Traditional and contemporary fire patterns in the Great Victoria Desert, Western Australia

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"When we left (the Great Victoria Desert) in 1986, that is when the really big fires started". Mr Rictor, Tjuntjunjara 2018.

Executive summary

The purpose of this study was to compare and contrast the recent fire pattern in the Great Victoria Desert (GVD) with that likely created by traditional (pre-contact) Aboriginal (Pila Nguru – Anangu tjuta pila nguru) burning. We used a chronosequence of Landsat satellite imagery from 2000-2016 to reconstruct and quantify the contemporary pattern over an area of 12,879, 615 ha, and the earliest black and white aerial photography, taken in 1960/61, to reconstruct and quantify 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. Based on best available knowledge, we acquired aerial photography over those areas where people were most likely to be, covering an area of 1,049,222 ha. To better understand how and why the GVD Anangu people used fire, we reviewed the limited literature, and via video link with the TjunTjunjara community, participated in discussions about fire with elders.

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. Over the 17 year study period, the mean and maximum fire sizes were 3,699 ha and 1,033,121 ha respectively. This contrasted strongly with the size of fires, mostly attributed to Anangu burning, visible on the 1960/61 aerial photgraphy. While the photography is literally a 'snapshot' in time and space, the mean and maximum fire sizes were 11.2 ha and 3,953 ha respectively. The fire scars on the photographs were clustered, probably reflecting the locations of small groups of people. Compared with similar studies in the Great Sandy / Gibson Deserts, the extent of recent burning evident on the old aerial photographs was limited, with only about 2.7% of the study area showing visible signs of having been recently burnt. This probably reflects the sparse population at the time of photography and relatively large areas of low flammability vegetation in this region of the GVD.

Fire played, and continues to play, an important role in the spritual and physical well being of people. It is clear from the old aerial photographs that the people who carried out the burning had a sound knowledge of fire behvaiour; they were able to keep the fires small because they understood relationships between fire behaviour, vegetation (fuel) and weather, especially wind. There were good reasons why fires were kept small; large fires were unnecessary, wasteful and of little benefit to Anangu. Reasons for burning were many and varied, and consistent with other Western Desert people, the predominant reason for burning was food acquisition. A beneficial consequence of broadscale patch-burning was that it mitigated, or buffered, the harmful effects of hot season bushfires.

While there is some level of fire management in the GVD, most of the region experiences unmanaged fire patterns dominated by large, hot bushfires, which are harmful to biodiversity, are environmentally degrading and are contributing to greenhouse gas emissions. Action is needed to increase the capacity of people to better manage fire in the GVD and to re-instate traditional Anangu fire management across larger areas of high cultural and conservation value. Traditional fire management carried out at appropriate scales, as well as other benefits, can reduce greenhouse gas emissions and increase carbon sequestration. The future carbon market could provide opportunities for self-funding fire management, delivering social, cultural, economic, environmental and conservation benefits.

1. Introduction

Spinifex grasslands are characterised by the dominance of perennial hummock grasses, primarily of the genus *Triodia*. They occur on a diversity of landforms and soils including sand plains, dune fields, stony plains and rocky hills in the semi-arid and arid regions of the remote and sparsely populated central and northern parts of Australia. Spinifex grasslands cover about 2.1 million km^2 (~27%) of the continent, of which about 800,000 km^2 (~40%) is on Aboriginal land (Allan and Southgate 2002). The climate is arid or semi-arid with annual average rainfall ranging from about 225 mm to 350 mm. In the north, rainfall is predominantly in the summer while in the south, it is somewhat 'non-seasonal'; remnants of tropical cyclones and thunderstorms associated with troughs can result in summer rainfall and the passage of cold fronts can result in winter rainfall. Typical of desert climates, rainfall is highly variable and long periods of drought are not uncommon. The summers are long and hot and winters cool and mild. Spinifex grasslands are generally structurally simple, with a discontinuous ground cover of *Trioda spp.* (spinifex) hummocks to a height of 25-50 cm. Scattered low shrubs, mallees and trees usually grow in association with spinifex (Burrows *et al.* 1991; Beard *et al.* 2013). Notable shrub, tree and mallee form genera sometimes associated with spinifex include *Eucalyptus*, *Corymbia*, *Allocasuarina*, *Acacia*, *Callitris*, *Hakea* and *Grevillea*.

The combination of accumulations of flammable vegetation, the physical structure of the hummocks and the often extreme fire weather conditions makes spinifex grasslands highly flammable (Griffin and Allan 1984; Burrows *et al.* 1991; Allan and Southgate 2002). Historically, lightning and deliberate burning by Aboriginal people were the main causes of fire. 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 (Burbidge 1944; Suijdendorp 1981; Griffin and Friedel 1984).

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 (Cane 2002; Davenport *et al.* 2005), 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 carnivores and competition with feral herbivores (Johnson 1988; Burbidge and McKenzie 1989; Morton 1990; Latz 1995; Gammage 2011). While knowledge of fire effects in hummock grasslands is incomplete, there is strong evidence of dramatically changed fire regimes in parts of the Gibson and Great Sandy 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 (Burrows and Christensen 1990; Allan and Southgate 2002; Bliege Bird *et al.* 2005; Burrows *et al.* 2006) over much of the spinifex grasslands.

1.1 Evidence of altered fire regimes

While there is considerable anecdotal evidence of changed fire regime following the departure of traditional Aboriginal burning in much of the spinifex grasslands (e.g., Bolton and Latz 1978; Latz and Griffin 1978; Latz 1995; Bowman *et al.* 1995), the most compelling and quantifiable evidence comes from a study linking oral evidence from Traditional Owners with relatively high resolution, good quality black and white aerial photography taken by the Australian / British military over a remote area of the Great Sandy and Gibson Deserts (west and south of Lake McKay) in 1953. At the time of photography, Aboriginal people were living a 'traditional lifestyle', more than a decade before

European contact (Davenport *et al.* 2005). Burrows and Christensen (1990) and Burrows *et al.* (2006) studied a sample of the aerial photography covering about 2,500 km^2 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 (Burrows *et al.* 2006). About 20% of the area was burnt by fires < 100 ha and ~36% by fires > 1 000 ha; the largest fire being about 6,000 ha. Burrows *et al.* concluded that 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. Aerial photography is a snapshot of a place at a time so caution is needed when extrapolating the fire patterns seen on the 1953 photos to other times and places. However, the early photographic evidence was entirely consistent with oral descriptions of traditional fire use (Burrows *et al.* 2006).

Plate 1: Early (1953), pre-contact aerial photography over the Great Sandy Desert clearly revealing fine scale Pintupi 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 /or the cessation of traditional burning from much of these lands. By the mid-1970s, some 15-20 years after the decline of traditional burning, 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 many orders of magnitude greater than the fires set under Aboriginal management.

As with the reported case study (Burrows *et al*. 2006) the fire regime in most of spinifex-dominated central Australia has changed from a stable pattern of numerous small, cool fires to an unstable pattern of large, hot 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. For example over the period 2000-2002, ~500,000 km^2 of spinifex grassland was burnt (Wright and Clarke 2007) and hot summer bushfires commonly exceed 200,000 ha (Haydon *et al*. 2000; Allan and Southgate 2003; Burrows *et al*. 2009). This 'boom and bust' fire regime is now largely driven by rainfall, which drives the rate of fuel accumulation (Griffin 1992; Allan and Southgate 2002; Murphy and Barr 2014), with lightning as the dominant ignition source, whereas for thousands of years, burning by people was a significant influence on the fire regime over much of the region.

While there has been work done on quantifying and documenting historical and contemporary fire patterns in the northern deserts (Gibson / Great and Little Sandy Deserts), little has been done in the Great Victoria Desert region of Western Australia. Therefore the overarching objective of this project is to better understand traditional Aboriginal (Anangu) burning patterns in the spinifex grasslands of the Great Victoria Desert (GVD), specifically the Spinifex Native Title Determination Area (Spinifex Lands) as a basis for informing contemporary fire management. The study attempts to reconstruct traditional burning patterns from the earliest aerial photography taken at a time when some Anangu were known to be living a 'traditional lifestyle'. The value of the aerial photography for understanding traditional burning practices depends on its timing in relation to the timing of the initial departure of Anangu and their burning practices from these lands. Using aerial photogrpahy to understand and quantify fire patterns was complemented by reviewing the literature and having some conversations with Anangu elders about traditional use of fire.

This project also aimed to compare and contrast traditional Anangu-induced fire patterns with the contemporary, lightning-induced fire patterns (2000-2016) reconstructed using Landsat satellite imagery. Knowledge of traditional fire patterns in the spinifex grasslands of the GVD, as well as being of cultural significance, can also inform contemporary fire management for ecosystem health and biodiversity outcomes.

2. Methods

2.1 Study site and target areas

The GVD, its location approximated by the GVD Interim Bioregionalisation of Australia (IBRA) (Figure 1) is characterised by sandplains and east-west trending dunefields. Vegetation cover is predominantly spinifex (*Triodia* spp.) often with an overstorey of scattered trees such as marble gum (*Eucalyptus gonglyocarpa*), mulga /wanari (*Acacia aneura*), yarltarrpa (*E. youngiana*) and Kingsmill's mallee (*E. kingsmillii*). Land tenure of most of the region is unallocated crown land, conservation reserves and Aboriginal land. The climate is arid with variable and unreliable rainfall. 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). By comparison, the mean rainfall for Warburton and Giles in the Gibson Desert to the north, is significantly higher at 259 mm and 292 mm respectively.

Following along the lines of earlier work in the Gibson Desert (Burrows and Christensen 1990; Burrows *et al*. 2006), the original intention was to acquire 1953 aerial photography (the earliest) associated with the Anglo-Australian military's Blue Streak Rocket project (BSR) to investigate traditional Anangu fire patterns. However, our research has shown that the Spinifex Lands, the area of interest for the current study, lies to the west and south of the BSR flight path corridor so was not photographed in 1953 (Figure 2). In addition, we discovered that only a relatively small section of the BSR flight path was actually photographed in 1953. This pertains to a remote area in the northern

Gibson Desert / southern Great Sandy Desert (Figures 2 and 3). This area was probabaly photographed for several reasons - firstly, at the time (1950s), it was the most remote part of the flight path corridor, inaccessible to vehicles; secondly, it was in the zone that rockets were likely to crash as they neared the end of their flight from Woomera. The military intended recovering crashed rockest, so probably required the photography to assist with this operation. Thirdly, the authorities attempted to remove Aboriginal people from the area for their safety (see Davenport *et al.* 2005), so needed the photos for planning and navigation. For these reasons, the 1953 BSR project aerial photography is not relevant to the current project, which aims to reconstruct traditional Aboriginal burning patterns in the Spinifex Lands of the GVD to the south and west of the BSR project. The earlierst (and only) aerial photography of the project area was flown in 1960/61.

Figure 1: Location of the Western Australian portion of the Great Victoria Desert (GVD) IBRA (map courtesty FloraBase, DBCA)
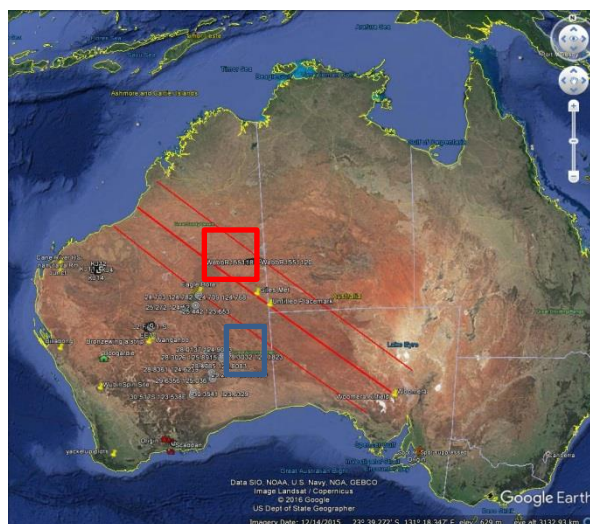

Figure 2: Approximate Blue Streak Rocket project flight path corridor (red lines), approximate location of BSR project 1953 aerial photgrpahy (red box) and approximate boundaries of Spinifex Lands (blue box).
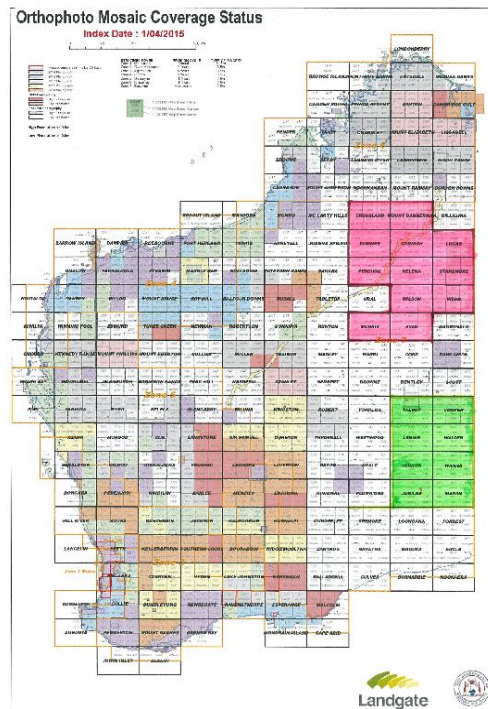
Figure 3: Map sheets covered by the 1953 aerial photography (pink) and map sheets covering the Spinifex Lands in the Great Victoria Desert (green), for which the earliest (and only) photography was flown in 1960/61.

