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The fire history of an arid grassland: the influence of antecedent rainfall and ENSO

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Abstract. Implementing appropriate fire regimes has become an increasingly important objective for biodiversity conservation programs. Here, we used Landsat imagery from 1972 to 2003 to describe the recent fire history and current wildfire regime of the north-eastern Simpson Desert, Australia, within each of the region's seven main vegetation classes. We then explored the relationship between antecedent rainfall and El Niño–Southern Oscillation with wildfire area. Wildfires were recorded in 11 years between 1972 and 2003, each differing in size. In 1975, the largest wildfire was recorded, burning 55% (4561 km^2) of the study region. Smaller fires in the intervening years burnt areas that had mostly escaped the 1975 fire, until 2002, when 31% (2544 km^2) of the study region burnt again. Wildfires burnt disproportionally more spinifex (*Triodia basedowii*) than any other vegetation class. A total of 49% of the study area has burnt once since 1972 and 20% has burnt twice. Less than 1% has burnt three times and 36% has remained unaffected by wildfire since 1972. The mean minimum fire return interval was 26 years. Two years of cumulative rainfall before a fire event, rainfall during the year of a fire event, and the mean Southern Oscillation Index from June to November in the year before a fire event could together be used to successfully predict wildfire area. We use these findings to describe the current fire regime.

Additional keywords: arid zone, Australia, GIS, Landsat, Simpson Desert, spinifex, wildfire regime.

Introduction

Implementing appropriate fire regimes requires an understanding of the fire history of a region and has become an increasingly important goal for conservation in recent years (Bond and Archibald 2003; Parr and Andersen 2006; van Wilgen *et al.* 2007). Fire may remove large areas of aboveground plant biomass in the short-term, but it also can stimulate subsequent germination and regrowth (Letnic 2004). This results in changes in plant species richness and abundance (Griffin and Friedel 1984*a*; Letnic 2004; van Wilgen *et al.* 2007), which in turn influence the species composition and population dynamics of small mammals, reptiles, and availability of forage for livestock (Griffin and Friedel 1984*b*; Masters 1996; Letnic 2004; Letnic *et al.* 2005; van Wilgen *et al.* 2007). Understanding of a region's fire history can thus be used by land managers to interpret current patterns in the distribution and cover of vegetation and fauna, and to predict and manage wildfire risk in the future.

In Australia, vast tracts of the central arid regions burn each year, with most fires started by lightning during summer storms (Griffin *et al.* 1983; Burrows and Christensen 1990; Burrows and van Didden 1991; Burrows *et al.* 1991). Comparatively few resources are available to combat these fires and most are left to burn and extinguish themselves. This can result in large areas (>1000 km^2) being burnt, particularly after large rainfall events when fuel levels are at their highest (Allan and Southgate 2002; Letnic and Dickman 2006). There is some contention about whether fires of such magnitude are recent phenomena that have been facilitated by changes in land use imposed over the last century and a half by European settlers. Whatever the case, an apparent change from frequent, small-scale burning, as practised by Aboriginal people, to large-scale, infrequent fires has been postulated as a potential cause for the drastic decline of mammals in the Australian arid zone over the last century (Griffin 1981; Burbidge and McKenzie 1989; Burrows and Christensen 1990).

Aboriginal burning in central Australia was recorded by many early European explorers (e.g. Eyre 1845; Giles 1875). In the Simpson Desert, several explorers noticed 'fires lit by the natives' during their excursions (Sturt 1849; Hodgkinson 1877; Winnecke 1884), and commented on the frequency and locations where they encountered fires, smoke or other evidence of recent burning. In summarising the fires reported by European explorers in this region in the 19th century, Letnic and Dickman (2006) suggested that half could be attributed to Aboriginals, with the remainder presumably being naturally occurring fires. Aboriginals used fire for hunting, signalling and ceremonial purposes, as well as to promote the growth of food plants and animals (Gould 1971; Kimber 1983; Cane 1987; Burrows and Christensen 1990; Bird *et al.* 2005; Murphy and Bowman 2007). Although explorers documented evidence of fires, little is known about Aboriginal-imposed fire regimes before European contact. The size, patchiness, frequency and, to a lesser extent, timing of burns are all largely unknown. However, Burrows and Christensen (1990) and more recently Burrows *et al.* (2006) have

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provided evidence of changed fire regimes in Western Australia. Since the exodus of the traditional owners from the Western Desert, fire patch size has been increasing and the numbers of patches decreasing (Burrows and Christensen 1990; Burrows *et al*. 2006). They argue that traditional burning created a patchwork of small burnt areas, thus limiting the spread of large wildfires. Aboriginal land use practices effectively ceased in the Simpson Desert in the early 1900s (Hercus 1985), and little is known now of the distribution and size of these deliberately lit fires and how far from permanent water sources they occurred.

