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Modelling fire dynamics in the West MacDonnell Range area

Karen King
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Working Paper 20

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Contributing author information

Karen King: The Fenner School of Environment and Society, The Australian National University, Canberra

Jon Marsden-Smedley: The Fenner School of Environment and Society, The Australian National University, Canberra

Geoff Cary: The Fenner School of Environment and Society, The Australian National University, Canberra

Grant Allan: Bushfires NT, NRETA, Alice Springs, and Desert Knowledge Cooperative Research Centre

Ross Bradstock: University of Wollongong

Malcolm Gill: The Fenner School of Environment and Society, The Australian National University, Canberra

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For additional information please contact

Desert Knowledge CRC

Publications Officer

PO Box 3971

Alice Springs NT 0871

Australia

Telephone +61 8 8959 6000 Fax +61 8 8959 6048

www.desertknowledgecrc.com.au

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Synopsis

This sub-project was concerned with implementing the FIRESCAPE landscape fire regime and vegetation dynamics model (Cary 2002; Cary et al. 2006; King et al. 2006) in the West MacDonnell Ranges in Central Australia. The study area is 4.1 million hectares, and is located about 40 km west of Alice Springs. It includes parts of Napperby, Aileron and Henbury pastoral stations, the West MacDonnell Range (west of about Standley Chasm), Finke Gorge National Park and the south-eastern half of Watarrka National Park. This study area contains a diversity of vegetation communities, each experiencing different historic fire regimes and having different requirements for fire. This, together with the diversity of land tenures and hence management objectives makes a fire regime model of this region a valuable research tool for investigating fire regime drivers, fire and land management outcomes, and the potential impacts of climate change and invasion by exotic weed species.

The development of FIRESCAPE for this study region involved collating background input GIS data layers (elevation, slope, vegetation, fire history and land tenure) and algorithms pertaining to weather, vegetation and fire history and behaviour.

Weather was included by looping 50 years of observed meteorological data from Alice Springs airport. Spatial variations in weather were based on algorithms derived by analysing correlations between weather data from Alice Springs airport and seven weather stations on and around the study area (Curtin Springs, Palm Valley, Tempe Downs, Uluṟu Rangers Station, Watarrka, Yuendumu, and Yulara airport), and incorporating spatial variability in elevation, longitude and latitude.

Vegetation types were summarised from the functional groups identified at a three-day workshop on fire and vegetation dynamics held in Alice Springs in November 2005 (Marsden-Smedley et al. in prep). Vegetation was mapped using polygons from a combination of pre-existing maps. Where no suitable pre-existing vegetation maps were available, on-screen digitising was performed and verified to 92% accuracy by ground-truthing at over 500 points.

A detailed fire history for the study was collated for the period between 1955 and 2003. Fire maps were pre-existing for this period, being a combination of mapped fire boundaries and those derived more recently from Landsat imagery (Grant Allan unpublished data). Due to the extensive areas burned between 21/06/2000 and 05/01/2003, and the complexity of boundaries for these fires, fires during this period were mapped using a classification method between different images. The resultant fire history GIS layer was used to initialise the modelled vegetation age, and validate model outputs pertaining to fire frequencies, fire behaviour and fire sizes.

Fire behaviour is influenced by a diversity of factors, including weather, topography and vegetation and fuel characteristics. The study area is dominated by spinifex and mulga communities, with ephemeral native grasses occurring only following periods of above average rainfall. These annual grasses provide a continuous fuel array where normally fuels are minimal below mulga stands or sparse between spinifex tussocks. Further, vegetation in this region exhibits high levels of annual growth following sufficient rainfall, and minimal or no growth during drought years. Fuel calculations were therefore based on the annual vegetation growth rather than the actual age of the vegetation. Ephemeral grasses were included in fuel calculations following high rainfall periods, and buffel grass was included where it occurs. Published fire behaviour algorithms were utilised to model fire spread across the simulated landscape. Consequently large fire events in this region are observed predominantly after periods of high rainfall, and this phenomenon has been successfully captured in the model.

This project has resulted in the development of detailed vegetation and fire history GIS layers for the study area, in addition to the parameterisation of a fire regime and vegetation dynamics simulation model. This model is a useful tool for which there is considerable scope for further management-oriented research. For example, it is possible to simulate the effects of buffel grass spread, and grazing on pastoral lands on fuel load dynamics and hence on fire regimes in the study area. Further, the effectiveness of alternate fire management practices for parks and Aboriginal lands can be evaluated in light of meeting biodiversity, cultural and property protection objectives. The impact of climate change on fire regimes and management values can also be explored. The FIRESCAPE model has been developed with these options in mind, and implementation of each of these is possible with minimal further model development or refinement to address specific research questions.

Objective

FIRESCAPE is a process-based model for simulating fire regimes in landscapes (McCarthy and Cary 2002; Cary et al. 2006). It simulates fire events according to empirical models of ignition location, fire spread and fuel dynamics, and according to temporal variation in weather and spatial variation in terrain. It has been implemented in the Australian Capital Territory region (Cary 2002), south-western Tasmania (King et al. 2006), and Glacier National Park, Montana (Cary 2003).

Fire regime modelling is central to understanding the implications of management, climate change and invasive species for fire regimes in central Australia. These are critical considerations for addressing the impacts of fire in the desert, a major objective of the DesertFire Project of the Desert Knowledge Cooperative Research Centre.

The objective of this sub-project was to implement the FIRESCAPE fire regime simulation model for the West MacDonnell Range Landsat scene in Central Australia.

Study location

The study area is located about 40 km west of Alice Springs and consists of an oblique polygon 4.1 million ha in size (Figure 1a). The area is covered by Landsat path 103, row 76 and part of row 77 (Figure 1b). This site includes parts of Napperby, Aileron and Henbury pastoral stations, the West MacDonnell Range (west of about Standley Chasm), Finke Gorge National Park and the south-eastern half of Watarrka National Park.

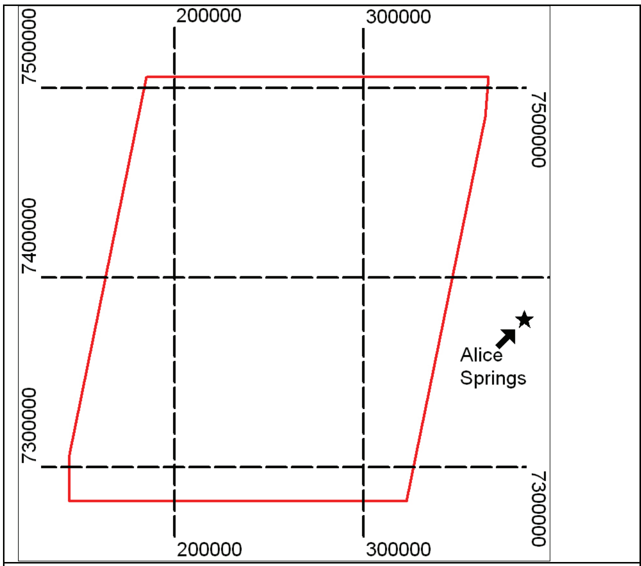

Figure 1a: Location of the study area

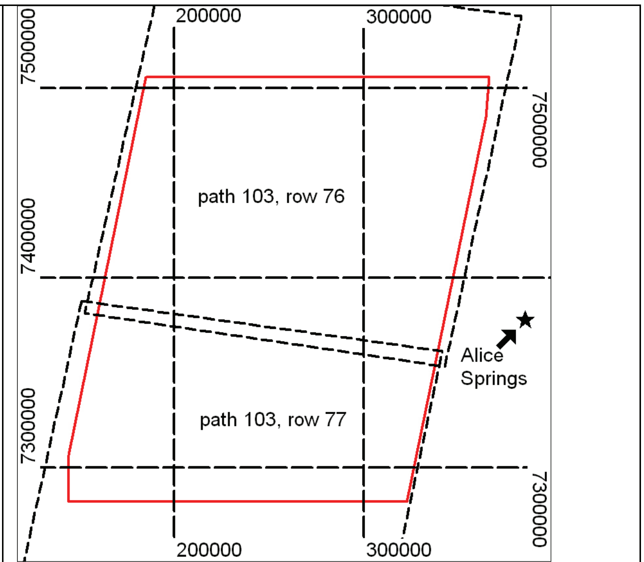

Figure 1b: Correspondence with Landsat images

The study site is divided into two zones. The inner zone is comprised of a 4.1 million ha polygon where information on vegetation, topography and fire history has been mapped. The outer zone (Table 1) provided a regular shaped region within which fire modelling was conducted.

Table 1: Study area boundary coordinates

Corner	Easting	Northing
North-west	144 300	7 505 900
North-east	365 900	7 505 900
South-west	144 300	7 282 100
South-east	365 900	7 282 100

Grid reference datum: GDA94/53.

All of the mapping uses the GDA94/53 datum. The generation of maps for the vegetation and fire history polygons was performed using MapInfo version 7.8.

The Landsat images included the Australian Greenhouse Office composite images for 1972, 1980, 1985, 1988, 1989, 1991, 1992, 1995 and 2000 along with images for 02/04/2000 to 21/06/2000 (composite image), 28/09/2001, 23/03/2002, 13/07/2002, 30/08/2002, 15/09/2002, 18/11/2002 and 05/01/2003. The images from 1972, 1980, 1985 and 1988 have a 50 m pixel size while all of the subsequent images have a 25 m pixel size.

The terrain model for simulation is presented in Figure 2. Datasets depicting major and minor roads, bores, and land tenure were digitised and are presented in Figure 3.

Vegetation mapping and validation

Vegetation types were summarised from the functional groups identified at a three-day workshop on fire and vegetation dynamics held in Alice Springs in November 2005 (Marsden-Smedley et al. in prep) (Table 2). Vegetation was mapped using polygons from a combination of pre-existing maps shown in Figure 4 and Table 3, with on-screen digitising performed where no suitable pre-existing maps were available.

Where the vegetation has been mapped using on-screen digitising (Area 1 in Figure 4), the majority of the mapping was done using the image composite taken between 02/04/2000 and 21/06/2000. This was the most recent image not affected by the extensive fires which occurred in the study area between 21/06/2000 and 05/01/2003.