A map of the areas of interest within the Spinifex Lands for interpretting aerial photos for evidence of traditional Anangu fire patterns is shown in Figure 4. These areas were chosen based on best available knowledge of where extant groups of Anangu were thought to be, either living a traditional or a transient traditional lifestyle – i.e., intermittently returning to country after visits to European-style communities and/or missions established in Western Australia (e.g. Cundeelee) and South Australia – in at least one case, this movement continued until 1986. While we were unable to obtain a detailed chronology of the pattern of displacement and depopulation of the GVD following contact with Europeans, the impression we have formed from the literature (Cane and Stanley1985; Cane 2002; Cane and Cane 2003) is that by the early 1960s, many, if not most, people had moved off, or were moved off, these lands to European-style communmities and missions, but a small number remained and others came and went at various intervals. No doubt that by the 1960s, there were fewer people living on these lands than was the case prior to European contact. It is not known exactly how many were extant at the time of the 1960/61 photography, and where they were, but fewer people obviously means less burning – this needs to be taken into account when analysing and interpreting fire patterns on the 1960/61 aerial photos. Information about where best to target our search for traditional burning patterns based on the 1960/61 photos was provided in confidence to us by Anangu (via Sam Doudle) and from the published literature (e.g., Cane 2002 and others cited above).

2.2 *Historical fire patterns from 1960/61 aerial photography*

It was cost prohibitive to acquire and process photography for the entire ~5.4 M ha of the Spinifex People Native Title area (more than 1,000 non-stereo, non-georeferenced photos). Depopulation by way of displacement, removal and migration of Anangu in the GVD commenced in the 1940s (and perhaps earlier) and accelerated into the 1950s, so it is likely that in the years prior to the aerial photography, only a few scattered groups remained. As described above, photography was acquired

over selected areas where people may have been just prior to (within a few years) the photography. The earliest (and only) aerial photography covering these areas was 1:49,000 scale black and white photography taken over the period 20/10/1960 – 27/4/1961. The areas shown in Figure 4 represent the most likely areas where traditional burning was still being practiced by some people in 1960/61 and for which aerial photography was acquired. This study area covers five map sheets; Waigen, Wanna, Jublee, Vernon and Mason (Table 1). Each map sheet covers an area of about 1.6 million hectares, so the area of interest totals about 8 million ha. It was beyond the resources of this study to acquire and analysise aerial photography of the entire area - each aerial photo covers about 5,670 ha, so to cover the area encompassed by the five map sheets as shown in Figure 4 would require about 1,410 photos. The area of interest was therefore further sub-sampled such that a total of 185 aerial photographs covering an area of ~1, 049, 222 ha (19.4% of Spinifex Lands) was used in analysis (see Table 1).

Map Sheet	Run	Number of photos
Waigen	9-12	32
Wanna	5-13	70
Jubilee	1-4	28
Vernon	16-18	23
Mason	2-6	32
	TOTAL	185

Table 1: Summary of 1960/61 black and white aerial photography (1:49,000 scale) acquired over the Spinifex Lands to reconstruct traditional burning patterns.

The photography was purchased in digital (scanned) format from Landgate and the individual photos were electronically merged or 'stiched' together by Ricky Van Dongen (Parks and Wildlife) to form a scale-rectified, georeferenced photo mosaic (Figure 4) suitable as a GIS layer. Two methods were used to identify fire scars. An autometd technique involved training software to recognise relatively recent 'fire scars' as evidenced by areas of burnt/denuded vegetation being lighter coloured than the surrounding unburnt vegetation. Areas such delineated were checked to ensure the feature was a fire scar (based on its shape and position) rather than some other feature. The second method, which was mostly used on fire scars that were older and so did not contrast as strongly with the surrounding unburnt vegetation, was to visually identify fire scars and manually digitise the perimeter. In this process, the clarity of the fire scar perimeter varied depending on the age of the scar (extent of post-fire recovery of the vegetation) and the age of the vegetation in which the most recent fire scar was embedded. In a GIS environment, a recent satellite image of the same scene underlaid the aerial photo mosaic to help with discerning fire scars from other features such as rock outcrops, lakes and other geological features or naturally sparesely vegetated features. Where there was doubt, the satellite image was turned on to check that the feature was a fire scar and not a 'permanent' feature. The following confidence ratings were allocated to each fire scar feature based on clarity of the feature and its perimeter:

Category 1 feature: Recently burnt, possibly within 3-5 years of photography. Strong contrast with surrounding unburnt vegetation, 100% of perimeter distinct, typical 'fire shape'. High level of confidence designating the feature as a fire scar and in defining its perimeter (see example Plate 1).

Category 2 feature: Possibly burnt 5-7 years prior to photography. Moderate to strong contrast with surrounding unburnt vegetation, 70-100% of perimeter distinct, remainder diffuse, mostly typical 'fire shape'. Moderate to high level of confidence designating the feature as a fire scar and in defining its perimeter.

<u>Category 3 feature</u>: Possibly burnt 8-12 years prior to photography. Low to moderate contrast with surrounding vegetation, 30-70% of perimeter distinct, remainder diffuse. Difficult to determine 'fire shape'. Low to moderate level of confidence designating the feature as a fire scar and in defining its perimeter.

There was a fourth category that was not mapped or digitised. A palimpsest of barely distinguishable, old fire scars was evident on many of the aerial photos, but because the scars were old with indistinct and often interlocking / overlapping perimeters, it was impossible to reliably map them. Having categorised and digitised the fire scar perimeters, the size (area) of each fire was able to be calculated.
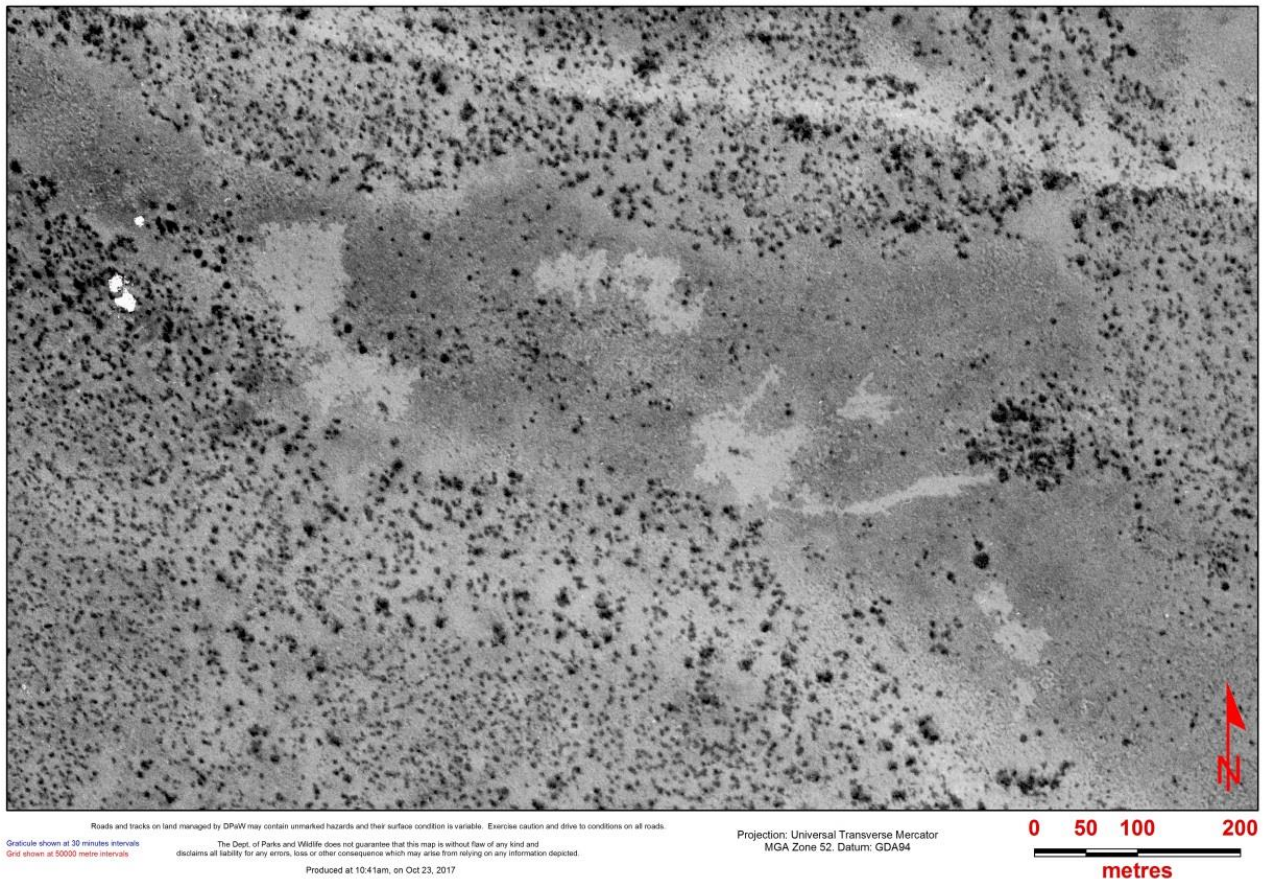
Plate 1: An example of category 1 fire scars on 1960/61 aerial photos (Vernon map sheet). These are probably Anangu hunting fires lit within three years or so of the photography. The fires at top left and top centre have been lit by dragging a firestick for 50-150 m. The small size and shape of the fires indicates they were low intensity 'cool' fires, lit under mild weather conditions (light winds) and probably light (young) fuels.
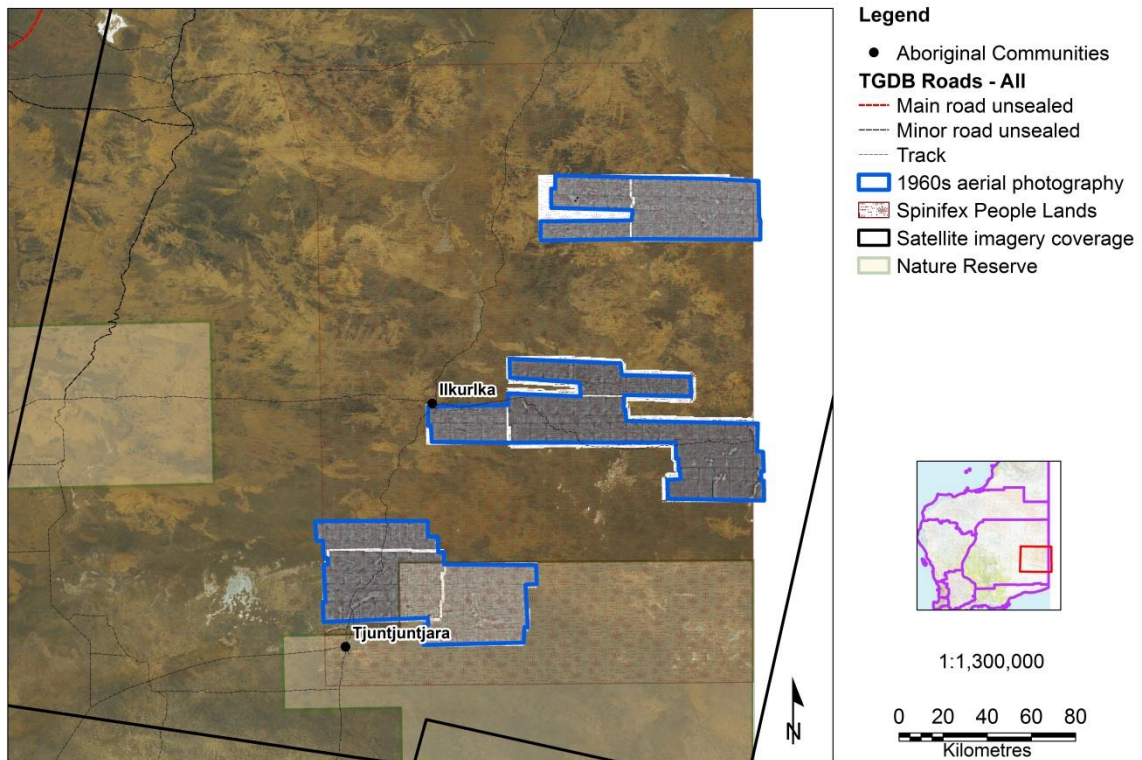
Figure 4: Area covered by 1960/61 aerial photography. Blue boxes indicate study focus areas where some Anangu may have been living at the time of the 1960/61 aerial photography.

2.3 Analysing recent fire patterns from satellite imagery

The Landsat satellite series has provided consistently captured imagery at 30 m ground resolution for the last 30 years and is available for download from the United States Geological Survey website (USGS 2018). With a 30 m spatial resolution, a single Landsat image (scene) covers approximately 170 kilometres by 183 kilometres. For the current study, satellite images comprising four Landsat scenes covered an area of ~12,879,615 ha portion of the GVD including the Spinifex Lands, for the period 2000 – 2016 were downloaded for the purpose of mapping 'scars' (denuded vegetation resulting from fires) over this period. There are four main steps to the fire scar mapping process using satellite imagery;

- Image processing
- Segmentation of the imagery
- Classify burnt area from segmented imagery
- Export and attribute the burnt areas.

Image processing

Carl and Benson (1999) found that the Normalised Burn Ratio (NBR) shown in equation (1) provided the best delineation between burnt vegetation (fire scars) and unburnt areas. This equation uses particular spectral bands of the Landsat 5 Thematic Mapper (TM) satellite imagery to enhance the visibility of burnt areas. Similar spectral bands in other satellite imagery can be successfully substituted into the NBR equation.

$$\frac{TM\ band\ 4 - TM\ band\ 7}{TM\ band\ 4 + TM\ band\ 7}$$

(1)

The equation for the NBR results in a single band satellite image with values from -1 to +1, where the fire scars have negative values. However, other features in the landscape that are not fire affected can also have negative values. To narrow down the number of features to which only fires occur in the period of interest we have used image differencing and created differenced Normalised Burn Ratio (dNBR) images. Image differencing is the subtraction of an image from another image of a different date to produce a change image. Figure 5 shows an example of a pre fire NBR; a post fire NBR; and the dNBR image. Some dark patches are fire scars, show in the red rectangle, with other darker areas representing changes in water levels shown in the blue ellipse.
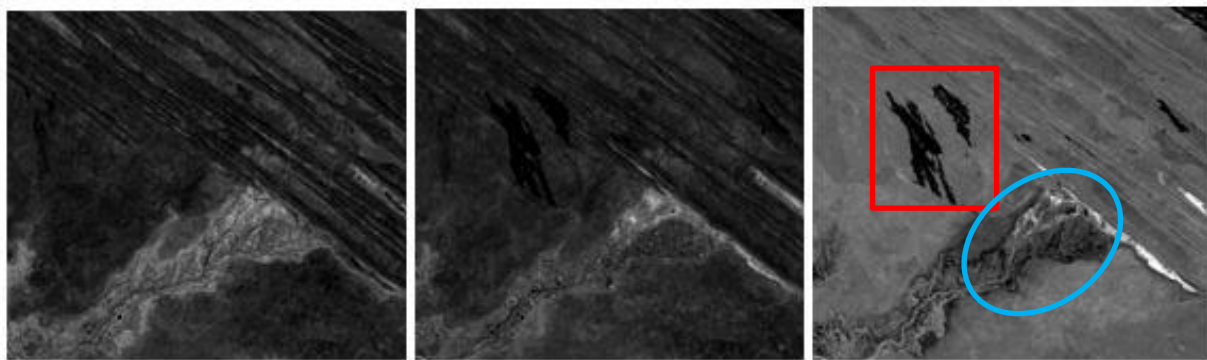
a)   b)   c)

Figure 5: a) pre fire NBR, b) post fire NBR, c) differenced NBR image; post fire image subtracted from pre fire image, resulting dark patches are fire scars and other changes in landscape.