Spinifex grasslands cover more than a quarter of the Australian continent (Allan and Southgate 2002). They are highly flammable and constitute the majority of the fuel load in the desert environment (Burrows and van Didden 1991). Major wildfires occurred in the Simpson Desert in 1917, 1951, 1975 and 2002. These fires were associated with rains of at least 400 mm that fell one or two summers earlier and that were coupled with the wet phase of the El Niño–Southern Oscillation (ENSO) (Letnic and Dickman 2006). The above fire events suggest that major fires return every 20–30 years in the Simpson Desert. Other regions in arid Australia have varied fire return intervals of 9 years for the Tanami Desert, 32 years for Uluru and 30 years for the Great Victorian Desert (Haydon *et al*. 2000*b*; Allan and Southgate 2002). This variability in fire return intervals is often linked to differences in rainfall between regions (Allan and Southgate 2002; Turner *et al*. 2008).

The ENSO has been shown to play a major role in global fire patterns (Le Page *et al*. 2008). In the arid lands of Australia and the Americas, episodic flooding rains associated with ENSO can produce an increase in the abundance and cover of vegetation (Nicholls 1991; Holmgren *et al*. 2006). Once dry, this high level of fuel connectivity can allow extensive wildfires to occur (Griffin *et al*. 1983; Myers *et al*. 2005). Unlike in the Americas, La Niña is associated with wet conditions in Australia and vegetation growth (Nicholls 1991). Rainfall has been identified as a factor that can predict wildfires (Allan and Southgate 2002; Letnic and Dickman 2006), and given that the Southern Oscillation Index (SOI) is a good predictor of rainfall, it may be able to be incorporated into models predicting the occurrence of wildfires. For example, studies from Argentina, America and Australia have found relationships between the SOI and wildfires, but most are from mesic environments (Kitzberger 2002; Beckage *et al*. 2003; Keeley 2004; Nicholls and Lucas 2007).

Landsat imagery has been used successfully by previous authors to document past and current fire regimes in arid environments (Burrows and Christensen 1990; O'Neill *et al*. 1993; Haydon *et al*. 2000*a*, 2000*b*; Brooks and Matchett 2006; Turner *et al*. 2008), and is a powerful tool for mapping the spatial and temporal distribution of fire across the regional landscape (Haydon *et al*. 2000*a*). Here, we use Landsat imagery to investigate the fire history of the north-eastern Simpson Desert, Queensland, from 1972 to 2003. This region was chosen because of its diverse vegetation communities that may be affected differentially by fire, and the region has been subject to long-term (>18 years) ecological studies investigating the interactions between fire, climate and its flora and fauna. We aimed to:

(1) Identify each fire event (year) and quantify the spatial extent (km^2) of each fire scar,
(2) Determine the fire frequency and the minimum fire return interval for the region,
(3) Quantify the area of fire in each vegetation class for each fire event, and
(4) Explore the relationship between four measures of antecedent rainfall, SOI and wildfire area.

Materials and methods

Study area

The study was carried out in an area between the Mulligan River and the Northern Territory border, in south-western Queensland, Australia. This region encompasses five pastoral leases, Carlo, Ethabuka, Cravens Peak (both Ethabuka and Cravens Peak are now private reserves), Marion Downs and Glenormiston Stations. The region covers 8227 km^2 and occupies the entire north-eastern corner of the Simpson Desert (Fig. 1).

The study region is characterised by dunes that run parallel in a north-north-west to south-south-easterly direction with the prevailing southerly wind. The dunes are up to 10 m high and spaced 0.6–1 km apart (Purdie 1984). They are usually separated by stands of gidgee (*Acacia georginae*), spinifex grasslands or clay pans, which fill with water temporarily after heavy rain. Spinifex (*Triodia basedowii*) is the dominant plant species across the study site, with highest cover in the swales between the dunes. On the dune crests, ephemeral plants and shrubs such as *Crotalaria* spp., *Tephrosia rosea*, *Goodenia cycloptera*, *Acacia* spp. and *Grevillea stenobotrya* occur patchily. Fuel loads are thus lower on the dune crests and highest in the swales.

