Pre-contact Aboriginal, and contemporary fire regimes of the savanna landscapes of northern Australia: patterns, changes and ecological processes

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Summary

- The paper provides a northern Australia savanna case study for assessing: first, differences (and similarities) between fire regimes operating under pre-contact traditional Aboriginal custodianship, and today under contemporary patterns of savanna landuse; and second, implications of such change(s) for biodiversity and ecological processes in northern Australia.
- Ethnographic, historical and contemporary observations concerning traditional burning, while sparse and geographically biased towards coastal and sub-coastal regions, consistently show that burning was undertaken throughout the dry season following landscape patterns of the curing of grassy fuels. In northern and north-western Australia at least, burning was concentrated particularly in the early- to mid-dry season under cooler, milder fire-weather conditions. Burning of clan estates was/is undertaken systematically and purposefully. Contemporary evidence (from coastal and sub-coastal situations) indicates at least half of any clan estate might be burnt in any one season. It is evident that, in accord with regional human population densities, burning was undertaken more frequently in higher rainfall coastal and sub-coastal regions.
- Based on regional mapping of fires from satellite imagery (mostly NOAA-AVHRR and LANDSAT) from the 1980s, we can identify two broad contemporary patterns concerning the application of fire in northern Australia. In north-western and northern Australia, and around the Gulf of Carpentaria, vast tracts are burnt annually, typically by intense wildfires late in the dry season. Conversely, elsewhere across northern Australia, but especially on more productive pastoral lands, landscape burning is infrequently applied.
- Major differences (and similarities) between traditional Aboriginal and contemporary fire regimes may be summarised as follows:
    1. Whereas burning was undertaken across northern Australia under Aboriginal custodianship, burning today is concentrated principally in non-pastoral, relatively high rainfall regions, especially in the Kimberley, in the Top End, and around the Gulf of Carpentaria;
    2. Whereas burning in most regions traditionally was concentrated in the early-mid dry season, today it generally occurs mostly in the late dry season (LDS). Generalisation of the contemporary situation, however, masks considerable early dry season (EDS) burning in some limited locations (e.g. Darwin region, Kakadu and Litchfield National Parks); and inability to burn until later in the year in north-eastern Arnhem Land and parts of eastern Cape York Peninsula.

3. Whereas it is evident that burning traditionally was/is undertaken systematically for a diverse range of purposes, today where burning occurs it often emanates from uncontrolled wildfire; and
4. Importantly for biodiversity conservation, whereas an essential feature of Aboriginal burning was/is that it tended to be highly patchy and thus contributed to developing habitat heterogeneity, today northern Australian savanna landscapes are either burnt frequently by typically intense, extensive fires, or seldom burnt (e.g. QLD, pastoral landscapes)

- Major ecological responses to above changing fire regimes include:

On frequently, typically intensely burnt savanna landscapes—

5. regional impact (ie. range contractions, loss of biodiversity) on fire-sensitive species (e.g. Cypress pine) and habitats (small rainforest patches; sandstone heathy communities);
6. reduced structural diversity in critical riparian, and more extensive, relatively fire-tolerant savanna formations, including incremental effects on tree mortality, nutrient capital, soil conservation;
7. associated reduction in fine-scale habitat patchiness and diversity of resources required for fauna;
8. invasion of fire-promoting alien species, especially vigorous grasses introduced originally for agricultural purposes.

And, on infrequently burnt, typically pastoral savanna landscapes—

1. woody thickening, and associated loss of herbaceous / grass-dominated savanna landscapes;
2. attendant loss of granivorous species;
3. loss generally of biodiversity associated with increasing intensification of land use

In conclusion:

- with respect to fire management of tropical savannas, by far the most important requirement for conservation of biodiversity is the imposition of patchy management regimes. No single fire regime, nor spatial scale, will suffice for all species; rather, imposition of a fine-grained mosaic will optimise habitat diversity. To date, outside of a small number of examples where such fine-grained management is undertaken, notably on indigenous lands, this ideal is still to be realised.
- with respect to research, there are a number of obvious requirements:
    1. further documentation and assessment of traditional Aboriginal burning practices, particularly in inland areas;

2. ongoing assessment of contemporary fire regimes with reference to continental-scale satellite monitoring—this consultancy demonstrates this general requirement; and
3. further assessment of the impact of contemporary fire regimes on targeted, fire-sensitive components of the biota, particularly the fauna.

Effective fire management is a critical requirement for conservation of northern Australian ecosystems.

Introduction

Fire regimes across the fire-prone savanna landscapes of northern Australia have changed markedly in many regions since the advent of European settlers (primarily pastoralists and miners) over a period spanning, at most, 150 years. This understanding has been built on a large and rapidly growing number of descriptive and experimental studies. As a result, significant concerns have been expressed recently with respect to the cultural, economic, and ecological sustainability of contemporary fire regimes across that region (e.g. McDonald and Batt 1994; Rose 1995; Grice and Slatter 1997; Jacklyn and Russell-Smith 1998; Russell-Smith *et al*. 2000).

Information concerning the practice and seasonality of traditional Aboriginal landscape burning, while geographically biased towards coastal and sub-coastal regions (of the Top End of the Northern Territory especially), is contained in various ethnographic sources and, more recently, in a number of regional analyses of the diaries of early European explorers and adventurers.

Our understanding of contemporary burning patterns across northern Australia has been assisted substantially through interpretation of satellite imagery at two main scales. Fire histories based on interpretation of relatively fine-resolution LANDSAT MSS (Multi-Spectral Scanner) and TM (Thematic Mapper) imagery, with pixel sizes of *ca*. 0.5 ha and 0.1 ha respectively, are available for certain areas (ie. scenes of 180 X 180 km^2), back to the early 1980s. Broader regional fire histories derived from relatively coarse-scale NOAA-AVHRR imagery, with minimum-sized pixels of 1.1 X 1.1 km^2 (see http://www.ngdc.noaa.gov/seg/globsys/avhrr.shtml), are available for the Kimberley region of Western Australia and the Top End of the Northern Territory back to the early 1990s, and for all of northern Australia from 1997. These latter data have been made available through funding principally from Western Australia Government agencies (especially the Department of Land Administration—DOLA), the Bushfires Council of the

Northern Territory, the Tropical Savannas Cooperative Research Centre (Darwin), and this EA / SOE project.

Likewise, and as the references presented in this paper attest, our understanding of the characteristics of northern Australian savanna fire regimes (e.g. fuels, fire behaviour, intensity, frequency, seasonality, areal extent), and the responses of different groups of plants and animals to different fire regimes, has developed rapidly and substantially over the past couple of decades.

The intent of this paper is not to provide a detailed review of the nature and effects of different fire regimes across the major savanna biomes of northern Australia—such a review recently has been compiled as a chapter (Williams, Griffiths and Allan 2000) for the forthcoming volume, *Flammable Australia* (Bradstock, Williams and Gill 2000). Rather, from all above sources, I address: first, identifying differences between fire regimes operating under traditional Aboriginal custodianship, and today under contemporary patterns of savanna landuse; and second, implications of such change(s) for biodiversity and ecological processes in northern Australia.

