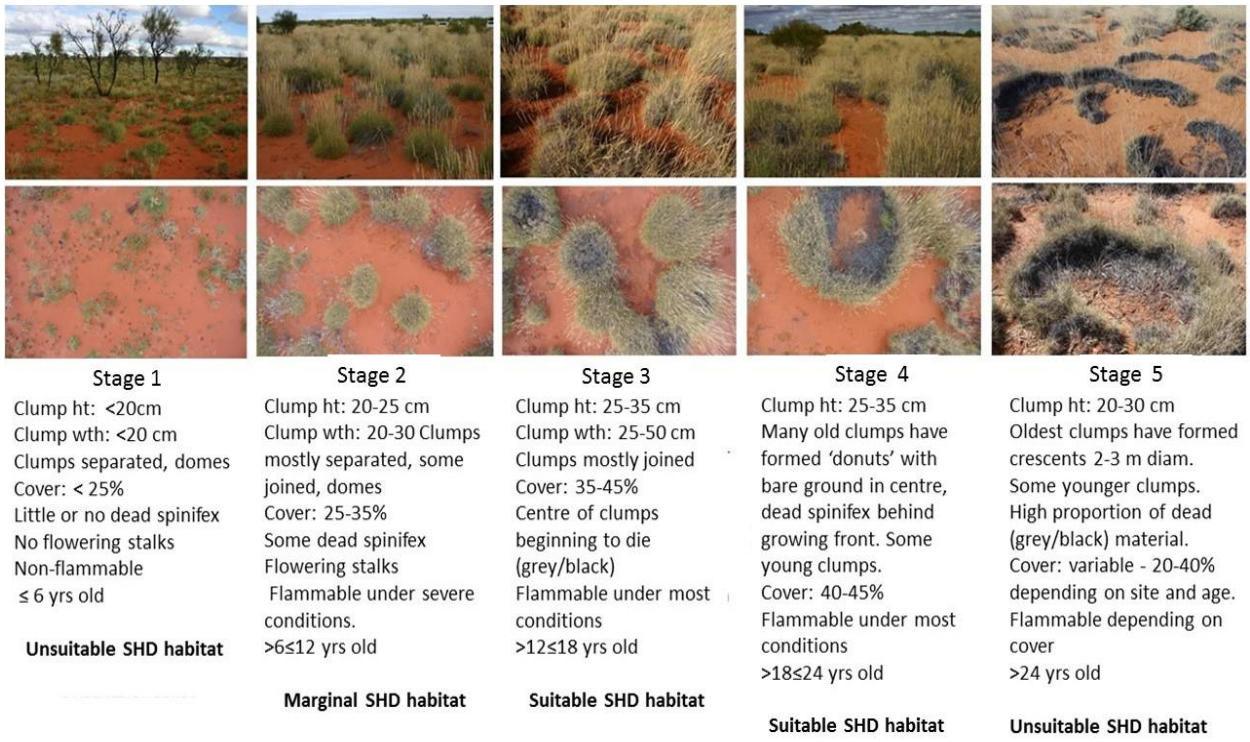


Figure 9: Five broad fuel / seral stages of spinifex as it regenerates and develops after fire (adapted from Burrows et al.[52]). Potential for sandhill dunnart habitat of each stage is shown.

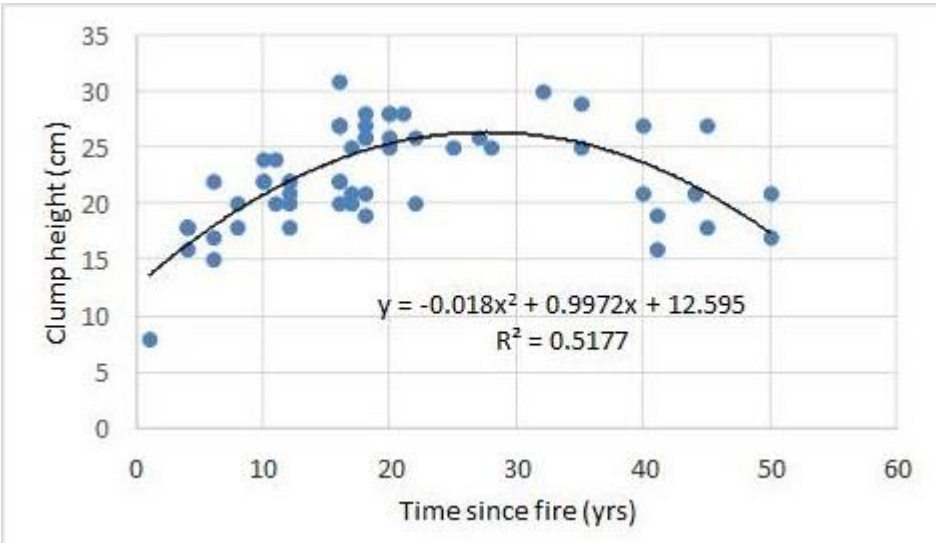


Figure 10: Great Victoria Desert mean spinifex clump/foliage top height with time since fire for sand plain communities. Each data point is the mean of 50 sample points along a 50 m line transect.

Based on the above information, and from the post-fire structural data for sand plain spinifex communities in the GVD (Figures 3, 10, 11), the optimal seral / structural stage for sandhill dunnart habitat in the GVD is about 12-24 years post-fire, when spinifex communities reach maximum cover and height. This equates to S3 and S4 seral stages

(Figure 9). A recent genetic study of sandhill dunnarts suggested that while the species is highly mobile and capable of relative long dispersal distances, maintaining connectivity of habitat (longer unburnt patches) was important for 'meta-populations' to find resources and for maintaining genetic diversity[101].

4.1.4 Malleefowl: a summary of fire ecology

Information about the known former and current distribution, fire ecology, life history and conservation status of the malleefowl is summarised in the Malleefowl National Recovery Plan[55], so will be dealt with only briefly here. While it occurs in mesic areas such as parts of the south west forest region of Western Australia, the malleefowl's preferred habitat is shrublands, low eucalypt woodlands, mulga groves and mallee heath / steppe of arid and semi-arid southern and central Australia[55]. The range of suitable habitats available to the malleefowl have not been well studied and described. From the literature, and given its former distribution, it is evident that the bird is able to utilise suitable habitat in a wide variety of vegetation types and landforms. In general terms, it appears that a sandy or loose substrate and an abundance of leaf litter / plant detritus generated by a relatively high overstorey canopy cover are necessary for the construction of the bird's incubator nest. In the GVD management area, malleefowl habitat comprises a relatively dense mallee overstorey with an understory of spinifex and scattered low shrubs on sandy soil, or areas of relatively dense mulga thickets, or groves, especially of so-called desert mulga (*Acacia miniyura*)[56].

Plate 3: Inactive malleefowl nest in low, dense, long unburnt mallee, Holland Track.

Fire history is also important, with birds requiring long unburnt vegetation for breeding. Presumably, long unburnt habitats provide an adequate localised source of plant detritus / litter necessary for the bird's nests, cover for the mound and emerging chicks, and habitat / food shrubs for both adult birds and chicks. Like many Australian habitats, malleefowl habitat is prone to bushfire. In Western Australia, New South Wales and South Australia, massive bushfires occur in malleefowl habitat every 20 years or so, usually following above average rainfall conditions[56]. Being poor fliers, large, rapidly spreading bushfires could kill many birds, and in highly fragmented landscapes, fires that burn remnant bushland further diminish available habitat, at least until the vegetation

recovers. Therefor it is conceivable that large fires could lead to the local extirpation of malleefowls. Large intense fires can denude the landscape, removing live and dead vegetation which is critical habitat for malleefowl. The temporal effects of large fires on malleefowl habitat will depend on the rate of recovery of the vegetation, but in arid areas, it could take 17-20 years before it is habitable. A number of studies, some of which were undertaken in desert environments, concur that mallefowls have a strong preference for long unburnt vegetation (>18 years since fire) for nesting /breeding sites[56].

However, fire behaviour and pattern is highly variable. Studies in Victoria have shown that birds survived low intensity, patchy fires by using the burnt patches for foraging and the unburnt patches for roosting, nesting and daytime shelter[56]. While breeding density was reduced by the patchy fire, it had returned to within 80% of pre-fire levels within 12 years and by 16 years it had significantly exceeded the pre-fire levels. However, this pattern of recovery following patchy (mosaic) burning is not always consistent, so further work is needed to understand the interaction between malleefowls and mosaic or patchy burning across different habitats, including in the GVD. Mosaic burning at the appropriate scales can break up the run of wildfires, thereby mitigating bushfire impact on malleefowls[56]. It is widely accepted that in central Australia, traditional patch-burning by Aboriginal people buffered the development of large bushfires that threatened malleefowl habitat. As described above, with the cessation of anthropogenic burning in desert landscapes, the fire regime has changed significantly to one of a cycle of large, intense bushfires that damage malleefowl habitat over large areas.

The scientific literature is in broad agreement that fire management that retains a ‘significant’ component of the landscape in a ‘long unburnt’ state is most appropriate for providing malleefowl habitat, especially for nest building. For the purpose of this management plan, and in the absence of specific data, ‘long unburnt’ malleefowl habitat in the GVD is assumed to be mallee – spinifex and mulga-spinifex associations > 18 years old. This equates to seral stages S4 and S5 in Figure 9.

There is uncertainty about how to achieve and maintain long unburnt vegetation[57,58]. This conundrum arises largely because most ecologists do not have a firm, practical understanding of the nuances and variability of landscape fuel patterning and seasonal fire behaviour, nor do they have experience with planning and implementing prescribed fire. Flammable landscapes will inevitably burn, whether from lightning or human ignitions. Despite the best efforts of firefighters, it is impossible to suppress bushfires burning in heavy, long unburnt vegetation under severe weather conditions. In expansive, poorly accessible remote areas, such as the GVD, bushfire suppression is not a feasible strategy for retaining long unburnt habitat.

Malleefowl habitat, both mallee-spinifex and mulga-spinifex associations with a relatively high overstorey canopy cover (>20%), are inherently less flammable than the surrounding spinifex-dominated sand plains and dune fields. This is because the cover of spinifex (fuel) beneath these associations is usually <25% due to soil factors and the competition effects of the mallee or mulga overstorey, which supresses spinifex growth[59,60] (Plate 4). While these vegetation associations will burn under severe spring/summer weather conditions, they are difficult to burn under mild, low wind, autumn/winter conditions because of the sparse, patchy fuels. This natural ‘flammability differential’ can be utilised by experienced fire managers to selectively burn more flammable components of the landscape, while not burning less flammable components, such as malleefowl habitat.

Carefully planned and executed patch-burning under mild fire weather conditions is the only practical, ecologically sustainable strategy for mitigating the effects of large bushfires and retaining long unburnt patches of vegetation as part of the mosaic. This requires frequent introduction of fire into the landscape under mild fire weather conditions to create a finer-scale mosaic of vegetation at different seral stages, including long unburnt. It is emphasised that 'frequent introduction of fire into the landscape' is *not* the same as 'frequently burning the landscape'. The optimal spatial and temporal scales of the desired fire-induced mosaic are unknown. However, the best available knowledge, including lessons learnt from traditional Aboriginal burning practices, is used here to develop a fire management plan for the management area.

5. Selection of project areas

This adaptive management project is a simplified BACI (before, after, impact, control) design, with a managed area and an unmanaged reference area. Being a large-scale operational program, spatial replication is neither feasible nor essential to achieve the program's objectives. As specified in the 'Scope of Work' (Appendix 1), the project areas must be;

- Unallocated Crown Land (UCL) in the south west GVD,
- ~100,000 ha in area,
- known to have supported populations of sandhill dunnarts and malleefowl, or to contain sandhill dunnart and malleefowl habitat,
- similar with respect to fire history,
- accessible by vehicle,
- at least 10 km apart.

Additional criteria are:

- not subject to native title claim, and,
- not on a mining tenement.

These criteria restricted the location of project areas to the white coloured area shown in Figure 11. At this scale, it is unlikely to find two areas that meet all criteria and are biophysically identical. A key criterion was to identify areas where sandhill dunnart and malleefowl occur, or occurred based on historical records. In the absence of up-to-date information, it is assumed that these species are extant at the project areas and that the areas contain suitable habitat for these species. It may be necessary to carry out pre-treatment surveys to confirm the current distribution and abundance of these species on the project areas. Methodologies for monitoring the distribution and abundance of the target species is out of scope for this contract and will be developed elsewhere.

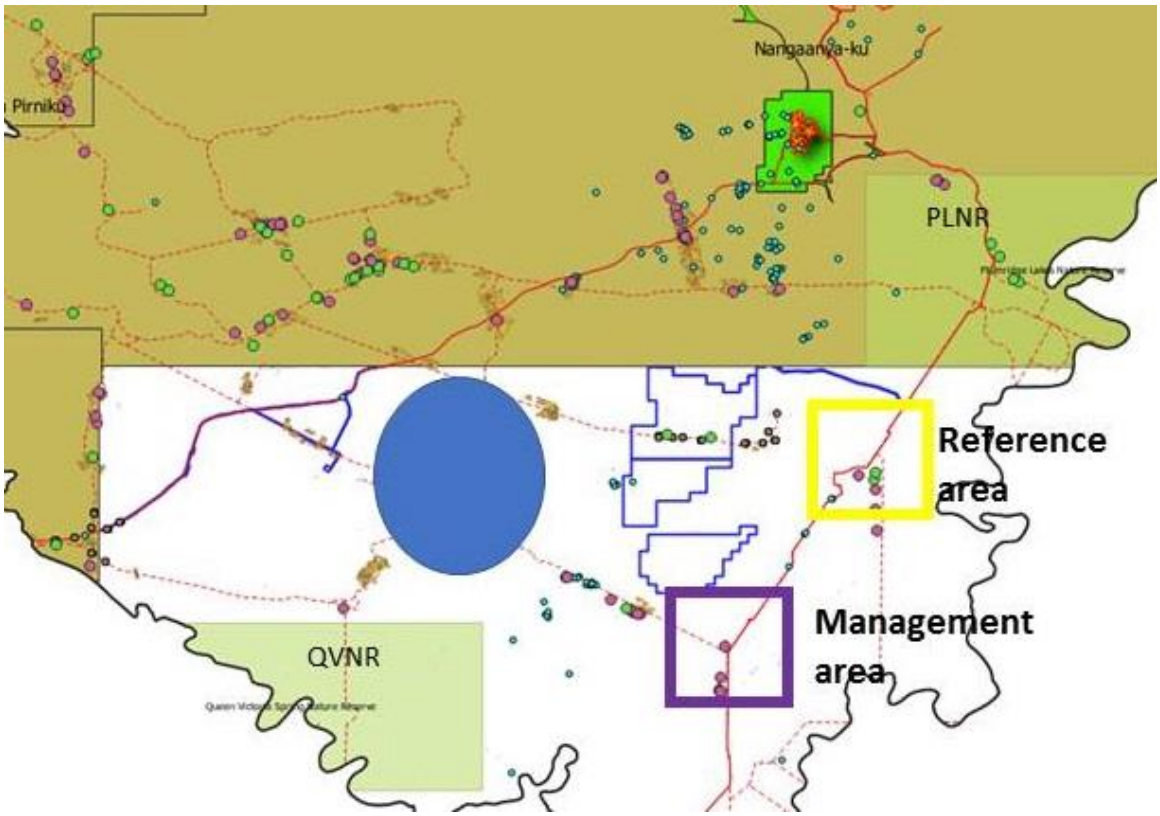


Figure 11: Selecton of project areas restricted to the white area shown on the map. Yellow square (32 km x 32 km) is proposed reference area and purple square (32 km x 32 km) is the proposed management area. Coloured areas are either nature reserves (light green), mining tenements (dark green and blue) or land under native title claim (khaki). Dots are malleefowl (green, purple) and sandhill dunnart (brown) reocrds.