Daily temperatures exceed 40°C in summer and during winter, the minima often fall below 5°C (Purdie 1984). The study region lies between the 150- and 100-mm median annual rainfall isopleths (Purdie 1984). The nearest long-term weather stations to the study area, at Sandringham, Glenormiston and Marion Downs, have average rainfalls of 181 mm ($n = 38$ years), 212 mm ($n = 104$ years) and 199 mm ($n = 94$ years) respectively. Rainfall is highly variable, both temporally and spatially (Dickman *et al*. 1999*a*). Highest rainfall occurs in the austral summer, but heavy rains (>100 mm) can fall throughout the year. There is a rainfall gradient, with precipitation higher in the north of the study region, but any area can receive rain while others miss out.

Fire history

Landsat images were obtained for the study region from 1972 to 2003 and georectified where necessary using *ArcGIS 9.0* (ESRI 2004). Two scenes were required per satellite pass to cover the region. Based on an examination of imagery taken throughout the calendar year, we found that wildfires occurred only during the warmer months (October–March). Thus imagery used for mapping scars was taken from the austral winter to encompass all the area burnt. This resulted in a total of 60 images from 1972 to 2003. Over the period of the present study, satellite technology improved and older satellite systems were replaced. Landsat 1 images were used from 1972, Landsat 4 from 1982, Landsat 5 from 1984, Landsat 6 from 1993 and Landsat 7 from 1999. Fire scars were digitised from one band, usually band 8, or up to three band composites, using bands 1, 2 and 3. Bands were chosen owing to availability and how clearly the fire scars could be seen. Resolution varied from 30 × 30 m to 82 × 82 m and a

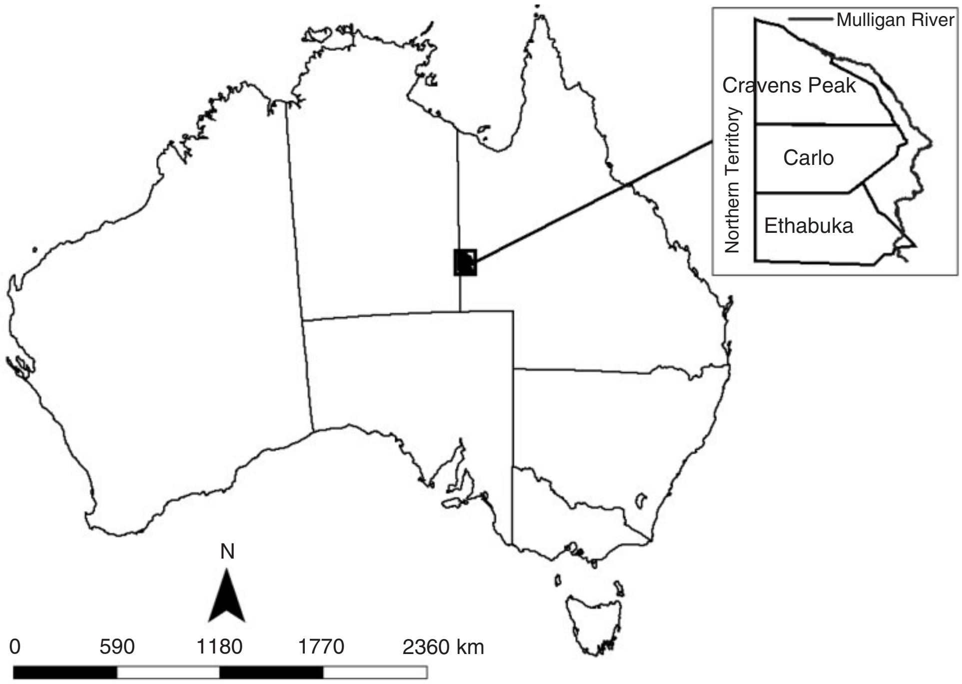

Fig. 1. Location of the study region in the Simpson Desert, south-western Queensland, and (inset) individual properties where the research took place. The study area encompassed an area west from the Mulligan River to the Northern Territory border.

wildfire was defined as an area burnt greater than 0.01 km^2. All fire scars were digitised using *ArcGIS 9.0*. Fire-scar maps were produced for each year a fire was recorded. Ground-truthing was carried out from 1995 to 2004, where access permitted, and fire boundaries confirmed with a hand-held Global Positioning System, several generations of which were used during the course of the study. Due to on-going research since 1990, the region is well known and regularly traversed for continuing studies. Thus extensive ground-truthing of areas identified as unburnt from the satellite imagery were also checked and corrected where necessary throughout much of the study period. Opportunistic aerial reconnaissance was also undertaken. We then used the Spatial Analysis extension in *ArcGIS 9.0* to map the age since a wildfire occurred across the study region.