Segmentation

Object based image analysis using eCognition (v9.3) software is used to group pixels which have similar spectral characteristics into individual objects (Trimble Geospatial 2018). In Figure 6 the segmentation algorithm has been run on the dNBR image and areas of similar pixel values are grouped together into "objects". Note the black areas of fire scar are neatly separated from the surrounding areas into distinct objects. Due to large spectral differences, the burnt area can then be classified from the surrounding objects using a value threshold.

Classification

Each object created by the segmentation step is attributed with a mean value based on the input dNBR image pixel values. By investigating the object mean dNBR values, the range of values for burnt areas can be determined. For example, in Figure 7 the burnt areas were classified with a threshold value of 'mean dNBR' < -16. This yielded good results and all burnt areas were classified, however other objects were incorrectly classified as burnt areas due to changes not caused by fire. For example, some parts of the drainage area were incorrectly classified, as between the two image dates the drainage area had dried out. Therefore, there is a manual component of all identified changes to attribute only those caused by fire (Figure 8). This decision is made with reference to false colour enhancements of the pre and post fire input satellite images.
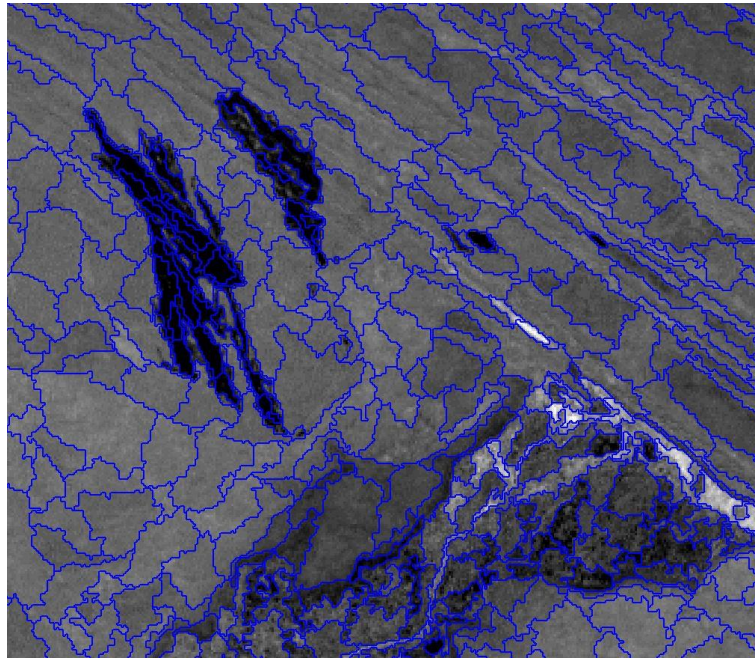
Figure 6: dNBR segmented into objects of similar spectral characteristics
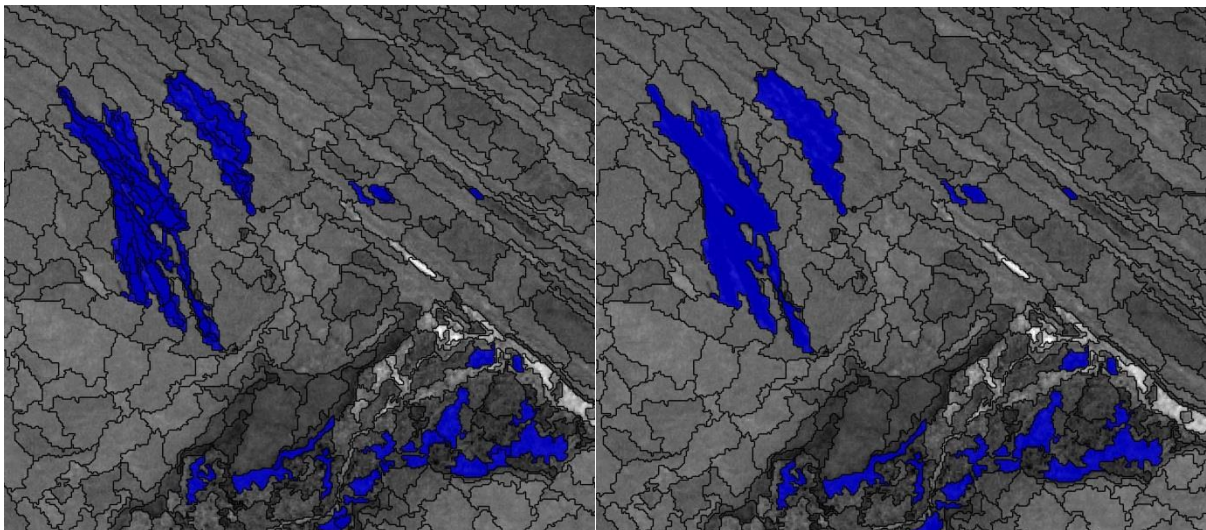
Figure 7: Left: objects which have been classified as change (blue) these were below a determined threshold value, right: merged single objects where change objects share a boundary.
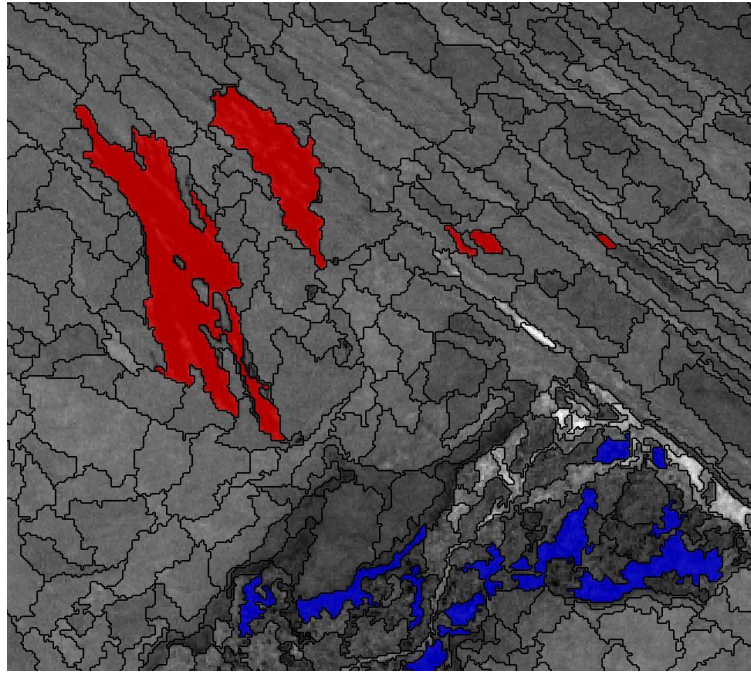
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Figure 8: Change objects that are manually attributed as burnt shown in red.

Export and attribute the burnt areas

Once the burnt areas have been classified into individual fire scar objects they are merged into a single vector and exported. The vector is then attributed in ArcMap 10.3 with the date and name of the satellite images used to identify the fire scar.

The accuracy of the fire scar mapping was validated in the field by vehicle traverse of the Anne Beadell Highway from Neale's Junction to ~30 km east of Ilkurlka, a distance of ~200 km. The position of all fire boundaries visually identified in the field were checked against the georeferenced map (on a Getac tablet) and all mapped fire boundaries intersected on the map were visually checked in the field. The satellite-based mapping proved to be very accurate both in terms of fire boundary position (±30 m) and the actual mapping of fire scars with the only discrepancies being small burnt and unburnt patches <0.09 ha being undetected/unmapped.

2.4 Oral evidence of traditional burning practices

We were unable to find much documented / published information about traditional Anangu burning practices in the GVD and what we did find was fairly general in nature. A consistent message was that Anangu did not appear to use fire to the same extent as other Western Desert people, perhaps best summarised by the following, " *While Anangu did historically burn within the park and the surrounding Great Victoria Desert, the practice was limited in extent and frequency''* (MCPBM 2011). We were unable to find solid evidence to support these conclusions and are interested to better understand why Anangu did not historically use fire to the same extent as people to the north, such as Martu, who used fire carefully and quite extensively for a myriad of reasons (e.g., Bird *et al*. 2005; Burrows *et al*. 2006).

We were able to obtain valuable information about traditional Anangu fire use from discussions with Anangu via video link (Samepage), and indirectly via Sam Doudle. The outcomes of these discussions are summarised in the Results section, but it is evident that, as with other Western Desert people who

live in a spinifex-dominated, flammable environment, fire played, and continues to play, a pivotal role in the physical and spiritual well-being of Anangu.

3. Results and discussion

3.1 Contemporary fire history from satellite imagery (2000-2016)

The 2000-2016 fire history map of the area of interest is shown in Figure 9. Of the total area (12,879, 615 ha), 5,412,595 ha (~42%) was burnt at least once over this period. (Note: The total area burnt shown in Table 1 (6,233,521ha) includes areas that were burnt more than once). The unburnt, or long unburnt areas in Figure 9 (7,467,020 M ha) included non-flammable features such as lakes and stony hills, non-flammable / low flammability vegetation types (sparse surface fuel cover), and flammable vegetation types that have, per chance, escaped fire over this period. Of particular interest is the large tract of country that remained unburnt in the south-east sector of the area (Figures 9 and 14). While no fires were detected in the general area over the sample period (2000-2016), faded fire scars indicate that large fires did occur prior to 2000. This is discussed later.
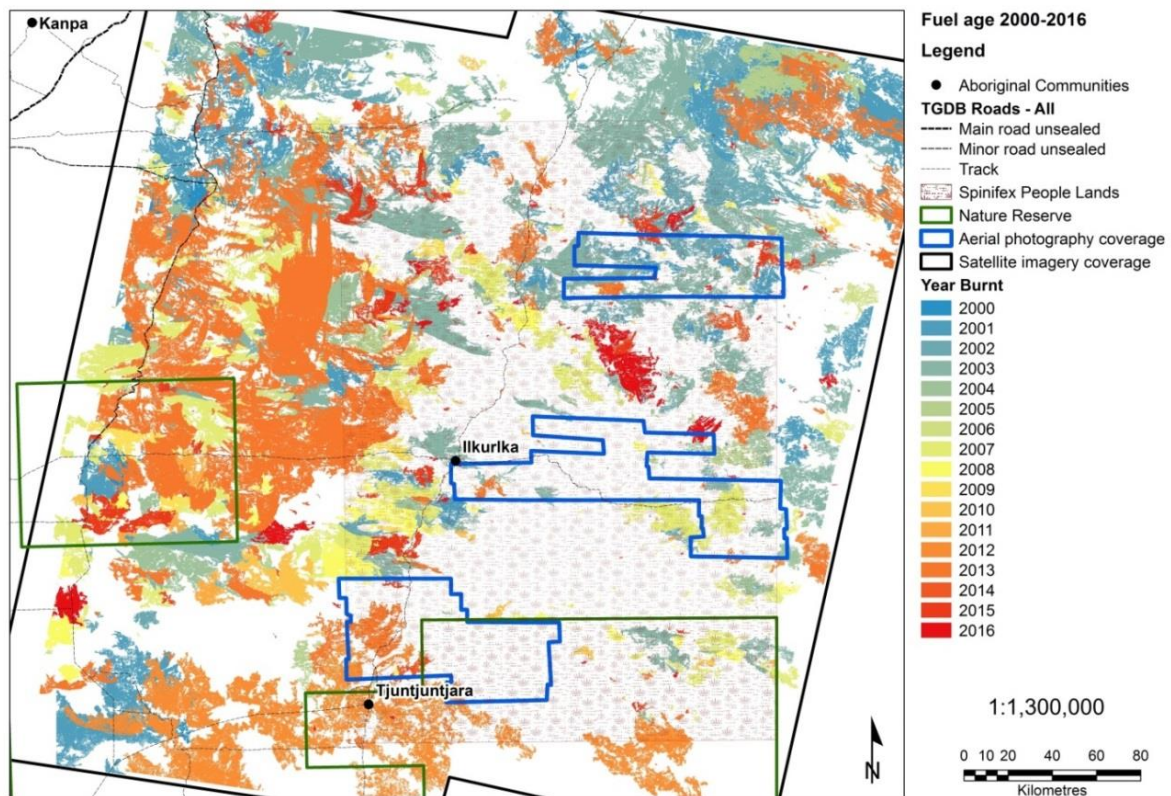

Figure 9: Fire history map 2000-2016. Blue boxes show areas for which 1960/61 aerial photography was acquired and analysed for fire scars.