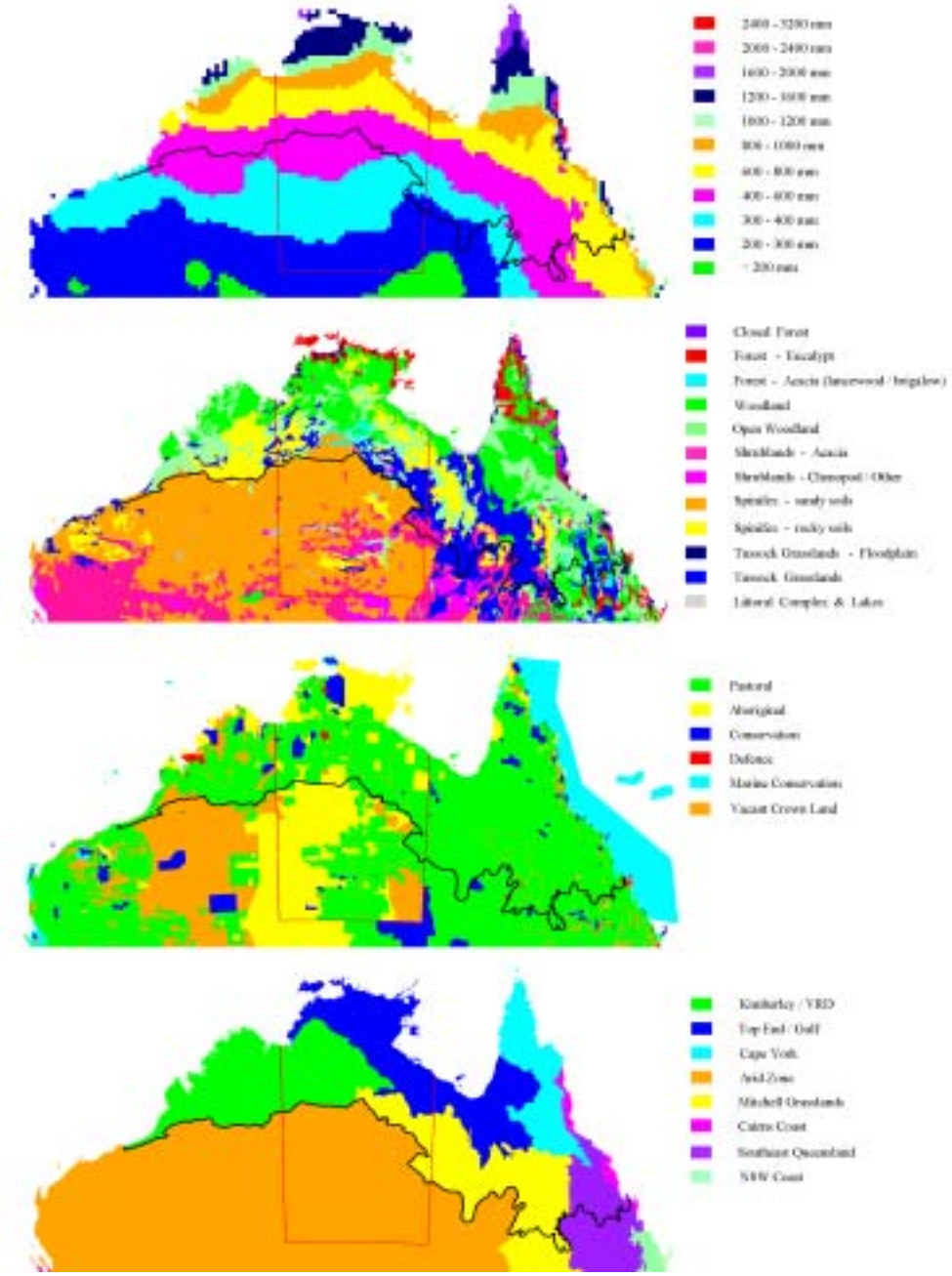
Defining the tropical savannas—climate, fire seasonality, vegetation, landuse, and biogeographic regionalisation

Broad-scale northern Australian rainfall distribution, vegetation, landuse and biogeographic features are described in Fig.1 (a-d), respectively. Rainfall, which occurs over the savanna region mostly between October-March under the influence of the Asian monsoon, declines rapidly inland, from over 2000 mm pa in a few coastal areas, to around 500 mm pa (Fig. 1a). Although the amount of rainfall received in any one area is highly variable from year to year, the wet season is a highly reliable event (Taylor and Tulloch 1985). Such rainfall spatio-temporal variability, however, has major implications for onset of grass curing, fuel load production, and hence intra- and inter-annual variability in important fire regime parameters.

Above climatic conditions are conducive for the production of grassy fuels sufficient for carrying ground fires on an annual basis in higher rainfall areas, to once every few years under lower rainfall conditions (Walker 1981; Williams, Griffiths and Allan 2000). Crown fires are typically absent. In some higher rainfall, mesic savannas (ie. regions receiving > 900 mm pa), equilibrium fuel loads may attain 10 t ha^{-1} in 2-3 years without fire (Cook, Hurst and Griffith 1995); however, over much of the region equilibrium fuel loads are significantly less than this. The vast majority of fires start through human ignition, although fires ignited by lightning associated with the onset of monsoonal conditions (typically Nov-Dec) may be a significant source in some locations. In sum, the fire (dry) season of monsoonal northern

Australia, mostly driven by dry south-easterlies, is counter-seasonal to that of southern Australia (spring thru summer).

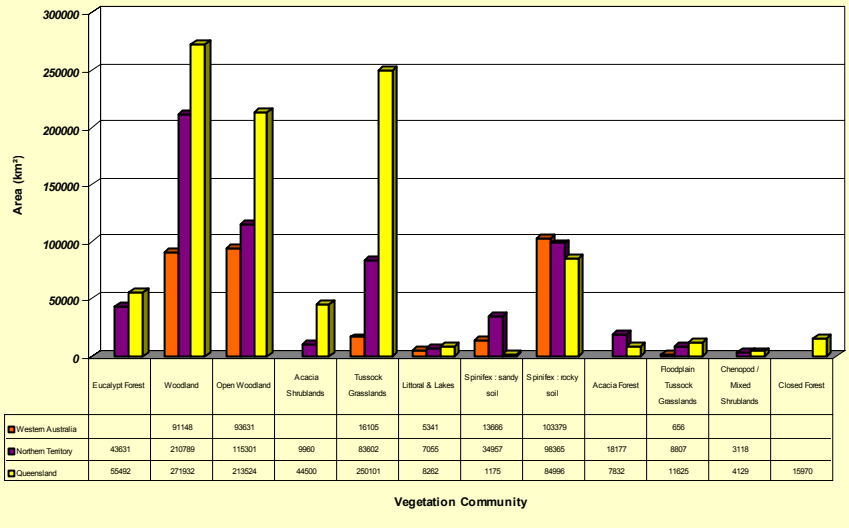
Fig.1: Maps of annual rainfall distribution, vegetation, landuse class, and biogeographic regionalisation, for the Australian tropical savannas region (indicated north of black line on all maps), where: (a) mean rainfall isohyets, 1969-1996 (source: Bureau of Meteorology, quarter degree grid-cell digital database); (b) major vegetation communities, derived from Australian Surveying and Land Information Group (1990); (c) landuse classes derived from Australian Surveying and Land Information Group (1993); and (d) Interim Provincial Regions, from Environment Australia (1996).



Throughout the paper the seasonality of fires in any one dry season is conveniently, if arbitrarily, defined as occurring in the early dry season (EDS), or late dry season (LDS), if fires occur before the end of July, or from August onwards, respectively (e.g. Russell-Smith, Ryan and DuRieu 1997b). Given intra- and inter-annual spatio-temporal variability in rainfall patterning mentioned above, and attendant variability in soil moisture / growing conditions (e.g. McAlpine 1976; McCown 1981), it follows that the distinction between EDS and LDS fires likewise varies considerably across the region. In particular, it may be noted that in north-eastern Arnhem Land, and eastern cape York, burning in some years may not even be able to commence until August or thereabouts. Despite these limitations, the EDS / LDS distinction applied here generally assists to illustrate changes in the seasonality of burning between pre-contact and contemporary fire regimes.