The mapped vegetation types and the location of boundaries between vegetation types were ground-truthed at over 500 points. These points were located along more than 1000 km of roads and/or tracks. The location of the points used to ground check the vegetation map are shown in Figure 5.

The vegetation map matched the observed vegetation from ground-truthing 92 percent of the time (Table 4). Further, the mapped and actual locations of boundaries between vegetation types was found to agree within 50 metres 75 percent of the time, and within 250 metres 94 percent of the time. The accuracy of different source maps is also indicated in Table 4. The survey data was used to correct the vegetation map (Figure 6) in places.

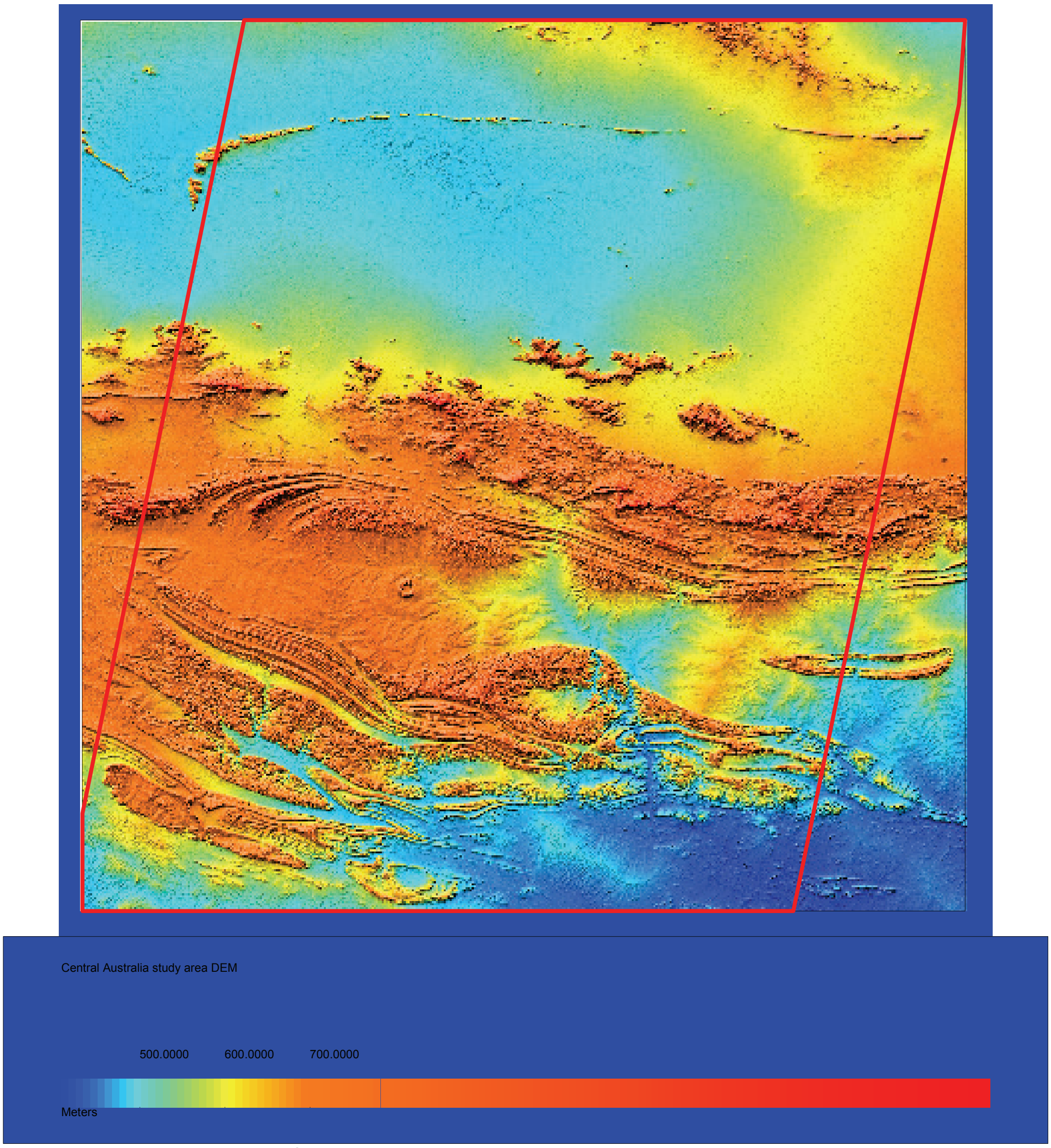

Figure 2: Digital elevation map of the West MacDonnell Range study area.

The horizontal distance across the bottom of the image is 225 km; North is to the top of page

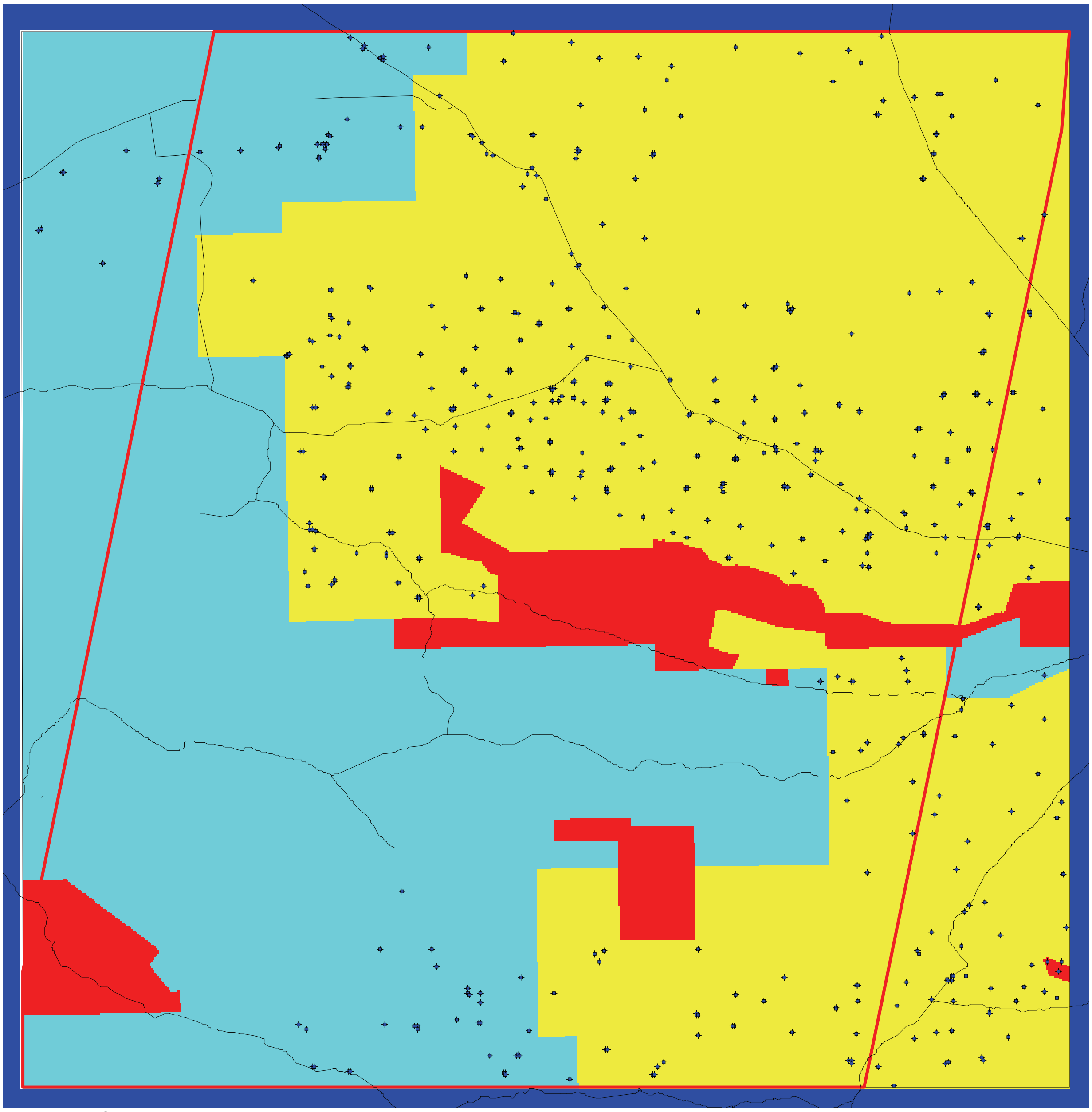

Figure 3: Study area map showing land tenure (yellow = pasture, red = park, blue = Aboriginal lands), roads and bores.

Areas with higher densities of bores are generally more heavily and more frequently grazed.

Table 2: Vegetation types identified at the workshop on vegetation and fire dynamics in the study area held in November, 2005.

				Landscape	Fuel char		Buffel	Pastoral	Fire	Fire
Id	Num	Habitat	Dominant vegetation	freq	load	freq	potential	value	dependant	freq
30	1.1	sand plain, sand dunes, swales	spinifex grassland	H-VH	H-VH	H	VL	VL	Y	VH
31	1.2	sand plain, swales	mulga-spinifex mosaic	H	M-H	M	VL	VL	Y	M-H
32	1.3	sand plain, swales	mulga woodland	VH	L-M	L-M	VL	VL	Y	L-M
33	1.5	sand dunes and sand plains	desert oak woodland	H	VH	H	L-M	VL	N	H
34	2.1	red soil plains	mulga woodland	VH	M	L	VL	VL	Y	VL
35	2.2	sandy loam plains	mulga open woodland	VH	M-H	L	L-M	M	Y	L
36	3.1	hills	spinifex grassland	H	H	VH	VL-M	VL	Y	VH
37	3.2	hills	shrubby, minor spinifex	H	M	L-M	VL	VL	Y	L-M
38	3.3	hills	woodland	H	M	L-M	VH	M	Y	L-M
39	3.4	hills	shrubby and grassy	H	M-H	L	M-H	L-M	Y	L-M
40	4.1	major river channels	red gum, coolabah	M	VH	VH	VH	VH	N	H-VH
41	4.2	minor river and creek channels	Melaleuca	M	H	H	H	H	N	H
42	4.3	channel floodplain and floodouts	coolabah, red gum, mulga	M	VH	M	L-M	VH	N	M
43	5.1	fertile alluvial plains	open grassy woodland	H	H	L	VH	VH	?	L
44	5.2	cracking clay plains	Mitchell grass	M	VH	H	L	VH	Y	M
45	6	saline plains, salt lake margins	chenopods, samphire	L-VL	M-H	VL-H	L-M	L-M	N	VL-H
46	8	salt lakes	non-vegetated	L	-	-	-	-	-	-
99	-	outside the study site	-	-	-	-	-	-	-	-

Note: the id is the vegetation identification number used in the FIRESCAPE model; the num is the vegetation number used in the vegetation map; VL = very low, L = low, M = moderate, H = high, VH = very high, Y = yes, N = no, V = variable response, ? = unknown response.