While fires occurred somewhere in the landscape every year, the annual areal extent burnt was highly variable, ranging from 0.2% to 12.7% of the total area (including non-flammable elements), which is typical of fire-prone environments (Table 2 and Figure 10). In total, there were 1,685 fires detected, with a mean fire size of 3,699 ha. The within and between year variation in fire size and number of

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fires was, as to be expected, high as indicated by the standard error values (Table 2, Figures 11 and 12). The largest fire, which occurred in 2013, was a colossal 1,033,121 ha; fires as small as 0.09 ha (30 m x 30 m) were able to be detected and mapped. The cause of individual fires is uncertain but is obviously either lightning or humans – the large fires at the hotter time of year were most likely caused by lightning. The contemporary fire pattern in the GVD, one dominated by periods of very large hot season (spring and summer) bushfires, followed by periods of less fire activity on a more-or-less 10 year cycle, is typical of Australian's spinifex-dominated deserts since the displacement of Anangu and consequent cessation or diminishment of traditional burning practices.

The area burnt and the number of fires that occurred each year in the satellite study area are shown in Figures 10 and 11, illustrating the annual variability and somewhat cyclic nature of area burnt by wildfire associated with trends in antecedent rainfall and responses to historical fires. Usually 'big' fire years (large area burnt) in a region 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, which is primarily a function of rainfall and time since fire. This cycle has been variously referred to as a "boom and bust fire cycle" or a "wildfire cycle" (Burrows and Christensen 1990; Allan and Southgate 2002; Murphy and Barr 2014). While there were many small fires it was a few large fires that accounted for most of the area burnt each year.
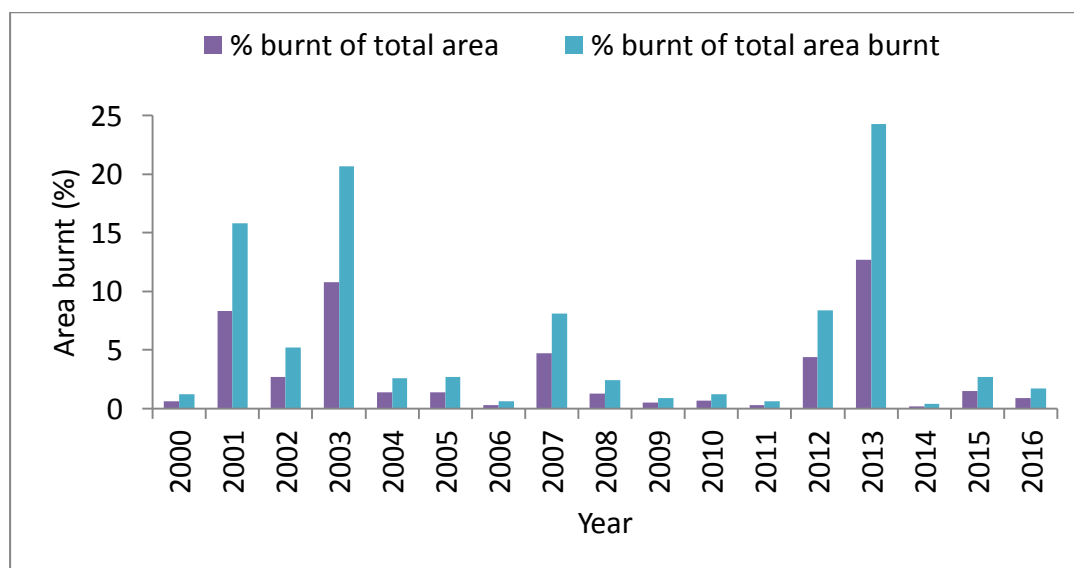

Figure 10: Annual area burnt (2000-2016) as a proportion of a) the total satellite study area (12,879,615 ha) including flammable and non-flammable habitats and b) the total area that was burnt at least once over the study period (5,412,595 ha).

The annual rainfall (where available) for the region over the period of interest is shown in Figure 13, and highlights the high year-to-year variability, a pattern similar to the area burnt each year; with a 2 - 3 year lag, periods of high rainfall are usually followed by large bushfires. As can be seen from Figure 13, rainfall was relatively high in 2016 and 2017, and if 2018 experiences above average rainfall, we can expect large bushfires in 2020-2022.

The fire frequency, or the number of times an area burnt over the period 2000-2016 is shown on the map in Figure 14. A large area (~58%) of the study site remained unburnt over this 17 year period, but faded fire scars in many of these areas are evident on the satellite imagery, indicating that much of this area was in fact burnt sometime prior to 2000. While most of the (flammable) area has only burnt once over this time, there is a significant area that burnt twice, and in the north-east corner, a small area that burnt three times. Such a high fire frequency is likely associated with the rapid growth of flammable soft grasses following good seasons. If these areas coincided with fire sensitive species such as mulga, then it is highly likely that such species have been depleted on these sites as the fire return interval is shorter than the juvenile period. Fire intervals lethal to mulga > ~26 years are required to sustain mulga populations (Ward *et al*. 2014). Having a soil-stored seed bank may have enabled mulga to persist under this regime, provided it was not sustained. The minimum fire return interval in spinifex grasslands in the absence of soft grass cover is about 5-10 years (depending on rainfall); the (primary) juvenile period of most spinifex species is about 3-6 years (depending on rainfall). Mulga in groves (as opposed to inter-grove) is able to persist in spinifex-dominated landscapes because spinifex cover in the groves is usually lower than the surrounding landscape, so a flammability differential exists and can operate to protect mulga groves from frequent fire, provided fires are not large and intense (more on this later).

Year	Min. fire size (ha)	Max. fire size (ha)	Mean fire size (s.e) (ha)	Total area burnt (ha)
2000	1.08	22,123	1,114 (416)	74,621
2001	1.30	319,601	7,886 (3,115)	98,5712
2002	1.17	138,758	2,087 (940)	325,598
2003	2.16	188,585	7,097 (1,713)	1,291,711
2004	2.07	43,138	1,299 (469)	162,401
2005	0.09	65,258	2,115 (993)	169,190
2006	4.36	9,379	860 (260)	38,716
2007	0.18	67,252	2,882 (603)	510,131
2008	0.09	27,700	1,167 (329)	154,049
2009	1.66	18,886	1,503 (602)	55,602
2010	0.18	42,557	1,458 (784)	80,200
2011	3.87	12,631	1,803 (771)	39,682
2012	0.90	422,305	17,016 (13,723)	527,498
2013	0.18	1,033,121	10,580 (7,265)	1,512,956
2014	2.38	9,963	761 (372)	25,097
2015	0.09	31,835	1,245 (341)	174,199
2016	0.18	40,938	786 (344)	106,158
All	0.09	1,033,121	3,699 (743)	6,233,521

Table 2: Summary statistics and metrics for fire scars derived from satellite imagery for the period 2000-2016 for the area shown in Figure 9 (s.e. = standard error).
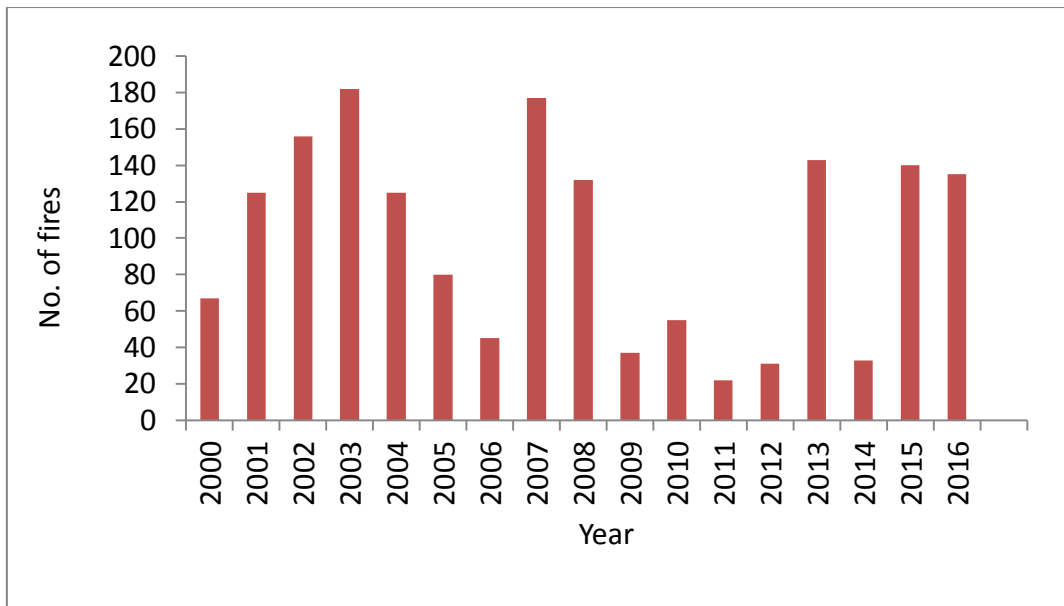
Figure 11: Number of fires per annum in the 12,879,615 ha area covered by satellite imagery over the period 2000-2016.
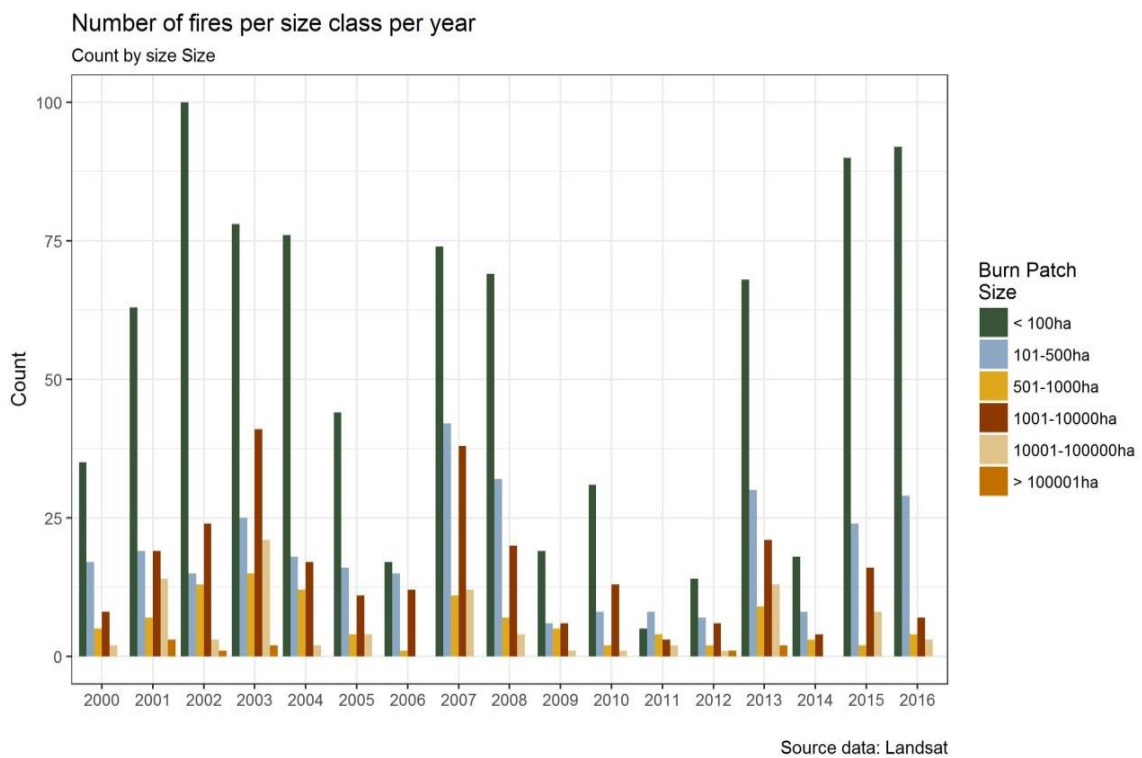

Figure 12: Number of fires by fire size class for the area covered by satellite imagery (2000-2016)
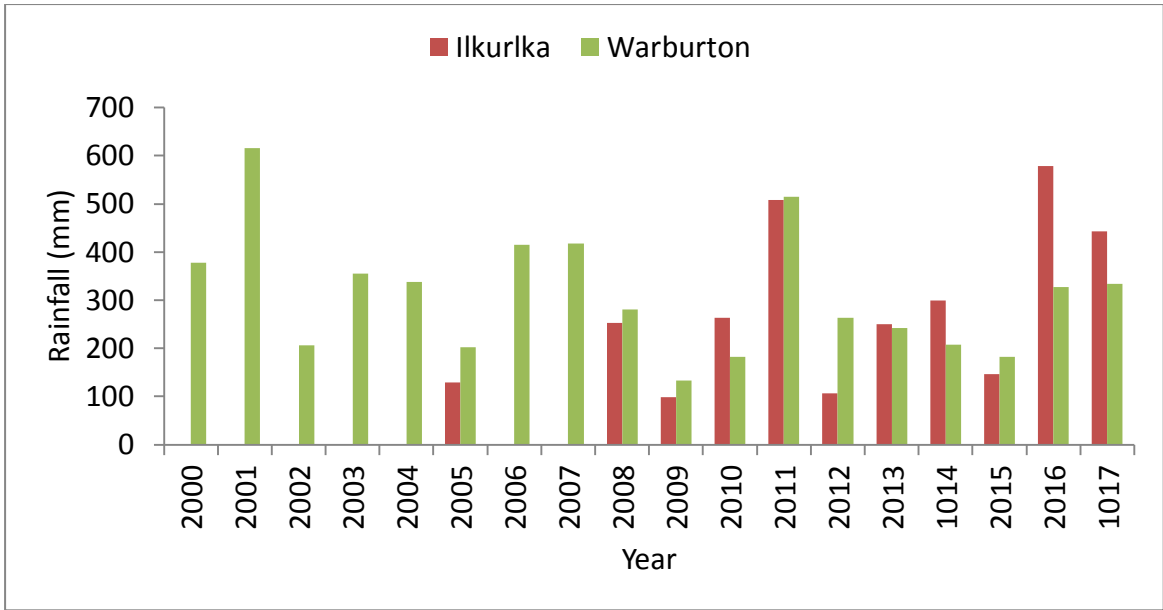
Figure 13: Annual rainfall for Ilkurlka and Warburton (~250 km NNW of Ilkurlka) 2000-2017(Source: Bureau of Meteorology Climate Data Online).
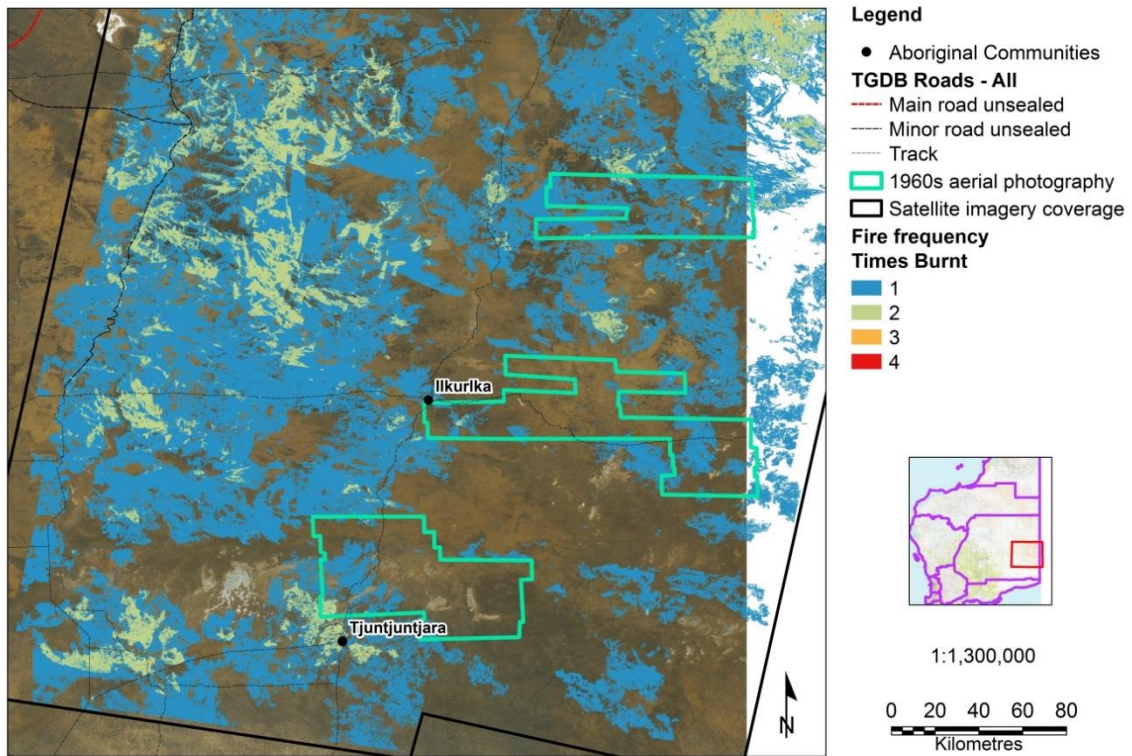