Within the white area in Figure 11, the two project areas, each ~100,000 ha were chosen based primarily on historical records of the target species in or near the project areas (Figures 12 and 13) while meeting other criteria as far as possible. Both areas are on UCL and in sub-region GVD01 (Shield - yellow sand plains) Vegetation of both areas is structurally similar, being characterised by spinifex-dominated sand plain / dune field land forms, and scattered patches of mallee -spinifex communities. The areas are separated by ~22 km to their nearest boundary and both areas have relatively good vehicle access, with ~45 km of track in each. The proposed management area is protected from bushfires entering from the west by a 2019 bushfire (Figure 12b) and its areal proportion of seral stages / fuel ages approaches the 'theoretical ideal' distribution so the area will require less effort and cost to manage with fire during the period of this plan. Both areas are west of the Nullarbor IBRA which contains tracts of low flammability or non-flammable chenopod vegetation, reducing but not eliminating, the risk of bushfires from the east.

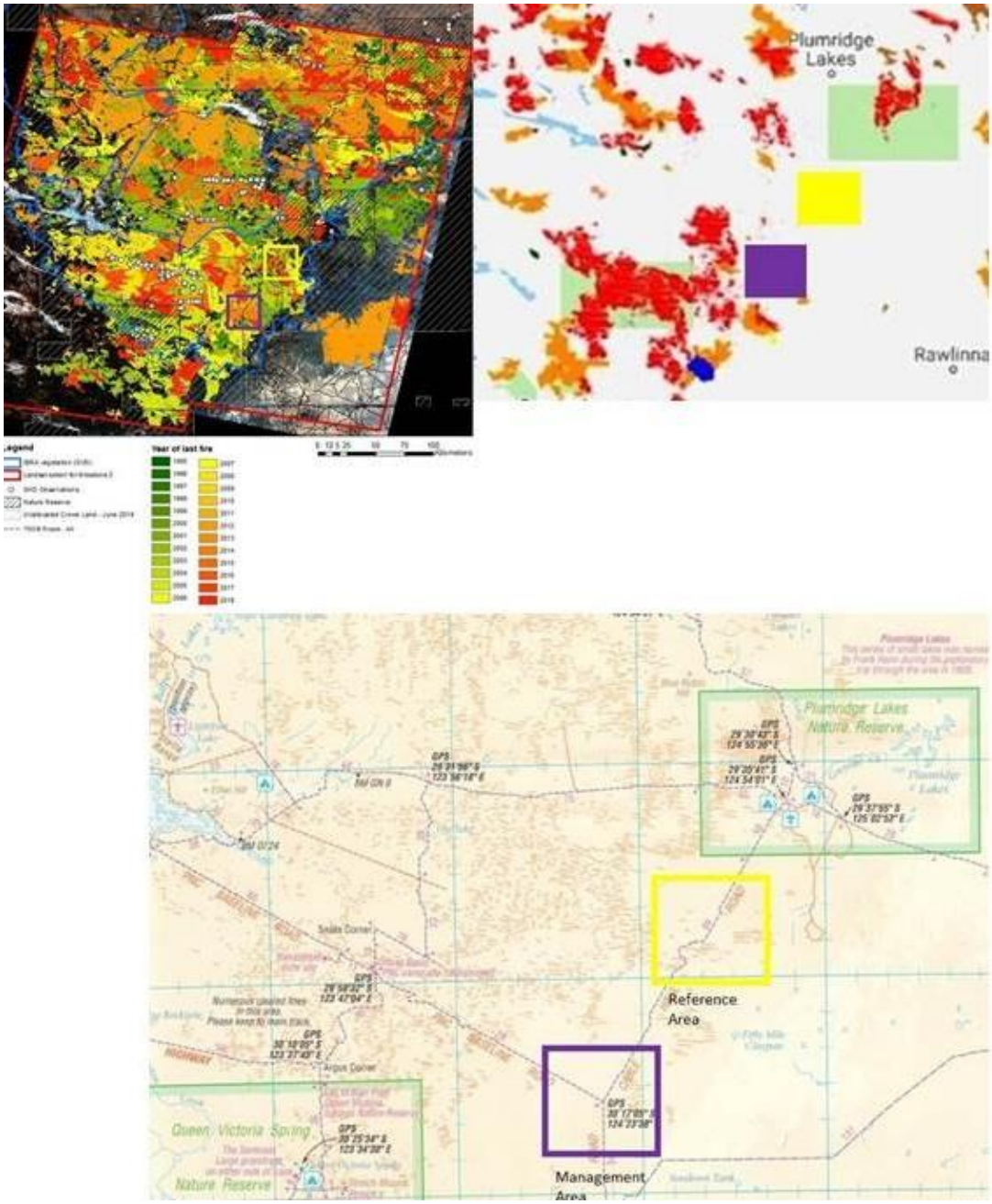


Figure 12a (Top L): Proposed project areas (yellow=Reference area; purple=Management area) with fire history as at December 2018. Figure 12b (Top R): Proposed project areas in relation to summer 2019 bushfires. Figure 12c: (Bottom) Proposed 32 km x 32 km project areas location map.

The locations (latitude / longitude) of the corners of the two proposed project areas are:

	Management area (south area)	Reference area (north area)
NW corner	30° 08 36.02" S 124° 13' 32.84" E	29° 41' 49.11" S 124° 33'47.39" E
NE corner	30° 08 36.02" S 124° 33' 30.14" E	29° 41' 49.11" S 124° 53' 27.79" E
SW corner	30° 25' 46.93" S 124° 13' 32.84" E	29° 58' 11.62" S 124° 33'47.39" E
SE corner	30° 25' 46.93" S 124° 33' 30.14" E	29° 58' 11.62" S 124° 53' 27.79" E

The current fire patterns on the project areas are not identical, but they are similar (Table 2, Figure 13). The main difference is the reference area contains a higher areal extent of older fuels and lacks intermediate-age fuels. There are records of malleefowl in each area, but not of sandhill dunnarts. Based on fuel age and a field inspection by the author, there appears to be adequate habitat for sandhill dunnarts so further survey is necessary to confirm their presence. It should be noted that very small patches are difficult to detect using automated Landsat imagery, so are not included in the statistics. These include small long unburnt patches scattered throughout the areas, but because of their relatively small size, are not detectable. Because of the ecological importance of small burnt and long unburnt patches, imagery from a higher resolution satellite such as SENTINEL-2 (10 m resolution) should be considered for future monitoring and measuring of burn patterns and patchiness.

Burnt patch size statistics	**Management area**	**Reference area**
Mean patch size (ha)	4761	5020
Median patch size (ha)	3463	3437
Max. patch size (ha)	35,460	22,070

Table 2: Summary statistics for fire patch sizes in the management area and the unmanaged reference area

Figure 13a (Top L): The areal proportion of fuel age classes (seral stages) on the 100,000 ha project areas. See Figure 9 for description of seral (C) stages. Figure 13b (Top R): The proportion of the area burnt by patch size classes for each of the 100,000 ha project areas.

6. Fire management plan

As described above, there is considerable evidence in support of the following hypotheses:

- Fire patterns have changed in much of the GVD following the cessation of traditional Aboriginal burning (and possibly exacerbated by climate variability).
- The contemporary bushfire cycle of large, intense 'hot' season fires is harmful to the biota, especially those elements, including sandhill dunnarts and malleefowl, that benefit from longer intervals between fire and smaller, patchier fires.
- Good fire management can mitigate damaging bushfires and maintain a variety of seral (post-fire) stages, hence diverse habitats, at appropriate scales that benefit biodiversity.

Fire is one of a number of environmental factors acting alone or together with other factors that influences biodiversity and ecosystem condition. While fire can kill and injure plants and animals, it also stimulates plant regeneration and rejuvenates ecosystem processes such as nutrient cycling and reproduction. Fire acts on ecosystems and species primarily through its action on the vegetation, at a variety of temporal and spatial scales. At both landscape and patch scales, fire, together with rainfall, alters the structure, composition and biomass of vegetation in space and time. Vegetation is important in its own right, and plants are also the primary producers in terrestrial ecosystems, providing food and shelter (habitat) for other organisms. Vegetation provides the energy to drive ecosystems and to drive fire. For these reasons, the conceptual approach taken by this fire management plan is to focus on the role of fire in altering the vegetation structure and biomass in time and space. Significantly reducing the scale of fires and retaining patches of longer unburnt vegetation in the landscape are critical and specific fire management challenges addressed by this plan.

As has been the case for many millennia, people are integral to fire management in these landscapes and today fire management is integral to ecosystem management and biodiversity conservation. While this plan utilises best available knowledge, it is important to acknowledge variability, uncertainty and knowledge gaps with respect to biogeographic patterns (e.g., inadequate vegetation maps, current species' abundance and distribution, the best fire mosaic, etc.), ecosystem and species responses to fire and

limitations of fire behaviour models. The plan also acknowledges that resources available to manage fire (and introduced predators) are limited. For these reasons, the plan will be holistic, it will be adaptive, it will be conservative and it will make a number of explicit assumptions.

6.1 Fire management objectives and targets

This section addresses the following in-scope items:

a. a goal of what the area should look like after 10 years of fire management (fire age distribution and mosaic scale),
b. a target of what percentage of the study area should be burnt each year, within the 10 (to 12) year time frame,
c. the optimum mean size of the patch burns each year and the maximum burn size,
d. detailed guidelines/methodology and an indicative annual schedule of how burns should be conducted, and the spatial arrangement of the patches, in order to achieve annual targets and reach the 10 (to 12) year goal,
e. detailed recommendations on how to maintain long unburnt areas as part of the mosaic, and how to protect culturally sensitive sites during prescribed burning or from bushfires
f. detailed recommendations on how annual rainfall effects fires and how this could affect the timing and size of burns,

The primary objectives of fire management are to:

- Interrupt the cycle of large, hot season bushfires. This fire management plan will not *prevent* bushfires but, once implemented, it will *significantly reduce their severity (size and intensity)*. Suppression is generally not feasible in these remote areas so is not part of the fire management plan.
- Create and maintain a fine-scale mosaic of different seral (growth) stages ranging from recently burnt to long unburnt. Protect particular fire sensitive species, habitats and communities from regular damaging, large, 'hot' bushfires.

6.1.1 Fire management target 1: Distribution of seral stages

A map of the recent fire history for the south west GVD region (to 2018), including the management area and the unmanaged reference area, is shown above in Figure 4. The current seral stage / fuel age class distributions for the south west GVD region and the project areas, are shown in Figure 14. In flammable ecosystems such as hummock grasslands, and in the absence of suppression activity, the form of the relationship of the proportion of the landscape at various seral stages / fuel age classes inherently approximates a negative exponential with a greater proportion of the landscape comprising early and intermediate seral stages[20,21,22,61,62]. The reverse of this, when the majority of the landscape is of late or very late seral stage, or fuels are predominantly older, is unstable and impossible to maintain in the longer term in the absence of a supreme suppression effort. That is, a 'bushfire cycle' of regular, large hot fires will be established without regular strategic patch-burning.

The shape of the negative exponential and of the fire size class distribution in flammable landscapes depends largely on tolerable fire intervals, fuel properties of the vegetation and the landscape ignition frequency. As discussed above, ignition frequency is not the same as fire frequency – it is the frequency with which fire is introduced into the landscape, whereas fire frequency is the frequency of fire at a specific location in the

landscape. These factors determine the extent of fire patchiness and combustion efficiency. Based on fire behaviour science and experience[12], the difference between landscape ignition frequency and fire frequency diminishes as fuels become heavier, drier and more continuous, and as the fire weather becomes more severe. For example, sparsely vegetated sand dune ridges and dense stands of mallee or mulga groves with sparse understoreys can stop head fire spread under mild fire weather fire conditions, but are no barrier to fire under severe conditions.

Fires burning under mild weather conditions leave a higher proportion of unburnt vegetation in the horizontal dimension (are patchy) and burn with a lower combustion efficiency (leave more vegetation unburnt in the vertical dimension) than fires burning under severe fire weather conditions. This fundamental understanding of fuels and fire behaviour underpins the implementation of a patch-burn strategy.

The shape of the theoretical ideal negative exponential distribution of seral stages for particular vegetation types can be mathematically derived using various plant life history attributes such as juvenile period and longevity (critical fire return intervals) of key fire response species[20,21,22,61,62]. This shape can be used as a *guide* to the proportion of the landscape at various seral stages / fuel ages. An example, taken from Burrows and Butler[63] and adjusted for the lower rainfall environment of the GVD, is shown in Figure 14.

At the regional scale and in the project management area, the current fuel age class distribution approximates the theoretical distribution (Figure 14). The distribution for the reference are is somewhat bimodal around young and intermediate age fuels. The extent of over- and under-representation of the various fuel age classes in relation to the theoretical ideal is clear in Figure 14. Using this methodology, and in the absence of vegetation maps and detailed fire response information, it is appropriate to adopt a conservative approach and base the idealised fire age class distribution on the vital attributes and fire cycle of spinifex species that regenerate from seed, such as *T. basedowii*, rather than those that resprout after fire.

Annual mosaic burning programs can be planned by comparing the actual seral stage / fuel age distribution to the theoretical ideal age distribution to identify age classes that are over-represented in the landscape. These can then be targeted for patch burning. This is discussed further in Section 6.

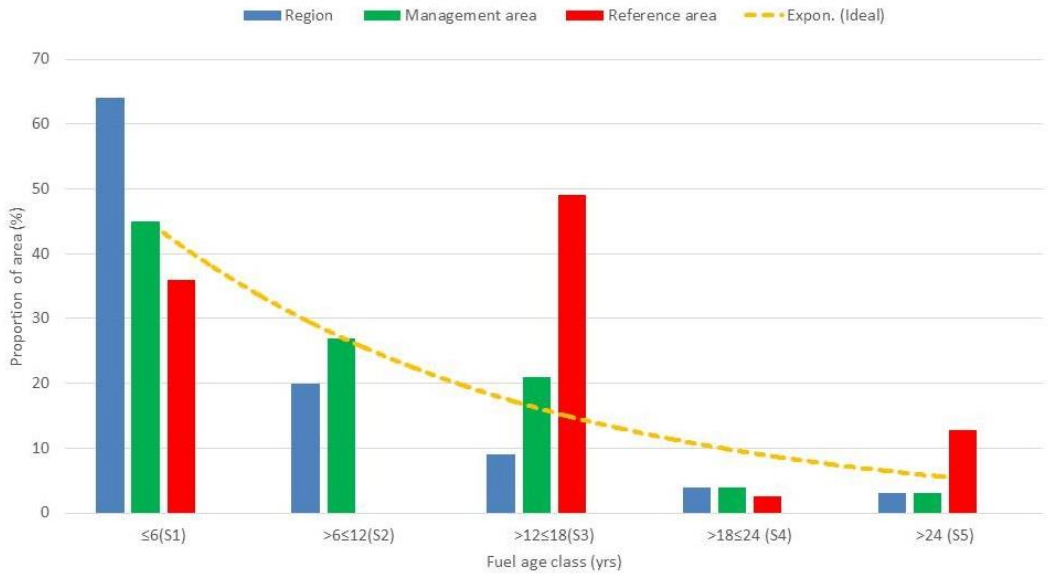


Figure 14: Current fuel age class (seral stage (S)) distribution for the region (as at December 2018) and for the project areas (as at March 2019), and the recommended theoretical ideal (adapted from Burrows and Butler[63]). The 'ideal' distribution provides ~25% and ~14% of the landscape as suitable habitat for sandhill dunnart and malleefowl breeding respectively.

The simplified theoretical ideal fuel age class / seral stages in Table 3 are adapted from the negative exponential in Figure 14. Due to the constraints and uncertainties of prescribed burning and unknowns such as extent of bushfires, it will be difficult, if not impossible to precisely achieve and maintain the theoretically ideal seral stage condition, but it provides *guidance and a target* for fire management.

Maintaining the seral stage proportions shown in Figure 14 and Table 3 by good fire management should ensure ~25,000 ha of sandhill dunnart habitat (S3 & S4) and ~14,000 ha of malleefowl breeding / nesting habitat (S4 & S5) is available in the 100,000 ha project management area in perpetuity.

Seral stage (Figure 9)	S1	S2	S3	S4	S5
	≤6 yrs	*>6≤12 yrs*	*>12≤18yrs*	*>18≤24yrs*	>24 yrs
Areal proportion of management Area (%)	44	25	17	8	6

Table 3: Idealised areal proportions of the various fuel age classes / seral stages for spinifex sand dunes and plains based on tolerable fire return intervals for Triodia basedowii. Age classes are a guide - vegetation / fuel development varies according to rainfall and soil conditions.