In northern parts of the tropical savannas, vegetation cover is mostly eucalypt-dominated woodland developed on a range of typically nutrient-poor soils, becoming increasingly open-canopied and lower in stature with declining rainfall (Fig. 1b,2). In the south, woodland savannas give way to the vast hummock grasslands of the central Australian dunefields. Other regionally significant vegetation types include: (1) pastorally productive tussock (or 'Mitchell') grassland communities predominantly in western Queensland, with restricted areas in the Northern Territory and Western Australia; and (2) scattered hummock grassland communities developed on rocky infertile substrates (eg. sandstone), with significant components of spinifex (*Triodia* spp.) and a range of typically fire-sensitive shrubby species. Rainforest communities are confined mostly to the humid tropics of north-eastern Queensland, elsewhere occurring as small patches scattered within the savanna mosaic.

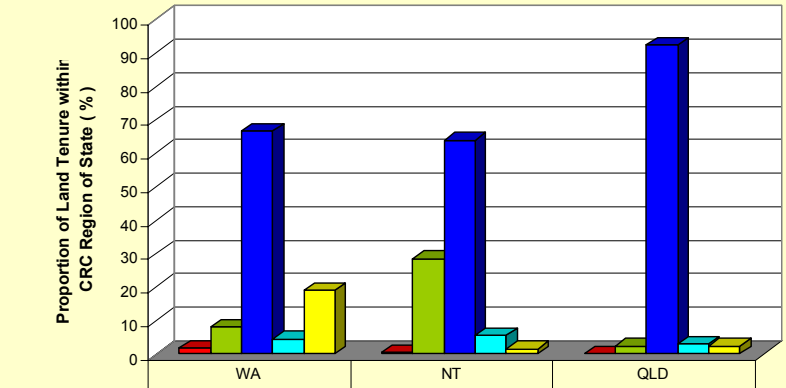
Fig. 2: Extent of major vegetation communities occurring in the tropical savannas region of Western Australia, Northern Territory, Queensland.



Generalised landuse of the savanna lands of northern Australia is given in Figs. 1c,3, and with respect to a recent cadaster in Fig.1d. As indicated below it is useful to distinguish between 'landuse class' and the more problematic issue of tenure, especially given recent legal recognition of the rights of indigenous people to share title ('Native Title') in a range of tenure situations:

- The great majority of land is allocated for pastoral production, especially the grazing of cattle (*Bos taurus* and *Bos indicus*), and also sheep in parts of western Queensland.
- Most of this land is leasehold, although in the Northern Territory leasehold pastoral properties when purchased by Aboriginal people have, from the mid-1970s until recently, been claimable as freehold following successful demonstration of unbroken traditional relationships to the land in question through the land claim process.
- In Western Australia, currently around a third of pastoral properties in the northern savannas are leased by Aboriginal-owned enterprises. Lands allocated to freehold Aboriginal tenure constitute the next most common landuse type, especially in the Northern Territory, followed by unallocated, but claimable through the 'native title' process, Government lands (ie. 'Vacant Crown Land'), especially in Western Australia (Fig. 1c).
- In the Northern Territory, lands set aside for conservation purposes include significant areas under Aboriginal freehold tenure (eg. Kakadu and Nitmiluk National Parks), managed jointly with Federal and Territory Government agencies, respectively.
- Mining is economically by far the greatest regional industry, followed by tourism (Gray 1996).

Fig. 3: Proportion of five major landuse classes occurring in tropical savannas region of Western Australia, Northern Territory, Queensland; VCL = Vacant Crown Land.



	WA	NT	QLD
DEFENCE	1.807062476	0.559102006	0.105487315
ABORIGINAL	7.96709352	28.57328922	2.253271406
PASTORAL	66.7507955	63.83848941	92.43765076
CONSERVATION	4.434613892	5.434725635	2.942524483
VCL	19.04043461	1.594393732	2.261066035

The tropical savanna region as defined here is based on the Interim Biogeographic Regionalisation of Australia (IBRA) of Thackway and Cresswell (1995), and as applied by the Tropical Savannas Cooperative Research Centre. For illustrative purposes the individual biogeographic regions of Thackway and Cresswell (1995) are grouped here as Agro-Ecological Provinces (Environment Australia 1996).

Fire regimes under Aboriginal custodianship at the time of European colonisation

While issues affecting Aboriginal custodianship of the land, rights to legal title, economic development, social development, social justice, health and education are properly part of the contemporary political landscape, so too is it fact that traditional land management systems and practices are applied in increasingly few places in northern Australia. In major part this is attributable to the pervasive culture and lure of pastoralism (Fig. 1c). Regardless, a considerable body of knowledge concerning the use of fire in traditional northern Australian cultures exists through:

- documented, at least for some coastal and sub-coastal, areas spanning northern Australia (e.g. ***QLD***—Thomson 1939; Chase and Sutton 1981; Hill, Buchanan and Laird 1999; ***NT***—Thomson 1949a,b,c; Jones 1975, 1980; Haynes 1985, 1991; Lewis 1985, 1989, 1994; Meehan 1991; Head *et al*. 1992; Lucas and Lucas 1993; Head 1994; Lucas, Gapindi and Russell-smith 1997; Russell-Smith *et al*. 1997a; Yibarbuk *et al*. 2001; ***WA***—Crawford 1982; Mangglamara, Burbidge and Fuller 1991)
- analyses of sparse historical records (***QLD***—Fensham 1997; Crowley and Garnett 2000; ***NT***—Braithwaite 1991; ***WA***—Vigilante 2000)
- and knowledge which continues to be applied into the present (e.g. ***QLD***—Chase and Sutton 1981; Hill, Buchanan and Laird 1999; ***NT***—Stevenson 1985; Head 1994; Bradley, Bayuma and Marrngawi 1997**;** Bridgewater, Russell-Smith and Cresswell 1998; Dhimurru Land Management Aboriginal Corporation 1998 **;** Yibarbuk *et al*. 2001; ***WA***—Saint and Russell-Smith 1998)

The salient points concerning traditional fire practices may be summarised by jurisdiction (states, territory) as follows:

Northern QLD—relatively few documented data are available concerning traditional fire use for most of the tropical savannas region. Both Thomson (1939) and Chase and Sutton (1981) provide ethnographic accounts of the seasonal cycle from parts of Cape York. For the Wik Monkan, on the western side of the Cape, burning off of country was undertaken from towards the end of the season they call *ontjin* (typically mid-March to July), as people started

to move around their estates after the wet season. Burning was undertaken especially in the season of *kaiyam* (July through October), and continued through *turrpak* (October through December) especially in association with macropod hunting drives (Thomson 1939). It is evident that a substantial proportion of respective clan estates was burnt each year (Thomson 1939: 212).

Chase and Sutton (1981) provide a similar account of burning on the eastern side of the Cape, emphasising that burning off of country was undertaken as soon as it dried out, but especially from around June onwards. They note that the burning of open grassy plains around Princess Charlotte bay was undertaken as a collective exercise, and that fire drives for hunting game, macropods especially, was a common feature. Hill, Buchanan and Laird (1999) also provide details of traditional fire practice from the wet tropics region of north-east Queensland.

The historical explorers' record regarding Aboriginal burning has been examined for Queensland generally by Fensham (1997), and for CapeYork specifically by Crowley and Garnett (2000). The latter authors note that the explorers' records provide clear evidence for burning throughout the period May-Oct, consistent with the ethnographic accounts cited above. While Fensham (1997: 17) notes that the explorers' records are "inadequate to make firm conclusions about seasonal patterns of Aboriginal fire in individual vegetation types", he concludes that the records indicate: very high frequency of burning around the Gulf of Carpentaria; also relatively high frequency of burning of most coastal and sub-coastal vegetation types; and relatively infrequent burning in inland Queensland.

