Conservation Science W. Aust. 5 (3) : 272–284 (2006)

Evidence of altered fire regimes in the Western Desert region of Australia

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SUMMARY

The relatively recent exodus of Aboriginal people from parts of the Western Desert region of Australia has coincided with an alarming decline in native mammals and a contraction of some fire sensitive plant communities. Proposed causes of these changes, in what is an otherwise pristine environment, include an altered fire regime resulting from the departure of traditional Aboriginal burning, predation by introduced carnivores and competition with feral herbivores.

Under traditional law and custom, Aboriginal people inherit, exercise and bequeath customary responsibilities to manage their traditional country. Knowledge of the fire regime during an estimated 30 000 years of Aboriginal occupation of these lands and the involvement of Aboriginal communities in contemporary land management are important issues to be addressed if conservation lands are to be managed appropriately. As part of this process, Pintupi Aboriginal men were interviewed and observed in the field to obtain information about their traditional use of fire and to obtain their views on how country could be managed with fire. Of particular interest were the reasons for burning country and the temporal and spatial variation in the size and distribution of burnt patches. This valuable but largely qualitative oral information was supplemented with a quantitative study of fire scars in a chronological sequence of early black and white aerial photographs and more recent satellite imagery. The study focussed on a remote region of the Western Desert, an area from which Aboriginal people living a traditional lifestyle had most recently departed. The earliest aerial photographs (1953) were taken as part of a military rocket development project over an area that was occupied by Aboriginal people living in a traditional manner at the time of the photography. The photography revealed a landscape mosaic of small burnt patches of vegetation at different stages of post-fire succession. This pattern was consistent with information provided by Pintupi men; that fire was used purposefully, frequently and regularly across the landscape for many reasons but mainly to acquire food. Analysis of satellite imagery since the early 1970s, and since the cessation of traditional burning practices, revealed that the fine-grained fire mosaic has been obliterated in recent times and replaced by a simpler mosaic consisting of either vast tracts of long unburnt and senescing vegetation or vast tracts of vegetation burnt by lightning-caused wildfires.

INTRODUCTION

The Great Victoria, Gibson, Great Sandy and Little Sandy Deserts (the Western Desert) occupy some 1.6 million km^2 of Western Australia, of which more than 100 000 km^2 is managed for nature conservation. The conservation reserves in the Western Desert are large, remote and relatively undisturbed. A management option for such reserves is not to intervene and allow natural processes to continue to shape the biota. However, in spite of the apparent relative pristine nature of these reserves and the lack of direct European impact, a sudden and alarming decline in native mammals has been reported (Bolton & Latz 1978, Burbidge 1985, Burbidge *et al.* 1988, and Burbidge & McKenzie 1989). Burbidge and Jenkins (1984) reported that about 33 percent of Western Australian desert mammals are extinct or endangered. They noted that this decline had occurred over the last 30 to 50 years. Burbidge and McKenzie (1989) have shown that all declines and extinctions have been restricted to native mammals with a mean adult body weight in the range from 35 grams to 5 500 grams (the critical weight range). Three main hypotheses have been proposed to explain the decline and in some cases, extinction of desert mammals; change in fire regime, predation by feral animals and competition from feral herbivores (Burbidge & Johnson 1983). The notion of a changed fire regime contributing to mammal decline has some support among Western Desert Aborigines. For example, Ngaanyatjarra Aborigines from the Warburton area of Western Australia believe that the *mitika*, or burrowing bettong (*Bettongia lesueur*), had "gone to the sky because the country had not been cleaned up" (de Graaff 1976). "Clean up" is a term often used by desert Aborigines for burning the vegetation (Jones 1980). Kimber (1983) reported that Pintupi people believed that perhaps a "big bushfire" caused the disappearance of the golden bandicoot (*Isoodon auratus*).

Aborigines first arrived on the Australian continent at least 50 000 – 60 000 years ago and occupied the deserts of the interior by at least 30 000 years ago (Mulvaney 1975, Flood 1983, Gould 1971 & O'Connor

et al. 1998). They showed remarkable resilience and resourcefulness to survive in a vast expanse of scattered food and water resources (Tonkinson 1978). They were highly mobile, were able to exploit a variety of resources in different areas at different times and developed a detailed knowledge of the environment.

Recent changes in the fire regime are believed to be a direct consequence of the exodus of Aboriginal people from the desert to European settlements, missions, outstations and other communities (Gould 1971, de Graaf 1976, Latz & Griffin 1978, Kimber 1983, Saxon 1984 & Burbidge 1985). Latz and Griffin (1978) postulated that Aborigines created a stable ecosystem by "burning the country in a mosaic pattern". They believed that mosaic burning reduced the extent and continuity of heavy fuels, and therefore reduced the occurrence of large, intense wildfires. They also stated that a second effect of mosaic burning was to create a range of 'states' in the vegetation, from early post-fire plant communities to old mature patches and that such diversity of states would host a greater variety of plants and animals. Latz (1995) observed that many of the most important food plants are only abundant in the first few years after fire. He reported that of the twelve plants that are most important to desert Aborigines, five are "fire weeds".

The extensive use of fire by desert Aborigines was recorded by early explorers (e.g., Warburton 1875, Giles 1889 and Carnegie 1898) and more recently by anthropologists and ecologists (e.g., Finlayson 1943, Jones 1969, Calaby 1971, Gould 1971, de Graaf 1976, Tonkinson 1978, Kimber 1983, Latz 1995 and Bowman 1998). Kimber (1983) observed that Pintupi used fire in a skilful and controlled manner for many reasons, such as hunting, signalling, to "clean up" country, for ceremonies, and for fun. He provided a general description of when fires were lit and the range in fire sizes and also made some crude estimates of the proportion of country burnt and the approximate age since the last fire, based on information in the diaries of Davidson, who explored parts of the Tanami Desert in 1900. Latz (1995) noted that, "*the judicious use of fire* (by Aborigines) *was, in the past, the single most important aspect of the desert economy*". Recently Bird *et al.* (2003), working with Martu Aboriginal people of the Great Sandy Desert, have described and quantified the efficiency of burning as a hunting strategy and conclude that mosaic burning increases the efficiency of women hunting for burrowing game but not of men hunting larger, more mobile prey.