At the end of each bushfire season (early autumn) and as part of the burn planning process for the coming patch-burning season (autumn/winter), fire managers must update Figure 14 (for the 100,000 ha project areas) and use this to identify fuel age classes to be targeted for patch burning in subsequent years. This process is described

in Section 6.2. Because of unknowns such as location and extent of bushfires, and the extent of patch-burning, planning of burning programs further ahead than the next fire season can only be indicative.

The seral stage areal proportions shown in Table 3 should provide sustainable habitat for a variety of other spinifex-dominated sand plain - sand dune fauna including those that require older vegetation. As has been emphasized, in the GVD, malleefowl breeding habitat is generally associated with denser stands of mallee and mulga over relatively sparse spinifex on heavier soils, a structurally different vegetation / fuel type to the spinifex-dominated red / yellow sand plains and dune fields with a sparse overstorey. Malleefowl breeding habitat is best retained in a long unburnt condition by understanding when and how to burn the surrounding more flammable spinifex plains without burning the malleefowl habitat. Selectively patch-burning the more flammable vegetation units (spinifex dominated sand plains) when the less flammable units (malleefowl habitat) are unlikely to burn, will provide a mosaic of 'firebreaks' throughout the landscape, reducing the risk of summer bushfires burning extensive areas of malleefowl and sandhill dunnart habitat. Based on the studies reported in Section 4.1.4 cool *patchy* burns in these older habitats are unlikely to cause long term harm to these species.

The optimal spatial distribution of the various seral stages in the landscape is unknown. In the absence of better information, fire management should aim for a random or scattered distribution, avoiding 'clumping' of the seral stages. Preferably, the distance between patches of older seral stages (S3, S4, S5) should be <3 km to enable dispersal by sandhill dunnarts[101]. Greater diversity and length of habitat boundary (edges or ecotones) is likely beneficial to fauna. Dispersed seral stages will maximise habitat boundary and will be more effective at interrupting bushfires. This can be managed to some extent by ignition pattern, natural and burnt firebreaks, and wind conditions.

6.1.2 Fire management target 2: Burn patch size range

In the context of landscape ecology and mosaics, the 'patch' is the fundamental unit[64]. The negative exponential relationship described above applies to the fuel age class / seral stage distribution metric only and *not* to burn patch size. While there is evidence that the current scale, frequency and intensity of bushfires in the GVD is harmful, there is no solid evidence of what the optimal range of burn patch sizes should be for these landscapes, nor for the target species – malleefowl and sandhill dunnarts.

Fire size and patchiness is a factor that is more relevant to animals than plants, although it may be applicable to seed dispersal of some species such as wind-borne grass seeds without a seed bank or propagules relying on animals for dispersal. When large areas of a landscape are subjected to a single, homogenous disturbance such as a large, intense bushfire, then this will likely diminish habitat diversity and threaten fauna that depend on cover, a diversity of seral stages or late seral stages. Fire size determines the 'patch' size of the various fire-induced seral stages, therefore the juxta-position of various habitats in the landscape. For fauna that have specific habitat requirements with respect to seral stage, they are more likely to find suitable habitats and refugia in a landscape where patch sizes are 'small' rather than 'large'. Such a landscape facilitates recolonization, dispersal of young and the functioning of meta-populations – i.e. migration and the functioning of sources and sinks. The rationale is that smaller patches make the landscape more 'permeable' to fauna but less 'permeable' to bushfires.

As mentioned, there are no sound biological indicators or evidence of the (ecologically) optimum scale of fires in spinifex ecosystems. From first principles, small fires / patches make better ecological sense than large fires for the reasons given above. While there is some patchiness in large and intense bushfires, unburnt patches within hot bushfires, as important as they are, are usually small and widely separated compared with the size of burnt patches. On the other hand, slow moving low intensity fires burning under cool, moist conditions are inherently patchier and patches are closer together[60]. Consistent with an adaptive management approach, it is prudent to use the best available knowledge, as limited as it is. This comes from two sources – documented knowledge of traditional Aboriginal burning patterns in spinifex grasslands and expert opinion.

Table 4 summarises documented knowledge of burnt patch metrics for Western Desert spinifex landscapes under traditional Aboriginal management. The table includes a summary of burnt patches mapped from 1953 aerial photography in a remote desert location that was under a regime of traditional Aboriginal (Pintupi and Martu) burning at the time of the photography, providing a rare insight into the fire landscape. Tracts of central Australia may not have been visited by Aboriginal people, or may not have been burnt for various reasons, so were subjected to lightning ignitions only.

While these statistics are interesting and provide some information about patch size under traditional Aboriginal burning, they do not reveal the full picture – the proportion of the landscape affected by various fire size classes. That is, while small patches were most numerous, the larger patches, although fewer, made up most of the burnt landscape. While the means and maxima varied between the four studies in Table 4, the median patch size was about the same (2-6 ha). The authors of the work cited in Table 4 concluded that such small patch sizes were achieved by purposeful and frequent introduction of fire into the landscape mostly under 'cool' conditions. However, within several decades of the cessation of Aboriginal burning in the Gibson Desert, the mean, median and maximum patch sizes had increased to 4,970 ha, 390 ha and 71,346 ha respectively.

Source	Area sampled (ha)	No. of recently burnt patches	Mean patch size (ha)	Median patch size (ha)	Range (ha)
Burrows & Christensen[34] 1953 aerial photos Gibson Desert	53,483	372	34	5	0.5 -1744
Burrows *et al.*[25] 1953 aerial photos Gibson Desert	241,219	846	64	6	0.5 – 6005
Bliege Bird *et al*.[35] satellite imagery contemporary Martu fires Great Sandy Desert	N/A	3856	217	4	N/A
Burrows and Chapman[36] 1960/61 aerial photos GVD	1.049 M	1942	11	2	0.01 - 3593

Table 4: Burnt patch statistics for spinifex-dominated sand plains and dune fields under traditional Aboriginal burning regimes

Fire patch size statistic	*Current condition*		*Recommended condition*
	Reference Area	**Management Area**	**Management Area**
Mean	5010 ha	4580 ha	<200 ha
Median	3437 ha	3463ha	<20 ha
Maximum	22,750 ha	35,460	<6000 ha

Table 5: Recommended fire patch size statistics for the project management area

Griffin[65] recommends some eleven different patch sizes for a variety of land units in the Uluru National Park, ranging from 1-5 ha patches within mulga groves, to 400-500 ha patches within sandplains. Burrows and Butler[63] recommended keeping the mean burnt patch size < 100 ha with the median patch size <10 ha, accepting that larger fires will inadvertently occur and that under traditional Aboriginal burning in the Gibson Desert, some 70% of the landscape was burnt by patches >100 ha but <6,000 ha. Pearson (pers. com.) suggested patch sizes of 20-200 ha were suitable for small mammal fauna of the GVD, provided there were scattered unburnt patches within the burnt patches. Based on this collective information, the recommended patch sizes for the project management area are shown in Table 5.

The metrics in Table 5 could be achieved by numerous small fires that only affect a small proportion of the landscape. To reduce the risk of a high proportion of the landscape being burnt by a small number of large fires, the following is a guide:

- 35% of landscape burnt by patches < 200 ha containing unburnt patches,
- 35% of landscape burnt by patches 200 ha - 1000 ha containing unburnt patches,
- 30% of landscape burnt by patches 1000-6000 ha containing unburnt patches.

6.1.3 Fire management target 3: Tolerable fire intervals

This regime element is important, primarily because it influences ecosystem resilience, or capacity of the vegetation to recover / regenerate following fire. Generally, the post-fire response of other species will be determined by the recovery pathway of the vegetation. Fundamentally, fire interval determines the size and viability of seed banks, fuel load/fuel hazard, structure, floristic composition and the energy reserves of storage tissue used by resprouters such as lignotubers, bulbs, corms and epicormic shoots. It also affects potential fire behaviour.

Plant vital attributes and life histories can be used to guide the range of appropriate fire lethal intensity intervals[20,21,25]. This involves identifying the vital attributes of key 'fire response species', which could be fire sensitive (umbrella species), keystone species or threatened species. Key fire response species are those that are most sensitive to fire because they are most likely to be disadvantaged by excessively short or long fire intervals. Having identified the key species it is possible to determine the time interval between fires required to conserve species, i.e. the maximum and minimum intervals between *lethal* fires. Fire is non-binary - all fires are not lethal to all 'fire sensitive' plants, either because the plants survive low intensity fires, or they escape being burnt. The

distinction between lethal and no-lethal fires is important, so in addition to vital attributes, fire intensity and patchiness is important in determining 'fire sensitivity'.

Time to first flowering after fire (juvenile period) is an important vital attribute as it indicates maturation and seed production. Muller[70] provides information on post-fire regeneration strategies and juvenile periods for a range of arid zone plants, based on observations of largely Pilbara flora provided by Stephen Van Leeuwen (DBCA). From this, it is clear that, a) many species in these environments depend on seed for regeneration following fire, b) some species, such as mulga and callitris, have long juvenile periods > 10 yrs, c) most other species have juvenile periods <10 yrs with most <7 yrs. (Note: juvenile period will also depend on post-fire rainfall). There is at least one taxon for which information about juvenile period and longevity is important, namely spinifex – because it is a keystone species in these landscapes and is the dominant fuel.

Based on studies from other arid regions, following average or better rainfall, precocious spinifex plants have been observed to flower within 2 years of fire. However, for the GVD, a more realistic time period for at least 50% of the population to reach maturity, and assuming average rainfall conditions over that period, is 4-5 years. Gill and Nichols (1989) provide a rule of thumb of allowing a minimum inter-fire period of at least twice the juvenile period for post-fire recovery of seedbanks. For GVD spinifex sandplain and sand dune communities, a conservative minimum fire interval given conditions of average rainfall is probably 8-10 years. While spinifex ecosystems could recover from an occasional shorter fire interval, 8-10 years is considered a safer interval under average rainfall conditions over the period. It is unlikely that fuel would be such that fires could be sustained in spinifex at an earlier age – the exception being after a sequence of above average wet seasons and proliferation of herbs and soft grasses. There have been observations in desert biomes where fires have occurred two years apart following good seasons, transforming spinifex dominated communities to simplified soft grass (*Eragrostsis* sp.) and herb communities (N. Burrows pers. obs.).

There are few biological indicators of the appropriate maximum interval between fires in the spinifex dominated land systems. One of these is the biomass, structure and vitality of spinifex plants. Clearly, it is desirable for a fire to occur before ageing spinifex plants (and other species) lose their vitality, seed production potential and their seed banks. The vigour of spinifex begins to decline from the time the plant centres die (Griffin 1984). While spinifex will recruit between fires, the combination of fire and rain provides conditions for a mass recruitment event, which is why many spinifex communities appear even-aged – although it is not uncommon for late seral stage populations to be multi-aged suggesting several inter-fire recruitment events – possibly stimulated by exceptional rainfall. From field observations, spinifex biomass declines and plants begin to break down and senesce after about 25 years and by about 40 years, cover has reduced to below 25%. Not only does this reflect a reduction in productivity and possible decline of seed banks, but the fuel can reduce to a point where fire spread cannot be sustained except under the most severe fire weather conditions. As fire and its associated by-products (heat, smoke, ash) are vital to cueing seedling germination of many species, including spinifex, this is undesirable. It also appears that sandhill dunnarts prefer cover >25% (Section 4.1.3). Therefore, the recommended maximum tolerable fire interval for spinifex-dominated sand plains and dune fields is 20-25 years.

Tolerable fire intervals for mallee-spinifex and mulga-spinifex communities (potential malleefowl habitat) are largely unknown. As discussed above, because these

ecosystems are less flammable, they are unlikely to burn under mild weather conditions, or will burn patchily, ensuring that much of these communities remain long unburnt (i.e., they can 'escape' frequent, low intensity fires). Over time, occasional bushfires will be adequate to regenerate these communities. In a patch-burnt landscape, the bushfires will be relatively small. Similarly for fire sensitive species such as callitris – a regime of low intensity, patchy fires should enable most mature trees to either survive the fires, or escape being burnt for long periods.

Plate 4: Mallee 'woodlands' (L) and mulga groves (R) are potential malleefowl habitat. With a relatively high overstorey canopy cover and a sparse / shrub spinifex understorey, these communities can remain unburnt for long periods provided fires in the surrounding landscape are relatively small and low intensity ('cool'). Regular hot season bushfires are a threat to these habitats and to species like mulga and callitris. Reintroducing a cool patch-burn strategy will help protect these communities from severe bushfires.

6.1.4 Fire management target 4: Retaining long unburnt areas (S4 & S5)

The only feasible way to retain long unburnt patches as part of the mosaic is to prevent or mitigate the development of large, intense bushfires, most of which are caused by lightning over the warmer spring – summer months. In the absence of a supreme suppression effort, this can only be achieved by carefully planned and implemented prescribed patch-burning under cool autumn – winter conditions (see Section 6.2) – the recently burnt patches (<8-9 years old) will interrupt the spread of summer bushfires. Through both stochastic and deterministic process, this will inevitably result in the retention of long unburnt patches, the size and spatial arrangement of which changes through time – it is a dynamic process. The prescription described in Section 6.2 is designed to ensure the persistence of scattered, long unburnt patches at any point in time. It is not possible nor desirable to retain large areas, or a large proportion of the area, in a long unburnt state – at some point these areas will burn under hot spring – summer conditions, converting them to large, homogenous areas of recently burnt vegetation, perpetuating the current (unmanaged) mega-bushfire cycle.

Summer bushfires will continue to occur and contribute to fire diversity, but implementing this fire management plan will significantly reduce their severity (frequency, size and intensity) and associated adverse ecological impacts.

Sandhill dunnart and malleefowl (breeding/nesting) habitat, by and large, occur in different vegetation types, hence, subtly different fuel flammability types. Sandhill dunnarts prefer mature (but not senescent), flammable spinifex-dominated sand plain

and dune field communities with a low 'tree' canopy overstorey. Malleefowls require older, less flammable mallee-spinifex and mulga-spinifex associations with a higher 'tree' canopy overstory cover for breeding – they can utilise younger areas for foraging. The flammability differential between sandhill dunnart habitat and malleefowl breeding habitat is due to differences in spinifex ground cover and fuel load – spinifex cover (fuel) in sandhill dunnart habitat is generally >25%, whereas in malleefowl breeding habitat it is generally <20%. This differential can be utilised to successfully patch-burn these landscape by burning under mild fuel and weather conditions when the more flammable spinifex sand plains will just carry fire (burn patchily) but the less flammable mallee and mulga communities won't because fuels are too sparse. As the fire danger rating (effectively the Spread Index - see below) increases, the flammability differential dissipates to a point when both habitats will burn under severe summer conditions. Understanding and working with this natural nuance in fuel flammability is the key to successfully patch-burning these landscapes and retaining long unburnt habitat.

6.1.5 Fire management target 5: Season of burning

There are several factors that influence when to burn. Probably the most ecologically significant of these is the timing of fire in relation to rainfall, which will strongly influence the early post-fire recovery rate and regeneration success. Rainfall in the GVD is unreliable, non-seasonal and unpredictable, however burning in autumn or early winter provides an opportunity for follow-up winter – spring rain which will stimulate regeneration.

The aim is to create smaller burnt patches and patchy burns. This is best achieved under mild weather conditions in late autumn and winter, when the fire danger rating is LOW to MODERATE. Lightning-caused spring and summer bushfires will continue to be part of the diversity of fire regime, which can be beneficial provided the fires are not large. An important aim of prescribed patch-burning in autumn – winter is to break up the run of bushfires, thereby reducing their size.

6.1.6 A summary of how the management area should 'look'

A summary of the desirable mosaic characteristics and associated metrics (burn targets) for how the management area should 'look' by 2028 is contained in Table 6. Due to uncertainties with respect to fuels, weather and fire behaviour, it is not expected that these metrics will be met exactly, so this is a guide to assist fire managers visualise how the landscape should look, and what to aim for and how to plan.