Top End of the NT—A considerable body of literature is available, including detailed contemporary accounts (e.g. Yibarbuk *et al*. 2001). However, as for the other two jurisdictions, available accounts describe principally traditional practice in coastal and sub-coastal situations. The Arnhem Land ethnographic record with respect to burning (e.g. Thomson 1949a,b,c; Jones 1975, 1980; Haynes 1985, 1991; Lewis 1989; Meehan 1991; Russell-Smith *et al*. 1997a; Yibarbuk *et al*. 2001) is particularly useful. As detailed in various of above references traditional burning over the seasonal cycle has many facets, from cultural obligations through to the more prosaic demands of hunting and managing resources.

Throughout the Arnhem region burning was/is conducted through the dry season, burning the grass as it cures. In effect, such practice involves burning hills and other higher ground situations where grasses cure first, and then repeatedly burning onto creek margins and other low-lying areas as the country dries. It follows that, as the dry season unfolds, a patchy mosaic of burnt and unburnt ground is created as people move around their own, and kinsmen's, estates. Ethnographic accounts indicate that substantial areas (e.g. as much as one

half of a clan estate) might be burnt in any one year (Leichhardt 1847; Thomson 1949a; Jones 1975, 1982; Haynes 1985; Yibarbuk *et al*. 2001). The accuracy and care with which fire was/is used has been commented upon by a number of authors (e.g. Jones 1975, 1982; Yibarbuk *et al*. 2001).

The peak burning period is associated with relatively cool 'winter' days, around June-July, or the period referred to as *wurrgeng* by Gunwingguan people in north-western Arnhem Land. Burning is also conducted in the hot dry months leading up to the new monsoon, and macropod and emu drives were undertaken at this time. An important point to make, however, is that such burning in the late dry season calls both for considerable preparation from earlier in the burning season, and considerable skill in being able to deploy fires which potentially may readily become uncontrollable. Similar patterns and practices with respect to burning are described for the north-west corner of the NT adjoining the WA border (Head *et al*. 1992; Head 1994), and on the Tiwi Islands (Stevensen 1985).

Based on examination of Top End explorers' records, Braithwaite (1991) demonstrates that burning was undertaken from March through to December, with a major peak of observations recorded in June-July, and a second peak in Oct-Nov before the storms of the new monsoon. In general terms, therefore, the ethnographic and historical records are substantially in agreement.

Kimberley region of WA—Again the record is both sparse and biased. Regardless, the key elements are consistent with observations made both for the Northern Territory and Queensland. The most comprehensive available ethnographic information comes from the vicinity of Kalumburu and Mitchell Plateau, in the coastal and sub-coastal far north-west (Crawford 1982; Mangglamara, Burbidge and Fuller 1991; Saint and Russell-Smith 1998). Crawford (1982: 27) indicates that by the end of the dry season, most clan estates would have been "thoroughly burnt". The account below, which summarises traditional fire management practice around Kalumburu (Saint and Russell-Smith 1998: 9-10), also has general application to many other areas across northern Australia:

> "The major period for burning in traditional society is *yirrma* (broadly May-Aug), the early-mid part of the dry season, when the south-easterlies begin to blow consistently, the grasses rapidly cure (except in receding creeklines and other moist sites), and the nights tend to be cool. This is the best time for *malgarra*, for burning the grass, for "cleaning up the country", when fires can be relatively easily controlled. Burning was/is undertaken in country as it dried out, effectively commencing on higher, well drained ground (particularly the basalt range country), increasingly becoming concentrated around creeklines and other moist sites as the dry season progressed. Burning continued through *yuwala*/*mirringin*, the hot time between Sept-Nov thereabouts, concentrating on remaining unburnt areas along watercourses. Burning ceased come *djarwarl* (broadly Nov-Dec), with the first storms of the monsoon.
>
> Burning was undertaken most places people went to provide for ready travel/access, to clear rank grasses and obtain succulent grassy regrowth for macropods and various other fauna, for

> hunting macropods with fire drives, for burning goannas out of logs, for a range of other purposes. No special attention was given to protective burning of jungle margins; if undertaken early in the season little damage would be done and the aerial parts of yams (eg. *kanmanngu—Dioscorea transversa*; *gunu—Dioscorea bulbifera*) entwined in trees and shrubs would still be locatable.
>
> Burning the country was (and to an extent still is) highly organised. The responsibility for burning/fire management of *gra*, or 'country', rested with senior men with recognised responsibilities for managing each gra. Burning arrangements would be discussed/planned with members of neighbouring gra prior to the burning season, and then thereafter as the dry season progressed. When it was time to burn country, in yirrma, the senior custodians would say *wari ngarrma,* now is the time to start burning. Fire drives were planned in advance, focusing on small areas that could be readily managed, and identifying other areas which were to be left for burning later in the season; such preparations were made with a long tradition of country to draw from.
>
> Fire drives involved burning around areas of unburnt grass, say in a small valley, with the object of driving macropods (eg. *yarrwara*—euros; *walambar*—antilopine kangaroos; *morlngei*—nail tail wallabies), and other animals, towards a small gap for the animals to make their escape and where the hunters with their spears would be waiting. Such fire drives were typically communal and might involve up to ten or so men. Another stratagem involved burning up in the rocks to chase macropods towards a creekline where hunters would be waiting. Hunting macropods with fire drives was a regular practice (maybe every few days) over the burning season. Women burnt as they went around their daily business, including when hunting goannas and generally smaller prey. Such hunting also involved using dogs."

From the historical explorers' record, Vigilante (2000) found that observations concerning the seasonality of traditional burning varied across the region. In higher rainfall, northern regions, burning was recorded from May through to October, with peak levels in june and september. In lower rainfall, southern regions, records of burning commence as early as february-march through to august. No fire observations were recorded for the late dry season period in southern areas.

Summary—Ethnographic, historical and contemporary data concerning the undertaking of traditional Aboriginal burning practices across northern Australia are generally sparse and biased towards coastal and sub-coastal regions. Despite these limitations, a number of conclusions concerning the application of fire regimes under Aboriginal custodianship prior to European colonisation and settlement may be drawn or inferred as follows:

- Burning was undertaken across northern Australia throughout the dry season period
- In many regions (but not north-east Arnhem Land, nor parts of eastern Cape York), burning was concentrated in the early-mid dry season, commencing in upland, run-off areas and situations, and extending generally to lower lying, run-on, moister areas as country progressively dried and fuels cured
- Burning was concentrated in higher rainfall, typically coastal and subcoastal regions, mostly as a function of resource availability and concomitant human population density
- Burning was/is undertaken systematically and purposefully for a diverse range of ecological (ie. resource management) and pervasive social values—burning was not

undertaken to conserve biodiversity *per se* (Braithwaite 1992; Healey 1993; Bradley, Bayuma and Marrngawi 1997)

- Nevertheless, in some situations burning was evidently directed at maintaining certain habitat conditions; for example, open, grassy floodplains (e.g. Leichhardt 1847; Chase and Sutton 1981)
- An essential characteristic of Aboriginal burning was/is that it tended to be highly patchy, and thus provided for the development of relatively fine-grained habitat.

Contemporary fire regimes across northern Australia

As a means for illustrating the contemporary spatial and seasonal patterning of burning across northern Australia, following is presented a landscape-scale assessment of the extent and seasonality of fires during 1997-1999. For these years, mapping of fires was undertaken every nine days through the dry season derived from relatively coarse-ground field of view (1.1 km X 1.1 km^2 pixels at orbital nadir) NOAA-AVHRR imagery (see McMillan *et al*. 1997 for details). See also http://www.ngdc.noaa.gov/seg/globsys/avhrr.shtml for an overview of the NOAA-AVHRR sensor. Mindful of qualifications made previously with respect to fire seasonality, fires occurring up until the middle of July are described here as Early Dry Season (EDS) fires; from August onwards they are described as occurring in the Late Dry Season (LDS). Geographic Information System (GIS) analysis of the patterning of EDS and LDS fires is undertaken here with respect to jurisdiction, vegetation and landuse.