Quantitative data on past and present fire regimes are of considerable interest to managers of arid zone nature conservation reserves who aim to maintain and improve the biotic diversity of desert ecosystems. If the decline of native fauna is to be halted and faunal diversity restored, then active management is necessary to control introduced predators such as the fox (*Vulpes vulpes*) and the feral cat (*Felis catus*), to ensure a fire regime similar to that which persisted during traditional Aboriginal usage of the land and, where possible, to re-introduce locally extinct and endangered fauna. While there is a growing literature arguing that fire regimes in many Australian biomes have changed since the departure of traditional use of fire by Aborigines (e.g., see review by Bowman 1998), there is limited reliable quantitative information about the scale of this change in terms of the size and distribution of burnt patches.

This study aimed to document some of the ways in which Western Desert Aborigines used fire and to compare their oral evidence with fire scar information extracted from early black and white aerial photography. Importantly, this study aimed to quantify the scale of the fire mosaic created by traditional Aboriginal burning, and for the first time to our knowledge, present both quantifiable and oral evidence of a changed fire regime since a departure from traditional burning practices. By integrating these sources of evidence, and by studying a substantially larger area of the Western Desert (~240 000 ha), we build on the earlier work of Burrows and Christensen (1990), who studied aerial photographs and satellite imagery of a 54 000 ha area of the Western Desert. Knowledge of traditional Aboriginal burning practices, especially the scale of burnt patches, would greatly assist with the formulation of appropriate fire management strategies for desert conservation reserves. We comment on the benefits of not only incorporating Aboriginal knowledge into land management decisions, but of meaningfully involving Aboriginal communities in decision making and on-ground management activities.

METHODS

The departure of Aborigines from their desert homelands started with first European contact at the end of the nineteenth century. Amadio and Kimber (1988) present a summary of European exploration and contact with Aborigines of the northern portion of the Western Desert and also describe the movements of Aboriginal people away from their homelands and into European settlements.

To gather information about the traditional use of fire, we decided to focus the study on a region of the Western Desert from which Aborigines had most recently departed from a more-or-less traditional lifestyle. We learnt that a very remote tract of land in Western Australia north of the community of Kiwirrkurra and west of Lake Mackay in Western Australia was the last homeland utilized in a traditional manner by Pintupi people (Richard Kimber, Billy Nolan Tjapinati and Warlimpirringa Tjapaltjarri, pers. comm.).

This sparsely populated region lies on the eastern edge of the Great Sandy Desert between longitudes 127° 30' E and 128° 50' E and latitudes 22° 8' S and 22° 50' S. Annual rainfall is highly variable with the average being about 220 mm. Almost all rain comes from summer thunderstorms or occasional tropical cyclones. Summer maximum temperatures are consistently in the order of 35°–45° C, with winter maxima in the range 20°–25° C. The red sand plains that cover most of the region are

crossed by longitudinal, stable dunes, which trend east-west. Playas are scattered throughout the area, the largest playa being Lake Mackay, which has a total area of about 3 500 square kilometres (Blake 1977). As a result of the arid climate and sandy soils, the vegetation consists mainly of low hummock grasses, or spinifex (mainly *Triodia basedowii* and *T.schinzii*) and associated small shrubs, herbaceous plants and scattered low trees.

Spinifex forms the dominant ground cover (35%–40%) and the dominant source of fuel for a bushfire. Having fine, well-aerated leaves arranged in dome-shaped clumps, fire spreads rapidly through spinifex, especially under warm, dry and windy conditions (Griffin & Allan 1984, Burrows *et al.* 1991). The vegetation of the region displays a range of traits enabling it to persist in this fire prone environment, including the ability to resprout or regenerate from seed following fire (Latz 1995, Allan & Southgate 2002). The rate of post-fire recovery of the vegetation is largely dependent on rainfall, with a variety of short-lived grasses and herbs dominant in the early years, giving way to spinifex which resumes dominance (cover and biomass) by about 2–4 years after fire (Latz 1995 and Allan & Southgate 2002).

To the best of our knowledge, the main exodus of Pintupi from this region commenced in the early 1960s, with the last of the bush people coming into Wulungurru