Over ten years, the average annual area burnt under a managed fire regime will be similar to that under an unmanaged regime (4-5%), but management will eventually a) even out the large annual variation in area burnt, b) significantly reduce fire severity (size and intensity), c) increase patchiness, and d), retain a higher proportion of longer unburnt vegetation in the mosaic. Any level of wise management will likely be an improvement on the current, unmanaged fire situation, and carefully considered management actions are unlikely to make the situation worse that what it currently is.

Fire mosaic factor	Factor metrics	Comments
Proportion of seral stages / fuel age classes	S1 ~44%: ≤ 6 yrs S2~25%: >6 ≤ 12 yrs S3~17%: >12≤ 18 yrs S4 ~8%: >18 ≤ 24 yrs S5 ~6%: >24 yrs	Seral stages scattered, not clumped. Controlled by lighting pattern and barriers to fire spread. Reduce / avoid ignitions in areas of high cover (>20%) of mallee and mulga.
Burnt patch size	Mean ≤ 200 ha Median ≤ 20 ha Max. ≤ 6000 ha	Unburnt patches within burnt patches to be < 3 km part. Controlled by burning under mild weather conditions, ignition pattern, natural and burnt firebreaks and exploiting flammability differentials.
Proportion of landscape by burnt patch size class	~35% burnt by ≤ 200 ha patches ~35% burnt by >200 ≤ 1000 ha patches ~ 30% burnt by > 1000 ≤ 6000 ha patches	
Tolerable fire intervals – spinifex sand plains	Min: 8-10 yrs Max: 20-25 yrs	Less flammable mallee-spinifex / mulga-spinifex communities are less likely to burn under mild weather conditions so will mostly remain long unburnt.
Window (seasons) of prescribed patch-burning	Late autumn (mid May) – winter (late August). Burning of some S2 fuels may have to be done in early spring (early September) under higher SI conditions.	Burn when >0 SI ≤ 3. No burning 10 days prior to, and 21 days after, aerial baiting. Inevitable spring and summer bushfires will add to the diversity of fire season.
Mean area (%) burnt annually	The mean over the 2020-2028 planning period is ~4% per annum.	Triennial burning targets to provide management flexibility.

Table 6: Summary of desirable fire mosaic characteristics and metrics (targets) in the project managed area by 2028. This is a guide to give managers a sense of what the landscape should 'look' like.

6.2 A prescription to achieve fire management objectives and targets

6.2.1 Risk management

Prescribed burning is not without risk and burning without hard edges (fire breaks / containment lines) in remote areas presents challenges. The worst scenario is if fires 'escape' and threaten people and assets. The next worst scenario is if burning exceeds the prescription (i.e., too much burns). A third, less harmful scenario is if too little burns. There are many uncertainties with regard to weather, especially wind and fuel moisture conditions in particular, that cannot be controlled, or forecast over several days with accuracy - and fire behaviour models are only about 70% reliable. Despite the best planning and preparation, things may not always go to plan. Therefore, 'plan for the worst but expect the best'. This means anticipating what could go wrong, not just on the day of ignition, but in the next 5-7 days after ignition. It is almost always an unexpected change in wind speed and direction that creates unexpected fire behaviour. Putting in place pre-emptive measures to mitigate or prevent harm to people and infrastructure should this happen, is paramount. In these environments, fire suppression is usually not

an option, so the fallback strategy is to ensure fires can't run too far and impact assets, before running into a burnt area – either a road buffer or a fire scar. The general area is traversed by roads and exploration tracks that can be strategically used as anchor points from which to construct buffers to contain fires, both prior to ignition, and post-ignition should the situation warrant. This is dealt with in more detail below.

The usual risk management and legal processes and procedures need to be followed prior to, during and after burning including notification of 'neighbours', communicating intentions to the general public via various media, road and traffic management, occupational health and safety, aircraft operations, etc. These matters are mostly covered off by the formal burn prescription preparation and approval/endorsement process (DBCA), and other SOPs, which will be the responsibility of the land manager / burn provider to undertake.

6.2.2 When (season) to burn

As discussed above, prescribed patch-burning is best carried out during the cooler time of the year but pausing during the baiting operation. Baiting is best done at the coldest time, which for the GVD is around mid-July. As a guide, burning should be done in the windows mid-May to the end of June, closing through July during baiting operations, then re-opening in August and closing by September. There may be opportunity to burn in early September, once the management area is 'secured' by a network of patch-burnt fire breaks and road buffers.

The actual day/time of burning will depend on the availability of resources, integration with other activities such as pre-treatment monitoring, burn preparation and weather conditions. While planning will be based on weather forecasts, it may be necessary to have assets on site for several days to take advantage of the right weather conditions.

6.2.3 What, when (year) and how much to burn

An annually up-dated fuel age / seral stage distribution graph (Figure 15) will provide guidance for determining which areas of the management area should be targeted for patch-burning each burning cycle. The strategy is to target those fuel ages / seral stages (other than S1 – which is non-flammable) with areal proportions in excess of the 'theoretically ideal' proportions. For example, Figure 15 shows that currently (as at November 2019) the fuel class S3 is slightly over-represented and fuel classes S4 and S5 are under-represented. Therefore, the 2020-2022 program will aim to burn just 5% (1000 ha) of the S3 fuels, or 1% of the management area (Figure 16).

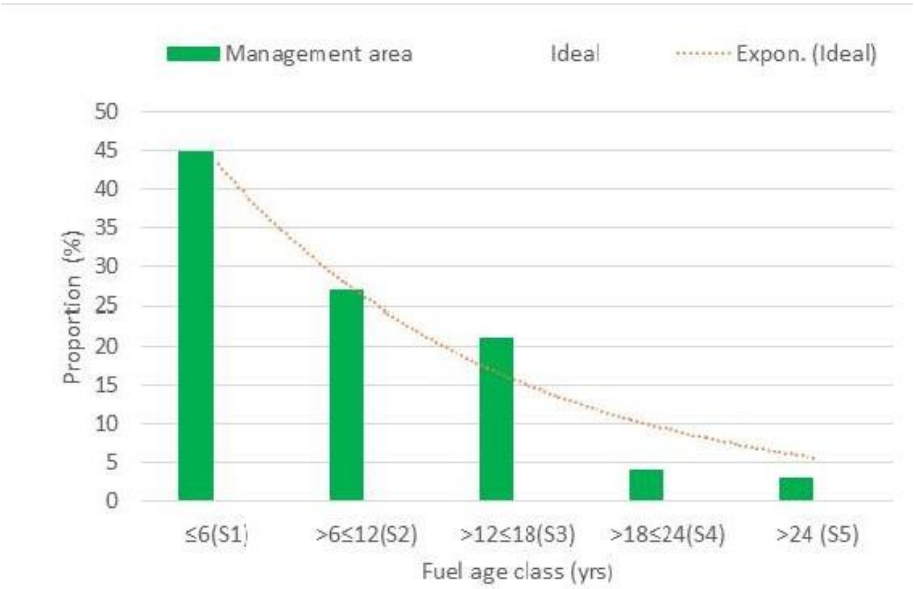


Figure 15: Current (October 2019) fuel age class / seral stage (S) and theoretical ideal distribution for the project management area.

The burn program presented below is based on a number of assumptions so is indicative only. As discussed, the actual burn program for the next fire season will be contingent on the extent of prescribed burning done, and bushfires, in the previous season. The program described below, which extends to 2028, assumes, a) the triennial prescribed burn program is achieved and b) the area is not significantly impacted by bushfires. It is for these reasons that the fuel age class distribution in the management area needs to be assessed annually to fine-tune the annual burning program.

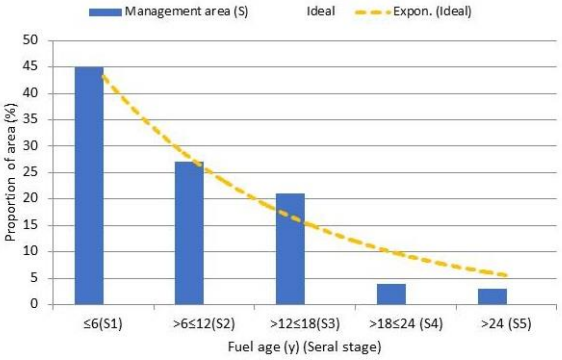
6.2.4 Indicative burn program 2020-2028

The indicative burn program for 2020-2028, in three-year planning periods, is shown in Figure 16. Over this period, the program equates to burning, on average, about 4% of the management area per annum. It is based on the theoretical ideal fuel age class distribution, the current and projected distributions, and 'average' rainfall conditions for the region. As can be seen from Figure 16, the 2020-2022 aerial burn program is 'light', with only 1000 ha to be burnt. This presents an opportunity to focus on strategic on-ground burning to establish the road buffers.

Rainfall will influence fuel load and cover, but the latter is of greatest interest in terms of setting fire spread thresholds. In years of well above average rainfall, expect above average rates of fuel re-accumulation and cover, and *vice versa*. In the absence of fuel accumulation models that incorporate rainfall, it will be necessary to determine the actual fuel cover of the area planned for patch-burning each year and using this value to calculate the Spread Index (SI – fire danger rating) values and potential fire behaviour rather than relying on estimates based on time since last fire. Alternative methods for assessing fuel cover are in Appendix 2. It is recommended that prescribed burning should continue according to the indicative program in Figure 16 in above average rainfall years, but because increased cover will elevate the SI for a given set of fuel moisture and wind speed conditions, burning may have to be carried out under lower wind speed and cooler conditions, and the ignition spacing adjusted accordingly. In any

event, the SI and rate of spread calculations will provide guidance on expected fire behaviour, provided model inputs reflect 'real world', regardless of rainfall.

As in all circumstances, to increase the likelihood of fires self extinguishing before becoming too large, based on weather forecasts, choose burn windows where forecast diurnal wind speeds do not exceed 17 km /hr during and for several days after ignition, and with long periods (overnight) when wind conditions are 'calm' (<7-10 km / hr).



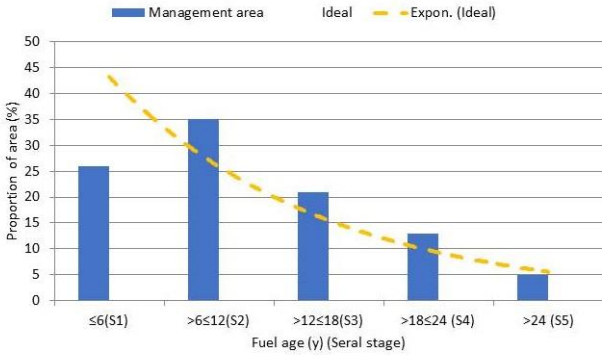
Indicative 2020-2022 burn program

Current (2019) fuel age class distribution

2020-2022 burn target:

- 5% (1000 ha) of S3 fuels

~Burn 1% of the management area over 3 years



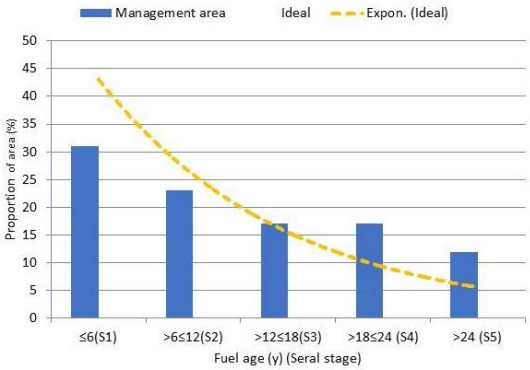
Indicative 2023-2025 burn program

Projected 2023 fuel age class distribution

2023-2025 target:

- ~27% (10,00 ha) of S2 fuels
- ~14% (3000 ha) of S3 fuels
- ~38% (5000 ha) of S4 fuels

~Burn 18% of the management area over 3 years



Indicative 2026 -2028 burn program

Projected fuel age class distribution for 2026

2026-2028 target:

- ~45% (9000 ha) of S4 fuels
- ~50% (6000 ha) of S5 fuels

Burn ~15% of the management area over 3 years

Figure 16: Indicative triennial prescribed aerial patch-burn program 2020 – 2028 inclusive. The program should be completed within the 3-year time frames indicated. Because the management area is near theoretical ideal fuel age distribution (as at March 2019), only 1000 ha needs to be burnt over the 2020-2022 period. The program will also include strategic road buffer burning each year.

In addition to the burn program in Figure 16, there will be an annual program of on-ground burning to establish road buffers to ~50 m deep. Once established, the road buffers can be widened to 100-150 m as part of the aerial burning program by delivering aerial incendiaries parallel to / along the inside of the road buffers at 200 m spacings. Most of this should be achieved in the 2020-2022 program.

Prime malleefowl breeding habitat (old mallee-spinifex or mulga – spinifex associations) will be interspersed through the areas that are planned for burning. Where such areas are distinct from the air, avoid placing ignitions / incendiaries into these habitats. It is not feasible to physically isolate these areas from burning so the flammability differential, as explained earlier, must be exploited to reduce the risk of burning these habitats. If the burn prescription is followed, it is likely that these habitats will not burn, or will burn patchily, for the reasons described above. From the research reported above, patchy burns cause little disruption to malleefowl. If resources are available, it may be advantageous to use a helicopter to patch-burn around known malleefowl habitat.

6.2.5 Traditional Owner engagement

Traditional Owners (TOs) should be consulted as part of the burn planning process and early in the process. Given that the management area is a defined area, it should be possible to commence discussions with TOs about burning the area as soon as possible, and well before the 2020 burn season. This may require field trips with TOs, or carrying out pre-burn reconnaissance in a helicopter to identify if there are any areas that are not to be burnt. Because this issue is context specific, it is not appropriate to be prescriptive in the current report. This is a matter for the GVDBT, the burn service provider and the TOs to address and resolve.

6.2.6 Future burn planning

Notwithstanding the 2020-2028 indicative triennial burn program summarised in Figure 16, because of uncertainty about the extent of prescribed burning and of bushfire, the schedule must be up-dated annually using latest satellite-derived fuel age / fire history information, and the appropriate adjustments made. Therefore, at the end of each fire season (March-April), satellite fire scar data for the managed area needs to be collected and analysed against the target / ideal conditions as a basis for re-scheduling the program.

Because of the relatively small scale of the project areas, and the importance of small patches, it is recommended that imagery from the SENTINEL-2 satellite (10 m resolution lor some spectral bands) be explored for application to this project. Otherwise, LANDSAT imagery will suffice.

6.3 How to burn

Both on-ground (‘hand’) and aerial burning should be employed. The proposed management area has some 48 km of road / track that can be used to install fuel reduced buffers. Within the prescribed burn window (Table 7) and prior to aerial burning, it is recommended that strategic ~50 m burnt buffers be installed on one side of roads/tracks within the management area to assist with the containment of bushfires and prescribed burns. The aim is to reduce fuel cover to 10-15% in the road buffers. This can be achieved by cleaning up existing tracks to at least 5 m wide either using a machine or a ‘drag' behind a 4 WD (taking care to ‘scrape’ the vegetation off with minimum soil

disturbance to avoid erosion), and using crews with drip torches to carry out the burning. On-ground hand burning of road buffers is an opportunity to engage Traditional Owners in the project, supported with fire fighting appliances.

Plate 5: Creating buffers along roads by on-ground (hand) burning (photo Ryan Butler).

On-ground Burning technique will involve crews with drip torches working in staggered (echelon) formation upwind of the track, allowing the fire to burn with the wind back to the track. Depending on fuel and weather conditions, the fires may or may not 'run'. If fires don't 'run', then 'cold' burning will need to be employed –i.e., burning individual hummocks to obtain a buffer (<10-15% cover), or using a vehicle mounted flame thrower. In most cases in spinifex, the back fire will self-extinguish. Where this doesn't occur due to high fuel cover, it can be extinguished using a light unit (Land Cruiser). The reason for this is in case of a wind change – a cool burning backfire can become a hot running head fire. At least one heavy duty appliance (truck) should be on site to provide water for suppression and mop-up should it be needed. All going well, and depending on the number of crew, buffers should be able to be installed at a rate of about 1.5 -2 km per hour. Once established, the 50 m road buffers can then be widened to 100-150 m during aerial burning operations by running an incendiary flight line parallel to and inside the buffers.