Fire frequency and return intervals

Fire return intervals are known from only a few areas in central Australia and range from 20 to 50 years (Allan and Southgate 2002). Owing to the relatively short time period of available satellite imagery, the mean fire return interval could not be calculated here. However, the minimum return interval from 1972 to 2003 was estimated from those areas that burnt more than once (Turner *et al*. 2008). For each fire year, a grid of 100×100 m was created and each cell was assigned 1 for burnt and 0 for unburnt. By combining these layers in Geographic Information System (GIS), the frequency with which each cell burnt was calculated. The minimum fire return interval for each 100×100 m cell was then calculated by combining another grid to show the years each cell burnt. The mean minimum fire return interval for all cells was then calculated. The 100×100 m area was chosen as it is large enough not to be influenced by mapping errors and is also at a scale that current research on the flora and fauna of the study region is taking place (see Dickman *et al*. 1999*a*, 1999*b*, 2001).

Fire and vegetation

To identify which vegetation types burn most frequently, we used Purdie's (1984) definition of vegetation classes for the study region and recorded the area of each class that burnt each year a fire was detected. The broad vegetation classes were: Chenopod shrub (*Atriplex* spp., *Maireana* spp. and other leafy chenopods), Forb (non-chenopod herbaceous plants), Spinifex (grassland dominated by *Triodia basedowii*), Samphire shrub (low, leafless shrubs such as *Halosarcia* spp. and *Tecticornia* spp.), Shrub (primarily *Acacia* spp., *Senna* spp., *Eremophila* spp. and *Atalaya* spp.), Tree (woodlands dominated by *Acacia georginae*, *A. aneura*, *Corymbia* spp. and *Eucalyptus* spp., often with a grassy understorey of *Aristida* spp. after summer rains), and Tussock grass (*Aristida* spp. and *Astrebla* spp.). We also calculated the frequency and area burnt of each vegetation class to determine if any vegetation class burnt more frequently than others.

Wildfire and rainfall

Rainfall and SOI data were obtained from the Australian Bureau of Meteorology and used to explore the relationship between rainfall and area burnt. Rainfall data were collected from Glenormiston and Marion Downs weather stations, which are the closest weather stations to the study area. We then calculated the following variables: rainfall from the year of the fire, rainfall

1 year before the fire, 2 years before the fire, the cumulative 2 years before the fire, cumulative rainfall since last fire, the SOI from the fire year, the SOI 1 year before the fire and the SOI 2 years before the fire. Year is defined from July to June as most rainfall occurs during the austral summer months and the SOI was averaged from June to November, as this can be used to predict summer rainfall in the study area (Letnic and Dickman 2006). We used a stepwise multiple regression procedure to predict which variables influenced the area burnt by wildfire. The best model was chosen using Akaike's information criterion (AIC). All variables were checked for normality using the Kolmogorov–Smirnov test and square-root transformed where necessary. Spearman rank correlations were used to assess if variables were highly correlated and were removed from the model if $r > 0.7$. The variable time since last fire was considered for including into the model, but could not be as wildfires could not be dated before 1975. All statistical analyses were performed using *R* v. 2.7 and *SPSS 15* (SPSS 2006; R-Foundation 2008).

Results

Fire history

Landsat imagery from 1972 to 2003 showed that fire scars were present in 1975, 1981, 1982, 1983, 1984, 1985, 1995, 1997, 1999, 2001 and 2002 (Fig. 2). A large wildfire burnt 55% (4561 km^2) of the study region in 1975 (Table 1). The next wildfire was 6 years later and occurred in areas that were spared in 1975 (Fig. 2). The same was true for the period from 1982 to 2001, with each successive wildfire burning more of the area that had not burnt in 1975. The wildfire of 2002 re-burnt areas that had burnt previously in 1975, but some patches that were burnt in 1982, 1983, 1985, 1995, 1999 and 2001 did not burn again (Fig. 2).

Fire frequency and return intervals

A total of 49% of the study area has burnt once since 1972 (4057 km^2) and 20% (1639 km^2) has burnt twice. Less than 1% (18 km^2) has burnt three times and 36% has remained unaffected by wildfire since 1972 (2942 km^2). From the 20% (1657 km^2) of the region that burnt more than once during the study period, we calculated the mean minimum fire return interval to be 26 years (s.d. = 4).

Fire and vegetation

Spinifex (*Triodia basedowii*) was the vegetation class most likely to burn from 1972 to 2003 (Table 2). This is expected as spinifex is both highly flammable (Burrows and van Didden 1991) and has considerable areal dominance across the study region, where it represents 5763 km^2 (79%) of the total area (Table 2). This vegetation class also burnt more frequently and over a larger area than the other vegetation classes (Fig. 3).