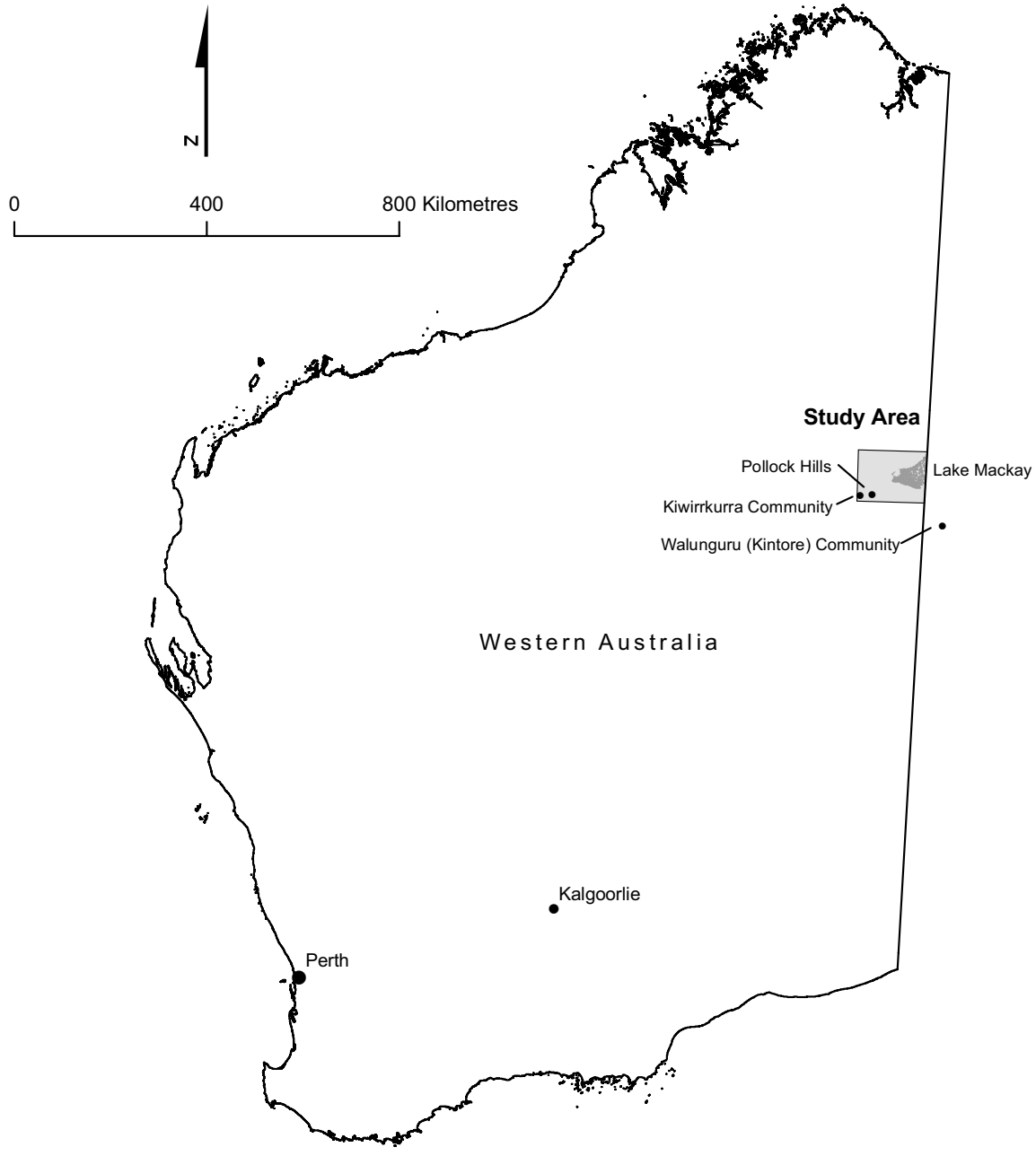

Figure 1. Location of the Aboriginal use of fire study area in the Western Desert.

(Kintore) and Kiwirrkurra communities in 1985. We interviewed men from the Kiwirrkurra-Kintore-Lake Mackay area (Figure 1) about their use of fire in the "old days". We compared this oral evidence with the quantitative data on temporal changes in fire size and distribution extracted from early aerial photographs and more recent satellite imagery, substantially increasing the size of the area studied by Burrows and Christensen (1990) to more than 240 000 ha; their original study area being about 54 000 ha.

Traditional Aboriginal Use of Fire: Oral Evidence

During August 1987, two of the authors (Andrew Burbidge and Phil Fuller) travelled to the remote desert Aboriginal communities of Mt Leibig, Walungurru (Kintore) and Kiwirrkurra (Figure 1) to talk to older Pintupi men and women about their traditional use of fire, especially bush fire. At this time, many people in this area had only recently come in contact with European society so retained a profound knowledge of their traditional lifestyle. In most cases, groups of people were interviewed at various communities. The individuals in the groups were older people who were willing to be interviewed and who had lived as nomads for a significant part of their lives. The groups of people interviewed were:

Group 1: 1 man interviewed at Mt Leibig.
Group 2: 3 women interviewed at Mt Leibig.
Group 3: 2 men interviewed at Walungurru.
Group 4: 3 men interviewed at Walungurru.
Group 5: several people (number not recorded) interviewed at Walungurru.
Group 6: 6 women interviewed at Walungurru.
Group 7: 2 women interviewed at Walungurru.
Group 8: 4 men interviewed at Kiwirrkurra

The interviews were conducted with the aid of a Pintupi linguist, John Heffernan. We experienced some difficulty obtaining interviews because of two local events that coincided with our visit. Many people had left the community to attend a sports meeting at Yuendumu, a community across the Western Australian border in the Northern Territory. Of much greater significance was the initiation ceremony being conducted at Kiwirrkurra, involving many of the knowledgeable old people with whom we wished to talk. We were not permitted to move about the area freely during the ceremony, which continued for several days. Eventually, we managed to conduct nine interviews with people recognised by the communities as knowledgeable and able to speak on the issue. As well as fire, we talked about the local mammals. We displayed the skins (obtained from the Western Australian Museum) of a number of mammals now locally or totally extinct. This proved a popular draw card with Aborigines and was a useful means of initiating more interviews and obtaining additional information about the animals and about fire. In September 1989, one of us (Neil Burrows) also spent seven days in a remote part of the Great Sandy Desert west of Lake McKay with Billy Nolan Tjapinati, a Pitjantjarra elder, and Warlimpirringa Tjapaltjarri, a Pintupi man who was one of a small group of people to recently emerge from this area, making first contact with Europeans in 1985. During the field trip we discussed how and why fire was used, visited sites where fire was used to hunt feral cats (*Felis catus*) and other game, and observed the two Aboriginal men regularly "cleaning up country" by burning the spinifex.

Fire size and distribution: Remotely sensed evidence

We expanded on an earlier study by Burrows and Christensen (1990) who used early (1953) aerial photography and Landsat satellite imagery to map fire scars and to quantify the size and spatial distribution of burnt patches. They examined imagery that covered an area of some 54 000 ha west of Lake Mackay (Figure 1). This region was chosen for study because it was known to be one of the last areas in which traditional Aboriginal burning was practiced. While the exodus of Pintupi from a traditional lifestyle to European-style settlements probably began in the early 1960s, the last people (including one of our informants Warlimpirringa Tjapaltjarri), to lead a traditional lifestyle without European influence, emerged from this part of the Great Sandy Desert in 1985. As part of a military rocket research project by the Australian and British governments (the Blue Streak Rocket Project) the flight path of the rockets was mapped from low level (1:50 000) black and white aerial photography flown by the Royal Australian Air Force in July 1953. This coincidence of events provided a unique opportunity to investigate traditional Aboriginal burning practices, combining first hand Aboriginal knowledge and aerial photography. We substantially extended the original study by Burrows and Christensen (1990) by selecting a second sample area of about 80 km x 30 km (about 240 000 ha) some 80 km south-west of their original site.