Plate 6: Conducting experimental fires and aerial burning in the GVD, May 2006.

Aerial ignition is the most cost-effective and safe way to carry out broad area patch-burning in remote, poorly accessible landscapes such as the GVD[66]. This can be done either by helicopter or fixed wing aircraft – each platform has pros and cons. Helicopters are more manoeuvrable and flexible, meaning ignition points can be placed with greater accuracy, and in desert environments, they can land and take off almost anywhere. Helicopters can also be used to transport people, including Traditional Owners (TO's), to carry out pre-burn reconnaissance. However, they are slower and significantly more costly to operate than a fixed wing – at least double the cost per unit area of land treated. It may be necessary to reconnoitre the burn area with TO's prior to burning, in which case a helicopter could be used if areas can't be accessed by vehicle – otherwise, either platform is acceptable and will depend on availability of aircraft and budget. It is beyond the scope of this contract to source and cost the options, as it is to organise the logistics of the operation – this is to be discussed with the burn service provider.

Managing the size of burnt patches relies on fires self-extinguishing before they become too large. Similarly, obtaining patchy burns requires 'cool' burning, or burning at just above the thresholds for fire spread. Due to the complexities of fire behaviour, fuel and weather conditions, fire managers have only partial control over the size and patchiness of fires. This can be achieved by:

- selecting the right fuel and weather conditions, especially diurnal wind speed patterns, under which to carry out burning,
- manipulating the lighting pattern (the location, orientation with respect to wind direction) and spacing of ignition points,
- using existing recently burnt patches or natural barriers to fire spread (sparsely vegetated or bare areas) as fire breaks.

In any event, burning should only be undertaken when fire weather conditions (temperature, humidity and wind speed) are mild and fuel moisture content is relatively high. Experienced spinifex burners will intuitively know and understand the best conditions of fuel and weather for cool burning. To assist with decision-making and for those with less experience, a field-derived spinifex fire behaviour guide is provided at Appendix 2. The Spread Index (SI) is a simpler but less accurate guide to the behaviour of spinifex fires. Wind speed, fuel cover and fuel clump moisture content are used to calculate the SI, a unitless number that indicates the likelihood of fire spreading – it is a 'fire danger index' for spinifex[12]. Instructions for calculating SI are contained in Appendix 2.

Table 7 is a guide to aerial patch-burning based on burning conditions as reflected by the SI. It is stressed that this is a *guide* – fire managers need to use professional judgement on the day of the burn to assess suitability of conditions and appropriate ignition spacings - the latter may have to be adjusted during the operation depending on observed fire behaviour and wind speed.

Bureau of Meteorology (BoM) spot or Meteye weather forecasts should be obtained to plan the timing of burning. Ideally, burns should be planned such that the SI range (essentially wind speed for a given fuel complex) is suitable for several hours after ignition, but then falls to <0 overnight due to a prolonged reduction in wind speed. A guide to ideal burning weather conditions at this time of year:

- Max. Temp: 20-27^{o}C
- Min. RH: 20-30%

- Wind speed: 10-17 km/h, gusting 20; but decreasing <7 km/h (calm) overnight. Higher wind speeds may be needed for sparser fuels such as S2 fuels.
- Five day post-ignition wind speed forecasts do not exceed 20 km/h for periods longer than 3 hours.

SI	Likelihood of sustained fire spread	Suitable for patch-burning?	Aerial ignition spacing (capsules x lines - m)	Likely capsule 'take' (%)
<0	Unlikely	No	N/A	<5
>0 ≤ 1	Low rates of fire spread likely	Yes	200m x 300m	5-10
>1 ≤ 2	Low to Moderate rates of spread very likely	Yes	200m x 500m	10-20
>2 ≤ 3	Moderate rates of spread likely	Yes	200m x 700m	20-30
>3	Moderate to High rates of spread very likely	No	N/A	30-40

Table 7: A guide to conditions suitable for aerial patch-burning in late autumn –winter based on the Spread Index (SI) (see Appendix 2). The SI should ≤ 3 for at least 5 days after ignition, so will need to be calculated daily using the 5 day forecast. Flight lines perpendicular to the wind direction, commencing down wind and moving up wind.

Plate 7: Aerial patch-burning,GVD. Long narrow fires are preferable because of the length of habitat boundary (photos Ryan Butler).

6.4 Fire management monitoring, evaluation and reporting

Consistent with an adaptive management approach, the outcomes of fire management operations with respect to the objectives and targets set in Section 6.1, must be monitored, evaluated and reported. This is important for validating the fundamental hypotheses relating to fire regime and fauna conservation that underpin this program, for

evaluating the efficacy of the patch-burn prescriptions, for evaluating management proficiency and for continuous improvement. The minimum level of annual fire management monitoring and reporting is shown in Table 8. Methods for measuring fuel parameters are described in Appendix 2. Method for mapping fire scars is described by van Dongen *et al*.[17], although it is recommended that data from SENTINEL-2 be considered. These annual monitoring data should be compared and contrasted with the fire management objectives and targets set out above and where necessary, adjustments made to the burning program to better align with targets. This may amount to re-scheduling the indicative burn program and / or adjusting the burn conditions recommended in Table 7.

At least one data logging tipping bucket rain gauge (e.g. HOBO RG3) should be installed in both the management area and the reference area. Other weather measurements such as temperature, relative humidity and wind can be obtained from the Tropicana mine site weather station.

Just prior to burning (management area)	**During burning (management area)**	**End of each fire season (April-May) (management area and reference area)**
Fuel: • Seral stage • Cover, height, load • Moisture content Soil • ALWB root zone moisture content	Weather (prior to ignition then hourly) using a Kestrel station: • Wind speed and direction • Temperature • Relative humidity • Dew point Fire behaviour: • Ignition spacing • Number of capsules used • % capsule 'take' • Rate of spread – average and range • Flame height – average and range • Spotting?	• Update the fire history map (Landsat satellite imagery). • Measure the area of each fire scar for each year and record whether it is a prescribed burned patch or a bushfire (wildfire) burned patch. • Measure unburnt patches within burnt patches. • Measure the distance between burnt patches (nearest neighbour) within burnt patches. • Construct current fuel age distribution graphs. Use this to plan next burn program. • Measure distance and depth of road / track buffer burning (edging). • Report outcomes of planned and unplanned (bushfires) fires against objectives and targets. • Report on costs of operations, what worked, what didn't work.

Table 8: Minimum data collection, monitoring and reporting requirements for evaluating the efficacy of fire management operations

7. Management plan for introduced predators

Introduced predators, including feral cats, foxes and wild dogs / dingos occur throughout the GVD, although their densities are unknown. Work in the Gibson Desert Nature Reserve to the north showed that in the absence of control measures, cat density based on footprint transects, varied with seasonal conditions but was about 4-6 times that of foxes and wild dogs[71]. Following aerial baiting in the Gibson Desert and at Matuwa using Eradicat®, foxes were virtually eliminated but the effect of baiting on the wild dog / dingo population was variable. Baiting naïve populations of feral cats in the arid zone has generally been successful with track activity being significantly reduced. For example annual aerial baiting with Eradicat® at Lorna Glen (Matuwa) maintained feral cat activity to <15% of pre-bait levels for more than a decade[72]. However, in about 2012, cat activity began to increase as baiting effectiveness became more variable - roadside trail cameras showed cats consistently walking past baits. Feral cats, unlike foxes and wild dogs, will only eat when hungry so need to encounter a bait when hungry. By 2018, the cat density on Matuwa was almost back to pre-baiting levels[73], although they were significantly reduced by an intensive trapping program in May 2019. A number of reasons have been proposed for the reduction in baiting effectiveness including increased live prey availability as a result of 'good' seasons and reduced predation, and the possibility that baiting has selected 'smart' cats who avoid the baits. Further research is needed to better understand this trend.

This introduced predator control plan for the GVD project area focusses on feral cats; they are the most serious predation threat to small-to-medium size fauna because of their relatively high density, their ability to prey-switch and historically, sustainable control has proved challenging.

Plate 8: Feral cat, Matuwa; elusive, damaging and challenging to control

7.1 Feral cat impact on native fauna

Being well adapted to arid environments, feral cats thrive in the semi-arid and arid regions of Australia. Their success as an invasive carnivore is due to their size, physiology, athleticism and fecundity. They are highly efficient hunters, being able to take prey species up to their own body weight; they prey on ground-dwelling species as well as arboreal animals; they eat a wide range of prey including insects, reptiles, birds and mammals (and at times, vegetation), and they do not need to drink water, obtaining sufficient moisture from their prey. Females can breed as early as 8 months old and in good seasons can have two litters per year, enabling rapid increases in population[74,75,76,77]. In the arid and semi-arid regions, based on limited data, cat density estimates vary depending on seasonal fluctuations of food supply (prey availability). For example, during prolonged drought, densities in the Gibson Desert were about 0.05 animals/ km^2, but following a well above average season (rainfall), this increased to 0.13/km^2 [78]. In the Shark Bay area of Western Australia with a high density of rabbits, cat density was as high as of 2.8 animals/ km^2 [79]. Casual observations by the author during a field trip to the GVD in November 2019 revealed very low levels of introduced predator activity, probably in response to drought and large bushfires in the region.

Being introduced to the Nullarbor coastline by whalers and sealers in the 1830s, cats have probably occupied the south western fringes of GVD since the middle of the 19th century[11]. In 1898, hundreds of cats were released near Eucla in an attempt to control rabbits[80,81] and by the early 1900s, they had likely colonised much of the GVD.

Cats have direct impacts on native fauna through predation but can have an indirect effect by carrying and transmitting diseases such as toxoplasmosis[82]. The predatory impact of cats on native wildlife was raised as a concern by early naturalists, including McKeown, who in 1922, observed, "*that cats do not appear to be having an impact on rabbits, but together with the fox, they were 'exterminating' ground-birds and other species*". The extent to which the feral cat has been the primary cause of declines of native fauna after European settlement is poorly documented and controversial largely because of confounding influences of other factors such as foxes, altered fire regimes, land use practices and disease[82,83]. However, feral cats have been implicated in the extinction of up to seven species of mainland mammals as well as regional and island extinctions of native mammals and birds[83,84]. It is well documented that feral cats have caused the failure of many endangered fauna reintroduction attempts in the semi-arid and arid zones and are recognised as the main barrier to reconstructing and protecting faunal assemblages in these environments[78, 85,86,94].

Today, 35 vulnerable and endangered bird species, 36 mammal species, 7 reptile species and 3 amphibian species are thought to be adversely affected by feral cats[75,84]. While there is debate about the role of cats in faunal extinctions, there is no doubt they are proficient hunters of Australian wildlife. For this reason, legislation has been introduced to many jurisdictions that aims to restrict the breeding and predation potential of domestic cats and to restrict the number of domestic cats becoming feral cats in peri-urban areas. Predation by feral cats was listed as a key threatening process under the Federal Endangered Species Protection Act 1992 (incorporated in the Environment Protection and Biodiversity Conservation Act 1999). A Threat Abatement Plan for Predation by Feral Cats was produced in 1999 and amended in 2008 to promote the recovery of vulnerable and endangered native species and threatened ecological communities, and up-dated in 2015[87]. It should be noted that in the absence of

traditional food species that have declined or become extinct since European settlement, desert Aboriginal people hunt feral cats (and rabbits) as a food source, so do not necessarily see them as a harmful pest.

7.1.1 Feral cat impacts on sandhill dunnart and malleefowl

A number of diet studies reveal that feral cats have a broad prey base[85,86]. While there have been no specific studies done in the south west GVD, this almost certainly includes sandhill dunnarts. There is evidence that, at least in some locations, sandhill dunnarts are able to co-exist with introduced predators, including feral cats, although the relationship of the interaction is poorly understood[48] and it is not known whether the GVD sandhill dunnart population is stable or in decline. The fundamental premise, or hypothesis under test in this adaptive management program is that the combination of large fires that destroy habitat and expose animals to predation by introduced predators has caused the decline / extirpation of sandhill dunnarts (and other fauna).

Predation of malleefowl adults and chicks by introduced predators is a major cause of mortality. Foxes are known to raid nests for eggs, and foxes and cats, together with native predators, are known to be significant predators on chicks, especially within the first few days of hatching. Many studies have reported large mortality rates of chicks during the first few days of release or emergence from hatching. For example, in one study using captive reared chicks, foxes and feral cats predated up to 68% of chicks following their release[56].

Plate 9: This bushfire in the south west GVD in spring 2019 removed vegetation cover over more than 300,000 ha, exposing fauna such as sandhill dunnarts to famine and predation, and rendering the habitat unsuitable for the species for at least 12 years.

7.2 Feral cat control options

Feral cats have colonised the vast and remote semi-arid and arid regions of Australia. This, together with their evasive and largely nocturnal behaviour, and their popularity as a companion animal, makes eradication of this harmful pest unachievable on the mainland. There have been successful eradication programs on a number of offshore islands, where the area is relatively small, and there is no ability for reinvasion[88,89]. However, on the mainland, the focus of conservation and land management agencies is to mitigate the harmful impacts of feral cats in and around targeted high-priority, high fauna conservation values. Most common control or 'predation-mitigation' methods include trapping, shooting, poisoning and fenced exclosures. Biological control including immunocontraception, gene drive technology and the introduction of infectious diseases is technically, operationally and ethically not feasible at the moment. Trapping can be very effective for removing animals from a relatively confined area but has limitations as a sustainable, broad-area control measure in remote, poorly accessible landscapes. Not only is it labour-intensive, trapping risks harming non-target species, especially if traps are set on the ground. Shooting is largely ineffective because of the relatively low density of feral cats in arid environments and because of their evasive nature. Well-designed cat-proof fenced exclosures can be very effective at protecting native animals from predation, essentially creating 'inland islands', or refugia. Construction and maintenance costs limit the number and size of enclosures that can be built, but where they exist in the arid zone, they have been very successful. There is likely to be an increase in the use of enclosures to provide refugia for threatened arid zone fauna.

Plate 10: Eradicat® bait environmental durability trial, Matuwa

Baiting using 1080 poison (Eradicat®) has shown most promise as a method for broad-area control of feral cats (and other introduced predators)[72,90,95]. Following the development of a novel cat bait medium by DBCA scientist Dr David Algar, broad-area aerial baiting using the toxin 1080 is now routinely used in targeted areas of the semi-arid and arid regions of Western Australia where there are high conservation values at risk of predation. While feral cats prefer live prey, they will scavenge if they are hungry

and the carrion is 'fresh'. However, there are periods when live prey abundance is low, imposing famine pressure on feral cats. Shortage of prey usually coincides with cold, dry weather, and operational trials in Western Australian deserts have demonstrated that this is the optimal time to deliver cat baits[72,90]. The window of opportunity for effective control by baiting is relatively narrow, and the effectiveness of baiting has been variable. Based on a track (footprint) count index and occasional radio tagging of animals before and after baiting, baiting efficacy (knock-down of the pre-bait population) can range from about 25% to almost 100% [71,90].

Trials in arid Western Australia using biomarkers have shown that there are a few native species including reptiles that will consume cat baits. These species have a high resistance to 1080 [91,92]. Carnivorous marsupials such as mulgara (*Dasycercus cristicauda*) consume the feral cat baits, but the nett benefit of reduced cat predation due to baiting resulted in a net increase in their numbers[47]. Malleefowl have a high resistance to 1080[69] so are unlikely to be adversely affected by baiting. Sandhill dunnarts are a small carnivorous marsupial so are likely to consume the baits, but it is unknown whether this will have an adverse impact on the population.

This plan recommends aerial baiting using Eradicat® to control introduced predators in the GVD project management area, supplemented by ground trapping should aerial baiting be ineffective.

7.2.1 Aerial baiting with Eradicat®

The current prescription for aerial feral cat baiting requires the delivery of 50 Eradicat® baits/km^2 (4.5 mg 1080/bait) from a fixed wing aircraft along flight lines 1 km apart. Details of the bait and its preparation prior to delivery are provided elsewhere[89]. In sum, for each drop, a bag of 50 baits is loaded into the 'cat bait carousel' by a 'bombardier' through a funnel. The aerial baiting computer navigation system releases the 50 baits at each 1 km map grid, along flight lines 1 km apart. The desired on-ground bait pattern is for 50 baits to be spread over a 200 m x 40 m 'footrprint'. To achieve this, the current baiting aircraft flies at an altitude of 500 ft AGL at a ground speed of ~160 knots.

