A SATELLITE ANALYSIS OF CONTRASTING FIRE PATTERNS IN ABORIGINAL- AND EURO-AUSTRALIAN LANDS IN TROPICAL NORTH AUSTRALIA

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ABSTRACT

We use satellite imagery to compare and contrast fire patterns across a repeating mosaic of vegetation types occurring within the tropical savanna of the Northern Territory, Australia. Our study area included different land management settings that encapsulate three contrasting styles of management that have developed following European settlement in northern Australia:

- Decentralized fire management carried out by small Aboriginal communities widely dispersed across a large landscape.
- Centralized fire management carried out by park rangers and military land managers who implement a fire management plan based on a paradigm of hazard reduction burning.
- Pastoral properties with a specific management objective of improving cattle yield by protecting and improving pasture with fire.

The lowland eucalypt savannas were the most burnt of any vegetation type, but within eucalypt savannas there were subtle differences in fire frequency. The highest fire frequencies were recorded in national park and military lands, intermediate frequencies on Aboriginal lands, and the lowest fire frequencies on pastoral properties. Aboriginal lands had an even distribution of fire throughout the dry season in contrast to the marked bias towards early dry season landscape burning on all Euro-Australian controlled lands. These findings illustrate the impact of different management paradigms and cultural decisions about fire on physical fire patterns.

Keywords: fire management, fire regime, GLM, indigenous land management, MODIS, regression tree, remote sensing, tropical savannas

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INTRODUCTION

The vast uncleared landscapes of northern Australia have become a focal point for biodiversity conservation in Australia (Woinarski and Braithwaite 1990). Much of the region is dominated by tropical savannas with fire return intervals of one to two years common in high rainfall regions (Russell-Smith *et al*. 2003, Russell-Smith *et al*. 2007). This flammability is primarily due to a combination of high rain seasonality, with over 90% of annual precipitation falling in the austral summer (between November and March), and a robust annual and perennial grass understorey that grows vigorously during the wet season and cures rapidly after the onset of the dry season (Williams *et al*. 1998).

The annual transition from dry season to wet season is marked by a period of intense tropical convection storms that create natural conditions highly conducive to the ignition and spread of large scale fires. However, human management plays a key role in determining fire patterns by influencing the timing of fires. Human modification of fire patterns in the tropical savannas of northern Australia probably began with the first arrival of Aboriginal Australians some 50,000 years ago. This saw a shift from large-scale, lightning derived fires occurring late in the dry season to numerous patchy, smaller-scale fires occurring throughout the dry season (Lewis 1994, Bowman 2002). Fire patterns changed again with the Aboriginal depopulation that followed European settlement in the late 1800s. Beyond these generalizations there remains much uncertainty regarding how landscape fire activity has changed over decadal to millennial time-scales. In this context it is not surprising that there is a robust debate among fire scientists and land managers about the most appropriate fire regimes for sustainable land management.

This debate centers around three interrelated factors: 1) fire frequency, 2) timing, and 3) fine scale heterogeneity (Russell-Smith *et al*. 2003). Analyses of archival satellite data have shown that fire frequency is remarkably consistent over the span of the record (since the late 1970s: Edwards *et al*. 2001, Russell-Smith *et al.* 1997). Indeed, although reduction in frequency has long been a management objective, in some settings it has proven remarkably difficult reduce the number of fires (Andersen *et al*. 2005).

There has been far more success in changing the timing of landscape fires. Most land managers in northern Australia divide the dry season into two fire seasons: the early dry season (EDS), between April and July, and the late dry season (LDS), from August to November. Studies from Kapalga research station in Kakadu National Park indicate that fire intensity and fire risk increase gradually through August and peak in September and October (Williams *et al.* 1998, Gill *et al.* 1996). Williams *et al.* (2002) report a fourfold increase in fire intensity from fires occurring in early June to those occurring in late September, although intense fires can occur in long unburned fuels early in the dry season (Bowman *et al*. 2003). Thus timing is widely seen by land managers as a rule of thumb surrogate for fire intensity (Gill *et al.*1996, Williams *et al.* 2002), as well as a means of increasing the internal patchiness of fires, potentially mitigating widely cited declines in mammalian and avian abundance within Australian tropical savannas (Woinarski *et al.* 2001, Franklin 1999).