Pereira (2003) identified many difficulties associated with mapping burned areas in tropical savannas using remotely sensed data, in particular, satellite imagery. These include short persistence of burn signals, heterogeneity of landform and vegetation, structural complexity of the vegetation and smoke haze and cloud cover. Bowman *et al.* (2003) reported that in tropical savannas in the Northern Territory, signatures of burnt areas faded within 100 days. However, visually identifying and mapping recent fire scars (up to 5–6 years since fire) in arid zone spinifex grasslands from aerial photographs or satellite imagery is relatively straightforward compared with some other vegetation types because:

- The vegetation is low (20–50 cm high) and simple in structure (ground cover only, little or no overstorey).
- Combustion of the vegetation is virtually complete, revealing the surface soil, the signature of which contrasts strongly with the unburnt vegetation,

- The red sandy loam soil is the dominant reflector post-fire, and is relatively uniform in colour and texture over large areas.
- Fire shapes in hummock grasslands are distinctive and are not readily confused with natural features such as changing vegetation types, surface geology or landforms.
- The rate of post-fire recovery of the perennial vegetation is relatively slow, with fire scars being visible for at least 5–6 years, and often longer during drought periods.
- There are few cloudy days.

We circumscribed (mapped) the boundaries of fire scars that were clearly visible on the 1:50 000 scale 1953 aerial photography and on a time sequence of relatively high resolution Landsat Multispectral Scanner (MSS) for 1973, 1981 and Landsat Thematic Mapper (TM)) for 1988, 1994 and 2000 satellite images. Satellite imagery only became available after the launch of the Landsat 1 satellite in July 1972. This time series of satellite imagery was a compromise between what we considered as adequate for detecting fire scars on the study area over this time frame and the cost of purchasing and processing images. The aerial photography provided a high level of resolution and we were confident of visually discriminating recently burnt patches larger than about 0.5 ha (approximately 70m x 70m). Landsat MSS imagery was processed to have a picture element (pixel) resolution of 50m and Landsat TM processed to a pixel resolution of 25m. Landsat MSS imagery was enhanced to display spectral band 3 (visible red), band 4 (near infared) and band 2 (visible green) in the red, green and blue colours respectively while Landsat TM (Landsat 5 and 7) was enhanced by displaying spectral band 5 (middle infared), band 4 (near infared) and band 3 (visible red) in the red, green and blue colours respectively. Landsat TM provided the greatest visual discrimination of recent fire scars in this landscape.

Because fire scars in this landscape remain clearly discernable on satellite imagery for at least 5–6 years, it was not necessary to use more complex mapping and processing techniques such as using difference thresholds between successive images, as described by Yates and Russell-Smith (2003). Ground truthing by deliberately burning different, known size patches of spinifex prior to acquiring satellite imagery (Landsat 5 MSS) of a test site showed that we were able to readily visually recognise fire scars larger than about 1 ha. We used a similar method of mapping and digitising fire scars to Burrows and Christensen (1990). Fire scars were mapped to a common, rectified base-map at a scale of 1: 50 000 with natural features such as small claypans and sand dunes mapped and used as control points. If the entire fire boundary was not readily discernible, then the fire scar was not mapped. Therefore, only relatively recent fire scars (probably up to 5–6 years since the fire) were mapped. Older fire scars were visible, but boundaries became diffuse as the vegetation recovered. However, the boundaries of some fire scars were still discernable on consecutive Landsat images up to 8 years apart. The 1981 Landsat imagery was difficult to interpret because several very large and often overlapping fires had burned almost the entire study area in the previous 10 years. While recently burnt vegetation was obvious, it was difficult to distinguish the boundaries of individual fires.

RESULTS

Oral evidence of the traditional use of fire

Not surprisingly, fire was an integral part of traditional Aboriginal life, as exemplified by the following summary of fire related Pintupi words and meanings (see Burbidge *et al.* (1988) for orthography):

waru is universally and commonly used for fire, firewood, and heat.

kunparatji is close relationship speech for *waru*.

kurrkalpi, *malarra*, and *kinparitji* are words for cooking fire.

tjangi is a firestick used for setting fire.

puyu is smoke.

kunarurru is a signalling fire in the distance (also a distant smoke plume or haze).

tili is flame.

tilirninpa is to make fire. Both men and women were able to make fire, although the implements used were different. Men used a *mirru* (spear thrower made from a hard wood such as mulga, *Acacia anuera*) on a piece of soft wood, often a *kurtitji* (a shield made from *Erythrina vespertilio* wood.) The verb for this is *patjipunginpa*. Women used a fire drill. Both sexes commonly carried fire sticks.

nyaru is the word most commonly used to describe the practice of burning off country. *Lunta* and *yarrpara* are synonyms. *Nyaruninpa* is the verb.

Pintupi people often referred to "cleaning up country" with fire. We did not fully understand what was meant by this but took it to mean a combination of clearing the ground to facilitate access on foot and for regenerating food plants. "Cleaning up country" also has spiritual connotations (Tonkinson 1978). At times during the interviews, we found it difficult to distinguish between information about fires lit for hunting and those lit to "clean up country". Fires were often lit to achieve a number of purposes. On the field trip into the Lake Mackay area, our Aboriginal guides found long unburnt and senescing spinifex aesthetically displeasing and would regularly "clean up country" by setting fire to it. They claimed that firing made country "healthy".