It is recommended that aerial cat baiting of the 100,000 ha GVD management area be carried out in July, the coldest time of year (avoiding rain periods), and following prescribed burning. Cold temperatures reduce the level of activity of potential prey species for feral cats, decreasing their hunting efficiency and increasing the likelihood that they will take baits[89,90].

The GVD project management area is located on Unallocated Crown Land for which DBCA has some bushfire and feral pest control responsibilities. Through the Western Shield program, DBCA have the expertise, experience and established procedures and protocols for carrying out aerial cat baiting. An aerial baiting procedures, protocol and checklist used by DBCA is at Appendix 3.

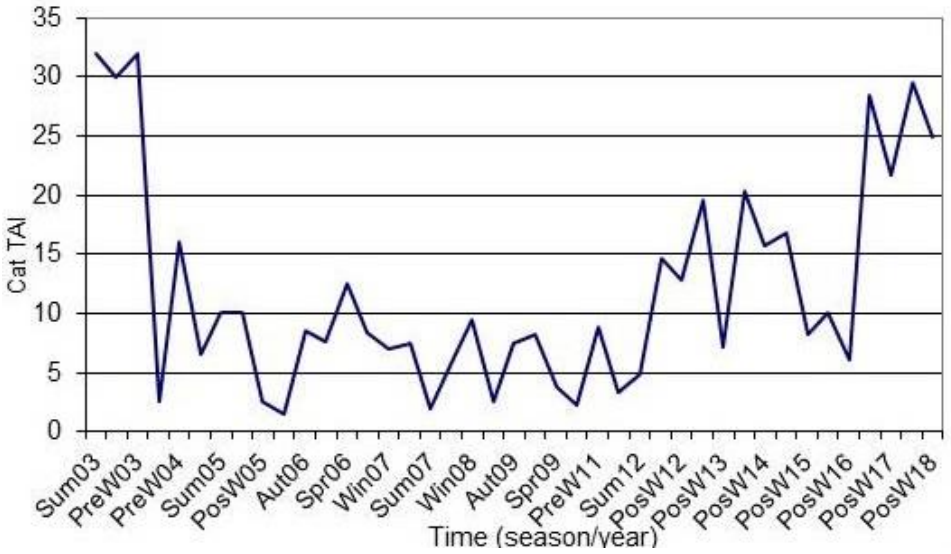


Figure 17: Variation in feral cat activity (TAI) based on footprints. Annual baiting with Eradicat® commenced winter 2003 (W03) and was very effective until about 2012.

7.2.2 Trapping feral cats

As discussed above, trapping can be an effective method for localised control and 'mop-up' of feral cats provided;

- the management area is reasonably accessible by vehicle,
- there are no significant non-target issues requiring special or complex trap setting methods, and,
- it is undertaken by experienced trappers.

It is recommended that trapping of feral cats be used as a 'mop-up' technique should aerial baiting fail to maintain low densities (definitions of baiting 'success' and 'failure' are in Section 7.2.4 below). Details of how to trap feral cats are contained elsewhere[89], but essentially involves the use of soft-jaw leg-hold traps set in the ground (or elevated if there are non-target issues) and using scent and / or sound lures. It should be noted that the use of leg-hold traps for trapping feral cats is not a prescribed method under the Biosecurity and Agricultural Management (BAM) Act. The technique can be employed if it is part of a research program and has AEC approval. In any event, trapping should only be carried out by experienced people.

7.2.3 Introduced predator monitoring

Consistent with adaptive management, it will be necessary to monitor the density of introduced predators to;

- assess the effectiveness of control measures (baiting and trapping) on introduced predator density, and,
- to enable an assessment of the response of native fauna, in particular, sandhill dunnarts and malleefowl, to fire management and introduced predator control.

There is no known simple method for measuring / monitoring the actual population of introduced predators, so scientifically validated surrogates, or indirect measures are

commonly used. These include radio telemetry, track (footprint) counting and using trail cameras. All three methods must be undertaken by skilled, experienced people.

Radio telemetry: For the purpose of estimating home ranges, distances travelled and habitat usage and efficacy of aerial baiting, it is suggested that in year 1, and 12 months prior to baiting, 20-30 feral cats (both sexes) in the management area are trapped and fitted with cat GPS collars (mortality function, with VHF download and preferably drop-off) in early May, prior to burning. If there is adequate resources, it would also be desirable, but not essential, to collar the same number of cats in the reference area. This knowledge can then be used to optimise baiting strategies and inform a camera-based methodology for monitoring feral cat density pre- and post-baiting. Studies at Matuwa have shown that about 80% of bait mortality occurs within the first 4 days or so of baiting and 100% by 10-14 days. Therefore the collars (batteries) will need to last until at least 3 weeks post-baiting, so the timing of the fitting of the collars, the programmed drop off date and the positional download frequency will need to be calculated to fit this regime. Usually, locations are recorded at 4-6 hour intervals, which should provide battery life of 3-4 months. However, this varies depending on the type of collar and environmental conditions – refer to the manufacturer's specifications.

There are a number of methods for estimating home range from radio telemetry data including minimum convex polygon (MCP) and fixed kernel density estimates (KDE)[93,96,100]. An estimate of the effectiveness of baiting is derived from the mortality rate of collared cats and assumes these are an unbiased sample of the cat population. While it can yield valuable information, radio telemetry is expensive – GPS collars are expensive, cats have to be trapped, sedated and fitted with collars, and data and collars retrieved.

Due to the high cost, radio telemetry is viewed by the author as desirable but not critical to the introduced predator control operation.

Plate 10: Sedated feral cat fitted with a GPS collar (Matuwa)

Track counting: Measuring the occurrence of footprints according to a standard protocol is a scientifically valid technique for estimating the 'density' of introduced predators by generating an activity index[88,89,90]. This technique is particularly useful on sandy substrates, such as is common in the GVD. Details are presented elsewhere[71,72,90], but involves skilled observers recording the daily occurrence of fresh tracks (footprints) along transects (vehicle roads/tracks). In both the managed area and the unmanaged reference area, cat Track Activity Indices (TAI) are calculated before and about three weeks after baiting from the total number of sets of tracks (footprint sets) recorded over a minimum of 5 nights on ~45 km of dragged transect line. A longer transect and multiple transects are preferable, but existing road/track access is limited in the project areas.

Camera trapping: Motion-triggered (trail) cameras are increasingly used in wildlife research and monitoring. They are relatively easy to deploy, comparatively low cost, are able to be deployed for long periods and are relatively non-invasive. However, as with most survey techniques, camera trapping is not without challenges including collecting sufficient data on individuals for statistical analysis and 'imperfect detections', when detection cannot be separated from abundance, leaving non-detection ambiguous[98,100]. Site occupancy models attempt to address imperfect detection by modelling the detection process separate from the ecological parameter of interest, and they do not rely on the identification of individuals. As with track counting, cameras cannot accurately provide actual abundance (number of individuals), but provided detection rates are reasonably high, they can provide an estimate of occurrence and density, which can provide a surrogate or index of abundance (MacKenzie and Bailey 2004). Details about the statistics and interpretation of site occupancy models are provided elsewhere [99,100] (e.g., MacKenzie and Bailey 2004; Gu and Swihart 2004).

In attempting to overcome the problem of low detection rates, cameras are often used in conjunction with lures and attractants, or placed in locations known to be frequented by, in this case, introduced predators. As part of his PhD thesis, Wysong (2016) trialled a variety of attractants and camera locations to study the detection rate of cats and wild dogs / dingoes at Matuwa and to estimate occupancy. Lures he used made little difference to detection rates but placing cameras on roadsides increased detection rate sixty-fold compared with off-track cameras. It is advisable to place cameras both roadside and off-road to better assess impact across the landscape.

A relatively simple feral cat camera activity index using roadside cameras has been used in conjunction with track counting at Matuwa for several years to assess baiting effectiveness. Data from fifty cameras set 2 km apart for 2-3 weeks before after baiting were analysed by recording the number of individual cats and dogs (and other fauna) 'trapped' by each camera each night/day. Distinguishing features (e.g., coat markings), time of capture and the travel direction of the animal were also noted. Where the same cat (or dog) was trapped at the same camera more than once on the same night/day, it was scored as one capture. On occasions when the same cat or dog was captured on one or more cameras (2 km apart) on the same night/day, it was scored as multiple captures, consistent with the rule-set for track counting. In many cases, individual cats could be identified, but not always, due to poor imagery (blurred, under/overexposed) or because of an incomplete picture of the animal (e.g., ears, tail, hind quarters, etc.). For similar reasons, and often because of lack of distinguishing features, it was not always possible to identify individual dogs. Data were standardised to the number of captures per camera per night and for ease of using the numbers, this was converted to a camera

activity index (CAI) of captures per 100 camera trap nights. There was a good correlation between this index and the track count index for feral cats but not for dogs.

Others have placed paired or single cameras off-track on various grid patterns. For example a study in Victoria[100] found that a monitoring protocol of 49 cameras set on a 1 km grid for 20 days successfully estimated occupancy rates of feral cats before and after control but was insensitive to small changes in cat density. They concluded the single camera per site technique could detect a reduction in the cat population >50%, and recommended two cameras per site.

There is a large literature on the options and performance of various trail camera methodologies for determining site occupancy and changes in density of feral cats (and other fauna). Proposing a techniques for monitoring native fauna (including sandhill dunnarts and malleefowl) is out of scope for the current project, however to improve cost-effectiveness, it is recommended that the possibility of using trail cameras to monitor changes in the density of both introduced predators and 'target species' (native fauna) be explored. This may mean a combination of roadside and off-road camera sites, as suggested above. The choice of method and sampling intensity will be a trade-off of between statistical reliability, camera security and available resources.

In sum, for monitoring the 'density' of introduced predators in order to evaluate the efficacy of control measures, it is recommended that in year 1, all three measures (radio telemetry, track counting and camera traps) be deployed. In subsequent years, having evaluated the most appropriate camera trap design for both introduced predators and native fauna, it should be only necessary to deploy cameras.

7.2.4 Effective introduced predator control

In pest control, it is generally assumed that a reduction in abundance of, in this case, introduced predators, will lead to a reduction in 'damage', in this case, to native fauna. While there have been impressive responses by native fauna populations following fox control in mesic environments, there has been little work done on prey-predator density relationships in the arid zone. Native fauna vary in their vulnerability to predation by feral cats[78,79,85,87] so there is no agreed level of predator pressure, or cat density threshold for fauna conservation in arid Australia - there are no reliable relationships between the feral cat TAI and the response of various prey species. However, some ten years of data from Lorna Glen (Matuwa) has shown a positive response by native fauna, including bilby and mulgara, when the cat TAI was maintained at <10[47,97]. The density relationships between introduced predators and the project target species (sandhill dunnarts and malleefowl) is unknown, but that these species have persisted in the GVD in the presence of introduced predators suggests that they are not as susceptible as some species that have become extinct in the region, probably due to predation.

This project is based on the hypothesis that good fire management and a significant reduction in the density of introduced predators will result in an increase in the density and distribution of native fauna. Where cats have not been controlled in the arid zone, the cat TAI (density surrogate) is usually 25-35, although it can be lower during prolonged drought and following intense megafires. Foxes are usually absent or at very low densities depending on the 'seasons'.

For the purpose of this project, to be considered 'effective', baiting / trapping should reduce the TAI (or other measures of density) of a bait-naïve population of feral cats by at least 75% and on-going control measures should aim to stop cat (and fox) population growth and keep the cat TAI <10.

8. Schedule of Major Tasks: 2020 -2021

TASK		TIME	COMMENTS
FIRE	Year 1 and annually: Update fire history /seral stage distribution graphs	April	Use satellite imagery to update, map and measure fire scars and patchiness for management and reference areas (See Tables 6 & 8). Compile seral stage / fuel age class graphs for both areas.
	Year 1 and annually: Plan burn program	April-May	Use current fuel age class distribution with theoretical ideal distribution to confirm determine what and how much to burn. Identify buffer burning requirements.
	Year 1 and annually: Aerial & buffer burning	June -August	See burn prescriptions Section 6.2. Cease burning during and 2 weeks after baiting operations.
INTRODUCED PREDS	Year 1: Trap and radio collar 20-30 feral cats	May-June	This task is not critical but will assist with designing control programs.
	Year 1 and annually: carry out track count (footprint) predator surveys	May-June	Base line and pre-bait data.
	Year 2 and annually: Deploy cameras for monitoring introduced predator density / occupancy.	May-June	Combination of roadside and off-road cameras. Design and number of cameras deployed will depend on available resources. If a small number of cameras is available, they should be deployed roadside because of higher detection rates.
	Year 2 and annually: Pre-bait track count surveys	May-June	Track count surveys complement camera surveys
	Year 2 and annually: Aerial baiting Eradicat®	mid July	See SOPs and guidelines at Appendix 3.
	Year 2 and annually: Post-bait surveys	July	Recover collars, download cameras, track counting.
	Year 2 and annually: Mop-up cat trapping in management area	August-September	Only if necessary – depending on baiting effectiveness
REPORTING	Year 1 and annually: Fire management & introduced predator control	September-October	Reports submitted to GVDBT

Table 9: Indicative schedule of major tasks. Assumes Year 1 = 2020; year 2 = 2021. Indicative burn program is contained in Figure 16 but needs to be checked / updated in case fires have occurred in the management area since October 2019.

Acknowledgements

I thank the Great Victoria Desert Biodiversity Trust for the opportunity to be involved in this exciting and important project. I also thank members of the Trust's Technical Advisory Panel, Dr David Algar (DBCA) and Gareth Catt (10 Deserts) for helpful comments on earlier drafts. I thank Dorian Moro (GVDBT) for his professional management of this consultancy.

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Appendix 1: Scope of work

Integrated Fire and Introduced Predator Land Management Project

1) Project purpose

Based on the premise that large, intense bushfires and introduced predators combine to threaten a range of fauna in the Great Victoria Desert (**GVD**), this project aims to improve the conservation status and population of Sandhill Dunnarts and Malleefowl through fire management and introduced predator (cat, fox, wild dog) control. The concurrent aim is to improve overall biodiversity in the selected area.
The project has 3 key strategies:
1) Select and define two areas (each ~100,000) within the GVD (WA) with similar habitat, fire regime and both containing known populations of Sandhill Dunnarts and Malleefowl (a management area and an unmanaged reference area). Areas are not to be part of the conservation estate.
2) Design a fire management plan for the management area which clearly defines-
a. A goal of what the area should look like after 10 years of fire management (fire age distribution and mosaic scale)
b. A target of what percentage of the study area should be burnt each year, within the 10-year time frame
c. The optimum mean size of the patch burns each year and the maximum burn size
d. Detailed guidelines/methodology and an indicative annual schedule of how burns should be conducted, and the spatial arrangement of the patches, in order to achieve annual targets and reach the 10-year goal. The best available information will be used to increase the likelihood of scattered arrangement of patches
e. Detailed recommendations on how to maintain long unburnt areas as part of the mosaic, and how to protect culturally sensitive sites during prescribed burning or from bushfires.
3) Design (in consultation with suitable technical expert/s on introduced predators in WA) an introduced predator baiting and monitoring plan for the management area which includes-
a. An optimal baiting regime for the treatment area.
b. Detailed methodology on pre-burn / pre-baiting (baseline) monitoring and analyses that should be conducted for introduced predators, in consultation with suitable scientists.
c. Detailed methodology on what post-fire / post-baiting monitoring should be conducted for introduced predators.