The mapped distribution of fires occurring in the northern Australia savanna region in the EDS and LDS of 1997, 1998 and 1999 is presented in Fig. 4 a,b,c respectively, and the breakdown by State and Territory jurisdictions is given in Fig. 5. In sum, the data indicate that pixels describing 244,000 km^2, 242,000 km^2, and 417,500 km^2 were burnt (at least partly, see below) in these three years respectively, with the greatest *extent* of burning occurring in the NT (mean=168,000 km^2; Table 1a), then WA (mean=77,000km^2) and QLD (mean=55,000km^2), and similar *proportions* of burning occurring both in the NT (mean=26%; Table 1b) and WA (mean=24%), then QLD (mean=5%). Burning across northern Australia has been conducted mostly in the LDS, although in 1999 slightly more burning occurred in WA in the EDS (Fig.5a,b).

Fig.4: Extent of mapped fires in the tropical savannas region for the Early Dry Season (EDS—green) and Late Dry Season (LDS—red) of: (a) 1997; (b) 1998; (c) 1999.

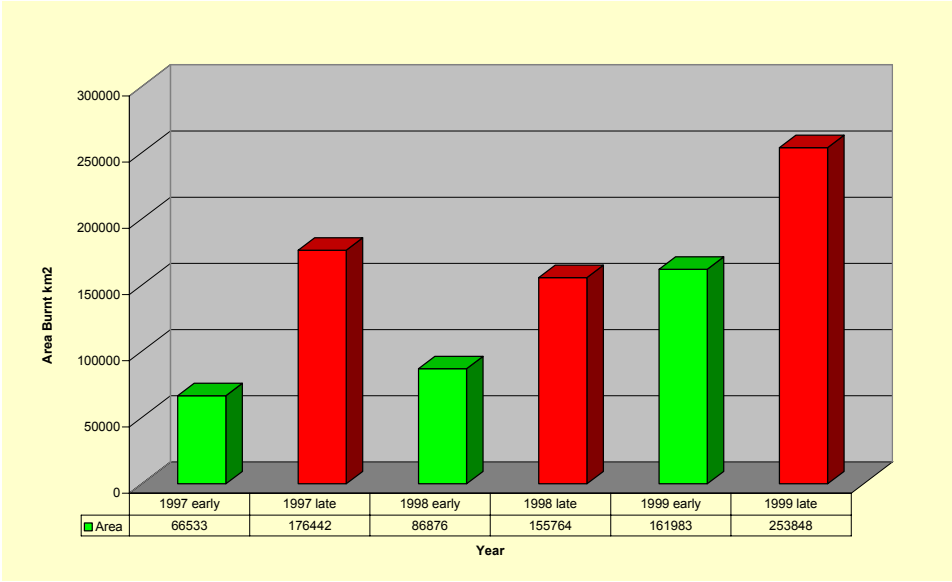
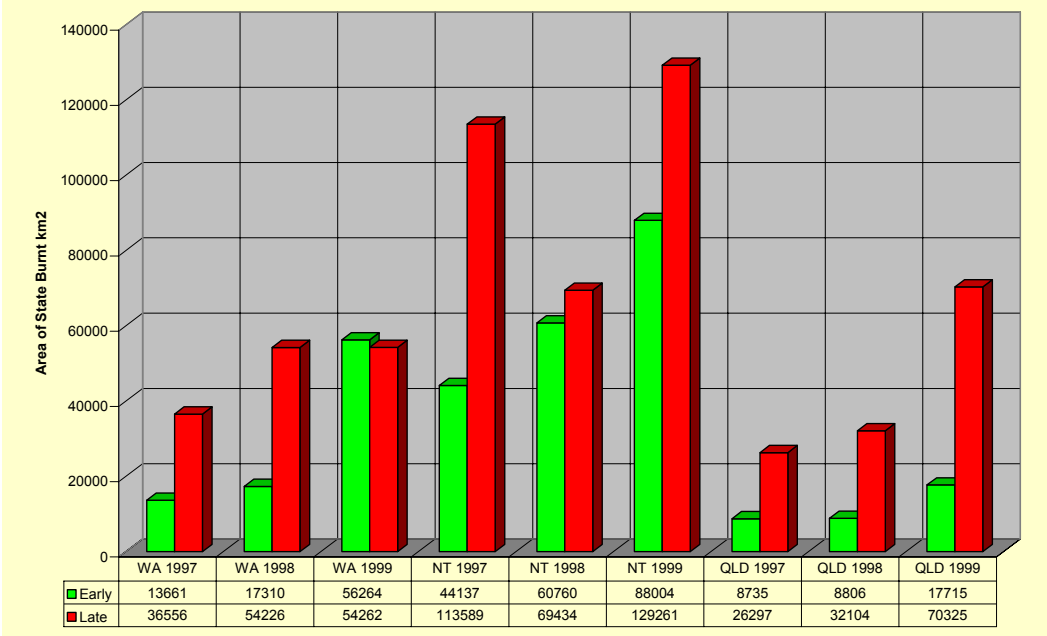


Fig. 5: Early Dry Season (EDS) and Late Dry Season (LDS) burning in 1997, 1998, 1999 for the tropical savannas region in Western Australia, Northern Territory, Queensland: (a) extent; (b) proportion.



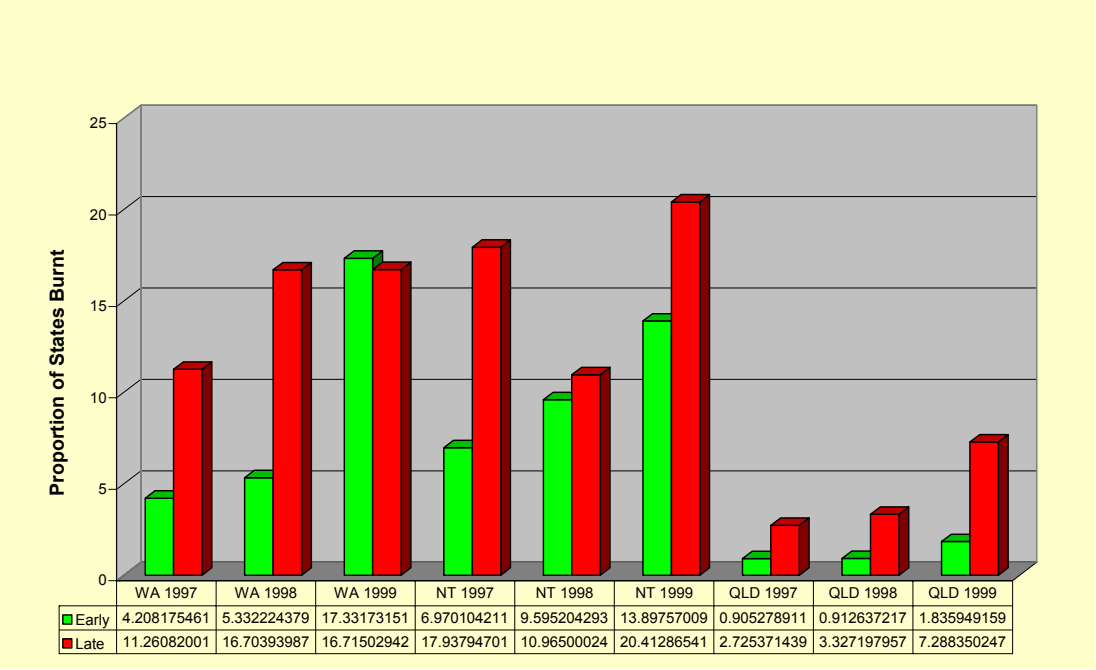


Table 1(a): ***Mean area (km^2) of tropical savannas region burnt by major landuse class in WA, NT and* QLD, *for the period 1997-1999, where: EDS =early dry season (pre August); and LDS=Late dry season***

