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FIRE FREQUENCY MAPPING USING SATELLITE IMAGERY FOR LAND MANAGEMENT AND RESEARCH

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ABSTRACT
An average 5 million hectares is burnt annually in Queensland's Cape York Peninsula (CYP) region, which totals approximately 13.5 million hectares. Fire scars in CYP have been mapped using satellite imagery since 1999 and a 9-year fire history GIS database has now been compiled. Mapping was initiated to determine the scale, extent, timing and use of fire and its influence on land condition and biodiversity. The database created allows the relationships between fire and natural feature including to topography, land use and biodiversity as well as pastoral economics. This will improve decision making and planning for the use of fire as a land management tool.

INTRODUCTION
The CYP area is dominated by *Eucalypt* woodland and many areas lack basic infrastructure such as roads, tracks and fences. The reliable summer rainfall provides a large annual fuel load which results in frequent fire, with many areas burning each year. Management of fire is difficult in this environment because of the large areas involved, difficult terrain, a lack of infrastructure and the extensive nature of the cattle properties. The region has over 100 cattle properties ranging from 63 ha to 404,000 ha in size. Average property size is 74,000 ha but more than 30 Stations boast an area between 100,000 to 400,000 hectares. Often fires can go undetected on a particular property without the managers being aware of its existence. Controlling fires is inhibited due the difficulties in locating the fire and access burn site.

In 2000, fire scar mapping using satellite imagery was instituted in CYP to determine the nature of fire in the landscape. The large fires that occur in the region permit the use of free and frequent, coarse resolution imagery. When used for regular mapping, this imagery provides data on the extent, scale and timing of fire. This data is currently available to access via the North Australia Fire Information (NAFI) website. The NAFI site displays current fire hotspots and current and past fire scar layers on top of topographic maps of different scales, assisting land managers to plan, manage and control fire.

The accumulated fire scar history is now providing important information on how local fire patterns relate to topography and land form, climate, landuse and infrastructure. The database is now being used as the basis of research projects investigating the effects of fire regimes on the economics of CYP pastoral properties and the effects of fire regimes on biodiversity.

APPROACHES
Mapping
Initially, fire scar mapping was undertaken using Landsat 7 ETM+ Quicklooks 'jpeg' images (250m resolution) of scenes captured over the same location every 16 days. From mid 2003, fire scars have been mapped using MODIS (MOderate Resolution Imaging Spectro-radiometer) imagery. MODIS is a key instrument aboard the Terra and Aqua satellites, which capture the reflectance in 36 wavelength groups (bands) from the entire earth's surface every 1 to 2 days. MODIS Bands 1 and 2 ('Red' and 'NIR') are used for fire scar mapping because they are best for distinguishing fire scars and have the best resolution (250 m).

Fire scars mapped using Landsat Quicklooks were visually identified and digitised. From mid-2003 to mid-2007 fire scars were identified by semi-automated classification of visually identified fire scars using ERDAS IMAGINE. Since mid-2007 fire scars have been identified by creating a 'difference' image highlighting changes between two images taken of the same locations roughly a week apart. The Definiens eCognition program automatically 'segments' and classifies the 'difference' image into polygons from which fire scars are extracted using the ArcView GIS program.

