Modelling fire dynamics in the West MacDonnell Range area

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Grant Allan
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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, Uluru 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.

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

<table>
<thead>
<tr>
<th>Corner</th>
<th>Easting</th>
<th>Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-west</td>
<td>144 300</td>
<td>7 505 900</td>
</tr>
<tr>
<td>North-east</td>
<td>365 900</td>
<td>7 505 900</td>
</tr>
<tr>
<td>South-west</td>
<td>144 300</td>
<td>7 282 100</td>
</tr>
<tr>
<td>South-east</td>
<td>365 900</td>
<td>7 282 100</td>
</tr>
</tbody>
</table>


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 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
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.

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

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.

<table>
<thead>
<tr>
<th>Source</th>
<th>Area covered</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 929 820</td>
<td>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.</td>
</tr>
<tr>
<td>Total</td>
<td>4 106 160</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Data source</th>
<th>vegetation accuracy</th>
<th>vegetation boundaries in different accuracy classes</th>
<th>&lt;50 m</th>
<th>50 to 100 m</th>
<th>100 to 250 m</th>
<th>250 to 500 m</th>
<th>&gt;500 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 this project</td>
<td>92</td>
<td>75</td>
<td>3</td>
<td>16</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2 Narwietooma</td>
<td>100</td>
<td>88</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3 Amburla</td>
<td>81</td>
<td>78</td>
<td>11</td>
<td>11</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4 Ormiston</td>
<td>80</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5 Finke</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6 Hermannsburg</td>
<td>70</td>
<td>67</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

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).

\[
\text{Normalised burn ratio:} \quad \text{NBR} = \frac{(R4 - R7)}{(R4 + R7)} \quad \text{Equation 1}
\]

\[
\text{Normalised difference vegetation index:} \quad \text{NDVI} = \frac{(\text{band 4} - \text{band 3})}{(\text{band 4} + \text{band 3})} \quad \text{Equation 2}
\]

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

<table>
<thead>
<tr>
<th>Period</th>
<th>Total area burned</th>
<th>Number of fires</th>
<th>Fire size range (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>min</td>
</tr>
<tr>
<td>Pre-1973</td>
<td>235803</td>
<td>55</td>
<td>14.3</td>
</tr>
<tr>
<td>1973 to 1980</td>
<td>1725886</td>
<td>51</td>
<td>4.2</td>
</tr>
<tr>
<td>1981 to 1989</td>
<td>677715</td>
<td>310</td>
<td>3.8</td>
</tr>
<tr>
<td>1990 to 1999</td>
<td>305745</td>
<td>320</td>
<td>0.2</td>
</tr>
<tr>
<td>2000 to 2002</td>
<td>1339608</td>
<td>177</td>
<td>1.4</td>
</tr>
<tr>
<td>Totals</td>
<td>4284757</td>
<td>913</td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-1973</td>
<td>Fire ages very approximate, and generally ±10 years; some fires are a composite of several smaller fires</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973 to 1979</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980 to 1989</td>
<td>50% of fires burning 87% of the area burned aged to between ±16 and 96 days; overall date average ±451 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990 to 1999</td>
<td>37% of fires burning 84% of the area burned aged to between ±8 and 80 days; overall date average ±603 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000 to 2002</td>
<td>67% of fires burning over 80% of the area burned aged to between ±16 to 64 days; overall date average ±126 days</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: Recorded fires 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.

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

<table>
<thead>
<tr>
<th>Classification</th>
<th>Potential evaporation</th>
<th>Rainfall</th>
<th>Percentage of seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>&lt; 10%</td>
<td>&lt;240 mm</td>
<td>46%</td>
</tr>
<tr>
<td>Average</td>
<td>10 to 20%</td>
<td>240 to 480 mm</td>
<td>47%</td>
</tr>
<tr>
<td>Wet</td>
<td>20 to 30%</td>
<td>480 to 725 mm</td>
<td>4%</td>
</tr>
<tr>
<td>Very wet</td>
<td>&gt; 30%</td>
<td>&gt;725 mm</td>
<td>3%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Vegetation growth condition</th>
<th>Range in conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>≥ 5 consecutive years, 4 with &lt;240 mm and no more than 1 year with 240 to 480 mm</td>
</tr>
<tr>
<td>Below average</td>
<td>≥ 2 consecutive years each with &lt;480 mm or 1 year with &lt;240 mm</td>
</tr>
<tr>
<td>Average</td>
<td>1 year with 240 to 725 mm</td>
</tr>
<tr>
<td>Above average</td>
<td>≥ 2 consecutive years, each with &gt;480 mm or 1 year with &gt;725 mm</td>
</tr>
</tbody>
</table>
## Table 9: Fuel types in different vegetation associations for different vegetation growth condition classes