The debate about sustainable fire management has been dominated by experimental studies (most notably the Kapalga and Munmarlary fire experiments) and various correlative studies within particular landscape settings, particularly Kakadu National Park (Price *et al.* 2005, Russell-Smith *et al.* 1997, Edwards *et al*. 2003) and on Aboriginal lands (Bowman *et al.* 2004). There has been far less attention paid to comparisons of similar landscapes under different management regimes. The north coast of the Northern Territory lends itself to such a study given the juxtaposition of tenures with sharply contrasting management objectives imposed on a catena of similar savanna landscapes on adjacent river catchments.

In this study we compare and contrast fire frequency and fire seasonality across three land management regimes representing Aboriginal and European land management styles:

1. Decentralized fire management carried out by small Aboriginal communities widely dispersed across a large landscape
2. Centralized fire management carried out by park rangers and military land managers who implement a fire management plan based on a paradigm of hazard reduction burning with the intent to create habitat heterogeneity and mimic traditional (pre-settlement) Aboriginal management
3. Pastoral properties with a specific management objective of protecting and improving pasture from fire during the dry season while improving cattle yield

METHODS

Study Site

The study area extends 450 km (280 mi) longitudinally and 100 km (62 mi) inland across northern coastal Australia from the Blythe River in the east to the Mary River in the west (Figure 1a). Aboriginal and Euro-Australian regimes divide the study area in half. Although both Aboriginal and Euro-Australian tenures are “Australian,” we will refer to Euro-Australian tenures as “European” to reflect the cultural origins of the management paradigm. The climate of the region is typical of monsoonal northern Australia, with little seasonal difference in daily maximum temperature, but extreme seasonality in annual rainfall — 90% of the 1200 mm to 1700 mm (47 in to 67 in) of annual rain falls erratically within a six month period during the austral summer.

The majority of vegetation within the study region (Figure 1b) is lowland savanna woodland on lateritic sandy or sandy-loam soils with little seasonal inundation dominated by the tree species *Eucalyptus tetrodonta* and *Eucalyptus miniata* (Wilson *et al*. 1991). Outcropping from the lowland savannas are rolling hills of dolerite and other metamorphics that support woodland savanna mixtures of eucalypts and closely related *Corymbia* spp. Although similar, these hills are structurally and compositionally distinct from their lowland savanna counterparts, and tend to be less productive, with a shorter and more open canopy layer. Interspersed within the savanna are seasonally inundated floodplains with deep estuarine and depositional clays. Except for small patches of *Melaleuca* spp. forest these floodplains are largely treeless and dominated by graminoids (Wilson *et al.* 1996, Finlayson and Woodroffe 1996).

The Arnhemland Plateau comprises the south eastern portion of our study area (Figure 1b). The plateau is formed by uplifted Proterozoic sandstone and is bordered by a rugged escarpment. Soils are skeletal and infertile and typically less than 150 cm (59 in) deep although on some parts of the plateau surface there are deep sandsheets (Russell-Smith 1995a). Vegetation communities are a mixture of *Eucalyptus tetrodonta* savanna, *Allosyncarpia ternata* forests, *Callitris intratropica* woodlands on deeper soils, and sandstone heath (*Acacia* spp.) communities on skeletal soils.

For the purposes of the analysis we divide the region into four distinct landform types: Arnhemland Plateau, floodplains, lowland savannas and rolling hills.

We also further divide this region into six management regions to reflect differences in land management approach among the four primary landform types (Figure 1a). Broadly, these can be classed into Euro-Australian (i – iii) and Aboriginal (iv) tenure systems:

(i) Military training ground – Mount Bundy Training Area (MBTA), a military reservation devoted to military training with live munitions.

(ii) Pastoral properties – properties where cattle are bred and raised both for export and domestic consumption.

(iii) National Parks – a) The proposed Mary River National Park (MRNP), a conservation zone maintained by the Northern Territory Parks and Wildlife Service. b) Kakadu National Park (KNP), a World Heritage National Park maintained by the federal government of Australia.

(iv) Aboriginal reserves – There are two Aboriginal Australian tenure zones in the eastern half of the study area, each with a distinctly different history of contact with European settlement: a) Oenpelli, extending from the East Alligator River to the Goomadeer River in central Arnhemland, and b) Maningrida, extending from the Goomadeer River to the Blythe River.

