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Do we know enough about vegetation dynamics to manage fire regimes in central Australia?

By Margaret Friedel, Grant E. Allan and Angus Duguid

Margaret Friedel *is an Honorary Fellow and arid zone ecologist with CSIRO Ecosystem Sciences (PO Box 2111, Alice Springs, NT 0871, Australia; Email: margaret.friedel@csiro.au; Tel: +61 8 8950 7140).* ***Grant E. Allan*** *is a fire ecologist with Parks and Wildlife Commission NT (PO Box 1120, Alice Springs, NT 0871, Australia; Email: grant.allan@nt.gov.au).* ***Angus Duguid*** *is an ecologist with the Department of Land Resource Management (PO Box 1120, Alice Springs, NT 0871, Australia; Email: angus.duguid@nt.gov.au).*

Summary **Ecologists have long been concerned that contemporary fire regimes of central Australia have poor consequences for some plant species, vegetation communities and the native animals they support. Fire frequency, size and intensity (the 'fire regime') have all been implicated in the decline of native biota and in vegetation changes that potentially constitute ecological drift. However, not all perceived declines and changes are quantified or proven. The fire regimes themselves defy quantification and are arguably unknowable. We examine the relationships between fire, vegetation and the physical landscape and consider the adequacy of available knowledge for guiding fire management. Devising targeted 'fire management regimes', which take into account vegetation type and management objectives such as pastoral production, conservation and cultural observance, and which actively use fire to achieve those objectives, is a more realistic goal than controlling unquantifiable fire regimes in spatially diverse landscapes.**

Key words: *Buffel Grass, climate change, ecological succession, fire, mulga, spinifex.*

Introduction

Fire regimes are driven by the interplay of climate, landscape and land use, and within central Australia, fire potential is strongly influenced by highly variable rainfall patterns and fuel availability (Bradstock 2010). Central Australia has experienced two periods of above-average rainfall and subsequent wildfire since the start of 2000. The two previous periods of widespread fire were the early 1920s and mid-1970s, tempting some observers to speculate that the proximity of the two recent events was influenced by climate change. That extensive wildfires follow several years of above-average rainfall has been well argued for the region (Griffin *et al.* 1983; Turner *et al.* 2011). It has also been generally accepted that modern fire regimes (fire frequency, size and intensity) are different to those prior to European settlement (e.g. Latz & Griffin 1978; Burrows *et al.* 2006).

Prior to European settlement in the 1870s, fire regimes were a function of lightning ignitions and traditional Aboriginal burning practices. Since the arrival of Europeans, the central Australian region has remained a relatively natural landscape with minimal clearing, agricultural cropping and infrastructure. However, new factors have affected fire regimes, including patterns of settlement, introduction of grazing livestock, camels and rabbits, establishment of parks, roads, railways and other infrastructure, introduction of alien plants especially Buffel Grass (*Cenchrus ciliaris* L.) and, potentially, change in climate (Edwards *et al.* 2008; Maru *et al.* 2012). The influence of all these factors is dynamic, because they change over different time frames relative to one another across a complex mosaic of vegetation types with differing capacity to produce fuel for fire. Hence, records dating back 50 or 100 years have limited predictive value.

Currently the majority of fires in central Australia are lit by people; many are lit for specific positive purposes related to land management or culture (Edwards *et al.* 2008; Broun & Allan 2011), some are accidental and some are lit with malicious intent. Fires are also caused by lightning. It is the combination of all these ignitions, in the context of time of year and seasonal conditions, that help to shape the present fire regime.

In our typically fuel-limited environment, the majority of fires are relatively small with localised impacts and are primarily distributed along roads and around settlements. However, a high proportion of the total area burnt is from large fires that extend across remote parts of the landscape during hot seasonal conditions following periods of above-average rainfall and grass growth (Edwards *et al.* 2008). These patterns could be similar to those prior to European occupation, with most traditional Aboriginal small fires associated with, but less confined to, living areas and travel patterns. However, the extent of maximum fire sizes and areas that could be considered remote was probably much smaller (Latz & Griffin 1978).

A number of important questions can be raised. Is enough known about vegetation dynamics to effectively manage fire regimes and their impact on native vegetation in central Australia? Can we balance these fire management ambitions with the imperative of protecting life, property and livelihoods? Can the impact of climate change on vegetation and fire be predicted?