We were told that everyone can light fires to hunt or "clean up", even the children. We were frequently given long lists of animal species that were hunted using fire. Of the larger mammals, such as bandicoots and wallabies, all were hunted this way except those that inhabited burrows. Many reptiles were also hunted this way. Feral cats were often hunted by first flushing the animal from its cover, chasing it up a small tree, firing

the spinifex to deny the cat cover, then throwing sticks and stones at the cat bringing it to burnt ground where it was readily caught, often with the assistance of dogs (Warlimpirringa Tjapaltjarri *pers. comm.*). *Kipara*, or Australian bustard (*Ardeotis australis*) is a prized food item and we were told that the best way to catch *kipara* was to light a bush fire; *kipara* would see the smoke and fly in and land on the recently burnt ground to feed on insects and lizards exposed or killed by the fire.

Our Pintupi informants told us that the size of hunting and plant regeneration fires varied. Some fires went out soon after they were lit, and so were very small, and other fires burnt for long distances. When we asked about how far fires travelled, we were usually told that it depended on the wind and the amount of fuel.

Some quotes from our interview reports in relation to fire size are:

Question: "How large did the fires get in the old days?"

Answer (informant A): "You could follow a fire for up to a few days. Some were big and some were small. Fires would sometimes go out at night. Sometimes they would go on for several days".

Answer (informant B): "You would follow a fire, camp overnight and follow it again the next day."

Answer (informant C): "Sometimes they could get quite large; could go for five nights."

Aborigines mentioned a recent fire that went from Kiwirrkurra to Jupiter Well (about 130 km). Another recent fire went from Kiwirrkurra to Walungurru (about 180 km). We were also told of a recent fire that went from Walungurru to Mount Liebig (180 km). These fires were considered by the Aborigines as very large and unusual.

An informant from near Tjukala said that in the old days fires often went only a short distance and they would often have to light them again. This suggests that burning may have been carried out under mild weather conditions, or that the spinifex cover and hence fuel load was low as a result of recent past burning.

Question: "What would people look for when deciding to light up?"

Answer: "When the spinifex gets dense. Sometimes you would light up small grass areas, often you would have to light these areas several times; it would depend on the wind and rain."

"People would come back to burnt areas after rain and about one year later to gather food and to track goannas" (*Varanus spp.*).

One informant commented: "We would burn areas and hunt while the fire was burning; then we would move on and return to these areas later to collect food from plants that had regenerated and to hunt animals that had moved in to feed on those plants".

Question: "Which animals can you find in burnt country sometime after fire?"

Answer: "You could burn up country, go away, visit family and relatives, come back after rain when animals would be there. Kids would burn up country to catch lizards. Fires would make it easier to track animals. People would walk and keep up with the fire front so they could hit ***kuka*** on the head as they came out". "***Kuka***" is literally meat, but in this context, it refers to food animals.

People could also tell whether an area needed burning by the amount of growth and by density of animal tracks. If, for example, they saw a lot of ***mala*** (rufous hare-wallaby) or goanna tracks they would burn so they could follow the tracks and find the burrows. ***Mala*** would move into sandhill areas to eat fresh plants after fire and rain. ***Mala*** were hunted with fire and were chased several hundred metres.

When questioned on their use of fire today, the Aborigines responded with: "No need to go hunting with fire any more because there is no longer any ***kuka*** there".

Question: "How often were hunting fires lit?"

Answer: "Every day".

When it was suggested to one group of Aborigines that the mammals might have disappeared because the people were no longer out in the bush lighting fires we received the reply: "That would be right; no longer any green shoots".

We were also told that fires were often lit for communication. For example the women would light a fire to let the men know that they had collected food. Fire was also used to communicate between groups. A party entering another group's land would light fires to let them know that they were coming.

Pintupi people have a good understanding of the relationship between fire and the germination of many important food plants. We were frequently given long lists of plants that regenerate following fire and rain. ***Ukiri*** is generic for new growth and ***mirrka*** is a collective word for all the non-meat bush foods.

We were told that lightning could start fires any time during the hotter months. One informant described the start of the lightning season as the time when goannas come out of their burrows. Lightning fires were more common on the hills but also occurred on the plains. Some people told us that lightning fires were not under their control so they did not have much to do with them. Others, however, said that lightning fires were also used for hunting. Our impression was that no fire should be ignored if it was suitable for hunting.

Pintupi people (and other Western Desert Aborigines) regret the passing of medium sized mammals (Burbidge *et al.* 1988) and want them returned to their country. During this series of interviews, Aborigines made it clear they were worried that all the animals had "finished" in their country. They would be pleased to see the animals back because they (Aborigines), "had been eating white fellows meat for so long that they had become weak". They wanted to eat their own ***kuka*** (meat from native mammals) so they would be strong again. After explaining to several older Ngaanyatjarra men that we wanted to reintroduce some of the mammals that were once common, they were overjoyed, but warned us that country had to be "properly" burnt first to provide food for the animals.

Evidence from remote sensing

The 1953 black and white aerial photography of the 241 210 ha study area revealed a mosaic of numerous small, recently burnt patches (see example in Figure 2) with about 22% of the area having been burnt recently (probably < 5–6 years prior to the photography). A fire palimpsest was evident and appeared to be similar to the contemporary mosaic suggesting that the 1953 photography was not a temporal outlier. Seventy five per cent of the burnt patches were less than 32 ha and 50% were less than 5 ha (Table 1 and Figure 3). Of the recently burnt area, about 20% was burnt by fires < 100 ha, and 36% by fires > 1 000 ha; the largest fire being about 6 000 ha (Figure 4). While it was not possible to determine the ignition source of all fires, the shape of many of the burnt patches on the 1953 photography was consistent with having been lit by a person dragging a firestick. The 1953 fire pattern contrasts with the more recent fire patterns mapped from satellite imagery, which reveals very large, contiguous recent fire scars. Since 1953, the number of burnt patches in the study area has decreased dramatically from 846 to a low of 4 in 1981, and the size of the burnt patches has increased markedly (Table 1). Habitat boundary, which is the total fire perimeter within the study site and is a measure of the boundary between vegetation of different ages since fire, decreased from 3 888 km in 1953 to 392 km in 2000. This indicates a substantial reduction in the diversity of fire ages or states of post-fire succession within the landscape and a massive increase in fire scale, or grain size. These findings are consistent with those of Burrows and Christensen (1990).