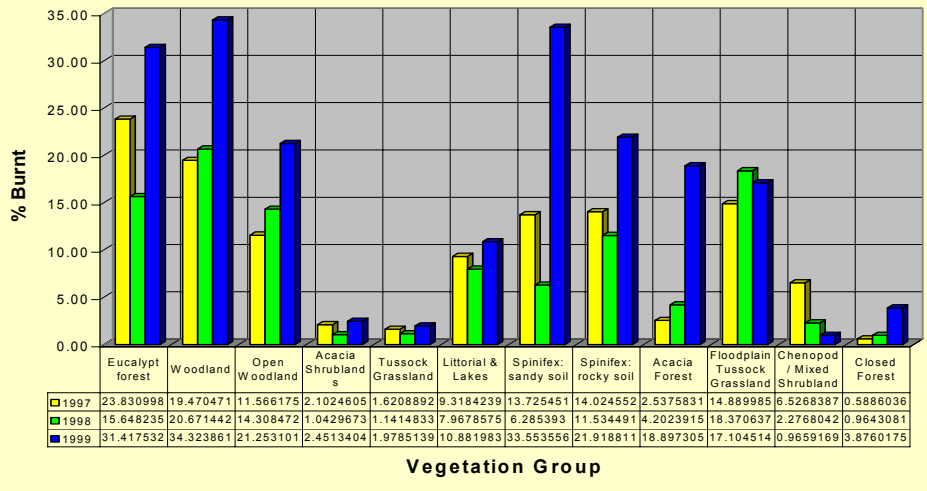
State	Burning season	Landuse class					
		Defence	**Aboriginal**	**Pastoral**	**Conservation**	**Vacant crown land**	**TOTAL**
WA	**EDS**	877	1974	20469	1179	4580	**29079**
	LDS	622	4192	29388	2320	11826	**48348**
	Total	1499	6166	49857	3499	16406	**77427**
NT	***EDS***	1305	19549	35418	7234	794	**64300**
	LDS	635	48639	49026	5152	644	**104096**
	Total	1940	68188	84444	12386	1438	**168396**
QLD	***EDS***	0	1156	9173	1395	28	**11752**
	LDS	52	3620	35446	2561	1230	**42909**
	Total	52	4776	44619	3956	1258	**54661**
Northern Australia	***EDS***	***2182***	***22679***	***65060***	***9809***	***5402***	**105131**
	LDS	***1309***	***56451***	***113860***	***10033***	***13700***	**195353**
	Total	***3491***	***79130***	***178920***	***19841***	***19102***	**300484**

Table 1(b): ***Mean proportion (%) of tropical savannas region burnt by major landuse class in WA, NT and QLD, for the period 1997-1999, where: EDS =early dry season (pre August); and LDS=Late dry season***

State	Burning season	Landuse class					
		Defence	*Aboriginal*	*Pastoral*	*Conservation*	*Vacant crown land*	TOTAL
WA	*EDS*	15	7	9	8	7	**9**
	LDS	10	16	14	16	19	**15**
	Total	25	23	23	24	26	**24**
NT	***EDS***	37	11	9	21	8	**10**
	LDS	18	27	12	15	6	**16**
	Total	55	38	21	36	14	**26**
QLD	***EDS***	0	5	1	5	0	**1**
	LDS	5	16	4	9	6	**4**
	Total	5	21	5	14	6	**5**
Northern Australia	***EDS***	***21***	***10***	***4***	***13***	***6***	**6**
	LDS	***12***	***26***	***8***	***13***	***15***	**10**
	Total	***33***	***36***	***12***	***26***	***20***	**16**

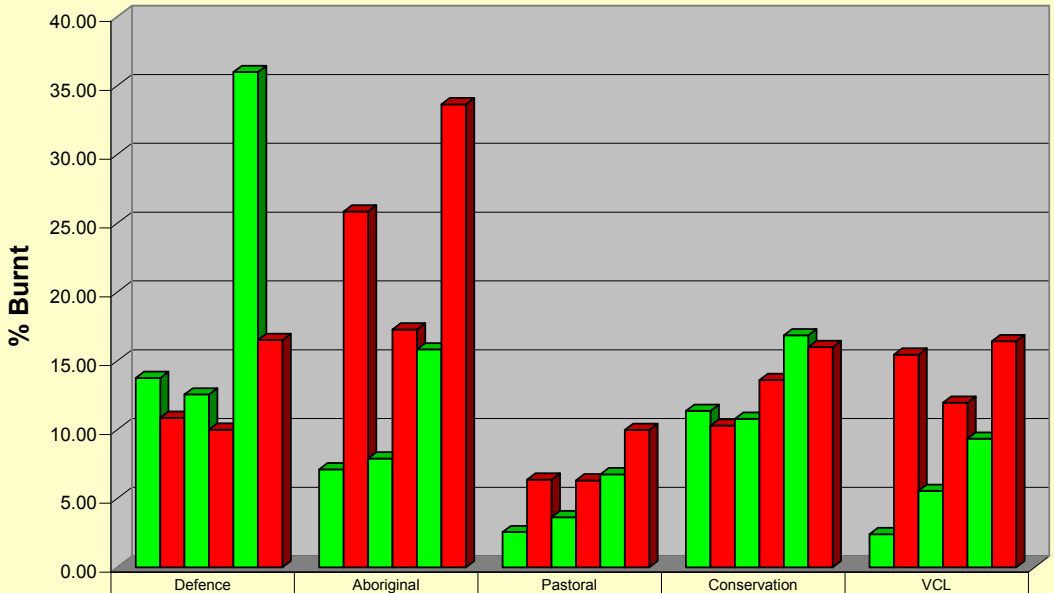
By vegetation types (Fig. 1b) it is apparent that, in all years, least burning (<5%) occurred in closed forest, shrubland, and pastorally productive tussock grassland habitats (Fig. 6). Conversely, relatively large proportions of other habitats were burnt during this period, namely: eucalypt-dominated woodland habitats occurring under relatively high rainfall conditions; and spinifex communities in rocky, typically sandstone habitats (Fig. 6). The relative lack of burning undertaken on pastoral lands is evident when considered also by landuse class (Fig. 7).

Fig. 6: Proportions of tropical savannas major vegetation communities burnt in 1997, 1998 and 1999.



	Eucalypt forest	Woodland	Open Woodland	Acacia Shrublands	Tussock Grassland	Littorial & Lakes	Spinifex: sandy soil	Spinifex: rocky soil	Acacia Forest	Floodplain Tussock Grassland	Chenopod / Mixed Shrubland	Closed Forest
1997	23.830998	19.470471	11.566175	2.1024605	1.6208892	9.3184239	13.725451	14.024552	2.5375831	14.889985	6.5268387	0.5886036
1998	15.648235	20.671442	14.308472	1.0429673	1.1414833	7.9678575	6.285393	11.534491	4.2023915	18.370637	2.2768042	0.9643081
1999	31.417532	34.323861	21.253101	2.4513404	1.9785139	10.881983	33.553556	21.918811	18.897305	17.104514	0.9659169	3.8760175

Fig. 7: Proportions of major landuse classes in the tropical savannas major landuse burnt in 1997, 1998, and 1999.