Presently there is a dearth of information about complex interactions amongst factors influencing fire regimes and their impacts, and our ability to quantify them is limited. We draw on the outcomes of a workshop which attempted to bridge this gap by tapping into expert knowledge (Marsden-Smedley *et al.* 2012), and we examine the adequacy of currently available data in order to weigh up the prospects for better fire management outcomes. The primary geographical focus of this paper is the southern arid portion of the Northern Territory, averaging <350 mm of rain per year but with a very high variability. Broadly similar landscapes also occur widely in northern South Australia and the interior of Western Australia.

Fire–Vegetation Interactions

What evidence or expert knowledge do we have for actual or likely changes in vegetation in response to fire? A glimpse into the past is provided by the earliest widespread air photographs of the 1950s (Burrows *et al.* 2006). Satellite imagery regularly acquired in Australia since 1979 has the potential to provide spatial records of fire regimes at regional levels. This imagery has already been used at local levels to create data sets on fire sizes, patterns of fire spread and seasonality that can be integrated with other data, such as rainfall, landscape patterns of vegetation and topography and land tenure data (e.g. Turner *et al.* 2011). However, fire and landscape mapping alone cannot tell us about the health of vegetation but must be combined with ecological assessment to guide understanding and management. In addition, fire effects are influenced by the juxtaposition of different vegetation types, often at a finer spatial scale than fires and patterns of -vegetation are currently mapped. Consequently, our ability to confirm expert knowledge is limited but improving as more fire information is recorded. Unfortunately, both the aerial photography and satellite imagery records are too recent to help us understand changes associated with the postsettlement spread of pastoralism, rabbits, drought and changed use of fire. Moreover, currently incomplete mapping of fire history may mean that we are missing changes that are happening now in association with the two fire events of the past decade and the increased influence of Buffel Grass. Just as importantly, the incomplete mapping means we cannot map vegetation communities to match 'then' and 'now', to determine whether they have changed over time.

Marsden-Smedley *et al.* (2012) used expert knowledge to create a table of predominant vegetation types in central Australia and their key attributes influencing fire regimes. This includes the likelihood of fire creating long-term change. Examples for 'plains' vegetation are presented in Table 1. One potential long-term change is the invasion or increase in abundance of grasses associated with greater frequency and intensity of fire and a concomitant loss or reduction in abundance of some shrub and tree species. Jackson (1978) described an equivalent shift from one vegetation type to another in Tasmania, driven by fire, as 'ecological drift'. It has been argued (e.g. Latz 2007) that spinifex grasses (*Triodia* spp.) are invading Mulga (*Acacia aneura* F.Muell. ex Benth.) shrublands as a consequence of increased fire incidence. There is some evidence of severe damage to Mulga populations at mulga–spinifex boundaries as a consequence of fire (Allan & Southgate 2002) but persistent change over many decades due to more frequent fire cannot be confirmed due to the lack of quantitative data of sufficient duration. Field studies to date (e.g. Bowman *et al.* 2007; Nano & Clarke 2010) do not support the proposition at a landscape scale, although Bowman *et al.* (2007) found that small patches of Mulga were more vulnerable than larger patches.

Riparian woodlands and shrublands (Table 1) may also exhibit ecological drift, in this case promoted by Buffel Grass. The invasion of Buffel Grass into these productive environments has been rapid (Clarke *et al.* 2005) and fire severity has increased for the overstory (Miller *et al.* 2010). This landscape type is small in areal extent, but is distributed widely through central Australia across all tenure types and occurs with a diversity of adjacent vegetation communities. Differences in land management practices influence the potential for fire and ecological drift. Grazing of invaded riparian woodlands and shrublands on pastoral lands reduces fire potential in most years. By contrast, fire potential on conservation reserves is high in all but the driest years and overstory diversity and structure are at risk if fire management and suppression programmes are unsuccessful. Within Aboriginal lands, the situation is less certain, due to uncontrolled grazing by feral animals and less precise fire management.

The potential direction of climate change in central Australia is becoming clearer over time. By 2030, under a high emissions scenario, annual temperatures are predicted to increase by 0.5–1.5°C and annual rainfall to decline by anything up to 15%; by 2070, these figures are >3.0°C and >15% (Maru *et al.* 2012). Whilst the fire weather components of fire regimes (temperature, rainfall, humidity and wind) are somewhat predictable, the effects of climate change on lightning ignition rates and on vegetation, and hence fuels, are less clear (Bradstock 2010). Bradstock suggests that higher CO_2 may enhance vegetation production but alter the tree–grass balance in favour of trees and shrubs (C_3), possibly reducing the quantity of grass fuels. It may also increase C/N in leaf litter, slowing decomposition and thus increasing litter fuel loads. Declining rainfall may reduce vegetation production long-term; higher temperatures and lower humidity may increase the risk of fire spread, but only if fuel loads are present (King *et al.* 2013). Vegetation which is sensitive to fire interval or intensity may be directly affected by climate change and indirectly through changes in fire regime. We suggest that the invasion of some vegetation communities by Buffel Grass, a C_4 species, may slow with declining rainfall and increased CO_2 but other grasses will be similarly disadvantaged, so the implications for fire regimes are uncertain. Bradstock (2010) proposes that landscape-scale fire will continue to be limited to periods of above-average rainfall, but that outcomes will depend not just on climatic factors but also on land use and its impacts on the amount and continuity of fuel.