The pattern of burnt patches evident on the 1953 photography was relatively uniform across the study area, although there were occasional patches of very concentrated burning such as around the Pollock Hills. A useful measure of the size and distribution of burnt and unburnt patches (patchiness), is the patch size variance-to-mean ratio (Peilou 1977). A random distribution of patch sizes produces a ratio near 1, a uniform or over dispersed distribution results in a ratio greater than 1, while a clumped or contiguous distribution yields a ratio value much less than 1. In 1953, the patchiness ratio of both burnt and unburnt areas was 0.62 to 0.72 respectively, indicating a near random distribution of patches (Burrows and Christensen 1990). They reported that mean length of continuous recently burnt vegetation had increased from 467 m in 1953 to 2 570 m in 1986 and the variance ratio had reduced to 0.43, indicating a clumped distribution of patch size and a significant increase in mosaic grain size.

It was difficult to identify significant areas of long unburnt vegetation on the 1953 aerial photographs. Areas not mapped as recently burnt showed evidence of having been burnt, but because the fire boundaries were diffuse, they were not mapped. By 1973, about a decade after Aborigines began to leave their homelands, Landsat imagery revealed that the small-grained mosaic of burnt patches evident on the 1953 photography had begun to be erased and to be replaced by a large-grained mosaic of tracts of recently burnt country that comprise about 16% of the study area, and large tracts long unburnt (probably > 10 years since fire), comprising about 80% of the study area. The largest fires were observed on the 1981 satellite imagery; four very large fires had burnt about 87% of the 240 210 ha study area in the last 5–6 years (Table 1).

Table 1

Area and perimeter statistics for recently burnt patches clearly visible on 1953 black and white aerial photography (1: 50 000 scale) and Landsat satellite imagery for a 241 210 ha study area 80 km south-west of Lake Mackay in the Western Desert of Western Australia. Burnt patches are estimated to be 5–6 years since fire (se = standard error).

YEAR	REMOTE SENSING MEDIUM	NUMBER OF BURNT PATCHES	TOTAL AREA RECENTLY BURNT (HA)	TOTAL BURNT PERIMETER (HABITAT BOUNDARY) (KM)	MEAN BURNT PATCH SIZE (HA)	RANGE – BURNT SIZE (HA)	75TH PERCENTILE (HA)	50TH PERCENTILE (MEDIAN) (HA)
1953	Aerial photography	846	54 234 (22%)	3 888	63.9 (se = 10.2)	0.5 – 6 005	32.1	10.2
1973	Landsat 1 MSS	24	38 014 (16%)	518	1 583.9 (se = 1 086.1)	15 – 24 780	236.6	60.6
1981	Landsat 3 MSS	4	210 576 (87%)	1 324	52 644.0 (se = 26 096.7)	17 113 – 129 646	–	–
1988	Landsat 5 TM	19	94 447 (39%)	814	4 970.9 (se = 23 080.2)	1 – 71 346	1 581.7	390.9
1994	Landsat 5 TM	83	46 589 (19%)	1 053	561.3 (se = 181.3)	8 – 11 992	234.0	91.2
2000	Landsat 5 TM	25	11 121 (4.6%)	392	444.2 (se = 164.9)	19 – 3 683	412.3	78.2

Figure 2. An example of fire scars (light patches) evident on 1953 aerial photography of a 241 210 ha area near Lake Mackay in Western Australia. Pintupi Aborigines who occupied the desert at the time of photography probably lit most fires.

DISCUSSION

Fire size

Oral evidence gained from interviews is consistent with the 1953 photographic evidence. During Aboriginal occupation of country, fire was used widely, frequently and for many reasons, inducing a fine-grained mosaic of burnt patches across the landscape and reducing the opportunity for very large and intense wildfires to develop. The number and size class distribution of the burnt patches further supports the oral evidence that burning was done routinely throughout the year. The relatively small size of the burnt patches could only be achieved by either only burning under marginal weather conditions (light winds, moist fuels) so that fires did not develop, or by burning frequently, thereby reducing the quantity and continuity of flammable fuel. Both factors probably contributed to controlling fire size, but given that Pintupi burnt all year round, it is probably the latter, frequent burning, that has mostly influenced the small grain size of the patch-burn mosaic. Kimber (1983) suggested that Aborigines had a good deal of control over fire, using wind, humidity and natural fire barriers such as claypans and sand dunes to control the size and intensity of fires. This accords with our