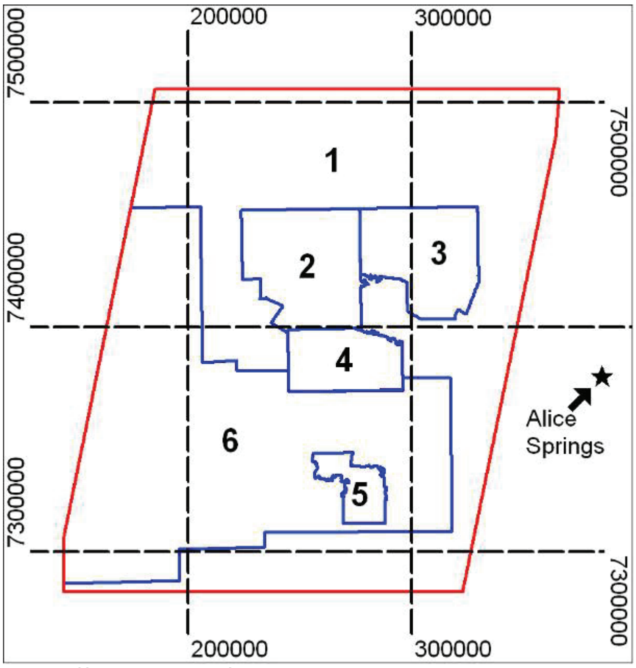

Figure 4: Data sources used in different areas for developing the West MacDonnell Range study area vegetation map.

Map datum: GDA94/53, 100 km grid lines and graticule shown. See Table 3 for an explanation of the different data sources.

Table 3: Data sources used to generate the West MacDonnell Range study area vegetation map.

Source	Area covered ha	Area covered %	Notes
1	1 929 820	47.0	Mapped by on-screen digitising of Landsat bands 2, 4, 7, path 103, row 76 and 77 (part); majority of polygons digitised from the image composite taken between 02/04/2000 and 21/06/2000, full image date range used: 1972 to 05/01/2003.
2	255 170	6.2	Bowman M and Villiger R 1995. The land resources of Narwietooma Station. Technical Memorandum 94/7. Northern Territory Department of Planning and Infrastructure, Alice Springs.
3	215 790	5.3	Grant AR 1989. The pastoral land resources of Amburla Station. Technical Memorandum 89/3. Northern Territory Department of Planning and Infrastructure, Alice Springs.
4	134 760	3.3	Ormiston Gorge National Park Bio-physical Vegetation Map. Parks and Wildlife Service, Department of Natural Resources, Environment and the Arts, Alice Springs.
5	63 060	1.5	Finke Gorge National Park Bio-physical Vegetation Map. Parks and Wildlife Service, Department of Natural Resources, Environment and the Arts, Alice Springs.
6	1 507 560	36.7	Nelson DJ 1985. Vegetation of the lands of the western MacDonnell Ranges, Central Australia, NT. CSIRO, Alice Springs.
Total	4 106 160		

Table 4: Vegetation type and boundary accuracies from the vegetation map ground-truthing.

Data source		vegetation accuracy	vegetation boundaries in different accuracy classes <50 m	50 to 100 m	100 to 250 m	250 to 500 m	>500 m
1	this project	92	75	3	16	3	3
2	Narwietooma	100	88	-	12	-	-
3	Amburla	81	78	11	11	-	-
4	Ormiston	80	100	-	-	-	-
5	Finke	100	100	-	-	-	-
6	Hermannsburg	70	67	10	10	8	5

Note: table shows the percentage of times that the mapped vegetation and/or boundary location was correct for the different data sources (Table 3) used to generate the vegetation map.

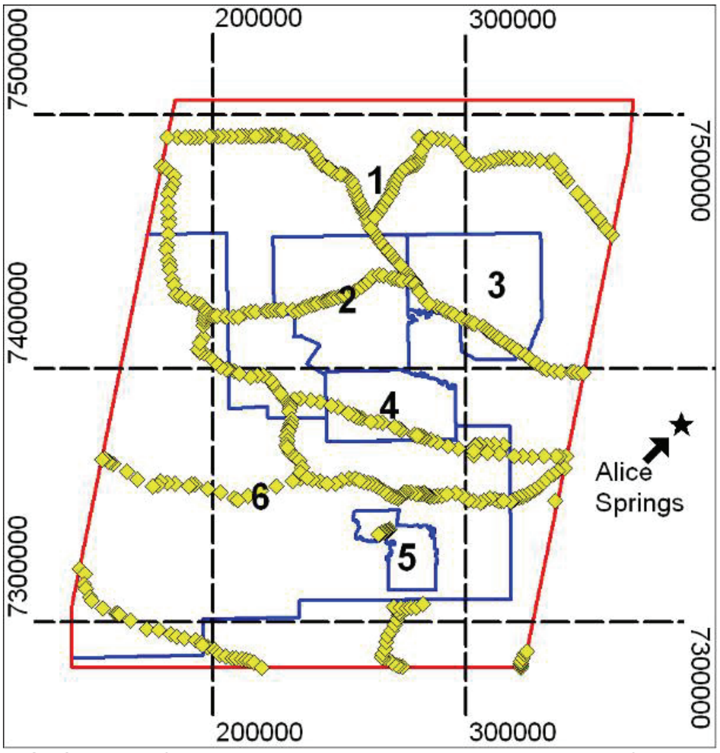

Figure 5: Location of the GPS points for ground-truthing the vegetation map of the West MacDonnell Range study area

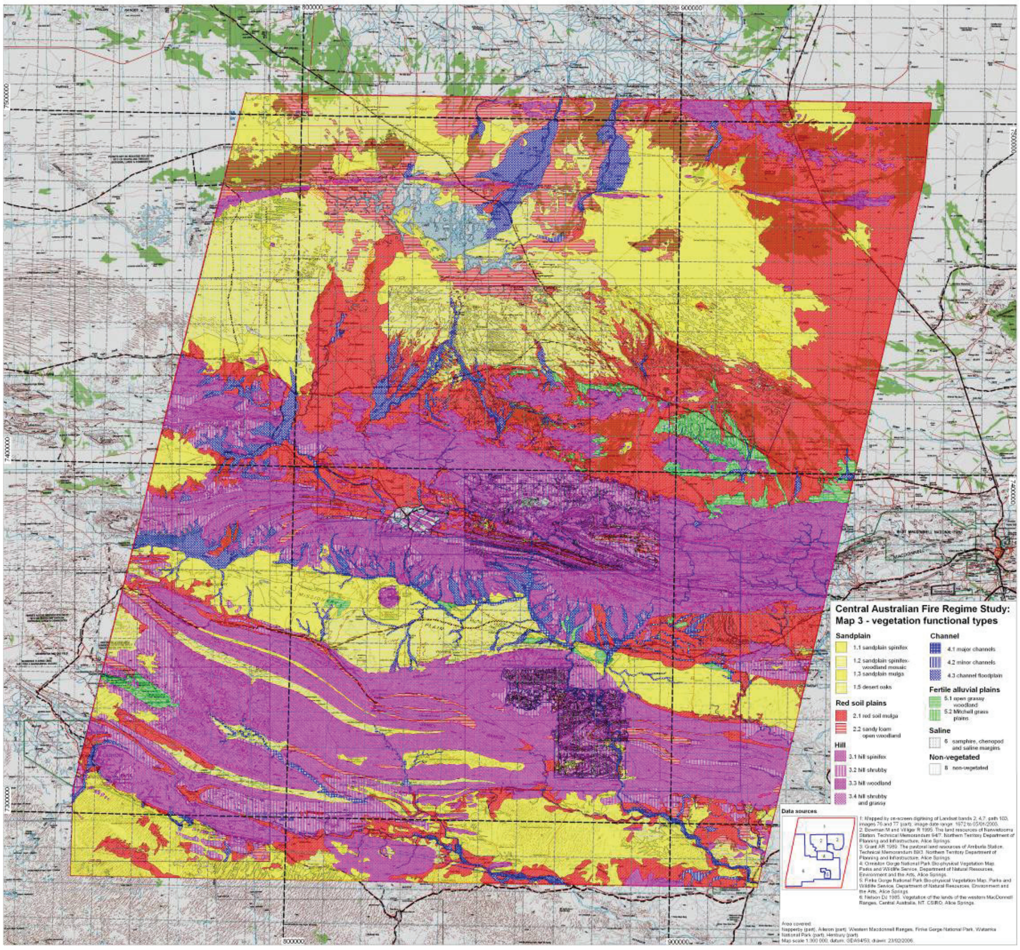

Figure 6: Final vegetation map of the West MacDonnell Range study area

Fire history

During the 30-year period between 1973 and 2002 (i.e. the period for which reasonable fire dating is available), a total of 4 048 950 ha burned (Table 5). The average annual area burned during this period was 134 965 ha or 3.3% of the study area. This translates into an inter-fire interval of about 30 years. Areas burned and fire intervals were similar to those reported for the Great Victoria Desert (Haydon et al., 2000).

However, more than 75 percent (i.e. about 3 065 500 ha) of this area was burned over a combined period of four fire seasons (i.e. during 1975 and 2000–2003). Around 650 000 ha, or about 16 percent of the study area, was burned per year during these major fire years.