Figure 14: Fire frequency for the satellite coverage area (2000-2016). While the brown coloured areas were not burnt over this period, old fire scars pre-dating the satellite imagery are visible (paler brown) in most of these areas.

3.2 Contemporary (2000-2016) fire pattern in the area covered by 1960/61 aerial photography

Table 3 shows satellite-derived fire metrics for 2000-2016, but only for the area covered by the 1960/61 aerial photography (1,049,222 ha). The general trend is similar to the greater area covered by satellite imagery (12,879,615 ha), but because the photo area is considerably smaller, the statistics and fire metrics are commensurately lower. Also, the large scale of fires means that some fires were clipped to the photo area boundary, thus under-stating their actual size. However, there is also a 'flammability' differential between the satellite area and the photo area. The total area burnt over the period 2000-2016 in the photo area was 26.6% (of the photo area). This compares with 42.0% for the greater satellite area, and even higher if the photo area is excluded. The aerial photography is biased towards the southern and eastern portion of the satellite imagery coverage, which has experienced a significantly lower incidence of contemporary fire (2000-2016) than other areas covered by satellite imagery since. This is discussed later.

Year	Min. fire size (ha)	Max. fire size (ha)	Mean fire size (s.e.) (ha)	Total area burnt (ha)
2000	55	55	-	55
2001	3.9	11,851	1,941(1,025)	29,115
2002	2.7	16,778	2,602(1,491)	31,224
2003	2.5	27,190	3,481(1,397)	83,544
2004	2.1	2,499	409(209)	6,135
2005	0.09	4,852	774(590)	6192
2006	7.5	663	335(328)	670
2007	2.5	23,648	2,057(1,690)	28,798
2008	6.8	1,731	391(138)	6,256
2009	5.9	318	162(156)	324
2010	2.2	249	69(60)	276
2012	12.9	14,237	6,101(4,232)	18,303
2013	3.5	31,366	2,283(1,574)	45,660
2014	354.1	6,637	3,495(3,141)	6,990
2015	22.4	7,572	1,780(1,043)	12,460
2016	6.7	2,554	449(356)	3,143
All	0.09	31,366	1,837(390)	279,224

Table 3: statistics for satellite derived fire mapping from 2000 to 2016 across study area (data were clipped to extent of the 1960s aerial photography)(Note: values rounded to nearest 0.1 ha (min.), and 1 ha (other))
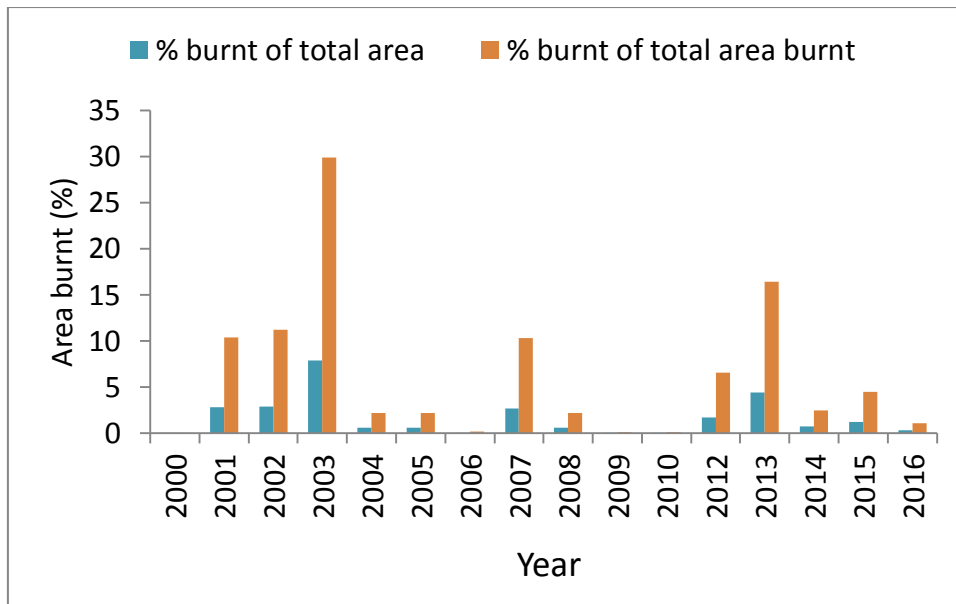
Figure 15: Annual area burnt (2000-2016) as a proportion of a) the total aerial photo study area (1,049,222 ha) including flammable and non-flammable habitats and b) the total area that was burnt at least once over the study period in the aerial photo area (279,153 ha) (derived from satellite imagery).
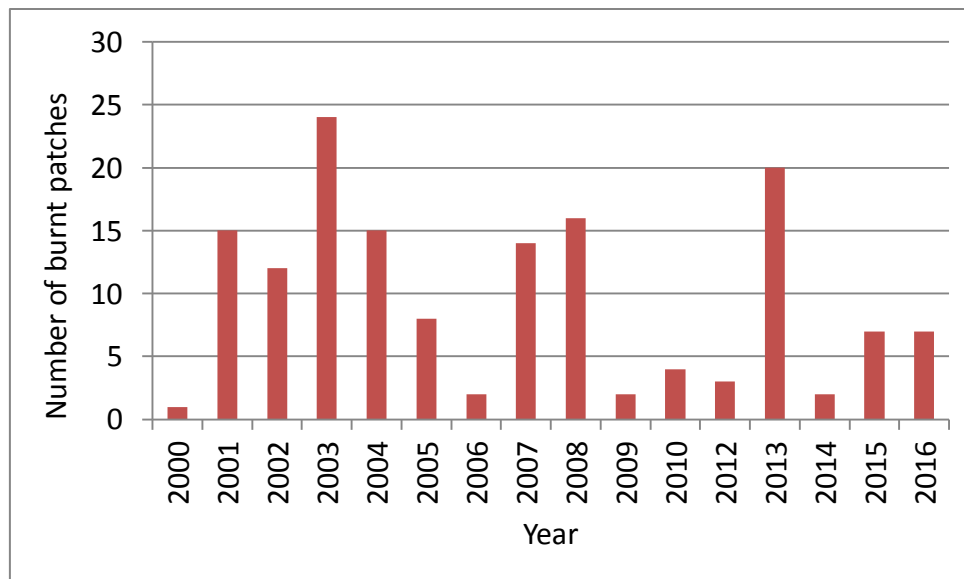

Figure 16: Number of fires per annum (2000-2016) in the 1,049,222 ha area covered by aerial photography (derived from satellite imagery).

3.3 Explaining large tracts of long unburnt country on the 2000-2016 imagery

We were curious about very large patches of country, primarily to the east and south of Ilkurlka, that had managed to stay long unburnt (apart from a few small fires), at least since 2000. There was also little evidence of recent fire (scars) in this area on the 1960/61 aerial photography. The tracts of long unburnt country were clearly exposed to ignition sources (lighting and possibly people) and were no

doubt challenged by fires in the surrounding more flammable country, but generally the fires did not burn far into these areas. As part of a field trip to the GVD in April-May 2018, we visually inspected sections of the long unburnt country from the Anne Beadell Highway and as far as about 30 km east of Ikurlka. On inspection, it became readily apparent as to why the areas, at least from what we could observe from the road, had remained long unburnt.

Plate 2 (L): Low fuel cover, height and load makes sustained fire spread difficult in this long unburnt tract of country east of Ilkurlka (~45 years since last fire). Plate 3 (R): Signs of past fire - partly occluded fire scar on a marble gum (E. gonglyocarpa) in a long unburnt tract of country east of Ilkurlka.
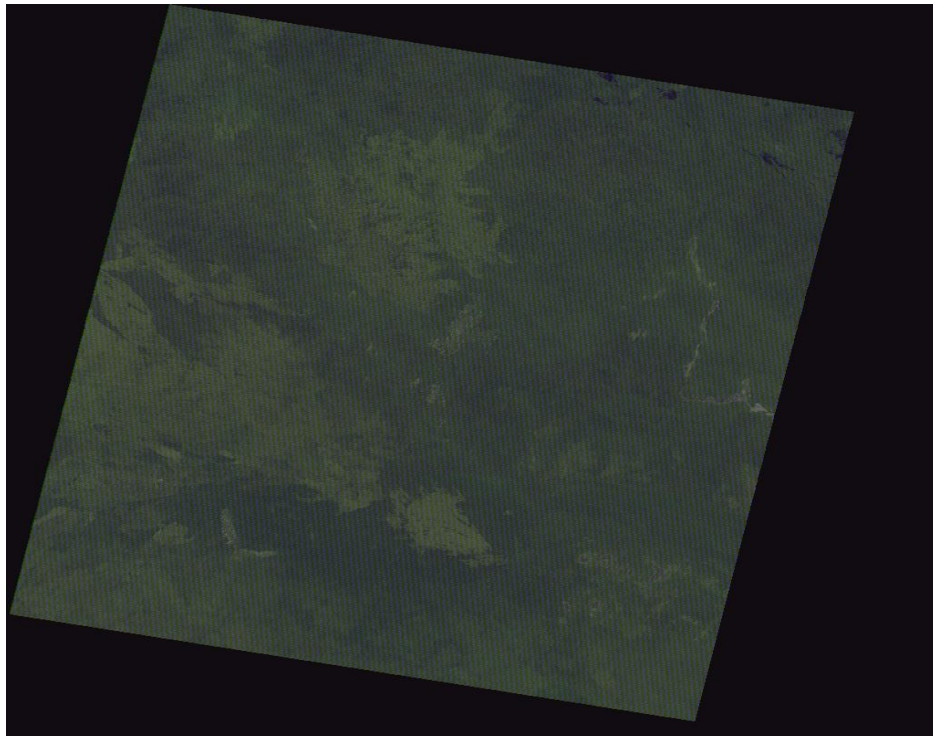
Figure 17: Large fire scars (pale shapes) in the area mapped as long unburnt on the 2000-2016 images (Fig. 9) east and south of Ilkurlka are evident in this July 1979 Landsat image. These fires probably occurred in the early to mid-1970s.

Our first task was to determine whether the area had burnt in relatively recent times, and if so, about how long ago. Cryptic signs of past fire included a partly occluded fire scar (hollowbutt) on a marble gum stem (Plate 3), small pieces of old and weathered charcoal on some stumps, tree hollows, stags and logs, and old fire-killed downed and decomposing mallee stems. These signs indicate that areas with spinifex ground cover had burnt, but some time ago. From these field indicators, together with the live stem diameter of mallees that had re-sprouted since the last fire, and the structure of the oldest spinifex plants, which had formed large interlocking crescents (Plate 2), we estimated the last fires in the area were in the early to mid-1970s, about 45 years ago. This estimate was later confirmed somewhat by inspecting a chrono-sequence of Landsat imagery back to 1979 - the earliest imagery we were able to obtain from the US Geological Survey website. The July 1979 imagery (Figure 17) clearly shows recent large fire scars some ~ 30-60 km east and south-east of Ilkurlka – most of the scars pre-date the 1979 imagery so this tract of land is at least 39 years old as at May 2018, and more likely about 45 years old, consistent with the field indicators.