These climate-related predictions can only provide a broad outlook for central Australian landscapes, given model approximations and limited data. How these predictions might impact on small but important components of the landscape is even more difficult to say. The effect of a combination of factors may be more significant and less predictable than that of individual factors. Future climate

Table 1. Common 'plains' vegetation communities in central Australia and key attributes influencing fire regimes; information drawn from literature and expert opinion at a workshop (see Marsden-Smedley *et al.* (2012)

Vegetation community	Description	Proportion of regional area†	Soil nutrient availability	Main fuel type	Average fire frequency	Pastoral value	Potential for Buffel Grass invasion	Potential for ecological drift promoted by spinifex (see Marsden-Smedley *et al.* (2012)	Potential for termite fuel removal
1. Spinifex plains with mixed overstory	Spinifex with a variable overstory including mallee eucalypts and wattles. Soil range from sandy to sandy clay loams.	VH	L-M	SG, (AG)	H	L	VL	n/a	L-M
2. Mulga-dominated plains and dune swales with nonspinifex understory	Plains dominated by mulga shrubland in various floristic and structural patterns. Soils range from sandy loams to clay loams.	H	(L-)M	WCL, MG	L(-M)	VL-M	VL-L	Some communities may go to community 1 or 3	H
3. Mulga plains with spinifex understory	Areas of Mulga with spinifex understory can form extensive patches (kilometres wide); typically in transition zones between nonspinifex Mulga and spinifex sand plain.	M	L-M	SG, (AG)	M	VL-L	VL	May go to community 1	H
4. Open grassy fertile woodlands	Characteristically occur on outwash plains surrounding hills and ranges. Overstory is frequently dominated by Ironwood *(Acacia estrophiolata)*, Bloodwood *(Corymbia opaca)* and/or Corkwood (*Hakea* spp.).	H	H	AG, MG	Variable, dependent on grazing	VH	VH	L	VH-H
5. Gidgee plains and dune swales	Gidgee shrubland dominated by Georgina Gidgee (*Acacia georginae*) or Myall Gidgee (*Acacia calcicola*) with intermediate textured, often calcareous soils.	M	H-M	WCL, ?MG	L	M	M-H	May go to 'spinifex dunes and plains' or community 2	VH
6. Stony plains	Stony plains, principally gibber plains with very sparse vegetation cover consisting of mainly herbs, short grasses and scattered low shrubs.	L	M-H	AG, MG	VL	M	L-M	L	L-M
7. Chenopod plains	Plains dominated by chenopods including saltbush (*Atriplex* spp.), bluebush (*Maireana* spp.) and burrs (*Sclerolaena* spp.). Some species are strongly associated with saline and/or alkaline soils.	L	M	WCL, AG	L, except where dominated by *Maireana aphylla*	M	M	L	L-M
8. Mitchell grass plains	Cracking clay soil plains dominated by Mitchell grass (*Astrebla* spp.).	L	M	MG	Variable, dependent on grazing	VH	L	L	M
9. Riparian woodlands/ shrublands	River channels usually lined with River Red Gum (*Eucalyptus camaldulensis*) with a grassy understory	L	H-VH	MG, LL	M-H	VH	H-VH	L	M-H

†Not all vegetation communities are accurately mapped and many intermingle in a fine-scale mosaic, so that areal estimates are not readily quantifiable. AG, annual grasses (includes short-lived perennial); H, high; L, low; LL, leaf litter; M, moderate; MG, mixed grasses (nonspinifex, mixed perennial and annual/short-lived perennial); n/a, not applicable; PG, perennial grasses (nonspinifex, moderately long-lived); SG, spinifex grasses; VH, very high; VL, very low; WCL, woody canopy and litter (leaves and fine twigs of trees and shrubs plus litter of fallen leaves). 'Main fuel type' refers to fuel type following high rainfall periods – secondary fuels in brackets. '?' indicates uncertainty. Plant species nomenclature follows Albrecht *et al.* (2007).

change interacting with other drivers of change may lead to new patterns and combinations of events beyond our current experience.

Can Fire Management Activity be Better Targeted?