The fire history between about the mid-1950s and 05/01/2003 was mapped for the West MacDonnell Range study area from a combination of fire history maps developed in the early to mid-1980s (Grant Allan unpublished data), and more recently from Landsat imagery. The boundaries of all fires were mapped as polygons. Fire boundaries prior to about 1970 were obtained from the pre-existing fire history maps (Grant Allan unpublished data) and have a reported accuracy of around ±250m. Fires between about 1970 and 1988 were mapped to an accuracy of around ±100m while fires between 1989 and 2003 were mapped to an accuracy of around ±50m.

For all fires prior to 1970, the minimum fire size that was reliably identified is about 25 ha. From 1970 to 2003, the minimum fire size that has been mapped is about one hectare in flat lying areas, and five hectares in hill areas. The difference relates to the much poorer contrast between burned versus unburned areas in hill sites in the Landsat images.

Fires up to and including the Landsat composite image of 02/04/2000–21/06/2000 were initially mapped using on-screen digitising of the Landsat images displayed as R7, G4, B2. The difference between images with adjacent dates was then used to identify additional burned areas. The difference images were created by subtracting the pixel values from one image date from the pixel values of the next image date. In flat lying areas, especially where spinifex and/or mulga vegetation was underlain by sandsheets, the R7, G4, B2 combinations gave the best resolution of burned versus unburned areas. In contrast, in hill areas, fires were typically not visible on the R7, G4, B2 combinations and the difference images gave moderate differentiation of burned versus unburned areas.

Due to the extensive areas burned between 21/06/2000 and 05/01/2003 and the complexity of their fire boundaries, fires during this period were mapped using classification of the difference images between the following images:

- 02/04/2000 to 21/06/2000 composite image versus 28/09/2001
- 23/03/2002 versus 30/08/2002
- 28/09/2001 versus 23/03/2002
- 30/08/2002 versus 05/01/2003.

The difference images were calculated using the normalised burn ratio (Howard et al. 2002) (Equation 1), and the normalised difference vegetation index (Tucker 1979) (Equation 2).

Normalised burn ratio:

$$NBR = (R4 - R7) / (R4 + R7) \quad \text{Equation 1}$$

Normalised difference vegetation index:

$$NDVI = (\text{band } 4 - \text{band } 3) / (\text{band } 4 + \text{band } 3) \quad \text{Equation 2}$$

Image processing was undertaken by Ben Kaethner of Low Ecological Services Pty Ltd, utilising two-image principal components analysis to identify differences between image pairs. Whichever of the normalised burn ratio or normalised difference vegetation ratio that gave the highest differentiation of burned versus unburned areas was used.

Dates were attributed to fire polygons using Landsat QuickLook images. These images have an approximate pixel size of 90 m and are acquired at 16-day intervals. Useable images are available every 60 days on average because of cloud and sensor dropout. All Landsat QuickLook images from path 103, row 76 (which covered around 70% of the study site), from 14/01/1980 to 05/01/2003 (with one additional image from 25/10/1979) which were useable, were geographically registered. This involved registering about 130 images to an accuracy of about ±250m. The fire history polygons were then overlaid with the QuickLook images and the pre-fire versus post-fire date range estimated. For the bottom part of the study site, the fire history polygons were visually compared against non-registered Landsat path 103 row 77 QuickLook images.

A total of 913 fires, burning a total of about 4 284 760 ha, were mapped in this project (Table 5, Figure 7). The period last burned (including areas where no fires were recorded) is shown in Figure 7. The fire history polygons were summarised into a series of date ranges, as described in Table 6 and shown in Figure 8.

Table 5: Areas recorded as burned in the West MacDonnell Range study area

Period	Total area burned	Number of fires	Fire size range (ha)		
			min	max	average
Pre-1973	235803	55	14.3	40914	4287
1973 to 1980	1725886	51	4.2	997277	33841
1981 to 1989	677715	310	3.8	82219	2186
1990 to 1999	305745	320	0.2	66106	955
2000 to 2002	1339608	177	1.4	134088	7568
Totals	4284757	913			4693

Table 6: Fire history date accuracies for the polygons mapped in the West MacDonnell Range study area

Period	Notes
Pre-1973	fire ages very approximate, and generally ±10 years; some fires are a composite of several smaller fires
1973 to 1979	fire ages approximate, with the fire polygons mostly dated to between 1973 and 1979 with the majority of the area being burned between 1974 and 1976; some fires are a composite of several smaller fires
1980 to 1989	50% of fires burning 87% of the area burned aged to between ±16 and 96 days; overall date average ±451 days
1990 to 1999	37% of fires burning 84% of the area burned aged to between ±8 and 80 days; overall date average ±603 days
2000 to 2002	67% of fires burning over 80% of the area burned aged to between ±16 to 64 days; overall date average ±126 days.