	Defence	Aboriginal	Pastoral	Conservation	VCL
Early 1997	13.75011895	7.120124041	2.557164477	11.37062566	2.396033269
Late 1997	10.85736036	25.8482491	6.368770733	10.29957582	15.44679036
Early 1998	12.56066229	7.8994614	3.633935121	10.78472959	5.547024952
Late 1998	9.991435912	17.28687231	6.307690063	13.59888653	11.95883984
Early 1999	35.98820059	15.82567144	6.75322746	16.84650053	9.3378119
Late 1999	16.50965839	33.64298279	9.976973715	16.00079533	16.41927916

The above data have a number of qualifications, including difficulties with mapping fires under cloudy conditions at the start of the wet season (Oct/Nov), and estimating the amount actually burnt in any one 1.1 X 1.1 km^2 pixel. Nevertheless, the data illustrate that relatively little burning occurred in Queensland in all three years, especially in the more productive pastoral areas of the tropical savannas. Other data available for the Northern Territory and Western Australia indicate that observations presented here concerning the extent and seasonal distribution (especially LDS dominance) of burning, are typical generally of other years in the 1990s, for these jurisdictions at least (Allan and Willson 1995; McMillan *et al*. 1997; Williams, Griffiths and Allan 2000).

As well as above NOAA-AVHRR data, a number of more localised regional studies have been undertaken, or are underway, using finer resolution LANDSAT MSS and TM imagery. For Kakadu National Park and environs in the high rainfall (*ca*. 1300 mm pa), mesic savanna zone of the Top End of the NT, Press (1988) showed that, for the period 1980-1985, each year over 50% of all lowland forests carried fire. Russell-Smith *et al*. (1997b) show that, for Kakadu NP in the period 1980-1994, a mean of 46% of the park was burnt each year, with most burning undertaken in the EDS. In early years of this same period, most burning

occurred in the LDS. By major landform type, 28% of floodplain and sandstone plateau units, and 55% of the lowland unit, were burnt over this period. Burning of the plateau unit has been concentrated in the LDS, and burning of the lowland unit in the EDS.

In other mesic savanna areas of the Top End, Edwards *et al*. (2000) show that 56% of Litchfield, and 40% of Nitmiluk National Parks, were burnt on average each year over a decadal period commencing in the late 1980s. Most burning in Litchfield has been undertaken in the EDS, and most burning in Nitmiluk in the LDS. Elsewhere in the Top End, work in progress by Cameron Yates and colleagues shows that over 40% of Bradshaw Station (ca. 700-900 mm pa), and approx. 20% of the Victoria River District (VRD) region (ca. 600-700 mm pa) have been burnt on average over 10 year, and nearly 20 year, study periods, respectively. In the case of the VRD region, the lack of burning on more arable pastoral lands is a conspicuous feature.

Ecological responses to changes in fire regime from Aboriginal to contemporary practice

From the previous two sections it will be apparent that substantial differences exist between burning patterns and fire regimes under Aboriginal custodianship and contemporary landuse. At least for coastal and sub-coastal parts of northern Australia, burning of country is likely to have been seasonally intensive under traditional practice given pre-contact population density estimates from 1 person per 8 km2 (Keen 1980) to as high as ca. 0.8 (Lourandos 1980) to 1-2 (Jones 1985) persons per km2. Patterns of settlement today are either far more aggregated in urban centres, or diffusely scattered across the remainder of the landscape. Major differences (and similarities) between traditional Aboriginal and contemporary fire regimes may be summarised as follows:

- Whereas burning was undertaken across northern Australia under Aboriginal custodianship, burning today is concentrated principally in non-pastoral, relatively high rainfall regions, especially in the Kimberley, in the Top End, and around the Gulf of Carpentaria
- Whereas burning in most regions traditionally was concentrated in the early-mid dry season, today it generally occurs mostly in the LDS. Generalisation of the contemporary situation, however, masks considerable EDS burning in some limited locations (e.g. Darwin region, Kakadu and Litchfield National Parks); and inability to burn until later in the year in north-east Arnhem Land, and parts of eastern Cape York peninsula
- Whereas it is evident that burning traditionally was/is undertaken systematically for a diverse range of purposes, today where burning occurs it often emanates from uncontrolled wildfire

- Whereas an essential feature of Aboriginal burning was/is that it tended to be highly patchy and thus contributed to developing habitat heterogeneity, today northern Australian savanna landscapes are either burnt frequently by typically intense, extensive fires, or seldom burnt (e.g. QLD, pastoral landscapes)

Ecological responses to these changed/changing circumstances may be conveniently considered to follow the two broad contemporary patterns of burning outlined above.

Frequently burnt northern Australian landscapes

With respect to those northern Australian savanna landscapes now ravaged by frequent fires, various lines of evidence indicate that relatively fire-sensitive plant species and communities are under severe pressure. Thus, a number of studies have, or are demonstrating that contemporary LDS fire regimes are incurring significant impacts on small rainforest patches (McKenzie and Belbin 1991; Russell-Smith and Bowman 1992), and relatively fire-sensitive, long-lived, obligate seeder species (*sensu* Gill 1981—ie. species which can regenerate only from seed once aerial stems are killed by fire) such as Cypress Pine—*Callitris intratropica* (in the NT—Bowman and Panton 1993; Yates, Russell-Smith and May 2000; A. Edwards *et al*., pers. comm.; in WA—G. Graham, pers. comm.) and lancewood (*Acacia shirleyi*) in the NT (Woinarski and Fisher 1995).

Frequent LDS fires are also known to be impacting heathy communities occupying sandstone and other sedimentary formations in the Top End and the Kimberley especially. Russell-Smith *et al*. (1998) have shown that the majority of shrub species associated with heaths of the Arnhem Plateau are obligate seeders, and that many of these have primary juvenile periods (ie. the time taken from germination to first seed production) of 5 years and more. Further work has demonstrated: (1) significant impact of fires recurring at short periods (e.g. three years) on populations of obligate seeder heath shrubs; and (2) when addressed in a regional context employing GIS analysis of fire regime data for a 16 year period in sandstone terrain in Kakadu National Park, 79% of the area (n=3,963 km^2) had been burnt at least once by recurring fires within 3 years, and 70% had been burnt with maximum recurring intervals of just 5 years (Russell-Smith, Ryan and Cheal, 2000).

Similar concerns have been expressed with respect to the status of dependent sandstone fauna, for example Leichhardt's Grasshopper (*Petasida ephippigera*; Lowe 1996), and the White-throated Grass-wren (*Amytornis woodwardi*; Woinarski 1992). Leichhardt's Grasshopper is notable by virtue of its reliance on food-plants of the genus *Pityrodia*, most species of which are restricted to very localised occurrences in sandstone heath. The White-throated Grass-

wren is also notable in its reliance on relatively long-unburnt areas of sandstone heath habitat, especially the occurrence of large *Triodia* hummocks (Noske 1992).

Williams, Griffiths and Allan (2000) provide a recent review of impacts of burning with respect to northern Australian eucalypt-dominated savannas. Such vegetation types are highly resilient in the face of frequent low- to moderate intensity fires; fire regimes dominated by frequent LDS fires, however, have major effects, as they describe below:

> "Within the eucalypt-dominated savannas, there are also considerable impacts of late dry season fires on the trees. Tree mortality increases linearly with fire intensity (Williams 1995; Williams *et al.* 1999). There is clear differential species susceptibility to the more intense fires. Stem mortality in the deciduous, broad-leaved trees (e.g. *Terminalia*), and the bloodwood group of eucalypts (e.g. *Eucalyptus porrecta*) is higher at fire intensities of 7-20,000 kWm^{-1} than is mortality in the dominant eudesmid group of eucalypts (e.g. *E. miniata*; Lonsdale and Braithwaite 1991; Williams *et al.* 1999). Late dry season fires can also reduce the floral and fruit reserves across all functional groups of tree by more than 50% for 2-5 years (Setterfield 1997; Williams 1997). The impact of such a regime on structure and phenology not only reduces diversity and potentially inhibits regeneration of the dominant trees, but it may reduce habitat suitability for fauna.
>
> Late dry season fires, via the incremental effect on tree mortality, and therefore biomass (Cook 1994; Hurst *et al.* 1996) may also reduce the nutrient capital of the savanna. Late dry season fires may increase surface run-off and erosion at the time of the first rains, due to reduced ground cover (Townsend 1997). This may increase the pulses of nutrient into small streams at the commencement of the wet season, with consequent increases in the diversity of aquatic invertebrate biota (Douglas 2000).
>
> What are the impacts of early dry season fires? Evidence is accumulating that the landscape-scale impacts of such a regime are either relatively benign or indeed advantage some elements of the biota. The Munmarlary and Kapalga fire experiments (Bowman *et al.* 1988; Andersen *et al.* 1998) have indicated relatively few impacts on: understorey composition and diversity (Bowman *et al.* 1988; Williams 2000), the density and survival of woody sprouts (Williams 2000), tree basal area and mortality (Williams *et al.* 1999; Williams 2000), and water quality (Townsend 1997). There appear to be variable impacts on tree reproductive phenology. The dominant trees, which flower in the mid-dry season (Williams 1997), continue to flower and set fruit in the weeks and months following early dry season fires, and flowering and fruiting is not reduced in the year(s) following annual early dry season fires (Williams 1997). However, seed output may be reduced in the dominant eucalypts following early dry season fire (Setterfield 1997), and the recruitment of seedlings may be inhibited by annual early dry season fire.
>
> Does fire frequency matter? The impacts of repeat late dry season fires have been highlighted above, but what about frequent low intensity, early dry season fires? Such fires have been hypothesized to represent a bottleneck to recruitment (Hoare *et al.* 1980; Braithwaite and Werner 1985; Werner 1986), by regularly destroying the tree seedling and small sapling bank, and/or preventing the recruitment of saplings into the tree canopy. However, on the basis of stand population structure, Fensham and Bowman (1992), discounted this hypothesis in the tall humid savannas on deeper soils on Melville Island. On poorer soils, e.g. those with low nutrients, or seasonally inundated, frequent fire may suppress woody species, and prevent the development of a tree stratum (Wilson and Bowman 1993). Williams (2000) showed no reduction in the size of the seedling and short sapling bank due to annual fire (early or late), compared with unburnt treatment, in all of the major tree species at Kapalga. However, Setterfield's (1997) data suggest that some years without fire may be necessary for seedling recruitment of the dominant trees in mesic savannas.
>
> With respect to the grass layer, both Williams (2000) and Bowman *et al.* (1988) detected no overall differences in the composition of the ground stratum of mesic savannas over 5-15 year periods in annually burnt savannas, compared with unburnt savannas. At Kapalga, the main changes in composition were driven by variation in annual rainfall. Annual burning may

> decrease the yield of some perennial grass pastures in the semi-arid savannas, but biennial burning had little impact on these variables (Mott and Andrew 1985). In the semi-arid savannas in the Victoria River District of the NT, Dyer *et al.* (1997) have indicated the importance of soil type and land condition as determinants of fire response in pastures. Annual-biennial fire had little impact on composition and productivity on tussock grasslands of the black soil plains. In contrast, the impact on savanna woodlands on red soils depended on condition. Red earths in poor condition – low cover of perennial grasses, and a high cover of annuals and bare ground – suffered subsequent declines in condition after fire, whereas red earths in good condition showed few effects of fire."

While different faunal groups and species exhibit a range of requirements, preferences, or tolerances for different fire regime components (see Williams, Griffiths and Allan 2000), it is generally recognised that savanna faunal biodiversity is best conserved in those landscapes where fire regimes themselves are highly patchy both in space and time, providing for a range of burnt, through to long unburnt, conditions (Woinarski 1990, 1997; Braithwaite 1995; Russell-Smith *et al*. 1997b; Woinarski and Recher 1997). There is evidence, for example, that at least some mammal species occur preferentially in structurally diverse, resource-rich (e.g. diversity of fruiting trees; availability of hollow logs), little fire-perturbed, eucalypt-dominated formations (e.g. Kerle 1985, 1998; Friend 1987). The grim reality is that there is evidence for contemporary catastrophic faunal loss across the savannas associated with intensifying land use generally (Finlayson 1961; Kitchener 1978; McKenzie 1981; Woinarski *et al*. 2000).

A further, compounding issue in these fire-prone savanna regions has been the introduction of highly invasive, high biomass, flammable, typically perennial agricultural plants (eg. the grasses Gamba grass—*Andropogon gayanus*, Para grass—*Urochloa mutica*, Mission grass—*Pennisetum polystachyon*). Such species have the potential to transform savanna fire regimes (e.g. significant increases in fuel load and fire intensity; also take longer to cure, thus extending the fire season), and hence promote ongoing degradation of woody vegetation types (Lonsdale 1994; Panton 1993). Such invasion and transformation is a global phenomenon (D'Antonio and Vitousek 1992).

Infrequently burnt northern Australian landscapes

By contrast, relatively little burning is undertaken in many other regions of northern Australia, especially on more arable lands under pastoral management (Craig 1997, 1999; Grice and Slatter 1997; Dyer *et al*. 1997; Landsberg 1997; Jacklyn and Russell-Smith 1998). Such regimes, especially the reduced use of intense, shrub-killing fires, in combination with sustained grazing pressure, has resulted in major woody thickening in various regions across northern Australia—particularly in relatively densely settled, predominantly pastoral western QLD (Figs. 1c,1d). Woody thickening comprises both native (eg. *Acacia*, *Eucalyptus,Terminalia, Eremophila, Melaleuca*) and exotic species (e.g.*Acacia nilotica*,

Cryptostegia grandiflora, *Parkinsonia aculeata, etc.*). It is a significant issue affecting pasture, hence pastoral, production across eastern inland, and northern Australia (e.g. Burrows *et al*. 1990; Hodgkinson 1991; Scanlan *et al*. 1991; Craig 1997, 1999; Crowley and Garnett 2000). Woody change issues are central also to national and international greenhouse debates.

Changes in habitat conditions, including woody thickening and over- or selective grazing of grass resources, have had profound consequences for certain faunal groups, notably the collapse of granivorous bird populations (Franklin 1998). In specific cases, the decline of granivorous avifauna can be correlated directly with reduced use of fire, grazing of key grass food resources, and associated woody thickening and changed habitat conditions (e.g. Golden-shouldered Parrot: Garnett and Crowley 1995). Further, it is apparent in some regions that critical areas of grassland habitat are rapidly disappearing under woody plant encroachment (e.g. Cape York Peninsula; Neldner 1999). As considered above, however, the reduced use of fire in most pastoral contexts forms only part of the overall impact on native biodiversity associated with ever-increasing habitat modification and landuse intensification.

Concluding remarks

The preceding discussion raises a number of important implications both for fire management of tropical savanna systems, as well as ongoing research requirements. I conclude with the following observations:

- with respect to fire management of tropical savannas, by far the most important requirement for conservation of biodiversity is the imposition of patchy management regimes. No single fire regime, nor spatial scale, will suffice for all species; rather, imposition of a fine-grained mosaic will optimise habitat diversity. To date, outside of a small number of examples where such fine-grained management is undertaken, notably on indigenous lands (e.g. Yibarbuk *et al*. 2001), this ideal is still to be realised.
- with respect to research, there are a number of obvious requirements:
    1. further documentation and assessment of traditional Aboriginal burning practices, particularly in inland areas;
    2. ongoing assessment of contemporary fire regimes with reference to continental-scale satellite monitoring—this consultancy demonstrates this general requirement; and
    3. further assessment of the impact of contemporary fire regimes on targeted, fire-sensitive components of the biota, particularly the fauna (e.g. Woinarski, Milne and Wanganeen 2000).

Effective fire management is a critical requirement for conservation of northern Australian ecosystems.

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