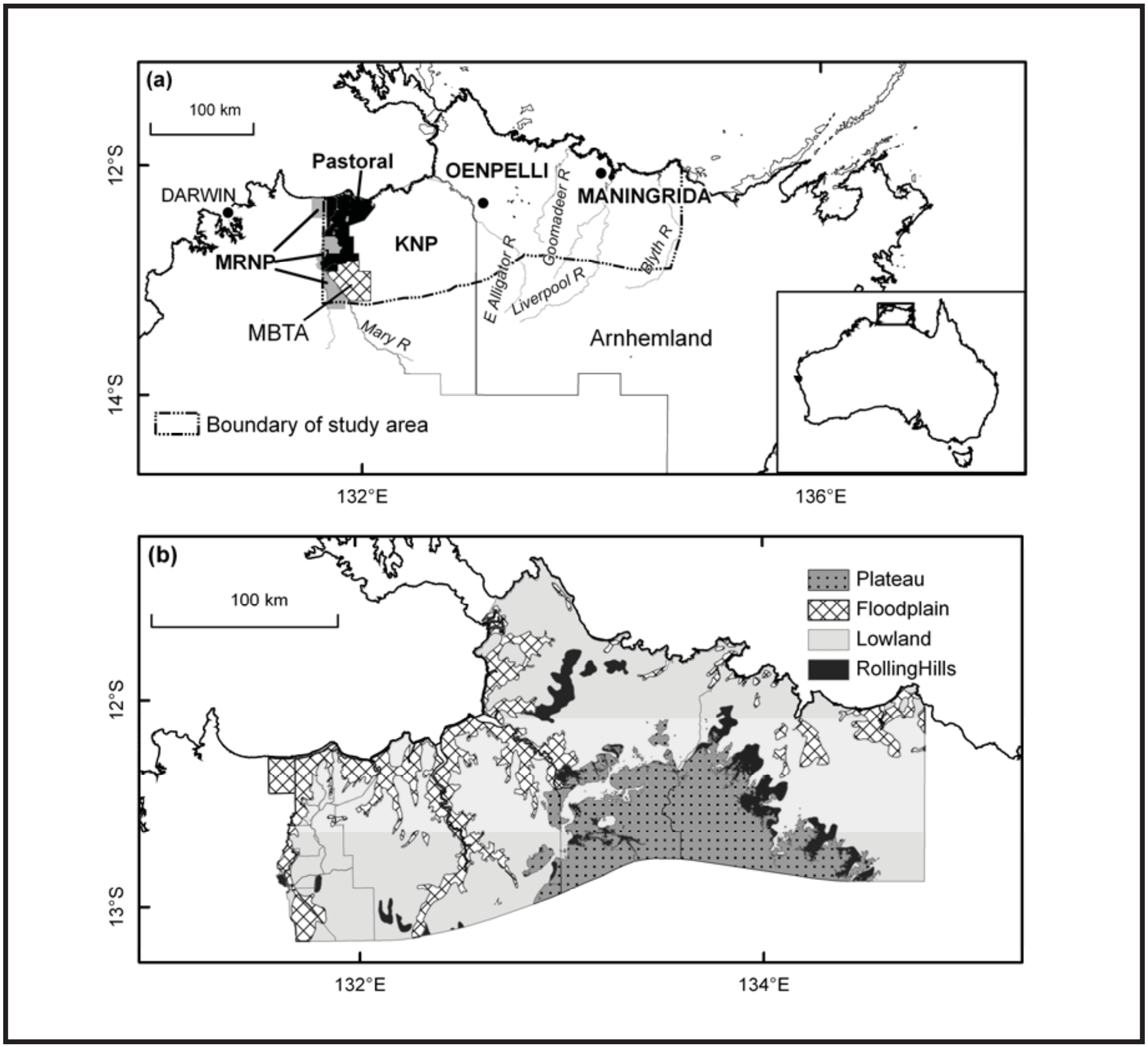

Figure 1: (a) Land tenure systems encompassed by the study area. Abbreviations used for land tenure systems are: MBTA is the Mount Bundy defence training area; MRNP is the proposed Mary River National Park, and KNP is Kakadu National Park. Oenpelli and Maningrida are the centers for two administrative units within Arnhemland, demarcated by the Goomadeer River. (b) Detail of study area showing landsystem units.

Fire History

The fire history for this study area was interpreted from MODIS satellite imagery (resolution 250 m) from 2002 through 2005. Within each year, MODIS images were captured in two- to four-week intervals.