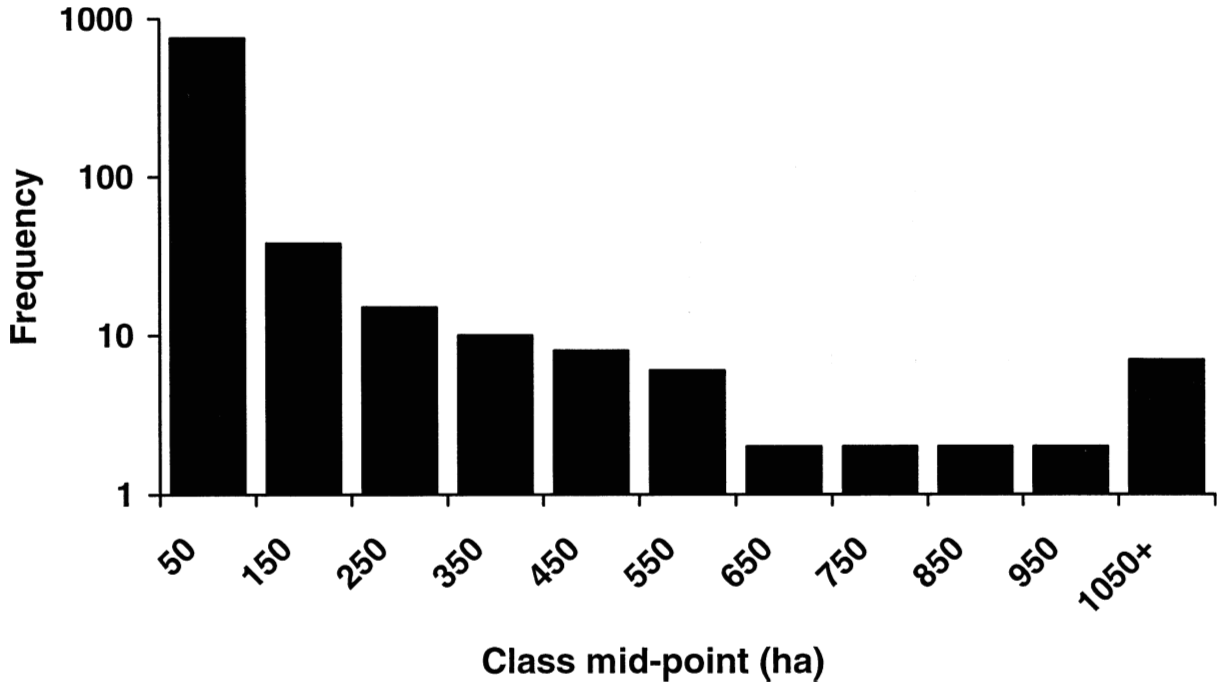

Figure 3. Frequency distribution of the size (ha) of recently burnt patches evident on 1953 black-and-white aerial photography of a 241 210 ha area of the Western Desert.

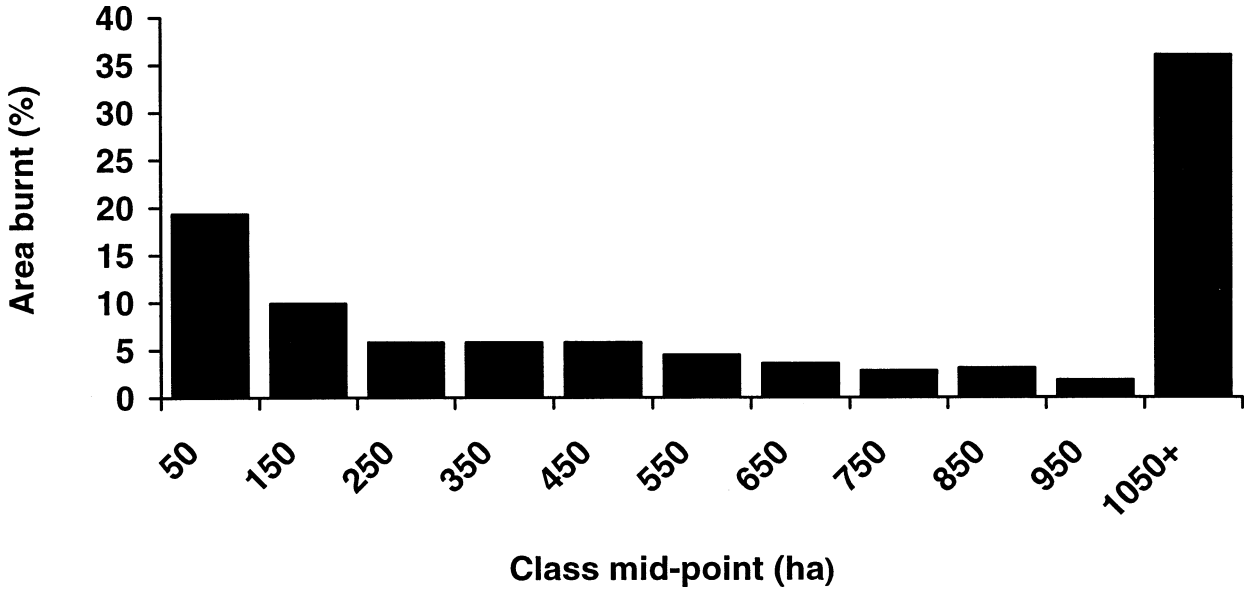

Figure 4. Proportion of the total area recently burnt (from 1953 photography) by burnt patch size classes.

observations while in the field with Aboriginal men. From our interviews with Pintupis, it was clear that they had a sound empirical understanding of the role of weather and fuel conditions in influencing fire behaviour.

Many generations of Aborigines frequently burning country as they moved through the landscape would have resulted in discontinuous, patchy fuels, ranging from recently burnt to occasional long-unburnt patches. However, when the human ignition source was removed from the desert, fuels accumulated over large, continuous tracts of land in a relatively short time. Today, lightning strikes often result in massive and intense wildfires, particularly during the hot and windy summer months. These fires can burn unchecked for days and sometimes weeks.

Fire interval

Following our discussions with Aboriginal informants, we were left with the impression that they burnt the vegetation as often as it would carry fire. Although it is only a snapshot in time, the 1953 photography of recent fires and the fire palimpsest supports this conclusion; there was evidence of only small patches of long unburnt vegetation within the study area. However, we cannot be confident of the spatial extent of this conclusion. If there were areas not frequented by Aborigines, then it is likely that these areas remained unburnt for longer periods. Griffin and Allan (1986) observed that Aboriginal burning patterns would have been intensified along popular travel routes. While rainfall history largely determines the rate of post-fire vegetation (fuel) development hence the minimum possible interval between fires (Griffin & Allan 1984, Griffin 1991, Allan & Southgate 2002), fire interval will also be influenced by the likelihood of ignition, which obviously decreases significantly in the absence of humans. Our observations suggest that for the study area the minimum possible interval between fires based, on fuel accumulation alone, is probably in the order of 5–7 years. However, we have observed that on some land systems in the Gibson Desert, a sequence of high rainfall events can encourage the growth of soft grasses and annual herbs which will support fire at more frequent intervals.