2) Project background

The core objective of the Great Victoria Desert Biodiversity Trust (the Trust) is to conduct land management activities that will increase the conservation of threatened species and biodiversity in the GVD. Given the limited knowledge about biodiversity and threatened species in the GVD, the initial projects initiated by the Trust have focused on consolidating known information and conducting surveys and research to increase knowledge of the distribution and habitat requirements of the Sandhill Dunnart and Malleefowl in the region. The surveys conducted have increased knowledge of these

species. At a Sandhill Dunnart presentation and workshop day, facilitated by the Trust in March 2019, a group of experts determined the need to commence on-ground conservation activities for the Sandhill Dunnart by simultaneously addressing what is thought to be the two biggest threats facing the species, fire and introduced predators, especially feral cats. The group determined the need to have a management area and an unmanaged reference area to monitor the results to determine if fire and introduced predator management could lead to an identifiable increase in the Sandhill Dunnart populations. Given that Malleefowl and Sandhill Dunnarts are found to exist in the south-west of the GVD, the decision was made that management areas should be selected that contain known populations of both the species.

The current project will provide a detailed fire and introduced predator management plan, including defining, and describing how fire management should occur and what end goals should be set. It will also describe and define an introduced predator baiting program (in consultation with suitable experts in this area) for the management area. Given that expertise will be required that specifically relates to Sandhill Dunnarts and Malleefowl, the Trust will use the Technical Advisory Panel (among other technical experts as required) to design an appropriate baseline and monitoring program for these native species.

3) Project Assumptions

In order for the Consultant to conduct this project, the Trust will provide, in a timely manner:

1) Current known locations of Sandhill Dunnarts in the GVD

2) Current known locations of Malleefowl in the GVD

3) Fire scar mapping for the south-west of the GVDfor the years 1995-2018 including long unburnt areas

4) Information on culturally sensitive areas through either available data systems (Department of Aboriginal Affairs) or through discussions with Traditional Owners

5) A map showing all roads , tracks including mining exploration tracks, airstrips and seismic lines

6) Regular meetings (a minimum of 2) and access to experts via the Technical Advisory Panel and including additional expertise as required such as:

- Sandhill Dunnart experts
- Malleefowl experts
- Feral cats experts
- Traditional Owners or their representatives
- GIS / Fire scar mapping experts

7) Assistance from the Trust's Operations Manager in integrating outcomes from the Technical Advisory Panel into the final report (this Scope of Work).

The Consultant will work with the Operations Manager to ensure the outcomes of these meetings are integrated into a Final Report.
In the case of information not being readily available, the Consultant will attempt to progress other aspects of the project, not requiring the unavailable information. Delays in the project, as a result of the above information not being available will be discussed in writing well before agreed milestone timeframes.

4) Project milestones, deliverables and deadlines

Milestone 1 – Deliverables by the 5 September 2019, on signing of the contract
1) Signed Contract

Milestone 2 – Deliverables by the 14th of October 2019
1) Participation in meetings of the Technical Advisory Panel

2) Regular phone conversations and/or Technical Advisory Panel members as required.

Milestone 3 – Deliverables by the 10th December 2019
A. Provision for up to 2 report submissions (a draft Revision A and, following revisions based on comments by GVDBT, a final Revision 0). The review process will be managed via a "Client comment response sheet" or "comment tracker", which would detail all comments made by GVDBT and specify which comments have been addressed (and how) and which haven't been addressed by the Client. Where comments have not been addressed, reasoning would be provided in the comment tracker. The final report shall cover the following:

1. Executive Summary

2. Background, including mention of the Trust Deed objectives;

3. Introduction (including work scope and objectives aligned to a Project Plan produced by the Trust);

4. Methodology and rationale for selecting land areas (reference and management). This will include advice from the Technical Advisory Panel on: size of area necessary for Sandhill Dunnarts and Malleefowl conservation; size of area necessary for effective (cat) baiting and; known areas of occupancy for Sandhill Dunnarts and Malleefowl.

5. Maps and GPS locations of the selected areas. Results from the Trust's Landsat Fire Scar Mapping project will also be incorporated into this section of the report.

6. Fire Management Plan to include:
a) A goal of what the area should look like after 10 years of fire management (fire age distribution and mosaic scale)

b) A target of what percentage of the study area should be burnt each year, within the 10-year time frame

c) The optimum mean size of the patch burns each year and the maximum burn size

d) Detailed guidelines/methodology and indicative annual schedule of how burns should be conducted, and the spatial arrangement of the patches, in order to achieve annual targets and reach the 10-year goal. The best available information will be used to increase the likelihood of scattered arrangement of patches.

e) Detailed recommendations on how to protect long unburnt areas or culturally sensitive sites during prescribed burning or from wildfires.

f) Detailed recommendations on how annual rainfall effects fires and how this would affect the timing and size of burns

g) Detailed recommendations on pre-burn activities or monitoring that should be conducted including conducting a fuel load transect (Conducting a standardised technique for a fuel load transect advice to be detailed in Appendix A).

h) Discussion on Spinifex fuel load modelling (Details in Appendix B).

i) Discussion on adaptive management and how to update the Fire Management Plan to incorporate lessons learnt from each year that managed burns are conducted

7. Introduced predator baiting and monitoring plan to include:
a) Design of an optimal baiting regime (including timing relative to planned burns, amount and dispersal of baits, bait type, required permits) for the managed area.
b) Methodology on pre-burn / pre-baiting monitoring and analyses that should be conducted for introduced predators
c) Methodology on what post-fire / post-baiting monitoring should be conducted for introduced predators
8. Fauna baseline and monitoring program (input will be provided by the Technical Advisory Panel and this section written with assistance from the Company Representative) to include:
a) Current known species locations of Sandhill Dunnarts and Malleefowl
b) Habitat specific requirements of Sandhill Dunnarts and Malleefowl that should be considered in conducting burns
c) Methodology on pre-burn / pre-baiting (baseline) monitoring and analyses that should be conducted for Sandhill Dunnarts and Malleefowl
d) Methodology on what post-fire / post-baiting monitoring should be conducted for Sandhill Dunnarts and Malleefowl.
9. General Discussion

Including process for adopting adaptive management principles into management plans
10. References
11. Appendices including Appendix A Standardised technique for conducting a fuel load transect; and Appendix B Spinifex Load Modelling
B. Presentation (including question time) to the Trust and other invited stakeholders.
C. Participation in meetings of the Technical Advisory Panel.

5) Required format of reports and other outputs
Report shall be provided in both a pdf and a non-pdf Word document format and include the content as outlined for each of the respective Milestones above (Section 4 in scope of works). These shall be quality-checked and produced to a professional business level, so that they can be easily understood by all parties without requiring in-depth knowledge of the project or subject matter. Reports will be publicly disseminated by the Trust.
All reports produced and submitted under the Milestones shall display the following information clearly and in a prominent position on the cover and/or first page: (a) author/s; (b) date of production; and (c) 'prepared for the Great Victoria Desert Biodiversity Trust' by…'. 28

6) Intellectual property and acknowledgements
The sources of all data/information in reports, maps and other outputs shall be correctly referenced and acknowledged, including contributions by third parties. Data / information-sharing sensitivities or restrictions shall be clearly identified and acknowledged, or avoided where possible.

Appendix 2: Spinifex fire behaviour guide

This guide to predicting fire behavior applies to spinifex-dominated grasslands that are:

- 6-24 years old
- Fuel load 3.5 -16 t/ha; fuel cover 20-70%; spinifex clump height 20-50 cm
    - Spinifex clump profile moisture content 12-40%
    - Winds @ eye level < 40 km/h (~<50 km/h @ 10 m)

The model explained about 78% of the variation in rate of spread of 158 mostly small (0.5 - 2 ha) experimental *line fires* (50-100 m long) in the Great Sandy, Gibson and Great Victoria Deserts conducted over the period 1988 – 2015. Data from four fires from the Mt Isa area (Qld) were kindly provided by Dr Paul Williams. Of these fires, 100 spread and 58 did not spread. Being an empirical model, it will be less reliable outside the range of experimental conditions (above).

The model does not incorporate spotting, which is not usually a feature of spinifex fires except where eucalypts/mallees or other tree species are present. In this situation, spinifex fires have been observed to spot ~200 m or so, but may be capable of spotting further under extreme conditions.

Direct measurement of model inputs is best but is not always feasible, hence indirect measures are included and should be treated as a guide. Weather observations can be made using a Kestrel 4000-4500 series set at eye level.

The use of the Australian Water Availability Project data (http://www.csiro.au/awap/) for off-site estimation of the moisture content of live spinifex clumps has had limited testing, but shows promise. Remote sensing (satellite imagery) to estimate 'curing' and cover is also being investigated.

There is a great diversity of structures of spinifex grasslands across central WA, so not all will fit neatly into one of the four fuel classes /seral stages shown in Figure 2 below. Spinifex develops at different rates depending on the species, time since fire and local site conditions (soil, topography, rainfall). If you can't directly measure the fuel variables (preferable), choose the fuel class seral stage that most closely resembles your situation.

As reflected in the model equation below, after peaking at 20-25 years, on some sites, fuel quantity and cover may decline.

Spinifex grasslands form a discontinuous fuel, so there are three critical thresholds to fire spread; wind speed, fuel moisture content and fuel cover. Therefore, predicting rate of spread is a 2-step process—the first step is to determine whether the spread thresholds are exceeded (SI>0). The second step is to calculate rate of spread and flame height.

Step 1: Will fire spread?

$SI = 0.41(U_{1.7}) + 0.31(c) – 0.67(m) - 4.07$ *or,*
$SI = 0.30\ (U_{10}) + 0.31(c) - 0.67(m) - 4.07$

Where:
SI = spread index.
$U_{1.7}$ = wind speed (km/h) @ eye level.
U_{10} = Open 10 m wind speed (forecast windspeed).
c = live and dead spinifex fuel cover (%) (see below)
m = clump profile moisture content (%) (see below)

If SI = 0, then the fire is *unlikely* to spread; the more negative the SI, the less likely is fire spread.

If the SI > 0, then the fire is *likely* to spread; the more positive the SI, the more likely is fire spread. If SI>0, then go to the next step and calculate the likely Rate of Spread (R). If SI = 0 then R = 0.

Step 2: If SI > 0, fire is likely to spread, so calculate Rate of Spread (R) and Flame Height (F)

$$R = 40.982 \frac{U_{1.7}^{1.399} c^{1.201}}{m^{1.699}}$$

$$F = 0.097R^{0.42} + 0.10fl$$

Where:
R = head fire rate of spread (m/h)
F= head fire flame height (m)
fl = fuel load (t/ha oven dry)
$U_{1.7}$ = wind speed (km/h) @ eye level. Note: coefficient for open 10 m (forecast) wind speed (U_{10}) is 1.275.
c = live and dead spinifex fuel cover (%)
m = clump profile moisture content (%)

1. Estimating fuel load (fl; t/ha)
1A: Directly by destructive sampling (preferred). At least five 1 m x 1 m quadrats. (see Burrows *et al*. 2008a and Burrows *et al*. 2018 for details)
1B: Estimated indirectly from fuel age (Figure 4 in report above), or,
Fuel quantity (t/ha) = 1.21(fuel age yrs) X ($e^{-0.041Xfuel\ age}$)
Note: This assumes average rainfall over the period.
1C: Estimated indirectly from fuel structural stage. Also assumes average rainfall. (see below).

2. Estimating fuel cover (%)
This is the projected ground cover of live and dead spinifex and other vegetation <1.5 m. Dead spinifex is the black spinifex in the middle of the clump or the 'mat' behind the growing front of older spinifex meadows. Fuel cover can be estimated by:
2A: Using a 50 –100 m tape and recording live/dead spinifex intercepts at 1 m intervals (preferred) (see Burrows *et al*. 2008a and Burrows *et al*. 2018).
2B: 'Stepping' (% of 100 steps falling on or off live/dead spinifex, bare ground).
2C: Satellite imagery.
2D: Estimated from fuel age or seral stage (see Figures 3 and 10 in report).

3. Estimating the moisture content of spinifex clumps (Profile Moisture Content- PMC)
This is the average moisture content of the whole clump including live and dead material.

- 3A: On site: Direct measurement (preferred) using a calibrated Wiltronics Fuel Moisture Meter, or by oven drying. Take at least five samples through the profile of separate but representative clumps.
- 3B: On site: Indirectly from clump colour (rough guide only —see examples next page).
- 3C: Off site: Indirectly from relative soil moisture using the Australian Landscape Water Balance Model, as follows;

Step 1: Determine the moisture content for a Stage 2 (m_2) spinifex fuel (6-10 years old, <5% dead material) using $ALWB_{RZ}$ or mid-point from colour charts below;

Using $ALWB_{RZ}$
$m_2 = 0.74x(ALWB_{RZ}) + 18.0$

Where:

- m_2 = Stage 2 clump profile moisture content (%) ;
- $ALWB_{RZ}$ = Australian Landscape Water Balance—root zone soil moisture for that location (http://www.bom.au.gov/water/landscape)

Step 2: Adjust the moisture content for older fuels, which have a higher proportion of dead material.

Stage 3 Fuel: $m_3 = m_{c2}$ - (1/(0.03 x RH)) x 2.0; If m_3 = < 12%, then set m_3 to 12%

Stage 4 Fuel: $m_4 = m_{c2}$ - (1/(0.03 x RH)) x 3.0; If m_4 = < 11%, then set m_4 to 11%.

Stage 5 Fuel: $m_5 = m_{c2}$ - (1/(0.03 x RH)) x 4.0; If m_5 = < 10%, then set m_5 to 10%.

RH = Relative Humidity

Example 1 (Stage 3 fuel to be burnt):

Step 1: From the website above, the $ALWB_{RZ}$ value for the location and date is 4.74%. So the *m* for a standard Stage 2 fuel (little dead material) is 21.5% (from m_2 equation above).

Step 2: RH = 20%.

Step 3: Now correct for the actual fuel stage to be burnt; Stage 3 fuel is to be burnt, so *m* correction is:

Stage 3 m_3 = 21.5 - (1/(0.03 x 20)) x 2.0

Stage 3 m_3 = 21.5 - (1.7 x 2.0) = 18.1%.

Example 2 using the colour of clumps. Stage 5 fuel to be burnt:

Step 1: The colour of live spinifex is straw yellow (4 below), so the m_2 (Stage 2 fuel) is ~18-20%, midpoint = 19%.

Step 2: RH = 15%

Step 3: Now correct for actual fuel class to be burnt; Stage 5 fuel is to be burnt, so *m* correction is:

Stage 5 m_5 = 19 - (1/(0.03 x 15)) x 4.0;

Stage 5 *m* = 19 - (2.2 x 4.0) = 10.2%; Stage 5 m_5 = 10.2%

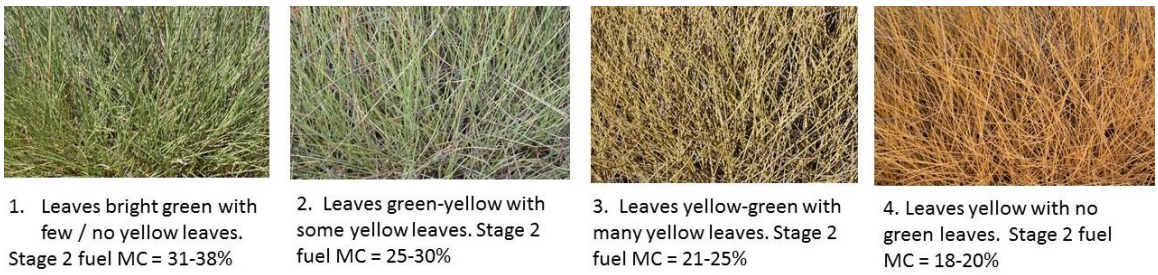

Figure 1: Colour *guide* to the moisture content of Stage 2 spinifex clumps (i.e., 6-12 year old). Use the moisture content corrections above for older plants with higher proportions od dead material.