Fire scar detection utilised a semi-automated approach. Polygons were segmented from the raster data layer using Definiens® ECognition™ v4.0. The automatic segmentation algorithm was selected to bias towards errors of commission, which were then removed by manual editing. All fire scars derived from MODIS were supplied by the Tropical Savannas Cooperative Research Centre.

We did not attempt to ground truth for this survey as we were principally concerned with relative patterns of fire history across the study region. However, the MODIS imagery is cross-validated with Landsat Thematic Mapper (TM) imagery at similar capture times to the MODIS imagery. Landsat TM has a much finer spatial resolution of 30 m. Furthermore, within the study region there have been several validation efforts for Landsat-derived fire histories (Gill *et al*. 2000, Russell-Smith *et al.* 1997, Bowman *et al*. 2003). Omission rates in the neighborhood of 20% are generally reported (Russell-Smith *et al.* 1997, Edwards *et al*. 2001, Yates and Russell-Smith 2003), although Bowman *et al*. (2003) caution that detection of fire scars with Landsat is problematic due to rapid fire scar fading in the tropics. To validate MODIS in terms of Landsat imagery, we divided the study area into a 10 km x 10 km (6.2 mi x 6.2 mi) grid and calculated the percentage of area burnt in each grid. Linear regression of the two datasets gave a reasonable fit (R^2 = 0.75, slope = 0.89, Figure 2). The Landsat imagery was classified for fire scars using an identical methodology to the MODIS imagery.

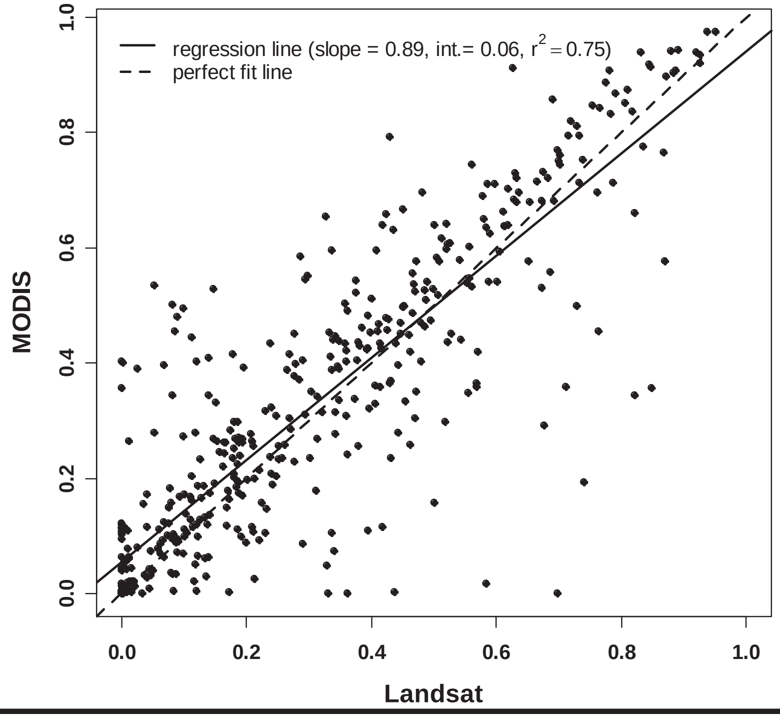

Figure 2: Plot comparing 2005 MODIS and Landsat derived fire scars. Values are the ratio of burned area within cells of a 10 km x 10 km (6.2 mi x 6.2 mi) grid encompassing the study area. MODIS data were supplied by the Tropical Savannas Cooperative Research Centre, Landsat data were supplied by the Northern Territory Bushfires Council and generated by the authors (see methods).

Variables of Fire Activity: Frequency and Timing

Each of four MODIS annual fire scar polygon layers (2002-2005) was transformed into a raster layer composed of 250 m^2 pixels containing values of 1 if a fire had occurred on that pixel at any time that year and 0 if there was no fire. We summed the four layers, creating a new raster layer with values ranging from 0 to 4 indicating the total number of fires occurring within each pixel.

Additionally, each MODIS-generated fire scar was attributed with the month of satellite capture. From this attribute we created two further raster outputs: 1) the ratio of early dry season fires (number of fires occurring before August 8) to total fire frequency within each pixel from 2002-2005, and 2) a raster layer for each of the eight fire season months (April to November) within each of the four years of MODIS capture. Each pixel within the 32 raster layers thus generated was attributed with a value of 1 if a fire was detected in that month and year, and zero if not.