Wildfire and rainfall

The model that best explained the area burnt by wildfire incorporated rainfall that fell in the July to June period of the fire year (Rain-that-year), the cumulative rainfall over 2 years before the wildfire (2-year-cumulative-rainfall) and the SOI from the year before (SOI-prior-year) the wildfire:

$$\sqrt{\text{Area burnt}} = -3.54 - 3.25\sqrt{\text{Rain-that-year}} + 2.71\sqrt{\text{2-year-cumulative-rainfall}} + 0.48\ \text{SOI-prior-year}$$

where $F_{3,24} = 5.324$, $P = 0.006$, $r^2 = 0.40$.

Discussion

Fire history

Satellite imagery from our study region in the Simpson Desert revealed that wildfires were detected in 11 years from 1972 to 2003 and burnt variable areas ranging from 4561 km^2 in 1975 to 0.06 km^2 in 1997 (Table 1). Landsat imagery was successful for distinguishing clear fire scars in this landscape and single bands or three-band composites (bands 1, 2, 3, 4 and 8) could be used to reliably identify fire-affected areas. Our choice of bands was validated by extensive ground-truthing between 1995 and 2004. Other studies have used band 5 or bands 3, 4 and 5 (Edwards *et al*. 2001), a combination of bands 3 and 4, 5 and 7 (O'Neill *et al*. 1993) or band 4 (Haydon *et al*. 2000*a*). Our choice of Landsat bands depended in part on the availability of bands but usually on the clarity of the fire scars across the landscape.

In the present study, all wildfires detected started in the warmer months (November–March) and most were started by lightning owing to the remoteness of the region. In arid Australia, most wildfires are started during the austral summer by lightning (Myers *et al*. 2005; Edwards *et al*. 2008), with few smaller (<10 km^2) fires started from human ignitions (Edwards *et al*. 2008). This is due to the low population levels in arid Australia and the reluctance of land managers to burn. In contrast, human ignition is the primary source for wildfires in mesic regions (Edwards *et al*. 2001; Maingi and Henry 2007; Nicholls and Lucas 2007). Fuel loads can build up year-round owing to greater rainfall and these regions are generally more populated, allowing for more opportunities for human-ignited wildfires to occur and spread.

Following a series of wildfires in 1975 that burnt 55% of the study region, subsequent wildfires from 1981 to 2001 occurred mainly in areas that did not burn in 1975 (Fig. 2). The year 1975 was considered a severe fire season across Queensland, South Australia and the Northern Territory, with extensive tracts of land being burnt throughout (Anon. 1975; Luke and McArthur 1978; Ellis *et al*. 2004). The lack of fire in areas burnt in 1975 probably reflects the time taken for the regeneration of spinifex and build-up of other ground cover (Allan and Southgate 2002). By 2002, large amounts of fuel had built up following the flooding rains of 2000 (Letnic *et al*. 2005), supporting the fire that then burnt 2544 km^2 (31% of the study region).

From 1972 to 2003, several areas within the study region routinely escaped wildfire (Fig. 2). These areas usually were devoid of spinifex, such as the rocky range landform to the north-west of the study area, or were sand dunes that are protected by natural barriers to wildfire. Such barriers included clay pans and large, open, non-spinifex flats; high dunes (>10 m) and dune crests appeared to confer protection against smaller fires. Given that most of the sand dunes, dominated with spinifex, have burnt at least once since 1972 and the last major wildfires before 1975