Aside from 'chance events' and the foibles of spinifex fire behaviour, which can see long unburnt patches of otherwise flammable fuel retained in the landscape due to a wind shift, or an impediment to fire spread such as a dune crest or a road, there are two fundamental reasons why tracts of country in what is otherwise a fire-prone environment, remain long unburnt, or never burn. The first is they occur in 'fire shadows' such as in and around lakes or in other landscapes where there are natural barriers to fire spread, including sparsely vegetated landsystems, non-flammable vegetation such as chenopods, or within a mosaic of recently burnt ground, which reduces the potential for incoming fire. The second reason is that there is 'naturally' insufficient continuity of flammable vegetation to sustain fire spread, i.e., non-flammable or low surface / ground fuel levels usually due to edaphic factors. In the GVD, as with other fire-prone landscapes, both situations occur.

Ground or surface fuels such as soft grasses / dried herbage, leaf litter beneath eucalypts, and spinifex (mostly), form the base of the fuel ladder - there are isolated situations in Australian deserts where fire will spread through elevated (heath-like) fuels but the dominant fuel is grass, predominantly spinifex. Where the cover of surface fuels (spinifex) is sparse, less than about 25%, fire spread is unlikely to be sustained even under extreme fire weather conditions because flames can't sustainably bridge the gaps between fuel (spinifex clumps in this case) (Burrows *et al*. 2018). The long unburnt country we inspected east of Ilkurlka comprised a mosaic of mulga groves and mallee and marble gum over spinifex. As mentioned earlier, spinifex cover beneath mulga groves is usually sparse for two reasons; firstly, mulga groves (as opposed to inter-grove mulga) usually occur on soils with a slightly higher clay content than the surrounding sand plain – while this favours mulga, it disfavours spinifex growth. Secondly, spinifex cover is disadvantaged by an overstorey of mulga greater than about 20% canopy cover. This leads to a reduced cover of spinifex beneath the mulga, and associated low flammability (Burrows 2014).

Ephemeral soft grasses often establish beneath mulga groves, the flammability of which, when dry, depends on extent of cover. Throughout the GVD (and other Australian deserts) patches of unburnt or long unburnt country are often associated with groves of mulga or sparsely vegetated landforms. The long unburnt (~45 years) country that included a mosaic of mulga groves and mallee and marble gum over spinifex was characterised by sparse, low ground cover, old spinifex that had formed into large crescents. We (visually) estimated the ground cover of spinifex to be around 20%, higher in some patches, lower in others, characterising it as 'low flammability'. Visually estimating the cover of spinifex from a vehicle can be deceptive because of the oblique projection, and seed heads can give the appearance of 'dense' cover, so it is necessary to 'walk' the area and visually project downwards. Sustained fire spread in areas of such low spinifex cover is likely only in hot, windy conditions, however where cover is <20%, then fire spread is unlikely under any conditions. Spinifex cover increases post-fire, the rate at which depends on local edaphic factors and rainfall. Figure 13 contains data from samples throughout the GVD and shows how cover increases with age, but after about 30 years, it declines, reducing the flammability, hence reducing the potential for meadows to burn. The

long term ecological implications of sites drifting from a flammable status to low flammability, and associated long periods of fire exclusion are unknown.

Plate 3: Mulga groves on slightly heavier soils and suppressed spinifex growth allows mulga to persist in a flammable landscape provided fires are relatively small and low intensity ('cool'). Cool fires are unlikely to burn into the groves because of the low fuel cover therein, but large, intense hot fires can. Regular hot season bushfires are a threat to species like mulga and Callitris in the GVD. Reintroducing traditional burning patterns in the broader landscape will help protect these species by mitigating the severity (scale, intensity) of hot bushfires. (Photo: Neales Junction Nature Reserve).

$$y = -0.0452x^2 + 2.6744x + 14.691$$
$$R^2 = 0.4117$$
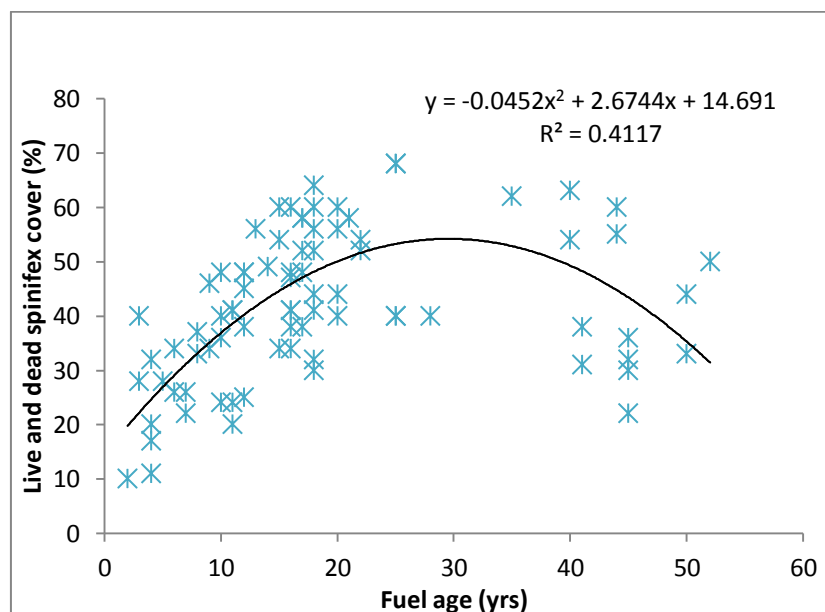
Figure 18: Relationship between time since fire and spinifex cover (flammability) for a range of sites throughout the Great Victoria Desert.

Plate 4: Fuel (spinifex) cover from 'eye' level can be deceptive. This looks like wall-to-wall spinifex, but the actual cover is 42% measured using a line transect method.

3.4 Fire patterns on the 1960/61 aerial photography

Being a snapshot in time, we don't have the same amount of data for the fire scar patterns from the 1960/61 photography as we have been able to present for the 17 years covered by satellite imagery. However, as evidenced by the figures below, there is a strong contrast between the fire patterns in 1960/61, and contemporary fire patterns – simply put, the size of the burnt patches has increased by several orders of magnitude and the area recently burnt is significantly less. For example, for the period 2000-2016, the mean and maximum fire size in the area covered by the aerial photography was 1,837 ha and 31,366 ha respectively - because fires have been clipped to fit this sample area, the actual sizes of the fires is greater than this.

For the entire area of satellite imagery analysed over the period 2000-2016, mean and maximum fire sizes were 3,699 ha and 1,033,121 ha respectively. The mean and maximum fire sizes measured on the 1960/61 aerial photography was 11.2 ha and 3,593 ha respectively; 98% of fires were <100 ha. Of the total area covered by the aerial photography, only about 2.1% was 'recently burnt'; it is not possible to reliably age the fire scars on the aerial photography beyond the 'clarity' categories described earlier.

We are confident that the numerous small burnt patches shown in Figures 19 and 20 are mostly the result of Anangu burning. Assuming all category (confidence) 3 features are fire scars, we detected 1,942 discrete, small burnt patches in a sample area of 1,049,222 ha (Table 4). By comparison, for the same area, we detected only 152 fires on the contemporary satellite imagery spanning 17 years.
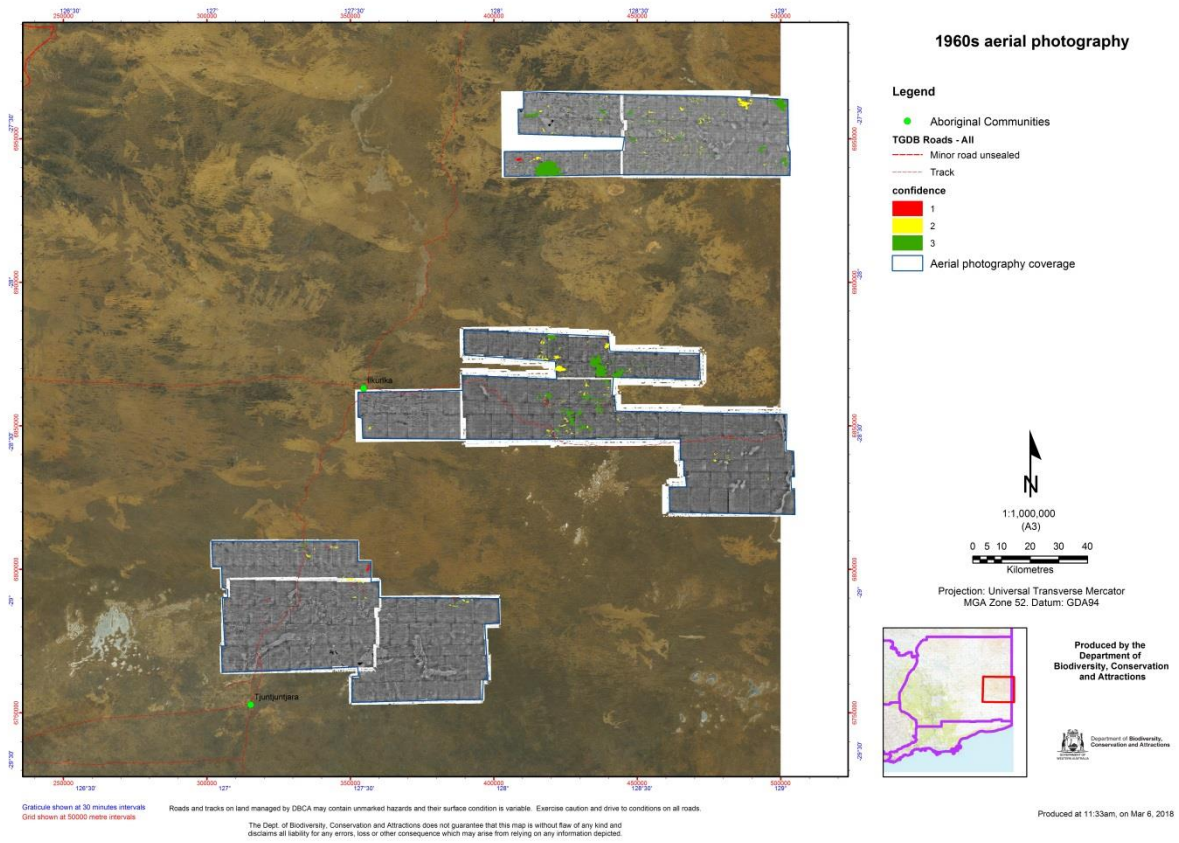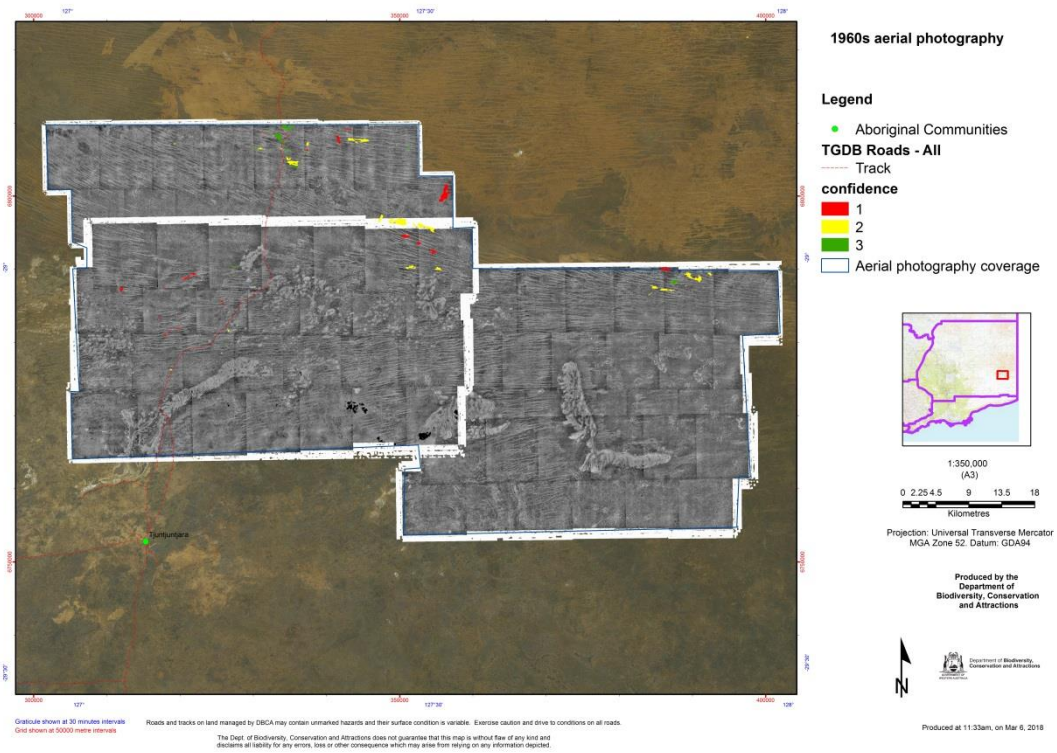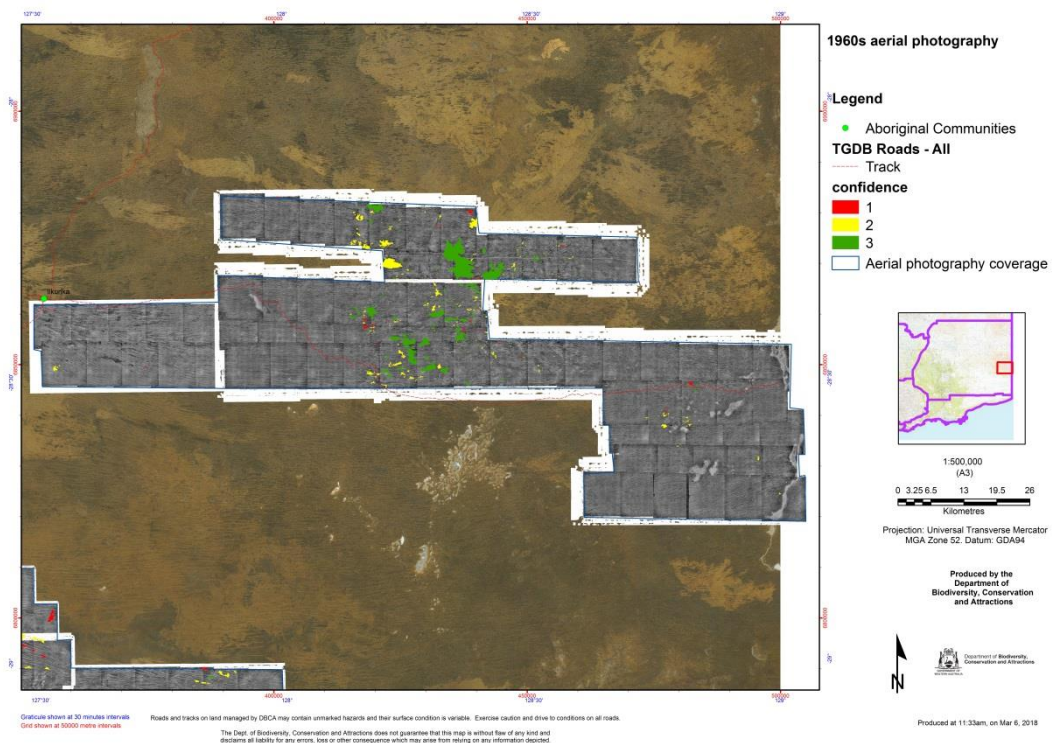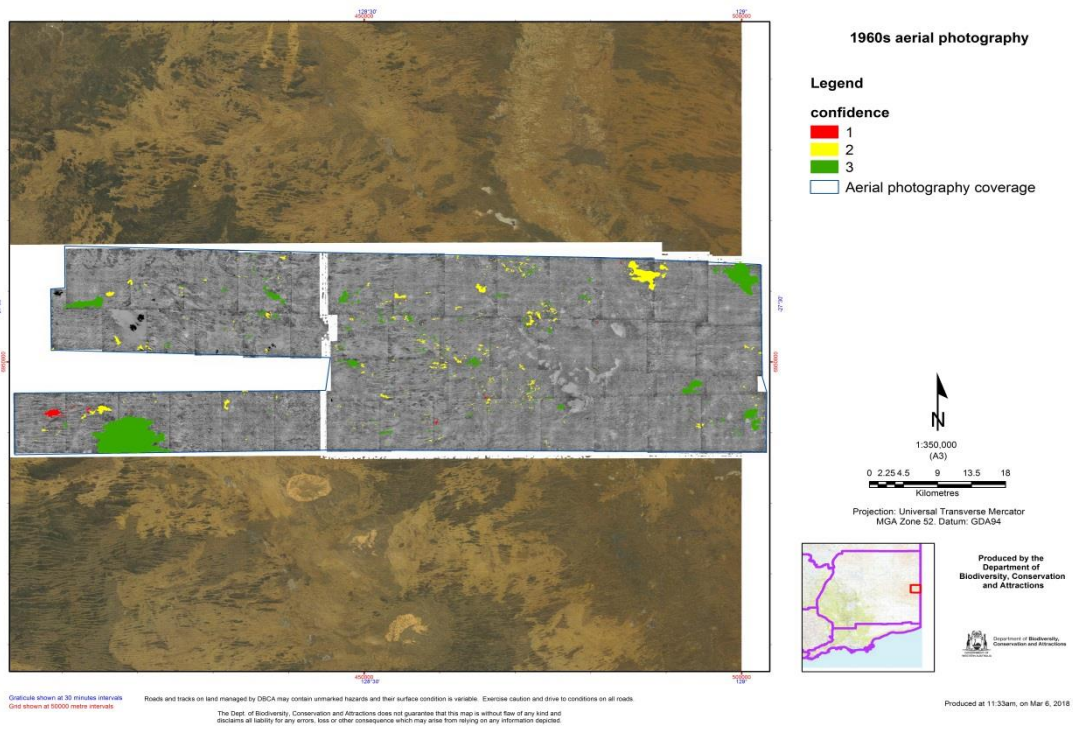
Figure 19: Overview of burnt patches on the 1960/61 aerial photgraphy.