Time of year of fires

Our Pintupi informants told us they burnt all year round (every day). Kimber (1983) believed that most burning by Aborigines was done in August to October and immediately prior to rains in December to February. Occasionally, large fires caused either by Aborigines or by lightning, burnt during the hot, dry, windy summer months. In the area studied here, it would not have been possible for a fire to become larger than about 10 000 ha in 1953 because the fuels were discontinuous as a result of frequent broadscale patch-burning and natural fire barriers. Kimber suggests that the time of year for burning is not as important to Aboriginal people as the opportunity to burn, which was the impression we gained from our interviews. de Graaf (1976) observed that Aboriginal fires in the desert were lit all year round and not seasonally. Both de Graaf (1976) and Kimber (1983) reported that Aborigines did not burn certain areas of the desert because they did not visit these places for religious reasons, or feared that fire would destroy sacred objects. The season of burning was, however, very important in the monsoonal regions of the Northern Territory (Jones 1980, Haynes 1985 and Russell-Smith *et al.* 1997) and to Wadjuk Aborigines in the south-west of Western Australia (Hallam 1975). Today the main ignition source in the remote deserts, away from communities, roads and vehicle access tracks, is lightning. Thunderstorms are common over the summer months and large, lightning-caused wildfires have been reported (e.g., Griffin *et al.* 1983).

CONCLUSION

Traditional, or classical use of fire by Aborigines and patterns of alteration to the fire regime following the cessation of traditional Aboriginal burning practices reported here are similar to observations reported elsewhere for other Australian biomes (e.g., Hallam 1975, Haynes 1985, Bowman 1988, Russell-Smith 2002). Western Desert Aborigines used fire skilfully and for a myriad of purposes, probably for thousands of years. Oral evidence provided by Pintupi Aborigines and quantitative evidence obtained from early black and white aerial photographs is consistent and supports the hypothesis that the fire regime changed significantly and quickly in parts of the Western Desert following the departure of Aboriginal people and the cessation of traditional burning. The size and intensity of fires has increased dramatically over the last 50 years. Today, in the absence of regular burning by Aborigines, fuels have accumulated over vast areas and when lightning (or people) ignites these fuels and under hot, dry, windy summer conditions, large and intense wildfires sweep across the desert. With the cessation of anthropogenic burning throughout most of the vast Western Desert, landscapes alternate from large areas long unburnt to large areas recently burnt, usually following exceptional rainfall periods and lightning-caused ignitions. More research is required, but there is at least limited scientific evidence to suggest that this has contributed to the decline in some native mammal species. This change may have further predisposed mammals to predation by introduced predators.

It is reasonable to accept the importance of temporal and spatial diversity within a landscape on resource levels and habitat opportunities (Latz and Griffin 1978, Pielou 1977). Saxon (1984) stated, "*When large areas of a single landscape type are subjected to large uniform disturbances, they threaten the survival of wildlife species which depend on irregular boundaries of natural fire patterns to provide a fine grained mosaic of resources*". Bolton and Latz (1978) have shown that a range of post-fire successional stages is important habitat for the western hare-wallaby (*Lagorchestes hirsutus*). Burbidge and Pearson (1989) explain the lack of rufous hare-wallabies in the Great Sandy Desert as being due to the lack of frequency of small-scale burns and to predation by foxes.

It is somewhat ironic that modern mammal extinctions in the Australian deserts may be due, in part, to the changed fire regime that resulted from the departure of Aborigines and cessation of traditional Aboriginal burning. Although contentious, some authors (e.g., Tindale 1959, Merrilees 1968, Jones 1968 and Flannery 1994) have suggested that extensive burning by Aborigines contributed to the extinction of the Pleistocene mega-fauna. Today, it is likely that the large, intense wildfires that occur throughout the deserts are placing extreme stress on some plant and animal communities (Griffin 1981, Latz 1995). These intense fires are damaging vast areas of fire-sensitive vegetation such as marble gum (*Eucalyptus gongylocarpa*), desert

oak (*Allocasuarina decaisneana*), and mulga (*Acacia anuera*) (Start 1986). There is sufficient evidence of the disadvantages of the current wildfire regime on the conservation status of desert reserves to warrant the development and implementation of managed fire regimes that mimic those in place during Aboriginal occupation of the land.

Limited resources available to conservation and land management agencies and the remoteness of many of the desert nature conservation reserves in Western Australia means that fire is not actively managed. There are many Aboriginal communities located in the Western Desert and given the knowledge and skills possessed by older people particularly, and the overwhelming desire by many Aboriginal people to care for country, a wonderful opportunity exists for co-management of these lands. The challenge for conservation and land management agencies is to develop processes that enable Aboriginal people to participate in land management in a meaningful and mutually beneficial manner. Hill (2003) presented a useful framework and mechanisms (bridging tools) to facilitate this. Her framework recognises an Indigenous "toolbox" founded on traditional knowledge and customary law and a non-Indigenous toolbox founded on science, legislation and policy. She identifies processes such as joint management, native land title and planning as the "bridging tools".

Fire management on desert nature conservation lands provides an opportunity for conservation agencies to facilitate and resource the reintroduction of traditional burning. In addition to conservation benefits, co-management provides an opportunity for Aboriginal people in remote communities to participate in an economic activity on their own terms, while at the same time, ensuring that important connections with country and traditional knowledge and skills are maintained.

ACKNOWLEDGMENTS

We thank the Central Lands Council, the Walungurru Community Council and the Kiwirrkurra Community Council for their assistance with the project. We also thank Billy Nolan Tjapinatai and Warlimpirringa Tjapaltjarri for willingly sharing their knowledge and John Heffernan for linguistic assistance. We thank Leigh Davis, Shane French, Graeme Liddelow and Alex Robinson (Department of Conservation and Land Management – CALM) who prepared satellite imagery, digitised the fire maps and provided technical support in the field, and CALM staff at Kalgoorlie for logistic support and for keeping vigil on HF radio.

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