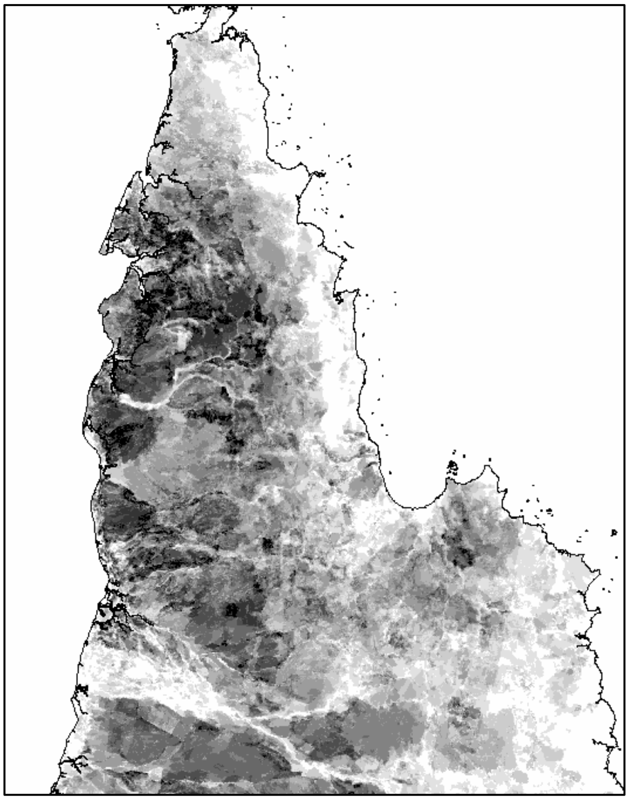


Figure 1: Cape York Peninsula fire frequency between 1999 and 2007.

Each year's digitised fire scars are converted to raster grids which are summed to produce a 'fire frequency' layer showing the number of years a pixel (6.25 ha) has been burnt in a given time period, 0 = never burned and 9 = burned annually.
The frequency image is then converted back to vector format for integration with other data to investigate their relationship to fire frequency.

The fire frequency is presented in map form with each pixel value represented by a gradational colour shade. The more frequent the fire regime, the darker the pixel colour (Figure 1).

Relating fire frequency to natural features
The vector fire frequency layer has been intersected with the GIS layers of topography (elevation, relief), landform (major land type, regolith class, soils, vegetation groups, rivers and streams) and rainfall (isohyets). This gives every fire frequency land parcel (polygon) an associated attribute of topography, landform or rainfall.

Regression analysis has been performed on this data to identify features natural to the landscape that may be more prone to fire, or perhaps promote fire. These land types, classes, or zones show either a positive or low correlation with fire frequency. Land (within a land type, class, or zone) that does not burn often shows a strong negative correlation with fire frequency.

Land types, classes, or zones that burn with high frequency in Cape York Peninsula (CYP) include:
Three Soil groups: 'Soils of the rolling downs group', 'Soils of the swamps' and 'Soils on deep remnant sands of a former sandstone surface' (r^2 ranging from -0.06 to 0.64; p-values ranging from 0.044 to 0.873)
Two Regolith classes: 'residual sand' and 'very highly weathered bedrock' (r^2 = -0.26 and 0.35, respectively; p-values = 0.324 to 0.461, respectively)
One Major Landtype: 'Rises' (r^2 = 0.23; p = 0.517)
Three Relief zones: 'low-very low', 'low-moderate' and 'low-very high' (r^2 ranging from -0.07 to 0.4; p-values ranging from 0.250 to 0.841)
Four Elevation zones: '140', '180', '200' and '350' metres above sea level (r^2 ranging from -0.41 to 0.58; p-values ranging from 0.076 to 0.242)
Three Rainfall ranges: '750-800mm', '800-900mm' and '900-1000mm' (r^2 ranging from -0.38 to 0.11; p-values ranging from 0.279 to 0.764)