Explanatory Variables

Three variables were used as independent variables and attributed to each cell in the grid layer:

Tenure: We derived the six land management regions from the Northern Territory Cadastral Map provided by the Northern Territory Land and Information Service, except for the boundary between Maningrida and Oenpelli, which was marked by the location of the Goomadeer River on 2005 Landsat imagery.

Landsystem: Elevation was derived from a 90-m Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) supplied by GeoImage Pty Ltd. Australia. Vegetation boundaries were derived from a 1:100 000 digitised vegetation map of the Northern Territory (Wilson *et al*. 1991). Details are provided in Table 1.

Distance from road: As corridors for human travel, roads provide an ignition point for fires and are more densely concentrated within European tenures. We controlled for this potentially confounding factor by calculating the distance to the nearest road within a 1:100 000 Northern Territory roads polyline layer supplied by the Northern Territory Land and Information Service.

Regression Tree Analysis

To explore non-parametric correlative relationships between variables we used a recursive partitioning algorithm, or “regression tree” (Breiman *et al*. 1984). A regression tree is a non-additive and assumption-free means of interrogating data sets that is particularly useful for non-linear data sets or sets with many categorical variables. It successively partitions a data set based on binary splits in the values of explanatory variables that best reduce overall deviance in the data set. Once a tree model has been developed it can be used as a prediction tool for other data sets. The latter approach is particularly powerful for testing model robustness with spatial data, where sample sizes are typically very large but spatially autocorrelated.

We divided the raster layer into two equally sized subsamples. A randomly selected 50% sample was selected as a training set, while the remaining pixels were allocated as the testing set. Models were generated using R 2.5.1, with package rpart v. 3.1-32. The minimum acceptable drop in deviance for a split was set to 0.1% to generate an over-fitted model.

We separately modelled fire frequency and the number of fires occurring in the early dry season against the three explanatory variables. The over-fitted training set model was successively reduced to smaller candidate sub-tree models (pruned). Each of these models

Table 1: Derivation of landsystem units. Vegetation follows the classification of Wilson *et al.* (1991).

Landsystem Type	Criteria
Plateau	Lying at an elevation above 180 m in the region of the Arnhemland Plateau or consisting of the Wilson *et al.* vegetation unit "*Allosyncarpia ternata* closed forest."
Rolling hills	Regions consisting of Wilson *et al.* vegetation unit "*E. dichromophloia, E. miniata* low open-woodland with *Plectrachne pungens* open-hummock grassland understorey" or localized distinct vegetation polygons adjacent to *E. dichromophloia* and generally following a higher elevation contour (over 90 m).
Floodplain	Regions consisting of the following Wilson *et al.* vegetation units: • Mangal low closed-forest (Mangroves) • Melaleuca forest (Paperbark Swamp) • *Melaleuca viridiflora,* Eucalyptus low open-woodland with *Chrysopogon fallax* grassland understorey • Mixed closed-grassland/sedgeland (Seasonal Floodplain) • Saline tidal flats with scattered chenopod low shrubland (Samphire)
Lowland	Regions consisting of the following Wilson *et al.* vegetation units and lying at low elevation (below 90 m): • *Eucalyptus miniata* woodland with grassland understorey • *E. papuana, E. polycarpa* woodland with grassland understorey • *E. tectifica, E. latifolia* woodland with Sorghum grassland understorey • *E. tetrodonta, E. miniata, E. bleeseri* woodland with Sorghum grassland understorey • *E. tintinnans* low woodland with Sorghum grassland understorey. • Coastal dune complex.

was used to predict values within the testing set. The sum of squares (SSQ) deviance between the predicted and true value was calculated for each sub-tree. The final pruned model was selected when further partitions failed to improve the predictive capacity of the model (i.e., there was no further improvement in the SSQ difference between predicted and true values).