Fire Behaviour Guide

FIGURE 2: FUEL STRUCTURAL DEVELOPMENT STAGES

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Clump ht: <20cm Clump wth: <20 cm Clumps separated, domes Cover: < 25% Little or no dead spinifex No flowering stalks Non-flammable ≤ 6 yrs old	Clump ht: 20-25 cm Clump wth: 20-30 Clumps mostly separated, some joined, domes Cover: 25-35% Some dead spinifex Flowering stalks Flammable under severe conditions. >6≤12 yrs old	Clump ht: 25-35 cm Clump wth: 25-50 cm Clumps mostly joined Cover: 35-45% Centre of clumps beginning to die (grey/black) Flammable under most conditions >12≤18 yrs old	Clump ht: 25-35 cm Many old clumps have formed 'donuts' with bare ground in centre, dead spinifex behind growing front. Some young clumps. Cover: 40-45% Flammable under most conditions >18≤24 yrs old	Clump ht: 20-30 cm Oldest clumps have formed crescents 2-3 m diam. Some younger clumps. High proportion of dead (grey/black) material. Cover: variable - 20-40% depending on site and age. Flammable depending on cover >24 yrs old
Unsuitable SHD habitat	**Marginal SHD habitat**	**Suitable SHD habitat**	**Marginal SHD habitat**	**Unsuitable SHD habitat**

Suggested patch-burn range

S2 Fuel (>6≤12 yrs)

Wind speed at eye level (km/h)

Head fire rate of spread (m/h) and flame height (m)

PMC (%)	>8 km/h Threshold	10	15	20	25	30	35	<40
35	0	0	0	0	0	0	300 1.4	1101 2.6
30	0	0	0	0	300 1.4	766 2.3	1451 3.0	2136 3.3
25	0	0	0	431 1.8	1116 2.6	1801 3.1	2486 3.4	3171 3.7
20	0	300 1.5	780 2.4	1466 3.0	2151 3.3	2836 3.6	3521 4.0	4206 4.3
15	446 1.8	1131 2.7	1816 3.1	2501 3.4	3186 3.7	3871 4.2	4556 4.4	5241 4.6
10	1481 3.0	2166 3.3	2851 3.6	3536 4.0	4221 4.3	4906 4.6	5591 4.7	6270 5.0

S3 Fuel (>12≤18 yrs)

Wind Speed at eye level (km/h)

Head fire rate of spread (m/h) and flame height (m)

PMC (%)	>7km/h Threshold	10	15	20	25	30	35	<40
35	0	0	0	0	0	0	625 2.0	1309 2.6
30	0	0	0	0	289 1.3	974 2.5	1658 3.1	2344 3.4
25	0	0	0	639 2.0	1325 2.6	2009 3.3	2694 3.6	3379 4.0
20	0	304 1.5	989 2.5	1674 3.1	2359 3.4	3044 3.7	3729 4.1	4414 4.5
15	645 2.0	1339 2.6	2024 3.3	2709 3.6	3394 4.0	4079 4.3	4764 4.5	5494 4.6
10	1689 3.1	2374 3.4	3059 3.7	3744 4.1	4429 4.5	5114 4.6	5799 4.8	6484 5.2

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Stage 4&5 Fuel (>18 years)

Wind Speed at eye level (km/h)

Head fire rate of spread (m/h) and flame height (m)

PMC (%)	>6 Threshold	10	15	20	25	30	35	<40
35	0	0	0	0	0	0	832 2.5	1517 3.0
30	0	0	0	0	497 2.0	1182 2.6	1867 3.1	2552 3.5
25	0	0	162 1.0	847 2.5	1532 3.0	2217 3.4	2902 3.7	3587 4.1
20	0	512 2.0	1197 2.6	1882 3.1	2567 3.5	3252 3.9	3937 4.2	4622 4.5
15	862 2.5	1547 3.0	2232 3.4	2917 3.7	3602 4.1	4287 4.3	4972 4.6	5657 4.8
10	1897 3.2	2582 3.5	3267 3.9	3952 4.2	4637 4.5	5322 4.6	6007 5.0	6692 5.2

Appendix 3: Aerial Feral Cat Baiting Protocol (DBCA)

Background

Due to the specific conditional requirements associated with feral cat baiting the following protocol has been developed to provide operational guidance to help achieve the most effective baiting outcome. This document defines the roles and responsibilities of Parks and Wildlife staff involved in the coordination and support of aerial feral cat baiting using the Western Shield aerial baiting contract.

The Senior Operations Officer (Invasive Species) of Ecosystem Health Branch is to remain the lead point of contact between Parks and Wildlife and the aerial baiting contractor for all matters of a contractual and program planning nature.

Key personnel

- Senior Operations Officer (Invasive Species) (SOOIS)
- Dr Dave Algar
- Bait Manufacture Facility (BMF) Manager
- Western Shield Coordinator
- Western Shield Aerial Baiting Coordinator (ABC)
- Project leaders

1. Seven, four and two day's prior to the day of baiting

- The SOOIS will review the applicable town and/or district weather forecast from the Bureau of Meteorology website http://www.bom.gov.au/wa/?ref=hdr and/or http://www.weatherzone.com.au. The applicable town and/or district weather forecast will be determined prior to the commencement of the round in consultation with the project leader.
- The SOOIS will liaise with the ABC to make a decision regarding proceeding with the baiting. Advice may also be sought from other key personnel.
- If rain is predicted and the decision has been made to reschedule the baiting the SOOIS will request the aerial baiting contractor to develop alternative flying schedules. If the Bait Manufacture Facility (BMF) staff are providing delivery of the baits and supporting the baiting the SOOIS will inform the BMF Manager. *Decision tree to be followed

2. On-site - the day prior to the day of baiting

In the days preceding the baiting and in particular the day prior, the aerial baiting contractor and support personnel such as the BMF staff are likely to be at or travelling to site.

3. Reschedule of baiting due rain

In the event that the baiting has to be rescheduled due to weather, the SOOIS will discuss with the Western Shield Coordinator or the Project Leader (whoever is applicable) whether to request that the aerial baiting contractor continue with baiting other aerial baiting cells or have the contractor remain on-site at the standby rate.

Standby Conditions for the Western Shield Aerial baiting Contract

Standby conditions will come into effect when the contractor is operating away from its Nominated Base and flying operations are unable to continue, due to any of the following occurrences:

a) Lack of baits;

b) Lack of fuel, supplied by Parks and Wildlife, if under a 'dry hire' arrangement; or

c) Request from Parks and Wildlife staff to stand down due to wet weather

The SOOIS will endeavor to reschedule baiting if poor weather conditions are predicted at feral cat baiting sites however, Project Leaders should note that they are responsible for standby costs incurred.

Decision tree for determining whether baiting should be postponed

Seven days prior to the day of baiting:
1. *Is any rainfall predicted on the day of the scheduled baiting?*
   - No, proceed with the scheduled baiting
2. If yes, *is the likelihood of rainfall ≥50%*?
   - No, proceed with the scheduled baiting
   - Yes, reschedule baiting or proceed and review the weather forecast four days prior to baiting

Four days prior to the day of baiting:
1. *Is any rainfall predicted on the day of the scheduled baiting?*
2. If yes, *is the likelihood of rainfall ≥50%*?
   - No, proceed with the scheduled baiting
   - Yes, reschedule baiting or, with agreement from the project coordinator, proceed and review the weather forecast two days prior to baiting
3. *Is any rainfall predicted on the first day following the day of the scheduled baiting?*
- If yes, review # 2 above; if no, proceed with the scheduled baiting.

Two days prior to the day of baiting:
1. *Is any rainfall predicted on the day of the scheduled baiting?*
2. If yes, *is the likelihood of rainfall ≥50%*?
   - No, proceed
   - Yes, reschedule the baiting
3. *Is any rainfall predicted on the two days following the day of the scheduled baiting*?
   - - If yes, review # 2 above; if no proceed.

The day prior to the day of baiting:
1. *Has it rained on this day?*
   - No, proceed and see #2
   - Yes, if ≥ 5mm then reschedule the baiting.
2. *Is any rainfall predicted on the day of baiting and for the two days following*?
3. If yes, *is the likelihood of rainfall ≥50%*?
   - No, proceed with scheduled baiting
   - Yes, reschedule the baiting

The day of baiting:
1. *Has it rained over night at the site?*
   - No, proceed and see #2
   - Yes, if ≥ 5mm then reschedule the baiting.
2. *Is any rainfall predicted through the day?*
   - No, proceed with scheduled baiting
   - If yes, *is the likelihood of rainfall ≥50%*?
   - No, proceed with scheduled baiting
   - Yes, if ≥ 5mm then reschedule the baiting.

All decisions and materials/evidence used to support the decision made to amend the baiting program or to postpone baiting is documented and forwarded to the SOOIS to be placed on file.

PROTOCOL AND CHECKLIST FOR THE USE OF THE WESTERN SHIELD AERIAL BAITING SERVICES CONTRACT FOR NON-WESTERN SHIELD AERIAL WORK PROJECTS

Purpose
This memo outlines the key responsibilities and timeframes for any non-Western Shield aerial work project proposed under the current Western Shield (WS) aerial baiting contract. This is to help ensure effective planning and delivery of both WS and non-WS baiting projects. It is relevant to any Department of Parks and Wildlife (DPaW) project leaders who are responsible for conducting aerial work projects (including baiting) and who plan to use the WS aerial baiting services contract.
Project Leaders of non-WS aerial work projects – could you please respond noting acknowledgement of the requirements outlined in this memo including the checklist of activities and timeframes.
What the Senior Operations Officer - Invasive Species will be responsible for :

- All contractual matters.
- General liaison with Aerial Baiting Contractor (contractor) regarding WS operations.
- Planning the WS baiting rounds* throughout the year and preparation of the WS Operations.
- Plan on a round by round basis. This will include proposed non-Western Shield aerial work projects.
- The Senior Operations Officer - Invasive Species (SOOIS) will keep the project leader up to date of changes to the baiting schedule as they occur and of any additional requirements for the baiting to occur successfully.
- Providing the .shp file of the area to be baited to the Contractor.
- Receiving and circulating the baiting report and data provided by the Contractor at the end of a round.
- Record management.

What the baiting project leader will be responsible for:

- Providing a current *1080 Baiting Application* and *Risk Assessment and Approval* to the SOOIS and WS Coordinator including an operational-based map for pilot and ground staff.

- Undertaking any conditions and details of the relevant approved baiting application e.g. erection of 1080 poison risk signs, neighbour notifications and provision of public maps to relevant district office etc.
- Organising the bait order (including the provision of the 1080 Authorisation Voucher) with the Bait Manufacture Facility (BMF) Manager (Harvey) including any necessary on-ground requirements e.g. bait storage and bait racks for sweating of baits.
- Providing funds for the bait order unless otherwise arranged with the WS Coordinator
- Liaising with the WS Aircraft Baiting Coordinator (ABC) within each district regarding the aerial operations relevant to the project including SARWATCH keeper/s.
- Organising trained SARWATCH keeper/s and SARWATCH via the VHF radio network and emergency response capacity as per SOP 004 Aircraft Flight Following SAR PROCEDURE Search and Rescue (SAR) Procedures or as defined by department's Aviation Manager.
- Ensuring that the relevant airstrips are authorised for DPaW use in consultation with the Aviation Manager.
- Preparing all relevant .shp files as per baiting application and risk assessment and providing to SOOIS.
- Provision of AVGAS fuel and other logistical support (e.g. a vehicle for longer campaigns) may be required. To be determined with Contractor at time of pricing. If feral cat baiting, then an 'on-site baiting coordinator' needs to be nominated as per feral cat baiting protocol. All effort will be made to avoid standby conditions however, if standby is invoked due to bad weather or bait supply issues then the project leader will be required to pay for this. If outside the WS operational area ensuring that the contractor completes any site specific health and safety inductions as per departmental requirements.
- Payment of invoice for works within 7 working days.

Key Actions:

- The project leader should provide a proposal of any aerial baiting projects anticipated for the calendar year ahead to the SOOIS and the WS Coordinator by 31 December or as soon as possible. This is to consider the compatibility with the WS aerial baiting program and contract requirements. Note: Bait requirements need to also be discussed with the Bait Manufacture Facility (BMF) Manager (Harvey) at this time.
- If compatible with the WS program the indicative operational details of the project should be provided to the SOOIS at least three months prior to the commencement of the applicable.
- WS baiting round. The SOOIS will provide the operation details to Contractor for their consideration and pricing. The details required include the type of baiting; location, area of baiting (km2); relevant airstrips and any other relevant logistical considerations.
- If required the price of the proposed baiting will be provided by Contractor via the SOOIS for the project leader to approve at least ten weeks prior to commencement of a WS baiting round.
- At least eight weeks prior to the commencement of a WS baiting round* the final details of the proposed baiting should be provided to the SOOIS for inclusion in the WS Operations. Plan for the baiting round. At this stage, the following final details are required by the SOOIS:

i. An approved baiting application.
ii. The requested date of baiting. Note the SOOIS will endeavour to ensure that the requested date of baiting is achieved. However, the actual date of baiting is dependent

upon instances such as WS priorities; the contractor availability and the weather.
iii. SARWATCH keeper's details (phone number, VHF channel and radio call signs).
iv. Airstrip to be used.
v. If applicable written confirmation from the department's Aviation Manager that the airstrip is appropriate for DPaW use.
vi. An area statement in km^2 (e.g.1000.56km^2) and number of baits required

- At approximately five weeks prior to the commencement of a baiting round* the WS Aerial Baiting Schedule will be sent by the SOOIS to the project leader to agree upon the scheduled date.
- At least four weeks prior to the commencement of a baiting round the project leader must provide a .shp file of the area to be baited to the SOOIS which is in consideration of any conditions and requirements (e.g. required exclusions) of the approved baiting application.
- The project leader must liaise with GIS Branch regarding the preparation of the final .shp file. To ensure consistency and assist in avoiding errors all .shp files will be named as per Western Shield file naming protocol by the SOOIS. The SOOIS will provide the .shp files to Contractor.
- Baiting proposed to occur within a WS aerial baiting cell needs to be discussed first with the WS Coordinator. If the baiting occurs within a WS aerial baiting cell (and the baiting does not include the entire WS cell) the project leader is also responsible for preparing a .shp file for the remaining portion of the cell that would otherwise be baited under the WS Program. Note where applicable a proposed baiting that incorporates a WS cell should use the boundary as it appears in the corporate data.
- WS Baiting rounds commence on 1 September, 1 December, 1 March and 1 June of each year and run for three months. Activity To be completed by Date complete
- Provided project proposal for aerial baiting projects anticipated for the calendar year ahead to the WS Coordinator 31 December for the calendar year or as soon as possible Indicative operational details provided to the SOOIS 3 months prior to the commencement of the applicable WS baiting round.
- Provided a current approved *1080 Baiting Application* and *Risk Assessment and Approval* to the SOOIS and WS Coordinator 8 weeks prior to the commencement of the WS baiting round Requested date of baiting provided to the SOOIS 8 weeks prior to the commencement of the WS baiting round. Organised trained SARWATCH keeper/s and emergency response 8 weeks prior to the commencement of the WS baiting round .
- Provided SARWATCH keepers details to SOOIS 8 weeks prior to the commencement of the WS baiting round.
- Provided details of the airstrip to be used to the SOOIS 8 weeks prior to the commencement of the WS baiting round.
- Provided written confirmation from the Aviation Manager to SOOIS regarding the use of the airstrip 8 weeks prior to the commencement of the WS baiting round.
- Provided and area statement and the number of baits required to the SOOIS 8 weeks prior to the commencement of the WS baiting round.
- On site baiting coordinator as per cat baiting protocol nominated and provided to SOOIS (if applicable) 8 weeks prior to the commencement of the WS baiting round.
- Prepared all relevant .shp files and provided to SOOIS and where the baiting does not include the entire WS cell a .shp file for the remaining portion of the cell baited has been prepared 4 weeks prior to the commencement of the WS baiting round.
- Organised bait delivery with the BMF manager including provision of the voucher/permit 4 weeks prior to the commencement of the WS baiting round.

- Contractor completed relevant health and safety induction 4 weeks prior to the commencement of the WS baiting round.
- Completed all actions required under the conditions of the baiting application and risk assessment 2 weeks prior to the commencement of the WS baiting round.
- Organised all on ground operation logistics and support including staff vehicles and bait racks etc. 2 weeks prior to the commencement of the WS baiting round.
- Payment of invoice for works within 7 working days of the invoice date Other relevant documents.
- Feral cat baiting protocol.
- SOP 004 Aircraft Flight Following SAR PROCEDURE. Note: Unless otherwise arranged with the SOOIS and WS Coordinator the Western Shield team reserves the right to refuse or cancel the use of the Western Shield aerial baiting contract if this memo is not adhered to.