Landscapes with a diversity of fire ages and patch sizes are commonly regarded as a desirable goal for biodiversity management, whilst big hot fires are not (e.g. Edwards *et al.* 2008), but the supporting evidence for specific vegetation types is limited. Frequent low intensity fires may have quite different effects on biota than less frequent but intense fires, but the effects are not well quantified. These and other knowledge gaps limit our ability to determine fire impacts and prescribe fire management actions. Moreover, budgetary and organisational constraints significantly limit capacity to undertake fire management and thereby influence regimes. What should be done, in these circumstances, to better manage fire and its impact on vegetation?

Quantifying fire regimes may be an unattainable goal because adequate records of intensity, severity and return time over large areas and long time frames are difficult to obtain (Murphy *et al.* 2011). An alternative is describing and implementing fire *management* regimes (Duguid *et al.* 2009). Fire management regimes prescribe how we can actively use fire in specific vegetation types or management areas and the preferred responses to unplanned and unexpected fires. They provide guidelines based on ecological knowledge to achieve goals such as pastoral production, conservation, the practice of traditional culture and a complex mix. They should reflect the scale of the management area and its spatial patterning, including the scale of potential fires and other ecological drivers. In the context of sparse and emerging ecological knowledge, fire management regimes must be adaptive.

New fire programmes in northern Australia have demonstrated that new techniques and partnerships can change fire management regimes over large areas and modify fire regimes (e.g. Russell-Smith *et al.* 2009). The West Arnhem Land Fire Abatement project (http://www.nailsma.org.au/walfa-west-arnhem-land-fire-abatement-project) is successfully combining traditional fire management practices with scientific knowledge to reduce the extent and severity of northern savannah wildfires. Programmes in central Australia are developing similar capacity (Broun & Allan 2011) based on partnerships amongst Aboriginal agencies, ranger groups, traditional owners, land management committees and government. These programmes seek to shift the seasonality of fires and reduce the impact of large, hot fires on vegetation, animals and infrastructure. Aerial burning is being accepted by traditional owners along with the use of satellite imagery to identify fuel loads and to plan burning programmes (Broun & Allan 2011). However, these programmes are affected by variable rainfall that can cause long intervals between burning activities. This makes it difficult to sustain funding programmes and maintain capacity for active fire use.

The challenge is to implement burning programmes that have a balance between caution and courage. The areal extent of prescribed burning should be expanded with a mix of ground and aerial ignitions and extended beyond an initial focus on spinifex landscapes (King *et al.* 2013). The fires should be variable in size, matched to the spatial patterning of the landscape. This is especially the case in remote areas distant from the current road network. The programmes must not be limited to periods of above-average rainfall when fuel is widespread and fire potential is increased. Such programmes also need to be collaborative with neighbours, responsive to Aboriginal cultural concerns and adaptive to new technologies.

We need to learn from our experiences, develop our skills, capture expert knowledge and establish monitoring and research programmes which enhance ecological understanding in order to maintain momentum. Lessons learnt during the widespread fires in 1974–77 were inadequately documented, and the 25-year interval to the 2001–02 fires was beyond the career span of most land managers. Consequently, the 2001–02 fires had a greater impact that they otherwise might have had. Our management of the 2011–12 fires was improved by the experience of those involved in the 2001–02 fires but was still far from optimal.

Over time climate change will almost certainly increase periods of dangerous fire weather but the direction of change in potential fire intervals is uncertain. There will be trade-offs between the influences of increasingly variable rainfall, increasing CO_2 and the continued rate of spread of exotic grasses. In the short term, increasing our capacity, improving our knowledge and dealing with the existing challenges of a highly variable climate in central Australia will be critical to developing an effective management response.

Conclusions

Knowledge of vegetation dynamics is presently inadequate to manage the impact of fire on native vegetation in central Australia as effectively as we might want. Our review shows that attributes of fire regimes that will sustain vegetation communities cannot readily be identified for many vegetation types. We suggest that improved fire management regimes that prescribe how we can actively use fire should instead be the goal: they are more readily achievable and an essential step if we are to influence the impact of wildfires when they occur, as they inevitably will.

Implications to Managers

Current fire regimes in central Australia may have negative outcomes for some plants, animals and communities, but the evidence is generally insufficient. We recommend using fire to achieve particular management goals, such as pastoral production, conservation and cultural observance, for specific types or mixtures of vegetation, with the aim of reducing the incidence of large fires and extending fire management over larger areas. Decisions should be based on experience and expert knowledge, combined with skills development and documented learning from new experiences and research. Maintaining skills and knowledge between major fire periods is critical.

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