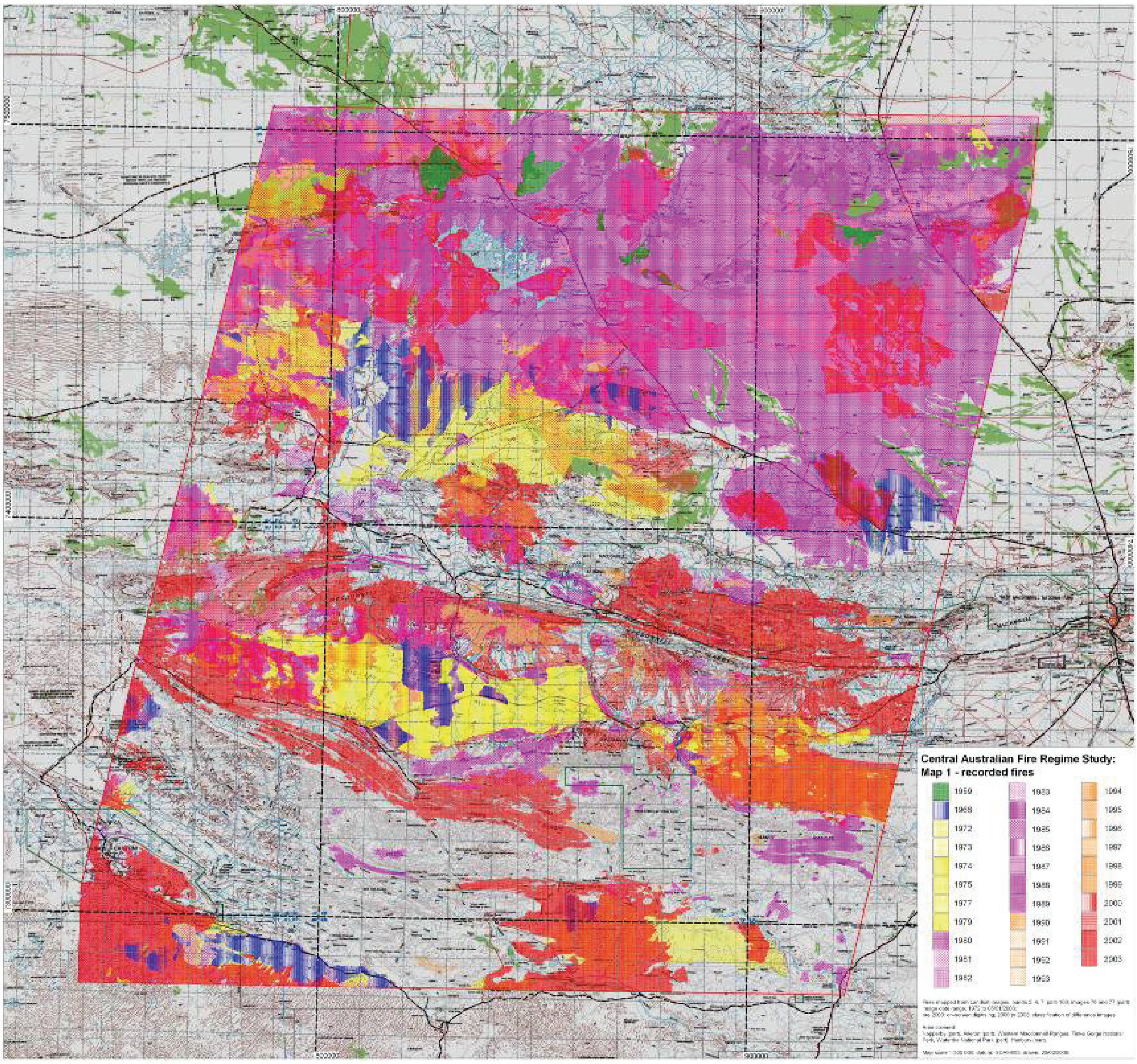

Figure 7: Recorded fires in the West MacDonnell Range study area

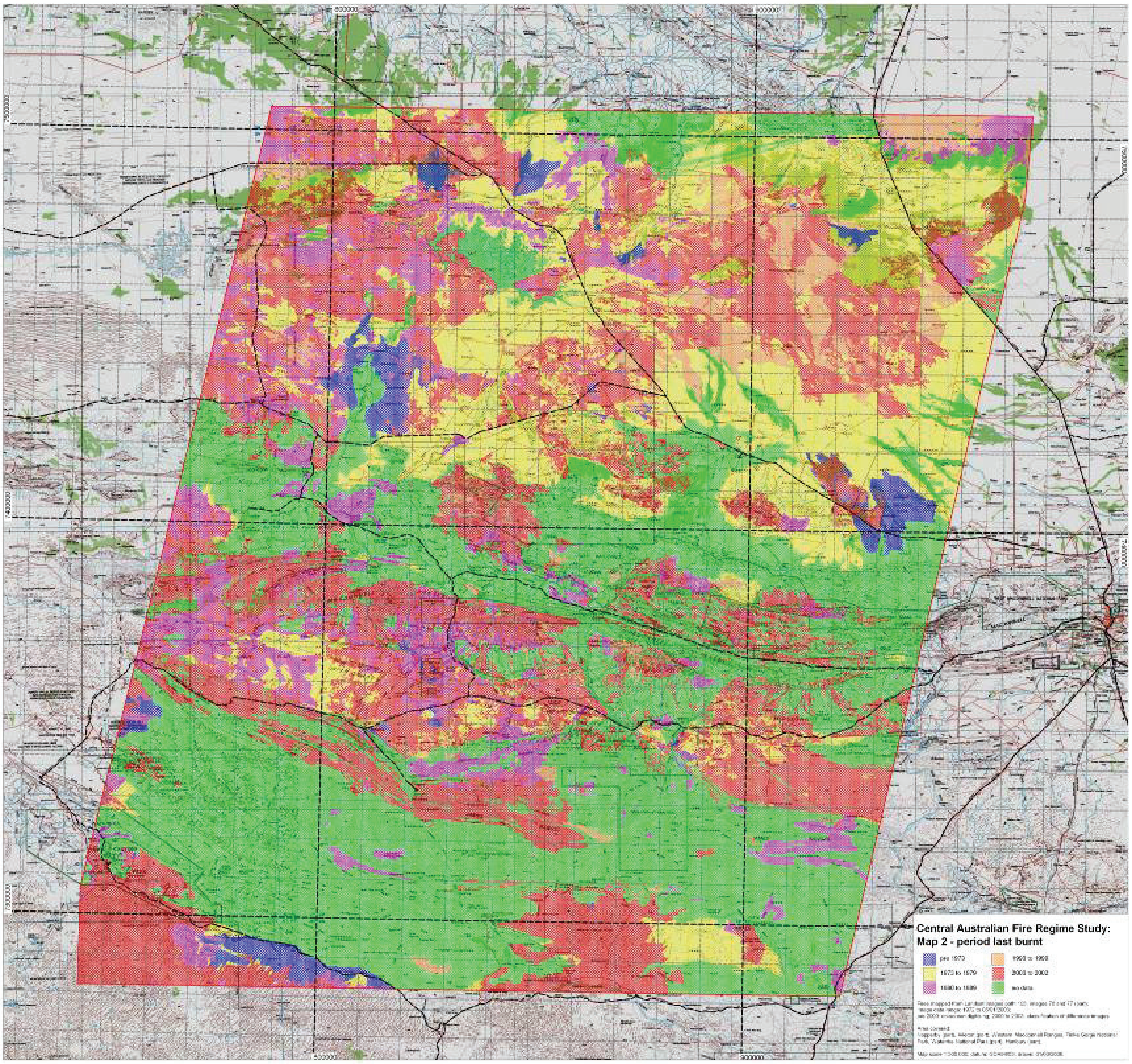

Figure 8: Time of last fire in the West MacDonnell Range study area

Modelling fire spread: algorithms and assumptions

In central Australia, years when large areas are burned occur primarily after periods of above average rainfall when the growth of ephemeral species increased the connectivity of otherwise largely discontinuous vegetation. This facilitates the propagation of fires under suitable weather conditions.

Fire behaviour is affected by a considerable range of variables, although the major influences are wind speed, fuel characteristics (e.g. fuel moisture, fuel load, fuel continuity and/or live to dead ratio of fuel) and topography. Some of these factors are in turn influenced by other variables. For example, in central Australia fuel load present at a site is strongly influenced by fire history, climate, vegetation cover and geological type, while fuel moisture content is influenced by temperature, humidity and rainfall.

The following steps are involved in predicting fire behaviour at a point for modelled fires in the study area:

1. Estimate vegetation parameters (type, growth, age, presence/absence of short lived species) from the rainfall for each year since the last fire
2. Predict the fuel load
3. Predict fuel moisture
4. Predict the rate of fire spread, fire intensity, flame length and fire danger rating categories.

1. Estimate vegetation parameters (type, growth, age, presence/absence of short lived species) from the rainfall for each year since the last fire

Vegetation types used in the FIRESCAPE model are those defined in Table 2. Vegetation growth condition classes are used to determine the effective growth of vegetation types and their respective fuel loads as they experience different climatic periods ranging from drought to above average rainfall conditions.

Four different types of weather years were identified using long-term precipitation and potential evaporation data from Alice Springs (Bureau of Meteorology) (Table 7). Annual rainfall and evaporation were calculated from July to June, rather than for calendar years, because of a tendency for summer precipitation. Around 46 percent of years were classified as dry, with less than 240 mm of precipitation. Similarly, around 47 percent of years were classified as average, with between 240 and 480 mm of precipitation. Around seven percent of years were classified as wet or very wet (> 480 mm precipitation). Vegetation growth condition classes are defined according to criteria outlined in Table 8.

Table 7: Weather year classifications for Alice Springs

Classification	Potential evaporation	Rainfall	Percentage of seasons
Dry	< 10%	<240 mm	46%
Average	10 to 20%	240 to 480 mm	47%
Wet	20 to 30%	480 to 725 mm	4%
Very wet	> 30%	>725 mm	3%

Note: potential evaporation percentages indicate the % of the total annual potential evaporation, Bureau of Meteorology unpublished data.

Table 8: Definition of vegetation growth condition classes

Vegetation growth condition	Range in conditions
Drought	≥ 5 consecutive years, 4 with <240 mm and no more than 1 year with 240 to 480 mm
Below average	≥ 2 consecutive years each with <480 mm or 1 year with <240 mm
Average	1 year with 240 to 725 mm
Above average	≥ 2 consecutive years, each with >480 mm or 1 year with >725 mm

Table 9: Fuel types in different vegetation associations for different vegetation growth condition classes

		Vegetation condition class			
Num	Vegetation type	drought	below average	average	above average
1.1	sand plain, sand dunes, swales				
	Spinifex grassland	spinifex	spinifex	spinifex	spinifex, grass
1.2	sand plain, swale				
	Mulga-spinifex mosaic	spinifex	spinifex	spinifex	spinifex, grass
1.3	sand plain, swales				
	Mulga woodlands	grass	grass	grass	grass
1.5	sand dunes and sand plain				
	Desert oak woodlands	spinifex	spinifex	spinifex	spinifex, grass
2.1	red soil plains				
	Mulga woodlands	grass	grass	grass	grass
2.2	sandy loam plains				
	Mulga open woodlands	grass	grass	grass	grass
3.1	hills				
	Spinifex grasslands	spinifex	spinifex	spinifex	spinifex, grass
3.2	hills				
	Shrubby, minor spinifex	grass	grass	grass	grass
3.3	hills				
	Woodland	grass	grass	grass	grass
3.4	hills				
	Shrubby and grassy	grass	grass	grass	grass
4.1	major river channels				
	Red gum, coolabah	grass	grass	grass	grass
4.2	minor rivers and creek channels				
	Melaleuca	grass	grass	grass	grass
4.3	channel floodplains and floodouts				
	Coolabah, red gum, mulga	grass	grass	grass	grass
5.1	fertile alluvial plains				
	Open grassy woodlands	grass	grass	grass	grass
5.2	Cracking clay plains				
	Mitchell grass	grass	grass	grass	grass
6	saline plains, salt lake margins				
	Chenopods, samphire	grass	grass	grass	grass
8	salt lakes				
	Non-vegetated	no fuel	no fuel	no fuel	no fuel

Note: vegetation types from Table 2, and vegetation condition class from Tables 7 and 8; the num is the vegetation number used in the vegetation map.

2. Predict the fuel load

Prevailing fuel type

Fuel types were broadly defined as spinifex, grass or mulga. These correlated with the dominant communities present and the published fire behaviour algorithms for grass and spinifex for this region. Fires spreading through mulga-dominated communities were assumed to be driven primarily by grass fires in the understorey. The dominant fuel type (i.e. spinifex or grass) in different vegetation associations depends on the vegetation type and the prevailing seasonal conditions (i.e. the vegetation growth condition class). Spinifex vegetation was assumed to grow preferentially in above average rainfall years, with minimal growth occurring during drought years. Therefore fuel calculations were based on the calculated *effective age* (based on the annual vegetation growth conditions) rather than the actual age of the vegetation. Table 9 shows the assumed dominant fuel type for each vegetation association (as defined in Table 2) and vegetation growth condition class (as defined in Tables 7 and 8).

Grass fuel loads

Fuel loads in grassy associations (Table 9), for different vegetation growth condition classes are given in Table 10. Values for fuel loads are estimated from Friedel (1981), Griffin et al. (1983), Griffin and Friedel (1984), Friedel and Shaw (1987a, 1987b), Stafford-Smith and Morton (1990), Allan and Southgate (2002), Miller (2003), Clarke et al. (2005). Estimates of the influence of buffel grass on fuel loads for different vegetation associations and vegetation conditions are also given.

Table 10: Grass fuel loads in different vegetation types in periods with different rainfall categories

	Grass fuel loads ($t.ha^{-1}$) for different vegetation conditions			
Vegetation	Drought	Below average	Average	Above average
Without buffel grass				
Spinifex, mulga-spinifex mosaic				
(Vegetation associations 1.1, 1.2, 1.5, 3.1)	0.1	1.0	1.5	4.6
Mulga, hill shrubby, hill shrubby and grassy				
(vegetation associations 1.3, 2.1, 2.2, 3.2, 3.3)	0.1	0.5	1.5	4.6
River channels, floodplains				
(Vegetation associations 4.1, 4.2, 4.3)	0.1	2.0	4.5	10
Open grassy woodland				
(Vegetation association 5.1)	0.1	1.0	2.6	10
Mitchell grass plains				
(Vegetation association 5.2)	0.1	1.0	4.5	10
All other associations				
(Vegetation associations 3.3, 6)	0.1	0.5	1.5	4.6
Sites with buffel grass (all suitable vegetation types)	0.3	3	6.7	15

Note: Spinifex associations have additional fuels from the spinifex component of the vegetation.

Spinifex fuel loads

Griffin and Allan (1984) published predictive models for spinifex fuel load based on empirical data for vegetation cover and patchiness collected at the Uluṟu National Park. However, data on vegetation cover and patchiness is not generally available from the methods adopted by us for this study.

As a result, spinifex fuel load data from the published literature, including Walker (1981), Suijdendorp (1981), Griffin et al. (1983), Burrows et al. (1991) and Allan and Southgate (2002), was examined. The available data suggests that during average rainfall periods, minimal fuel remains immediately following fires, average fuel loads increase to about:

- 2 $t\ ha^{-1}$ by 2 years of age

- 2.3 t ha^{-1} by 3 years of age
- 2.9 t ha^{-1} by 4 years of age
- 4.2 t ha^{-1} by 7 years of age
- between 8 and 10 t ha^{-1} by about 15 to 20 years of age
- about 14 t ha^{-1} in long unburnt sites (assumed to be 30 to 40 years since fire).