<table>
<thead>
<tr>
<th>Num</th>
<th>Vegetation type</th>
<th>Vegetation condition class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>drought</td>
</tr>
<tr>
<td>1.1</td>
<td>sand plain, sand dunes, swales</td>
<td>Spinifex</td>
</tr>
<tr>
<td>1.2</td>
<td>sand plain, swale</td>
<td>Mulga-spinifex mosaic</td>
</tr>
<tr>
<td>1.3</td>
<td>sand plain, swales</td>
<td>Mulga woodlands</td>
</tr>
<tr>
<td>1.5</td>
<td>sand dunes and sand plain</td>
<td>Desert oak woodlands</td>
</tr>
<tr>
<td>2.1</td>
<td>red soil plains</td>
<td>Mulga woodlands</td>
</tr>
<tr>
<td>2.2</td>
<td>sandy loam plains</td>
<td>Mulga open woodlands</td>
</tr>
<tr>
<td>3.1</td>
<td>hills</td>
<td>Spinifex grasslands</td>
</tr>
<tr>
<td>3.2</td>
<td>hills</td>
<td>Shrubby, minor spinifex</td>
</tr>
<tr>
<td>3.3</td>
<td>hills</td>
<td>Woodland</td>
</tr>
<tr>
<td>3.4</td>
<td>hills</td>
<td>Shrubby and grassy</td>
</tr>
<tr>
<td>4.1</td>
<td>major river channels</td>
<td>Red gum, coolabah</td>
</tr>
<tr>
<td>4.2</td>
<td>minor rivers and creek channels</td>
<td>Melaleuca</td>
</tr>
<tr>
<td>4.3</td>
<td>channel floodplains and floodouts</td>
<td>Coolabah, red gum, mulga</td>
</tr>
<tr>
<td>5.1</td>
<td>fertile alluvial plains</td>
<td>Open grassy woodlands</td>
</tr>
<tr>
<td>5.2</td>
<td>Cracking clay plains</td>
<td>Mitchell grass</td>
</tr>
<tr>
<td>6</td>
<td>saline plains, salt lake margins</td>
<td>Chenopods, samphire</td>
</tr>
<tr>
<td>8</td>
<td>salt lakes</td>
<td>Non-vegetated</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Vegetation</th>
<th>Grass fuel loads (t.ha⁻¹) for different vegetation conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drought</td>
</tr>
<tr>
<td>Without buffel grass</td>
<td></td>
</tr>
<tr>
<td>Spinifex, mulga-spinifex mosaic</td>
<td>0.1</td>
</tr>
<tr>
<td>Mulga, hill shrubby, hill shrubby and grassy</td>
<td>0.1</td>
</tr>
<tr>
<td>River channels, floodplains</td>
<td>0.1</td>
</tr>
<tr>
<td>Open grassy woodland</td>
<td>0.1</td>
</tr>
<tr>
<td>Mitchell grass plains</td>
<td>0.1</td>
</tr>
<tr>
<td>All other associations</td>
<td>0.1</td>
</tr>
<tr>
<td>Sites with buffel grass (all suitable vegetation types)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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 Uluru 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), Suijendorp (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.

\[
\text{Spinifex fuel load (t.ha}^{-1}) = 12 \times (1 - \exp(-0.08 \times \text{effective age})) \quad \text{Equation 3}
\]

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).

\[
\text{Grass fuel moisture} = \frac{(97.7 + 4.06 \times \text{relative humidity})}{(\text{temperature} + 6.0)} - 0.00854 \times \text{relative humidity} + 3000 / \text{curing} - 30 \quad \text{Equation 4}
\]

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 * Wind2m0.951)* exp(-0.0966 * GrassFuelMoisture)) * 60 * exp(0.0693 * slope) Equation 5

where
rate of fire spread is in m min⁻¹,
wind2m 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 * age²) Equation 6
Bare ground cover = 100 - (2.3 * age - 0.02 * age²) Equation 7
Patchiness = 0.07 * age Equation 8

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

Spinifex fuel factor = √((spinifex cover / bare ground) * √patchiness) / √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 = √((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 * √(fuel factor * weather factor)) * 60 Equation 11

where
spinifex fuel and weather factors are dimensionless,
rates 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,
rates 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

<table>
<thead>
<tr>
<th>FSI</th>
<th>Fire Danger Rating (FDR), likelihood of fire spread and potential ROS (m/h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSI &lt; -2</td>
<td>FDR Very low – fire highly unlikely to spread</td>
</tr>
<tr>
<td>-2 &lt; FSI &lt; 0</td>
<td>FDR Low – fire could spread</td>
</tr>
<tr>
<td>0 &lt; FSI &lt; 2</td>
<td>FDR Moderate – fire should spread</td>
</tr>
<tr>
<td>2 &lt; FSI &lt; 4</td>
<td>FDR High – fire will spread</td>
</tr>
<tr>
<td>4 &lt; FSI &lt; 6</td>
<td>FDR Very High – fire will spread</td>
</tr>
<tr>
<td>6 &lt; FSI &lt; 10</td>
<td>FDR Extreme – fire will spread</td>
</tr>
<tr>
<td>FSI &gt; 10</td>
<td>FDR Very Extreme – fire will spread</td>
</tr>
</tbody>
</table>

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 Intensity

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 = \( \frac{H \times W \times R}{600} \)

Flame length = \( 0.0775 \times (I_B)^{0.46} \)

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](image-url)
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.

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).
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).

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.

Acknowledgments

We would like to gratefully acknowledge Peter Latz for his insights into fire and vegetation dynamics in central Australia. Thanks also to attendees of the workshop on fire and vegetation dynamics held in Alice Springs in November 2005 who provided considerable input on the topic. They include Dave Albrecht, Grant Allan, Chris Brock, Angus Duguid, Marg Friedel, Malcolm Gill, Karen King, Peter Latz, Jon Marsden-Smedley, Jock Morse, Bertram Ostendorf and Dot Turner. Neil Burrows of the Department of Conservation and Land Management, Western Australia kindly provided much of the information in the spinifex fire behaviour prediction system.
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