Figures 20a,b,c: Burnt patches on the 1960/61 aerial photgraphy by map sheets.Size, shape and position in the lanscape typify classical Aboriginal burning patterns. Note the contrasting scale of the fires on the old photos and on the background satellite image.

Category	No. of fires	Min. fire size (ha)	Max. fire size (ha)	Mean fire size (s.e.) (ha)	Total area recently burnt (ha)
1	198	0.01	150	5.2 (1.1)	1,030
2	863	0.03	623	6.9 (1.1)	5,955
3	881	0.001	3,593	16.8 (5.2)	14,800
All categories	1942	0.001	3,593	11.2 (2.4)	21,750

Table 4: Statistics and some metrics of fire patterns evident on the 1960/61 aerial photography (rounded).

Rather than being more-or-less evenly distributed across the landscape, the 1960/61 fire patterns are somewhat clustered (Figure 20). This is probably a consequence of the low density of people extant in the region leading up to and around the time of the photography; as discussed above, by the 1950s and 60s, many people had moved, or were moved, into 'European' style settlements, missions, etc. The other noticeable feature on the photography is the lack of large fire scars – the largest being only 3,593 ha. A significantly higher pre-contact population in the region would have no doubt resulted in much more patch-burning, hence restricting the development of large fires. Work in the Gibson Desert showed that it took about 15 years for the fire regime to 'flip' following depopulation and cessation of traditional burning (Burrows *et al*. 2006). The fine scale of the fires indicates that burning was done with skill and a sound empirical knowledge of fire behaviour – people were able to control the size of the fires to some extent by understanding the fundamentals of fire behaviour (interactions between fire behaviour, vegetation (fuel) and weather, especially wind) learnt from generations of experience and observation. Almost all fires were set in dune swales, with the sparser fuels on dune crests used to contain the fires. It is also likely that fires were set under relatively mild fire weather conditions (cooler time of year). Fires lit under severe fire weather conditions, either by people or lightning, can become intense, fast spreading and large, especially in older fuels – dune crests do not stop fast spreading, high intensity head fires burning under strong winds.

The other factor that most likely contributed to fires being low intensity and 'controllable', was fuel age / structure. Burning young fuels results in lower intensity, more manageable fires because young fuels have lower ground cover, biomass and proportion of dead material. This suggests that, pre-contact, a significant proportion of the landscape was probably burnt relatively regularly, maintaining 'younger' fuels – less flammable vegetation types (as discussed above) would remain unburnt for longer periods. The result, over time, was probably a fine grain mosaic of vegetation of a variety of ages with most patches being in the younger fuel age classes. If this were not the case, that is, if fuels were old (heavier) over larger areas, we would have expected to see much larger fire scars in the aerial photography. Martu recognise, or have words for, five post-fire developmental stages of spinifex based on vegetation recovery and what each stage offers to Martu by way of resources (Bird *et al*. 2005). The oldest and apparently least productive stage refers to meadows that are older than about 12-20 years (depending on rainfall).

The spatial and temporal pattern of human ignitions and the resultant landscape-scale pattern of fire scars is a function of the population density, their mobility, travel routes, the regional extent of fuel coverage (seasons, edaphic factors) and the requirement or otherwise to use fire. No doubt some areas were not visited or not burnt for various reasons, but to protect these areas from fire, it may have been necessary to carry out some 'controlled' burning around these sites, as was done by Martu. While Aboriginal people may not have travelled to all parts of their country, their fires, and lightning fires,

would have unless the fuel levels in the broader landscape were relatively young and broken up as a result of recent burning, thereby restricting fire spread.

4.   Traditional use of fire

As discussed above, for various reasons we were unable to schedule field interviews with Traditional Owners regarding traditional use of fire. However Sam Doudle has been interacting with key elders / informants and has been able to pass on some information about traditional burning practices, and invited us to participate in the fire talk meeting via Samepage, for which we are grateful. In addition to learning 'first hand' (via Samepage link) from elders via the March 2018 Waru Wangka meeting (see below), we have also researched the available literature in relation to fire use by GVD Traditional Owners. While there are no published studies or observations dedicated to this subject, anthropologists and others make reference to it in a number of documents (e.g., Cane and Stanley 1985; Cane 2002; Cane and Cane 2003). From the published literature, it is clear that fire was (and is) an important tool for acquiring / promoting / protecting food and important sites, and is also important for ceremonial and ritual purposes. However, a consistent emergent theme from the literature is that fire was apparently used less in the GVD than in other areas of the Western Desert. A summary of knowledge from these sources is included below. I was amused by an anecdote related to me by Sam that sometimes fires were lit for fun. I heard similar stories when speaking with Pintupi and Martu (people further north) in the late 1980s, who informed me that children in particular occasionally lit fires for 'fun' – that's got to be better fun than playing on an iphone!

4.1 The following is cited from the literature (Cane and Stanley 1985; Cane 2002 and Cane and Cane 2003):

Where and why did people burn on Spinifex?
The individuals that made up the extended family group each had a 'range' where they had the right to live, hunt and gather. The range of an individual extended from where they first touched the earth after birth to where their umbilical cord fell off. An individual also had the right to live, hunt and gather in their mother's range. Therefore, a normal extended family group (probably made up of grandparents, adults and children) had a number of ranges available to them and lived primarily in a particular 'estate' (collection of ranges) depending on food resources and social events and cultural obligations. Individual ranges often overlapped or alternatively could be at some distance from the collective groups' most frequented part of their estate.

The most frequented ranges had a series of water sources on them – rockholes and soaks that the extended family groups rotated around.

A family would live, hunt and gather near a rockhole or soak until water or food resources ran out. While living in that general area, the men would use fire for hunting, e.g. to flush out game and for signalling where they were to those left back at camp. While hunting the men would also burn country in order to ensure that there would be fresh vegetation and therefore an abundance of animals for next time they visited. Women would use fire to flush out smaller game, e.g. tingka (goanna) and to cook maku (witchetty grubs) and other mai (bush vegetable foods).

Once the water and food resources became low, the family would then travel to the next water source in their range. As they travelled they would make fire to signal that they were coming (bush telephone), to clean up country that hadn't been burnt for a while, small fires to catch tingka (goanna), cook maku (witchetty grubs) and other mai (bush vegetable foods). At each evening camp along the way they would burn the area first to payantjaku snakes (banish them from that location) and sometimes chase away mamu (bad spirits).

When they arrived at the next water source there would new kuka (meat animals) and mai attracted by the new growth caused by the previous fires. Animals had also returned because there had been no human activity there for a while.

So within an estate there would be an endless cycle of walking between main water sources, with burning in a radius surrounding the main water source and burning along the path to the next water source. There were large areas in between where Anangu didn't go unless it was a very wet season or because it was culturally inappropriate.

Anangu were very careful to only burn in their own estates as it was bad protocol to burn someone else's estate. Anangu didn't burn at milmilpa (sacred sites).

4.2 From the Pila Nguru Waru Wangka (fire talk with Spinifex People, March 2018; notes by Sam Doudle).

Mr Rictor said that when they left (the Great Victoria Desert) in 1986, that is when the really big fires started.

Why were the fires smaller in the old days?
- *Not allowed to light big fires as might attract attention of raiding parties. If you did this you got into big trouble.*
- *Everyone took account of the weather before they burnt. They were never aiming to light big fires because they didn't want to burn other people's areas or burn other people.*
- *Also no need to light big fires to attract kuka (food animals) or to bring up food and medicine plants – small fires make it easier to hunt and gather food.*
- *Light small fires and bring kuka (food) to you rather than you walking after kuka for long distance.*
- *Small fires concentrate game, easier to hunt. Large fires would dissipate the 'game' or the 'attractant' affect that fire and post-fire regeneration has on foragers such as kipira (bustard), emu, and herbivores such as marlu (kangaroo) and more recently, rabbits).*
- *Fires kept small but picking right weather (wind) conditions and burning between the dunes (bare areas on dune crests stopped low intensity fires but not 'hot' fires).*

Who could use fire?
- *Everyone who was old enough to hunt – men and women.*
- *Children were left in the camp to look after babies and old people while others hunted, gathered food.*

Why burn?
- *To signal people – let them know where you were, or that you were coming into their country.*
- *To make it easier to find goanna holes, animal tracks.*
- *To flush out game*
- *Burrowing animals – pick a big spinifex and shove it into the entrance of a burrow and light it up – smoke out animals, easy to catch like foxes, dingos.*
- *Also for flushing cats out of hollow trees.*
- *To attract game – kuka comes in to feed on green pick after fire – marlu (kangaroo), kipira, emu, rabbit (today).*
- *To create small areas of fresh growth for food (and medicine) plants like bush tomatoes, quandong, acacia bushes that host witchety grubs (noongi)?*

How to light fires?
- *People always carried around fire sticks*

- *Witnessed a demonstration of how to make fire by rubbing sticks together*
- *Burnt all year round but not on hot windy days. Big fires no good.*

While far from exhaustive, the information we were able to glean about traditional fire use in the GVD is consistent with knowledge of fire use in other parts of the Western Desert (Jones 1969; Kimber 1983; Burrows and Christensen 1990; Bird *et al.* 2005; Burrows *et al.* 2006), which is unsurprising given the cultural and environmental similarities. Clearly, fire used deliberately and skilfully, was vital to the physical and spiritual well-being of people in the Great Victoria Desert. We suggest that pre-contact when there was a much higher population of people on country, the fine scale patch-burning would have been a much more common feature in spinifex-dominated landscapes than is revealed by the 1960/61 photography.

5. Fire management implications

The contemporary fire pattern / fire regime in much of the GVD is similar to other spinifex-dominated Australian deserts – that is, cycles of very large tracts of country burnt by intense spring / summer bushfires followed by periods of less fire activity - the cycle being largely driven by rainfall and lightning. This is in contrast with the fine-scale fire patterns established by traditional Anangu burning practices pre-contact – it could be argued that pre-historically, people through their careful and widespread use of fire 'controlled' the fire regime and consequent fire patterns to a large extent. Their patch-burning buffered landscapes against the 'boom and bust' fire cycles experienced today – with an understanding of fire behaviour, this is logical, but is has also been clearly demonstrated by contemporary Martu fire management based on traditional practices (Bliege-Bird *et al.* 2012). In the absence of adequate patch or buffer burning, large hot season bushfires will continue to occur in the GVD as long as there is fuel to burn. Patch burning, done at appropriate scales, won't prevent bushfires but it will reduce their size, frequency and impact.