A function was developed from this data, with the assumption that there was an asymptotic relationship (see Olson 1963) between the effective age of vegetation and fuel load. It was also assumed that there was minimal fuel breakdown between fire events (see Allan and Southgate 2002). The resultant function is shown in Equation 3.

Spinifex fuel load (t.ha^{-1})	= 12 x (1 - exp(-0.08 x effective age))	Equation 3
where	fuel load is in t ha^{-1},	
	effective age is the time since fire in years modified according to seasonal conditions.	

Mulga fuel loads

The influence of mulga fuels was important in vegetation associations 1.2, 1.4, 2.1, 2.2, 3.3. It was assumed that fires burning in mulga were predominantly under the influence of grassy fuels. However, in mulga stands greater than 20 years of age, an additional 6 t.ha^{-1} of fuel was added to the fuel load, representing fuel resulting from the mulga stand.

3. Predict fuel moisture

Equations for grass fuel moisture were used for determining both grass and spinifex fuel moisture, as those derived from the spinifex data available in Burrows et al (2006) may not be representative of a typical year (pers. comm. Neil Burrows). Grass fuel moisture equations provided a good approximation of fuel moisture in Spinifex during model validation. Dead fuel moisture in grass was calculated using McArthur's Mark 5 Grass Fire Meter (Noble et al., 1980) (Equation 4).

Grass fuel moisture	= (97.7 + 4.06 * relative humidity) / (temperature + 6.0) -	
	0.00854 * relative humidity + 3000 / curing - 30	Equation 4
where	grass fuel moisture is in %,	
	temperature is in degrees C,	
	relative humidity and curing are in %.	

Dead fuel moisture above 35 percent oven dry weight will prevent propagation of fire in grassy fuels (Allan and Southgate 2002; Craig 1999), and this was incorporated into FIRESCAPE.

4. Predict the rate of fire spread, fire intensity, flame length and fire danger rating

Vegetation communities containing multiple fuel types

After above average rainfall years, when there is significant cover of short-lived grass fuels, both grass and spinifex fire spread models may be applicable. In vegetation associations containing these multiple fuel types, fuel loads derived from each fuel type were combined. Fire spread rates in these communities were assumed to be the higher rate of spread from the fire spread prediction equations for grass and for spinifex.

Grass rate of fire spread

The CSIRO grass fire spread model (Cheney et al. 1993) is used when the dominant fuel type is grass (see Allan and Southgate 2002). Rates of spread are modified according to the slope correction factor of McArthur (1967) (Noble et al. 1980) (Equation 5).

Grass fire spread rate = $(0.4539 * (0.278 * Wind_{2m}^{0.951}) * \exp(-0.0966 * GrassFuelMoisture)) * 60 * \exp(0.0693 * slope)$ Equation 5

where rate of fire spread is in m min^{-1},
$wind_{2m}$ is the wind speed recorded at 2 m above the ground in km hr^{-1},
GrassFuelMoisture is the dead fuel moisture in %,
slope is in degrees.

Spinifex rate of fire spread

Two sets of algorithms were available for determining the rate of fire spread in spinifex. Using data from Uluru National Park, Griffin and Allan (1984) developed equations for spinifex fire spread as a function of cover, patchiness, fuel moisture and weather (Equations 6 – 11).

Spinifex cover = $0.8 * (1 - \exp(-0.45 * age)) * (2.3 * age - 0.02 * age^2)$ Equation 6

Bare ground cover = $100 - (2.3 * age - 0.02 * age^2)$ Equation 7

Patchiness = $0.07 * age$ Equation 8

where cover is in %,
patchiness is dimensionless,
age is in years.

Spinifex fuel factor = $\sqrt{((spinifex\ cover / bare\ ground) * \sqrt{patchiness}) / \sqrt{fuel\ moisture}}$ Equation 9

where spinifex fuel factor is dimensionless,
spinifex cover, bare ground and fuel moisture are in %,
patchiness is dimensionless and varies between <1 to about 3.

Spinifex weather factor = $\sqrt{((temperature * \exp(0.2778 * wind\ speed)) / RH)}$ Equation 10

where spinifex fuel factor is dimensionless,
temperature is in °C,
wind speed is in km hr^{-1}.

Spinifex fire spread rate = $(-0.419 + 1.125 * \sqrt[3]{(fuel\ factor * weather\ factor)}) * 60$ Equation 11

where spinifex fuel and weather factors are dimensionless,
rate of spread is in m min^{-1}.

More recently, Burrows et al (2006) developed equations based on empirical data from the western desert. These are shown in equations 12 and 13 and Table 11.

Fire spread index = $0.57 * wind\ speed + 0.96 * fuel\ load - 0.42 * profile\ fuel\ moisture - 7.42$ Equation 12

where wind speed is measured at 2 m above the ground in km hr^{-1};
fuel load is in t ha^{-1},
profile fuel moisture is in %.

Rate of fire spread = $((154.9 * wind\ speed + 140.6 * fuel\ load - 228.0 * profile\ fuel\ moisture + 1581)/60) * \exp(0.0687 * slope)$ Equation 13

where wind speed is measured at 2 m above the ground in km hr^{-1};
fuel load is in t ha^{-1},
profile fuel moisture is in %'
slope is in degrees,
rate of fire spread is in m min^{-1}.

Table 11: Relationship between fire spread index (FSI), fire danger rating (FDR) and rate of fire spread (ROS) in spinifex fuels

FSI	Fire Danger Rating (FDR), likelihood of fire spread and potential	ROS (m/h^{-1})
FSI < -2	FDR Very low – fire highly unlikely to spread	0
-2 < FSI < 0	FDR Low – fire could spread	< 500
0 < FSI < 2	FDR Moderate – fire should spread	500 –1,000
2 < FSI < 4	FDR High – fire will spread	1000 – 1500
4 < FSI < 6	FDR Very High – fire will spread	1500 – 2000
6 < FSI < 10	FDR Extreme – fire will spread	2000 – 3000
FSI > 10 FDR	Very Extreme – fire will spread	> 3000

Source: Table 2 in Burrows et al. (2006)

The equations of Burrows et al (2006) resulted in a better fit between the observed and simulated fire-size frequency distribution in the study area. A negative fire spread index can be interpreted as fires that are unlikely to spread. Fires are expected to be sustainable when the fire spread index exceeds 2. Fires burning with a fire spread index above 10 are considered uncontrollable.

Flank and back fire rate of spread predictions

Back and flank fires are frequently not self-sustaining, resulting in head fires forming long, narrow burned areas with complex shapes as the wind direction changes (Burrows et al. 1991; Craig 1999). There is little information on the fuel and weather threshold conditions for propagation and extinguishment of back and flank fires in arid Australia. Therefore, it has been assumed for initial model runs that the extinguishment thresholds for back and flank fires in spinifex fuels are a fire spread index of 4 and 2 respectively. In grassy fuels, it is assumed that back and flank fires only sustain burning after years of above average rainfall when grassy fuels are above average.

Flame length predictions using Byram's iIntensity

Byram's fireline intensity (I_B) (Byram 1959), and the associated function for flame length, was used for all vegetation types. Both spinifex and grass fuel heat yield is assumed to be 15 500 kJ kg^{-1} (see Griffin and Friedel 1984).

Byram's Intensity $= (H * W * R)/600$ — Equation 14

Flame length $= 0.0775 * (I_B)^{0.46}$ — Equation 15

where Byram's Intensity (I_B) is in kW m^{-1},
H is the fuel heat content in kJ kg^{-1}, assumed to be 15 500 kJ kg^{-1},
W is the fuel load in t ha^{-1},
R is the rate of fire spread in m min^{-1},
flame length is in meters.

Fuel breaks

The majority of major roads in central Australia (i.e. those roads mapped on the 1:250 000 map) are assumed to form effective fuel breaks under conditions of up to moderate levels of fire danger while minor roads (i.e. roads and tracks mapped on the detailed roads map) are assumed to act as fire breaks at low levels of fire danger. Major water courses are also assumed to be effective fuel breaks up to moderate levels of fire danger due to their typically having a sand or gravel bed. In contrast, minor channels are assumed to be ineffective fuel breaks.

Ignition sources

A comprehensive fire history for the study area has been developed, although locations and sources of ignitions are largely unknown for the majority of fires. In the present implementation of FIRESCAPE, lightning ignitions are treated as spatially random. The framework to implement management ignitions has been developed. This could be implemented with minimal additional coding after consultation as to which management scenarios should preferentially be modelled.

Weather

Weather was included by looping 50 years of observed meteorological data from Alice Springs airport. Spatial variation in weather were based on algorithms derived by analysing correlations between weather data from Alice Springs airport and seven weather stations in and around the study area (Curtin Springs, Palm Valley, Tempe Downs, Uluru Rangers Station, Watarrka, Yuendumu, and Yulara airport). Elevation and longitudinal and latitudinal differences between stations were used to derive the equations for determining local weather variables. Weather is modelled daily in the absence of fires, and hourly when fires are occurring in order to maximise on simulated predictions of fire spread.

Climate change scenarios for the study area are available from the CSIRO publication *Climate Change Projections for Australia* (CSIRO 2001). The framework for implementing these has been developed, with minimal further coding required to refine the modelling of climate change to address specific research questions.

Simulation results

Validation against observed fire history

Simulations from the FIRESCAPE model parameterised for the West MacDonnell Range study site produced a fire-size frequency distribution similar to that for the independently developed fire history of the study region (Figure 9). The frequency of larger fires was somewhat over-predicted, whereas the frequency of smaller fires was slightly under-predicted. Nevertheless, the reasonable match between the simulated data and the observed fire history indicates that the model is reproducing this key aspect of fire occurrence in the study site.