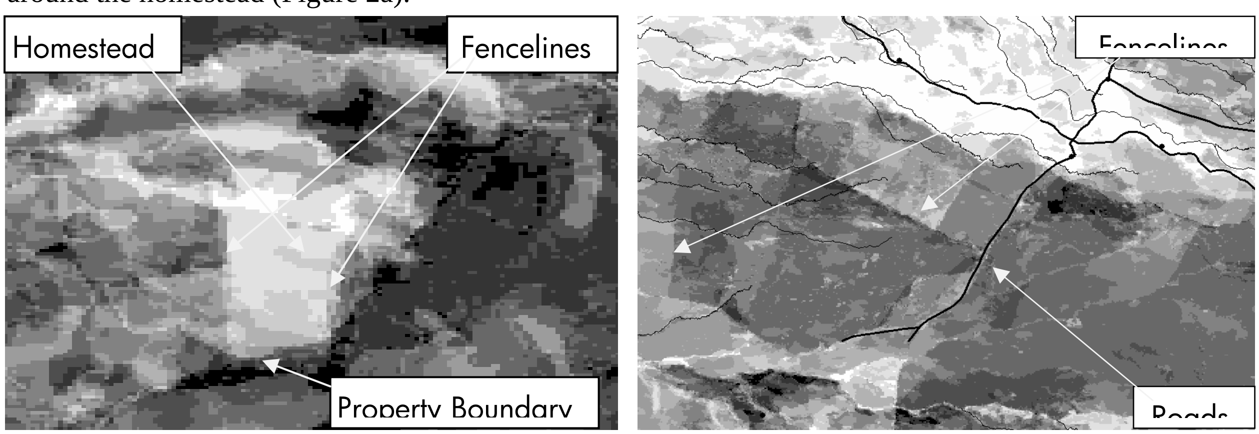
Land types, classes, or zones that burn with low frequency in CYP:
The strongly negative correlation and probability values for these types, classes, or zones were:
Soils groups: r^2 ranging from -0.73 to -0.98; p-values ranging from 0.000 to 0.016
Regolith classes: r^2 ranging from -0.76 to -0.96; p-values ranging from 0.000 to 0.012
Vegetation Community groups: r^2 ranging from -0.59 to -0.96; p-values ranging from 0.000 to 0.071
Major land types: r^2 ranging from -0.65 to -0.96; p-values ranging from 0.000 to 0.040
Relief zones: r^2 ranging from -0.39 to -0.96; p-values ranging from 0.000 to 0.268
Elevation zones: r^2 ranging from -0.65 to -0.95; p-values ranging from 0.042 to 0.208
Rainfall ranges: r^2 ranging from -0.60 to -0.98; p-values ranging from 0.024 to 0.064

Buffers of 10, 250, 500, 750, 1000 and 2000 metres were created on either side of the major rivers and creeks in CYP using a GIS. Zonal statistics were calculated to investigate the relative effectiveness of rivers and creeks as a barrier to fire the mean fire frequency was calculated at different distances from the watercourses (Table 1). Table 1 shows that, in general, the land immediately adjacent to rivers and creeks burns infrequently (1 to 2 times in 9 years). The results confirm what is seen from the fire frequency map, which is that larger rivers are more effective barriers to fire than smaller creeks, but this difference disappears 2000 m away from the watercourse.

Table 1: The effectiveness of rivers and creeks as a barrier to fire.

	River			Creek		
Metres away from the watercourse	**Mean Fire Frequency (X times in 9 years)**	*St.Dev.*	*Median Fire Frequency (X times in 9 years)*	**Mean Fire Frequency (X times in 9 years)**	*St.Dev.*	*Median Fire Frequency (X times in 9 years)*
10	**1.8**	*1.9*	*1*	**2.2**	*2.3*	*1*
250	**1.8**	*1.9*	*1*	**2.2**	*2.3*	*1*
500	**1.9**	*1.9*	*1*	**2.2**	*2.3*	*1*
750	**1.9**	*2.0*	*1*	**2.2**	*2.3*	*2*
1000	**2.0**	*2.0*	*1*	**2.2**	*2.4*	*2*
2000	**2.2**	*2.2*	*2*	**2.3**	*2.4*	*2*

Visual interpretations of the effect of human management on fire frequency
The fire frequency layer can be used to easily view the effects of grazing intensity and fire management, as well as the impact of fences and roads on fire (Figures 2a and 2b). Black shows areas of high fire frequency, white shows areas of low fire frequency. Note the lower fire frequency due to grazing pressure around the homestead (Figure 2a).



Figures 2a and 2b: Landuse, infrastructure and fire management effects seen through fire frequency.

Researching the impacts of fire frequency on biodiversity, the atmosphere and economics
The current 9-year CYP fire frequency layer is currently being used to guide research investigating the economics of fire management in Cape York Peninsula, as well as woody thickening and vegetation change. The fire regimes of pastoral properties were explored to determine the area, timing and frequency of fires in the last decade and this is being linked with economic, production and management data from the corresponding period. Historical aerial photo analysis is confirming woody thickening sites on these same properties, which will be correlated with fire frequency.