We conclude that the fire regime in much of the GVD has changed significantly with the displacement of Anangu and their cultural practices, including their use of fire. What is uncertain is the regional or spatial extent to which this has occurred. Some argue that the fine scale mosaic created by Aboriginal burning only applied where people went – they burnt on their travel routes between water points for example. This sounds reasonable, but water points were / are quite ubiquitous throughout the Western Desert and usually no further than a few days walk apart. Also, and as mentioned above, while people may not have ventured into parts of the landscape for various reasons, if the landscape was flammable, then some of their fires, and lightning-caused fires, would have under certain fuel and weather conditions.

5.1 Implications for managing biodiversity in the GVD

How fire is managed in the spinifex-dominated landscapes of the GVD has important social, cultural and environmental implications. While scientific knowledge is incomplete (and always will be), what is certain is that in the absence of good proactive fire management, the 'bushfire cycle' will continue unabated. Is this condition desirable or undesirable? We argue unequivocally that it is socially, culturally and environmentally undesirable, and that good management is needed once again to *buffer* these landscapes from the adverse impacts of the current 'bushfire cycle'.

As this project was funded by the Great Victoria Desert Biodiversity Trust, we present a brief over-view of the role of fire in maintaining biodiversity and ecosystem health in spinifex grasslands generally, again acknowledging that scientific knowledge is incomplete.

Fire is a strong driver of biotic assemblages, which are not only important in their own right, but which have important cultural significance. As mentioned, scientific knowledge of the ways in which spinifex ecosystems and species respond to fire is incomplete, and consistent with an adaptive

management approach, contemporary fire management on these lands must draw on best available science, Aboriginal knowledge, and experience to provide best possible fire management outcomes aligned with the land manager's objectives. In desert ecosystems there are key feed-back loops involving fire, vegetation, biome productivity and rainfall. Antecedent rainfall drives vegetation growth, which results in increased fuel levels and increased potential for large hot fires (Griffin and Friedel 1984). Generally, periods of above average rainfall are followed by extensive fires due to the build-up of fuel cover (continuity) and load. Primarily through its influence on vegetation, rainfall also determines the quality of habitat available for animals, including cover, food and water resources, and nesting / breeding sites. On average, spinifex fuel in the Great Victoria Desert bioregion re-accumulates at ~0.55 t ha^{-1} annum^{-1} for the first 10-12 years post fire, then slows to about 0.15 t ha^{-1} annum^{-1} over the next 30 years (if unburnt), more-or-less stabilising around 7-8 t/ha. Some productive sites can carry much higher fuel loads but these are exceptional. On very long unburnt sites, spinifex fuel load and cover have been observed to decline.

Season of fire and post-fire rainfall will determine the composition, structure, biomass and rate of recovery of the vegetation (habitat) and its associated fauna. For example, Griffin and Friedel (1984) working near Alice Springs found that winter fires favoured forbes and caused less physical damage to woody shrubs and trees than summer fires, which favoured grasses, stimulated better regeneration of some woody species but damaged and felled many trees. Southgate and Carthew (2007) working in the Tanami reported that seed from post-fire ephemeral plants like *Yakirra australiense* are an important component of the diet of the bilby and that the season and amount of rainfall and time since fire were most important in determining regeneration of *Yakirra*.

Unlike sclerophyllous vegetation that dominates much of southern Australia, spinifex-dominated ecosystems tend to follow a *pseudo-classical* succession post-fire. In the early period, annual and biennial herbs and soft grasses often dominate cover and biomass, with spinifex and woody shrubs present as either very 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 unreliable and highly variable from year-to-year. This makes predicting post-fire response and fuel accumulation imprecise and indicative only (Burrows *et al*. 2009).

At various stages of post-fire development (seral states), the floristic composition and structure of the vegetation provides different habitat opportunities for a variety of organisms. Data gathered either retrospectively or longitudinally for a variety of terrestrial fauna (vertebrates and invertebrates) show a consistent pattern – that there is no specific or optimal seral state, or time after fire, that suits *all* organisms. Some functional groups prefer the early seral states, others the later seral states and some species occur in all seral states. This fundamental ecological principle of niche partitioning associated with diverse fire-induced habitats is the ecological basis for promoting the fine scale mosaic or patch burning over large scale bushfires. Pianka (1996), writing about the incredible richness of lizards in the GVD and Australian deserts generally noted that;

 "One of the most important factors contributing to this is fire, which generates a patchwork of habitats at different states 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".

Masters (1996) reported that a higher number of reptile species were trapped in mature spinifex and that fire mosaics maximise reptile diversity because of the preference by some species for earlier seral states. She also made the observation that recently burnt areas act as fire breaks and ensure that mature spinifex patches are always present. Langlands *et al.* (2006; 2012) studying the relationship

between fire and spiders on Matuwa (ex Lorna Glen) reported similar findings – that different spider assemblages preferred different post-fire states with about 50% of species restricted to a particular state. Similarly, Haydon *et al.* (2000) concluded that the patch-work of habitats at different stages of post-fire recovery (seral states) played a vital role in the conservation of biodiversity in desert landscapes. Smith and Morton (1990) studying scorpions in the Tanami Desert, found that one species (*Lychas alexanddrinus*) was caught most frequently 2-3 years after fire.

The relationship between patch-burning and small mammals is similar, but perhaps not as pronounced. Masters (1993) found that patch-burning spinifex grasslands to create a diversity of seral states maximised the species diversity of small mammals by ensuring that suitable successional states were always present. She concluded that this was particularly important for species that are restricted in their distribution such as mulgara (*Dasycercus cristicaudata)*. Letnic and Dickman (2005) working in the Simpson Desert found that while some species preferred long unburnt spinifex and others preferred regenerating spinifex, the greatest capture rates were made at sites that received most rainfall. Like Masters (1996), they concluded that recently burnt patches were an important part of the mosaic because they reduced the extent of bushfires. Partridge (2008) working in the Purnululu National Park concluded that small scale patchy spinifex fires were very important for *Pseudomys desertor* and *P. nanus*, which utilised long-unburnt patches for food and shelter.

However, interactions between fire and introduced predators can lead to flawed conclusions about habitat preference. For example, it was long thought that mulgara were *only* found in long unburnt spinifex. However, recent monitoring at Matuwa has shown that this species will inhabit recently burnt spinifex with low vegetation cover once introduced predators (foxes and cats) are reduced or eliminated, suggesting that the cover provided by longer unburnt spinifex is vital when introduced predators are present.

As mentioned, the co-occurrence of fire sensitive mulga (and its close relatives) groves and flammable spinifex is an apparent contradiction. Muller (2005) referred to this as a "conundrum" and suggested that the co-occurrence of old, mature mulga and younger spinifex was as a result of either a) spinifex recruiting in the absence of fire or b) low intensity fires that did not kill the mulga. It is also possible that on ex-pastoral leases grazing by sheep and cattle may have reduced fuel flammability, helping to exclude fires from these areas and allowing mulga to reach an old age (50+ years).

Nicholas *et al.* (2009) working in the Tanami Desert reported that soil properties (heavier soils and a cryptogamic soil crust) and fire frequency defined the partitioning of mulga groves. Burrows (2014) working in the Gibson and Great Sandy Deserts, reported that where relatively dense groves of mulga form on soils with slightly higher clay content (5-6%), the spinifex is noticeably suppressed; its ground cover is lower and therefore less likely to carry intense fire. Thus, a fuel flammability differential exists between mulga groves and the surrounding hummock grasslands on lighter soils. This flammability differential operates best under marginal or mild burning conditions, but dissipates under more severe burning conditions when fire is able to overcome fuel discontinuity and burn the mulga groves. Therefore, the groves are able to persist for periods longer than the fire interval in the surrounding landscape only if landscape fires are relatively small and low intensity rather than infrequent, large and intense.

It is neither desirable nor possible to exclude fire for very long periods (80+ years) where groves of mulga occur in flammable landscapes. Rather than attempting fire exclusion (which will eventually fail), or attempting to burn around the plethora of groves with convoluted boundaries, an alternative strategy to protect the groves is to reduce the likelihood of frequent, large, intense bushfires burning into them by creating and maintaining a 'bushfire buffered' landscape comprising a patchwork of spinifex at different seral states / fuel ages. This is best achieved by a strategy of landscape-scale low intensity patch-burning under mild weather conditions. This will not prevent bushfires, but it will significantly reduce their damage potential (scale and intensity).

The occurrence of inter-grove mulga, or scattered trees over a higher cover of spinifex, is more ephemeral and dynamic – it's a pulsing phenomenon, in time, appearing and disappearing across the landscape depending on inter-fire periods, regeneration success and subsequent rainfall.

Occasionally, and driven by soil properties, acacia shrublands comprising fire sensitive species such as mulga, sandalwood and others are embedded in the broader spinifex landscape. These patches are relatively small and are scattered throughout the landscape, depending on soil properties. Although small, in some landsystems they are quite numerous and an important part of the biodiversity of the region. On closer inspection, while there may be occasional dense spinifex patches beneath fire sensitive plants, it is mostly scattered clumps of heavier fuel separated by large bare soil patches. It would be difficult for fire to spread through these landscapes except under the most severe fuel and weather conditions. Even then, because of the patchy nature of the fuel, the fire is likely to be patchy. These ecosystems require and experience very long intervals between fires, and may even be fire independent.

Bliege Bird *et al*. (2012) working with Martu in the Great and Little Sandy Deserts reported that where contemporary Aborigines hunted with fire, usually within about 50 km of their settlements, the fires were smaller, more tightly clustered and importantly, remained small even when wet periods were followed by very large fires in areas beyond where Aboriginal people were actively burning. They demonstrated that Aboriginal patch burning does not prevent 'wildfires', but it significantly buffers the 'boom and bust' fire cycles associated with rainfall variation in the absence of Aboriginal burning. Furthermore, they proposed that the mitigating effect of Aboriginal hunting fires on large summer bushfires reduces the mortality on small mammal populations, promotes more rapid recolonisation and enhances their persistence in these landscapes.

As well as being implicated in the decline of medium-size arid zone mammals such as bilbies and mulgara, there is evidence that large and intense hot season bushfires are adversely impacting on fire sensitive plant communities associated with or adjacent to hummock grasslands, such as mulga and cypress pine (*Callitris* spp.) (e.g. Start 1986; Griffin *et al*. 1990; Bowman and Latz 1993; Latz 1995; van Leeuwen *et al*. 1995; Allan and Southgate 2002; Bowman *et al*. 2008; Marsden-Smedley *et al*. 2012; Ward *et al*. 2014). In addition to ecological and cultural consequences of altered fire regimes resulting from the reduction in anthropogenic burning following the displacement of Aboriginal people and their burning practices throughout most of the desert, there are likely to be significant environmental consequences, including increased greenhouse gas (GHG) emissions and a reduction in biosequestration associated with the contraction of mulga and other fire sensitive and potentially long-lived woody vegetation (Burrows *et al*. 2013). Therefore, appropriate fire management of the spinifex grasslands, including the broadscale re-introduction of the fire regime known to be in existence prior to European settlement and industrialization (the 'natural' fire regime), will have multiple environmental and ecological benefits. If it can be demonstrated that the 'natural' fire regime also reduces GHG emissions and increases biosequestration, then there may exist significant social and cultural benefits, including providing a culturally appropriate sustainable economic activity for remote desert Aboriginal communities.

6. Concluding remarks

There is compelling evidence that the fire regime in the GVD, as with other parts of the Western Desert, has changed dramatically following the depopulation of Aboriginal people from these lands and the associated decline in traditional burning practices. For thousands of years, people carefully and skilfully managed fire in these landscapes for their livelihood - the resultant fire regime, a fine grained mosaic of vegetation at different seral stages, ranging from recently burnt to long unburnt, with occasional larger wildfires, also benefitted biodiversity and the environment, or at least, the biota

'adjusted' to this regime. In the absence of people on country managing fire based on traditional burning practices, the cycle of large areas structurally homogenised by hot bushfires will continue, with ongoing insidious consequences for the environment and for biodiversity. The return to people managing fire, the right way, is fundamental to protecting biodiversity and building ecosystem resilience in the GVD.

Returning these vast landscapes to the pre-historical fire patterns will be challenging for land owners / managers, both Aboriginal and non-Aboriginal. However, there are also exciting opportunities. As well as being an important environmental factor, fire has important cultural significance to Aboriginal people and is a mechanism by which to maintain current and future generation's connection with country and with culture. The challenge lies in adequately resourcing land managers to carry out the enormous task of mitigating the adverse impacts of bushfires over such a large area. Notwithstanding the use of modern technology such as aircraft to carry out burning, it is unlikely that there will ever be adequate resources to manage fire across the entirety of one of the largest deserts in the world. This means systematically prioritising areas for appropriate fire management, based on the values at risk from bushfires, or on cultural imperatives.

Currently, federal and state government funding underpins management of Aboriginal and conservation lands in the GVD, with some support from the resources sector. Relying on these source of funding can be risky as governments cycle through periods of 'budget repair', which usually means cuts. In densely populated areas of the continent, bushfires can cause massive loss of human life and property, so fire and land management agencies are relatively well resourced to mitigate this threat. This is not the case in remote regions. Therefore, the longer term goal should be for self-funding, sustainable fire management that provides social, cultural, economic and environmental benefits. The carbon market may provide this opportunity. In addition to cultural and environmental benefits, reducing the area burnt by hot bushfires in the GVD will also reduce greenhouse gas emissions and increase carbon sequestration through greater retention of plant biomass (Burrows 2014). Into the future, this commodity (carbon) will be tradable. There is already a successful example of how this can operate in the West Arnhem Land Fire Abatement Project (Russell-Smith *et al*. 2009). Carbon-funded fire management in Australian deserts has also received recent attention by the Indigenous Desert Alliance group and a proof of concept funding proposal has been developed for funding via the Ten Deserts Project.

The last word to elder Mr Rictor:

"When we left in 1986, that's when the really big fires started". Mr Rictor , TjunTjunjara 2018.

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