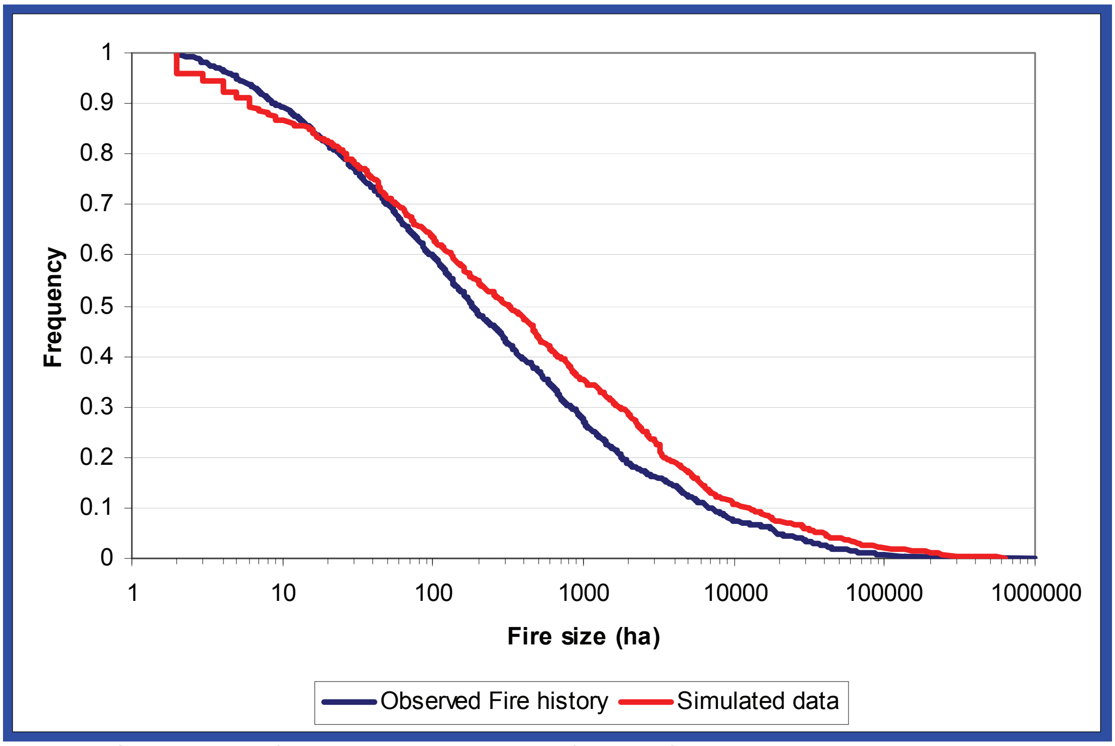

Figure 9: Comparison of observed and simulated fire-size frequency distribution in the West MacDonnell Range study area

In the observed fire history, fire occurrence is higher during warmer months in the study area with significantly lower areas burned during the months of March to August inclusive. The general aspects of this dynamic were reproduced in model results. Figure 10 presents the relative areas burned by month for a one-hundred-year simulation of the FIRESCAPE model for the West MacDonnell Range study site.

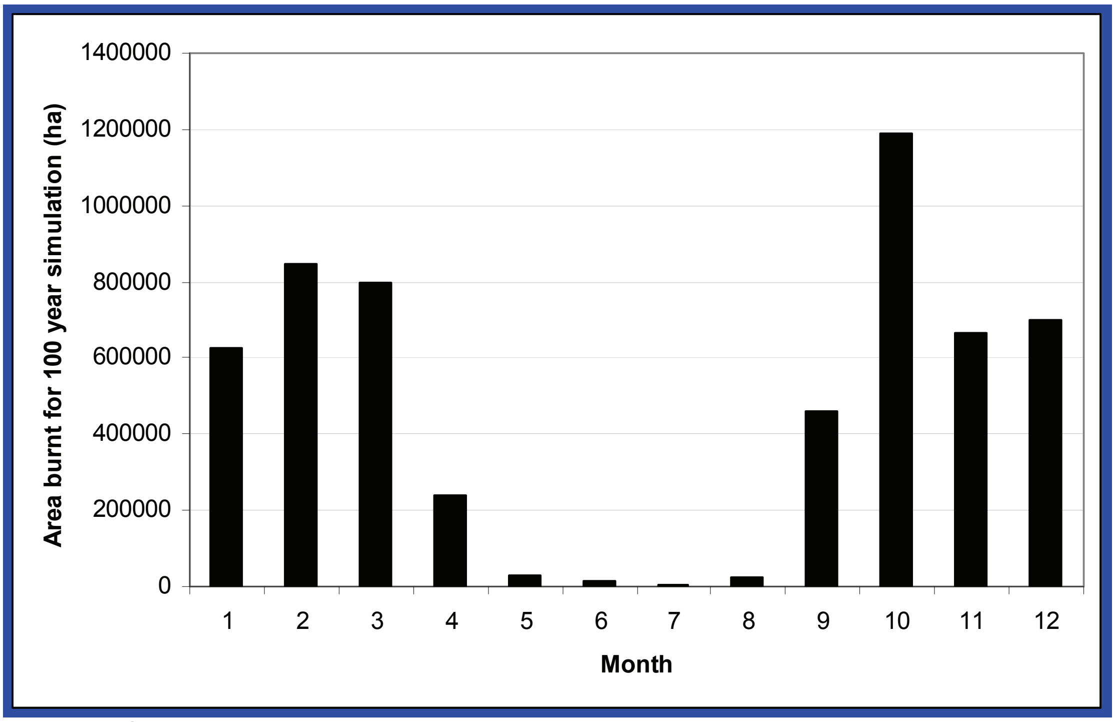

Figure 10: Simulated areas burned by month in the West MacDonnell Range study area

In simulations, the average annual area burned was positively correlated to annual rainfall. This was consistent with the data from the observed fire history for the study area, and generally with observed fire regimes for arid Australia (Figure 11).

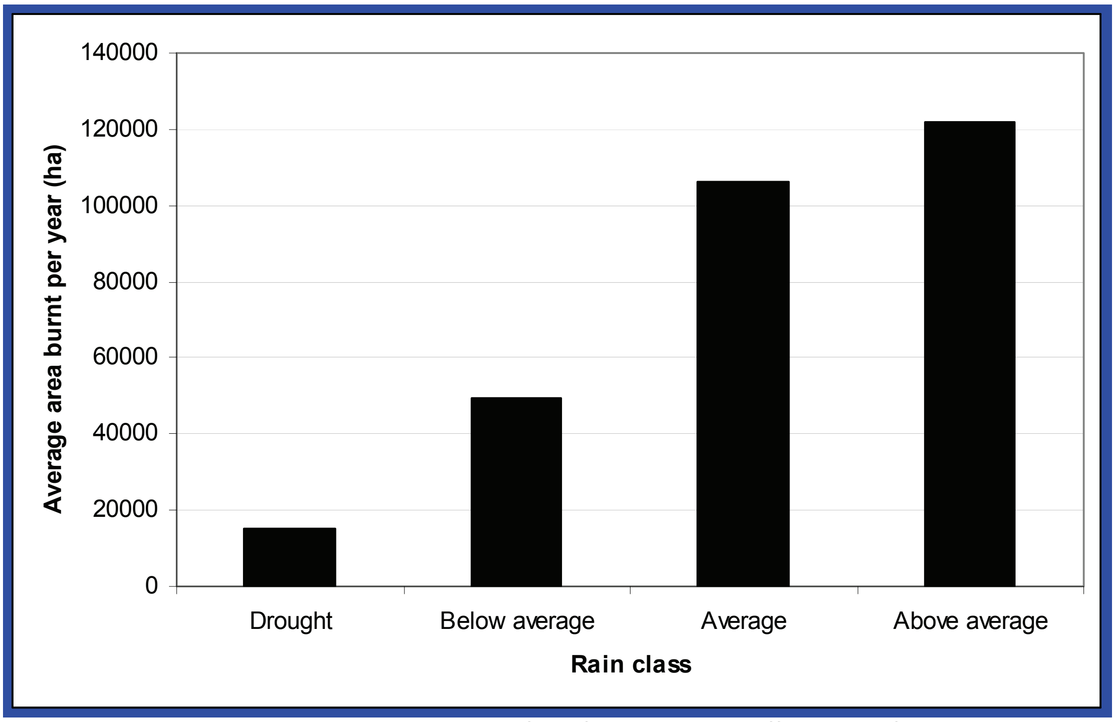

Figure 11: Average area burned by simulated fires for years with different rainfall categories in the West MacDonnell Range study area

Demonstration of application in management

Buffel grass represents an important management issue in the study region. For example, there may be changes in fire regimes resulting from enhanced fuel connectivity that occurs with invasion by this species. The potential for buffel grass to invade different vegetation communities was assessed by experts at a workshop on fire and vegetation dynamics in Alice Springs in November 2005 (Table 2). Vegetation communities were ranked according to their potential for invasion by buffel grass, including (i) very high potential (6.7% of study area), (ii) high potential (0.4% of study area), (iii) moderate potential (15.9% of study area), (iv) low potential (21.2% of study area) or (v) very low potential (55.8% of study area) for invasion by buffel grass.

Simulations representing three different buffel grass invasion scenarios were conducted. These were: (i) no buffel grass; (ii) buffel grass present on all sites with a very high potential for buffel grass invasion (6.7% of study area); and (iii) buffel grass present on all sites with a very high, high and moderate potential for buffel grass invasion (21% of study area). Simulation results indicate that fire-size frequency distributions are highly sensitive to differences in buffel grass invasion scenarios (Figure 12). The differences arising from different buffel grass scenarios are large compared with the model bias, or the differences between modelled and observed fire history (Figure 9).