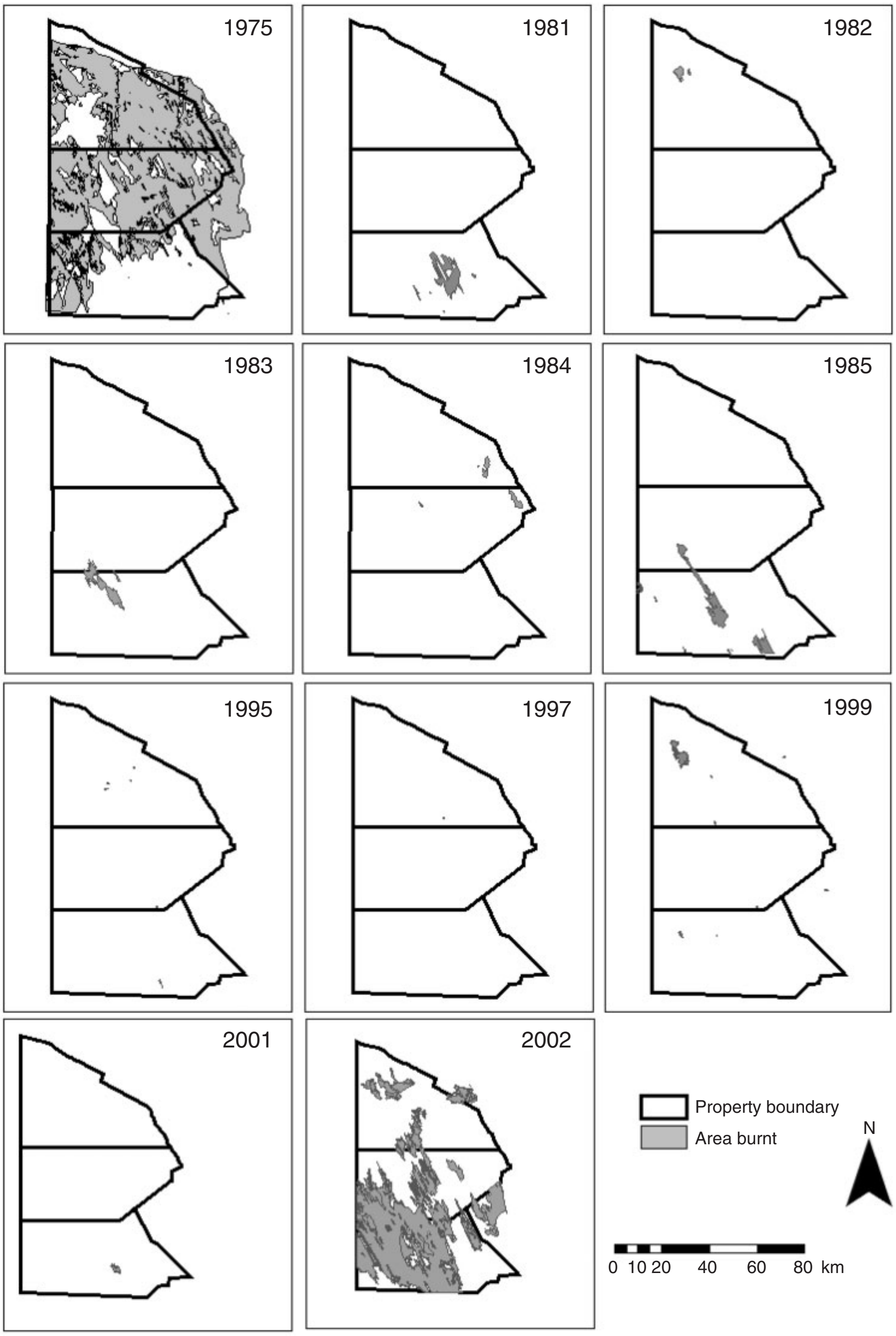

Fig. 2. Fire scars mapped each year that a fire was found from 1972 to 2003 in the Simpson Desert study region, south-western Queensland, Australia.

were in 1951 and 1917 (Letnic and Dickman 2006), the small unburnt patches of spinifex may be in excess of 50–90 years old.

Fire frequency and return intervals

A total of 49% of the study area burnt once from 1972 to 2003 (4057 km^2) and 20% (1639 km^2) burnt twice. Less than 1% (18 km^2) burnt three times and 36% (2942 km^2) did not burn during the study period. The mean minimum fire return interval was 26 years. Although the time period of the current study is too short to calculate mean fire return interval, the mean minimum fire return interval estimated here is comparable with that in other arid regions where mean fire return intervals range from 20 to 50 years (Haydon *et al*. 2000*b*; Allan and Southgate 2002).

Table 1. Summary of areas burnt during wildfires from 1972 to 2003 in the Simpson Desert, south-western Queensland
No fires were recorded in other years

Fire year	Area burnt (km^2)	Percentage of study area burnt
1975	4561	55
1981	96	1
1982	14	0.2
1983	62	0.8
1984	25	0.3
1985	119	1
1995	2	0.02
1997	0.06	0.0007
1999	28	0.3
2001	8	0.1
2002	2544	31

A trend towards increased fire sizes and pyric homogeneity has been reported for Australian desert areas burnt at similar times by one or multiple lightning strikes (Burrows and Christensen 1990). Little hazard reduction burning occurs in our study area and Aboriginal burning practices have long ceased (Hercus 1985; Burrows and Christensen 1990). A similar fire regime has been reported from other deserts in Australia (Burrows and Christensen 1990; Burrows and van Didden 1991). These large-scale ($>1000\,km^2$) fires occur every 20–30 years, often following large rainfall events associated with the La Niña phase of the ENSO cycle (Letnic and Dickman 2006). However, for this region, the extent to which this fire regime differs from that in pre-European times is largely unknown. Given the lack of available water to the west of the study region, large areas of country may not have been regularly burnt by the traditional owners, and Aboriginal burning was likely concentrated to the east of the region where natural springs occur. The archaeological and oral records support this; artefacts found near permanent water are greater in number and size, and stories of large wildfires are also documented in Aboriginal mythology (Hercus 1994; Barton 2003). Given this reasoning, the current large-scale ($>1000\,km^2$) regime may not differ greatly from that prevailing in pre-European times (see Griffin 1992; Gill 2000). Clearly, further studies investigating the pre-European fire regime are needed (see Burrows and Christensen 1990; Burrows *et al.* 2006).