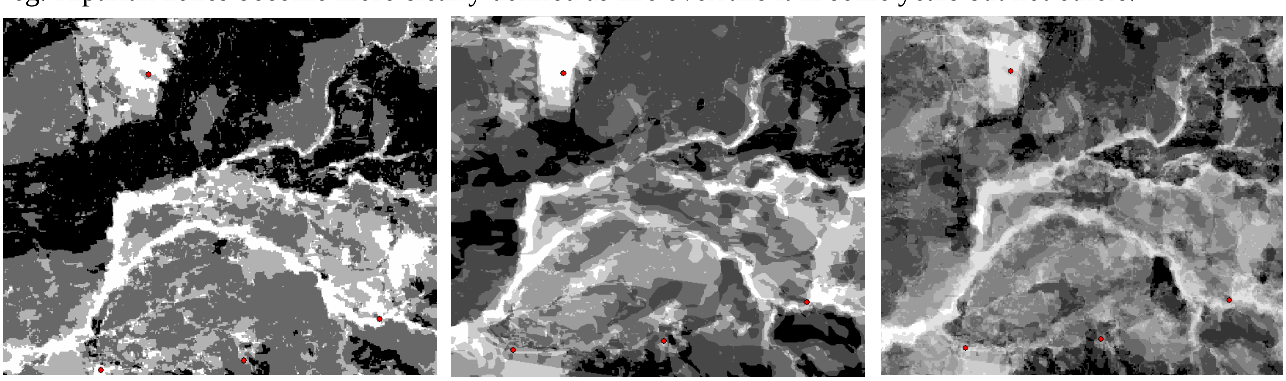
A proposal is currently being developed to explore the impact of fire frequency in Cape York on Biodiversity (flora and fauna). The project will use the fire frequency map as an indicator for potential monitoring sites across CYP.

The above-mentioned projects, as well as a partitioned fire frequency layer (producing early-season, mid-season and storm-season fire frequency maps) will contribute to the process of determining appropriate fire regimes for best practise management.

It is envisaged that in the foreseeable future the fire frequency data will be used in determining Greenhouse Gas emissions from the CYP savannah woodlands as has occurred in West Arnhem Land, Northern Territory, which will lead to carbon trading opportunities for landholders.

DISCUSSION
Fire frequency maps provide a formal, effective mode of presenting large amounts of fire information visually correlated with on-ground factors. The maps demonstrate regional climatic and environmental variability on fire regimes, but are also applicable for extensive properties to investigate management and infrastructure effects and the consequent drivers of change.

The compositing of annual fire layers results in a progressively more accurate, more heterogeneous and higher resolution fire frequency product (Figures 3a, 3b and 3c). The patchiness of the landscape is illustrated more clearly as the micro-landscape and micro-topographic effects that determine the susceptibility and recurrence of fire reveal themselves over the long-term. With a single year's data, homogenous fire scar areas may be mapped over an area that hasn't burnt for a while. The next time it burns, one part of the same country burns more easily than another due to heterogeneity in the landscape eg. Riparian zones become more clearly defined as fire overruns it in some years but not others.



Figures 3a, 3b and 3c: The effect compositing annual fire scar layers have on increasing the definition of heterogeneity. From the left: **3a** – 3 year fire history; **3b** – 6 year fire history; **3c** – 9 year fire history

The 9-year 'fire frequency' layer graphically illustrates fire patterns associated with topography, landform, regional ecosystems, infrastructure and land use. It can also link to land condition status, highlighting over-burnt, over-grazed or under-burnt areas. Land use (pastoral, indigenous and conservation) can be differentiated, identifying appropriate fire management regimes so guidelines can be developed eg. best practice fire regimes to manage woody thickening. The fire scar data is also being used in applied projects like investigating the effect of fire on CYP biodiversity and pastoral economics.

Similar research has been carried out in Namibia, where Landsat Quicklooks imagery was used to develop a 13-year fire history which was used to investigate relations between fire frequency, rainfall, land cover, fire management and trees (Verlinden and Laamanen, 2006).

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