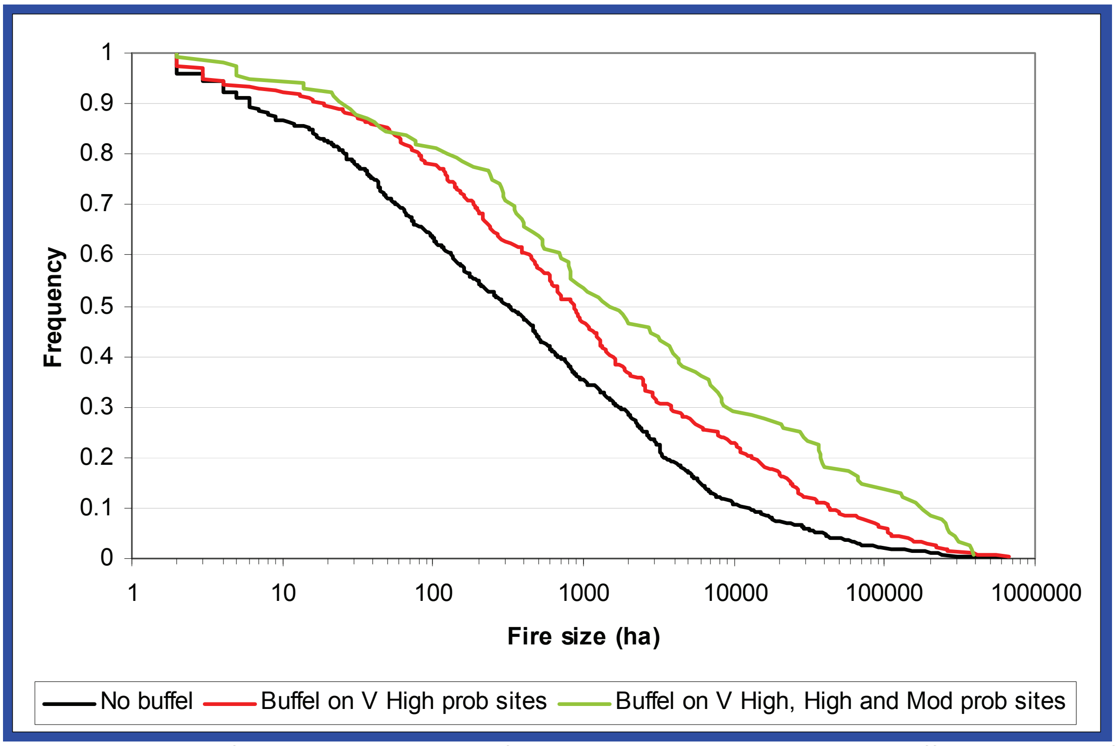

Figure 12: Fire-size frequency distributions for 100-year simulation with (i) no buffel grass; (ii) buffel grass present on all sites with a very high potential for buffel grass invasion; and (iii) buffel grass present on all sites with a very high, high and moderate potential for buffel grass invasion.

Further management-oriented research

This sub-project was concerned with implementing the landscape fire model in the West MacDonnell Range study area and collating background data and algorithms to inform this. It is worth noting there is considerable scope for further management-oriented research using the simulation tool. For example, it is possible to simulate the effects of grazing on pastoral lands on fuel load dynamics and hence on fire regimes in the study area. Further, the effectiveness of alternate fire management practices for parks and Aboriginal lands can be evaluated in light of meeting biodiversity, cultural and property protection objectives. The impact of climate change on fire regimes and management values can also be explored. The FIRESCAPE model has been developed with these options in mind, and implementation of each of these is possible with minimal further model development or refinement to address specific research questions.

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References

Allan GE and Southgate RI 2002, 'Fire regimes in the spinifex landscapes of Australia', In Bradstock RA, Williams J and Gill AM (Eds.), *Flammable Australia: the fire regimes and biodiversity of a continent*, pp. 145–176. Cambridge University Press.

Bowman M and Villiger R 1995, *The land resources of Narwietooma Station*, Technical Memorandum 94/7, Northern Territory Department of Planning and Infrastructure, Alice Springs, Northern Territory.

Burrows ND, Ward B and Robinson AD 1991, 'Fire behaviour in spinifex fuels on the Gibson Desert Nature Reserve, Western Australia', *Journal of Arid Environments* 20: 189–204.

Burrows ND, Ward B, Robinson AD and Behn G 2006, 'Fuel dynamics and fire behaviour in spinifex grasslands of the western desert'. In Tran C (Ed.), *Life in a fire-prone environment – translating science into practice*, Proceedings of the Bushfire 2006 conference, 7–9 June 2006, Brisbane, Queensland.

Byram GM 1959, 'Combustion of Forest Fuels', In Davis KP (Ed.), *Forest Fire Control and Use*, McGraw-Hill, New York.

Cary GJ 2002, 'Importance of a changing climate for fire regimes in Australia', In Bradstock RA, Williams J and Gill AM (Eds.), *Flammable Australia: the fire regimes and biodiversity of a continent*, pp 26–48, Cambridge University Press.

Cary G 2003, *Evaluation of an Australian Landscape Fire Model Applied to a Northern Rocky Mountain Landscape*, USDA Forest Service International Joint Venture Research Agreement 01-JV-11222048-110 report.

Cary GJ, Keane RE, Gardner RH, Lavorel S, Flannigan MD, Davies ID, Li C, Lenihan JM, Rupp S, Mouillot F 2006, 'Comparison of the sensitivity of landscape-fire-succession models to variation in terrain, fuel pattern, climate and weather', *Landscape Ecology* 21: 121–137.

Cheney NP, Gould JS and Catchpole WR 1993, 'The influence of fuel, weather and fire shape variables on fire-spread in grasslands', *International Journal of Wildland Fire* 3: 31–44.

Clarke PJ, Latz PK and Albrecht DE 2005, 'Long-term changes in semi-arid vegetation: invasion of an exotic perennial grass has larger effects than rainfall variability', *Journal of Vegetation Science* 16: 237–248.

Craig AB 1999, 'Fire management of rangelands in the Kimberley low-rainfall zone: a review', *Rangeland Journal* 21: 39–70.

CSIRO 2001, *Climate change projections for Australia*, Climate Impact Group, CSIRO Division of Atmospheric Research.

Friedel MH 1981, 'Studies of Central Australian semidesert rangelands. I Range condition and biomass dynamics of the herbage layer and litter', *Australian Journal of Botany* 29: 219–231.

Friedel MH and Shaw K 1987a, 'Evaluation of methods for monitoring sparse patterned vegetation in arid rangelands. I. Herbage', *Journal of Environmental Management* 25: 297–308.

Friedel MH and Shaw K 1987b, 'Evaluation of methods for monitoring sparse patterned vegetation in arid rangelands. I. Trees and shrubs', *Journal of Environmental Management* 25: 309–318.

Grant AR 1989, *The pastoral land resources of Amburla Station*, Technical Memorandum 89/3, Northern Territory Department of Planning and Infrastructure, Alice Springs, Northern Territory.

Griffin GF and Allan GE 1984, 'Fire behaviour', In Saxon EC (Ed.), *Anticipating the inevitable: a patch-burn strategy for fire management at Uluru (Ayres Rock – Mt Olga) National Park*, CSIRO Melbourne, Victoria.

Griffin GF and Friedel MH 1984, 'Effects of fire on central Australian rangelands. I Fire and fuel characteristics and changes in herbage and nutrients', *Australian Journal of Ecology* 9: 381–393.

Griffin GF, Price NF and Portlock HF 1983, 'Wildfires in the Central Australian rangelands 1970–1980, *Journal of Environmental Management* 17: 311–323.

Haydon DT, Friar JK and Pianka ER 2000, 'Fire-driven dynamic mosaics in the Great Victoria Desert, Australia. I. fire geometry', *Landscape Ecology* 15: 373–381.

Howard SM, Ohlen DO, McKinley RA, Zhu Z, Kitchen J and Loy A 2002, 'Historical fire severity mapping from Landsat data', *Pecora 15/Land Satellite Information IV/ ISPRS Commission I Symposium*, Proceedings 10–15 November 2002, Denver, CO USA, American Society for Photogrammetry and Remote Sensing.

King KJ, Cary GJ, Bradstock RA, Chapman J, Pyrke A and Marsden-Smedley JB 2006, 'Simulation of prescribed burning strategies in south west Tasmania, Australia: Effects on unplanned fires, fire regimes and ecological management values', *International Journal of Wildland Fire* 15: 527–540.

Marsden-Smedley JB, Albrecht D, Allan GE, Brock C, Duguid A, Friedel M, Gill AM, King K, Latz PK, Morse J, Ostendorf B and Turner D (In prep), *Fire-vegetation interactions in the Australian arid zone: development of a descriptive ecology for the region*, School of Resources, Environment and Society, Australian National University, Canberra, Australian Capital Territory.

McArthur AG 1967, *Fire behaviour in eucalypt forest*, Leaflet 107, Forestry and Timber Bureau, Department of National Development, Commonwealth of Australia, Canberra, Australian Capital Territory.

McCarthy MA and Cary GJ 2002, 'Fire regimes of landscapes: models and realities', In Bradstock RA, Williams J and Gill AM (Eds.), *Flammable Australia: the fire regimes and biodiversity of a continent*, Cambridge University Press.

Miller G 2003, 'Ecological impacts of buffel grass (Cenchrus ciliaris L.) invasion in central Australia – does field evidence support a fire-invasion feedback?' Unpublished honours thesis, School of Biological, Earth and Environmental Sciences, Faculty of Science, University of New South Wales, Sydney, New South Wales.

Nelson DJ 1985, *Vegetation of the lands of the western MacDonnell Ranges, Central Australia, NT*, CSIRO, Alice Springs, Northern Territory.

Noble IR, Bary GA and Gill AM 1980, 'McArthur's fire-danger meters expressed as equations', *Australian Journal of Ecology* 5: 201–203.

Olson JS 1963, 'Energy storage and the balance of producers and decomposers in ecological systems', *Ecology* 44: 322–32.

Stafford Smith DM and Morton SR 1990, 'A framework for the ecology of arid Australia', *Journal of Arid Environments* 18: 255–278.

Suijdendorp H 1981, 'Responses of the hummock grasslands of northwestern Australia to fire', In Gill AM, Groves RH and Noble IR (Eds.), *Fire and the Australian biota*, Australian Academy of Science, Canberra, Australian Capital Territory.

Tucker CJ 1979, 'Red and photographic infrared linear combinations for monitoring vegetation', *Remote Sensing Environment* 8:127–150.

Walker J 1981, 'Fuel dynamics in Australian vegetation', In Gill AM, Groves RH and Noble IR (Eds.), *Fire and the Australian biota*, Australian Academy of Science, Canberra, Australian Capital Territory.

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