Fire and vegetation

Spinifex is the dominant type of vegetation in the study region, especially in the dune fields near the border with the Northern Territory, but the areas that burnt over the 30-year study period are still over-represented compared with other vegetation classes. In 1983, for example, only spinifex burnt (Table 2). Spinifex is highly flammable due to its high resin content and will ignite with a moisture content of up to 30% (Burrows and van Didden 1991). Other studies have shown similarly that spinifex-dominated vegetation makes up a large proportion of the area burnt by wildfire (Griffin *et al.* 1983; Russell-Smith *et al.* 2003), and accounts by at least some of the early European explorers in central Australia appear to have arisen from observations made in spinifex-dominated areas (Sturt 1849; Hodgkinson 1877; Winnecke 1884).

Wildfires from 1972 to 2003 did not burn large proportions of the areas of the tree or shrub vegetation classes (max. 349 and 197 km^2 respectively). However, with the exception of trees and shrubs of the *Eucalyptus* spp., these species are frequently killed by fire (Latz 2004) and they are often of primary concern to land managers owing to their provision of food for livestock or habitat for native species. In the present study, tree and shrub communities seemed to be largely protected from fire and appeared likely to burn only if spinifex surrounded them or penetrated them as ground cover. This is in agreement with the findings of other studies investigating fire in mosaics of *Acacia aneura–Triodia*. For example, Bowman *et al.* (2008) recorded little change over a 50-year period in patch size and the total area covered by *A. aneura* communities, despite evidence of fire damage at the boundaries. Radiocarbon dating and carbon stable isotope analyses indicated further that these communities had been stable for at least 1000 years (Bowman *et al.* 2007).

Wildfire, rainfall and ENSO

The model that best explained the area burnt by a wildfire incorporated rainfall that fell in the same fire year (July–June), the 2-year cumulative rainfall before the wildfire, and the mean SOI from June to November from the year preceding the wildfire. The area burnt was associated negatively with rainfall that fire year, but positively with the 2-year cumulative rainfall before a wildfire and the mean SOI from June to November the year before a wildfire. This suggests that wildfires are less likely to occur during wet periods when the fuel has not cured, but are more likely after two consecutive wet seasons, similarly to results from other spinifex-dominated deserts in Australia (Griffin *et al.* 1983). Griffin *et al.* (1983) found that wildfire area was correlated with cumulative rainfall in 2 and 3 years before the wildfire. In the present study, the two largest wildfire events had cumulative rainfalls greater than 831 mm and 575 mm for 2 years before wildfire. Letnic and Dickman (2006) identified that a rainfall event of 400 mm or more occurred in at least 1 or 2 years before a large ($>1000\,km^2$) wildfire in the study region. Thus rainfall events approximately double the mean annual rainfall for 2 consecutive years appear to be useful predictors for broad-scale wildfires. These rainfall events are often associated with the La Niña phase of the ENSO cycle (Letnic and Dickman 2006), thus explaining the positive relationship with wildfire area and the SOI the year before a wildfire.

Antecedent rainfall has been shown in many arid environments to have a strong relationship with wildfire (Schmid and Rogers 1988; Brooks and Matchett 2006; Letnic and Dickman 2006; Edwards *et al.* 2008; Turner *et al.* 2008). In arid lands, large rainfall events allow the accumulation of fuel (Allan and Southgate 2002). In our study, fuel load is dominated by spinifex, but extensive wildfires only occur after a build-up of annuals that increases the conductivity of fuel between spinifex clumps (Myers *et al.* 2005). Two or more large rainfall events are usually required for this increase in fuel conductivity to occur (Myers *et al.* 2005). The rates of recovery of spinifex until it can support a wildfire again are highly variable. Spinifex can recover from

Table 2. Areas of different vegetation classes that burnt (km²) in different fire years from 1972 to 2003 in the Simpson Desert, south-western Queensland

Total area represents the area (km²) of that vegetation class in the study region. Study area is 8227 km²

	Total area	Year										
		1975	1981	1982	1983	1984	1985	1995	1997	1999	2001	2002
Spinifex	5763	3539	93	13	62	22	111	2	0.06	25	8	2343
Tussock grass	633	280	0	0.4	0	0.4	0	0.1	0	2	0	18
Tree	625	349	2	0	0	2	8	0.2	0	0	0.05	88
Shrub	505	197	0	0.03	0	0	0	0	0	0	0	13
Forb	305	95	0	0	0	1	0.3	0.06	0	1	0	15
Chenopod shrub	109	13	0	0	0	0	0	0	0	0	0	0
Samphire shrub	68	15	0	0	0	0	0	0	0	0	0	0

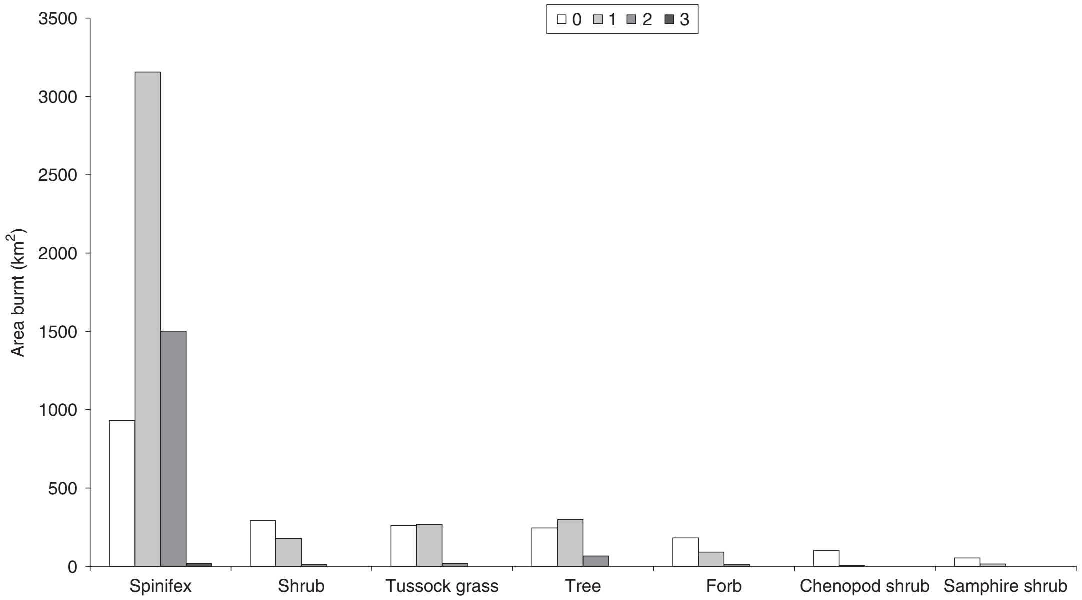

Fig. 3. The frequency and area burnt by wildfires in each vegetation class from 1972 to 2003, north-eastern Simpson Desert, Australia.

as little as 3 years under favourable rainfall to up to 15 years depending on regional conditions (Griffin *et al*. 1983; Allan and Southgate 2002).

ENSO effects are more pronounced in the semiarid and arid systems than other environments owing to the pulses of high rainfall, and hence productivity, that are associated with the wet phases of ENSO (Nicholls 1991; Holmgren *et al*. 2006). In arid Australia, this can lead to high fuel build-up during La Niña events, coupled with a rapid shift back to dry conditions that often occurs following La Niña events (Nicholls 1991), allowing for conditions that are conducive for large wildfires. ENSO has been linked with wildfires in previous studies (Skidmore 1987), but in mesic regions, ENSO-initiated droughts are associated with wildfires rather than ENSO-related increases in rainfall (Kitzberger 2002; Beckage *et al*. 2003; Nicholls and Lucas 2007). In the present study, the SOI from the year before (averaged from June to November) was positively associated with wildfire area. In addition to antecedent rainfall, the SOI can be used to predict the occurrence of wildfire in arid Australia.

Conclusion

Spinifex burnt more readily than the other vegetation classes owing to its dominance in the study area, but also its highly flammable nature, whereas fire-sensitive vegetation seems largely protected from wildfires. Fire-sensitive vegetation was found in areas protected by natural fire breaks or non-flammable country. We postulate that the distribution of fire-sensitive communities throughout the landscape is influenced by soil type and areas naturally protected from wildfires, rather than wildfires *per se*.

Antecedent rainfall and the SOI can be used to predict the area within this landscape that is likely to have been burnt by wildfires. Rainfall events of approximately double the mean annual rainfall in 2 consecutive years and the mean SOI from June to

November of the preceding year can be used as predictors of broad-scale wildfires.

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