Generalized Linear Models (GLM)

We then used a generalized linear model (GLM) to develop a more fine-scale, parametric model that could predict fire frequency within each month. We modelled the occurrence of fire as a binomial variable with a logit link against the following variables:

a) Month of satellite capture (categorical, ranging from April to November)

b) Distance from road and its interaction with month

c) Tenure (Aboriginal or European) and its interaction with month. We combined the six land management units into two tenure types to simplify analysis. Our regression tree analysis of early dry season percentage showed this was justified as tenure was the strongest predictor regardless of vegetation type with no further meaningful partitioning of the data set.

d) Landsystem type

In order to mitigate against spatial autocorrelation effects, we used a random 5% subsample of the data to generate the model. To improve the robustness of the linear predictors thus generated, we averaged the results from ten models generated using ten independent subsamples. We attempted mixed effects models with both year and location as random effects. In both cases the random effect estimate was nil, so in the final analysis we used a fixed effect model. We also attempted model selection using the Akaike Information Criteria (AIC [Burnham and Anderson 2002]), however, the global model containing all variables and interactions had an Akaike weight >0.99 for all iterations of the model, so the other candidate models were dropped from further analysis. All parameters were highly significant ($p << .001$).

RESULTS

Fire Frequency

The regression tree model for fire frequency explained 24% of the SSQ difference between predicted and actual values (Figure 3). The primary split in fire frequency was between lowland savanna land systems and all others, regardless of tenure type (Figure 3). The mean number of fires per pixel over four years within all lowland savannas was 2.2, which is contrasted by 1.4 fires per pixel for all other landsystem types. Tenure was not an important factor in splitting non-lowland savanna data, with the exception of pastoral properties, which burned less frequently in general. Of all land system types, the plateau burned the least frequently (1.1 mean fires per pixel). Floodplain and hill landsystems closer to roads burned more frequently than those further away.

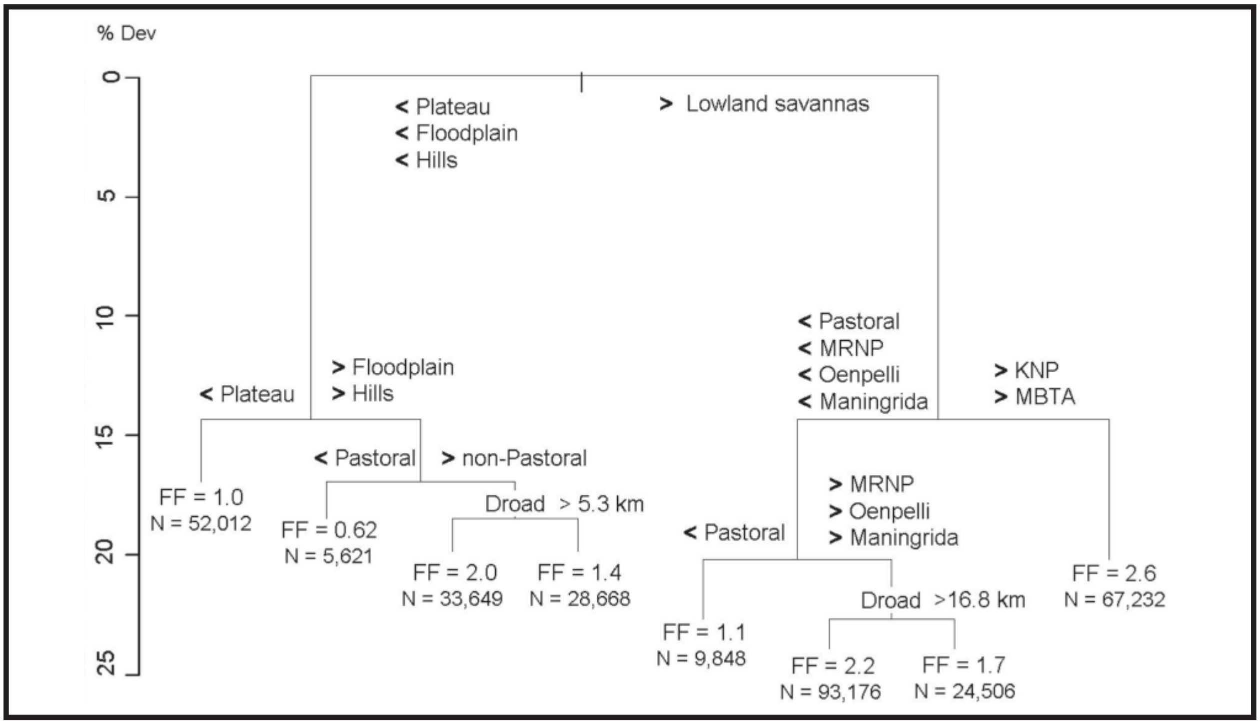

Figure 3. Tree diagram of fire frequency (FF, the number of fires recorded per pixel from 2002 – 2005) described by landsystem type, tenure type, and distance from road. Length on the vertical axis is proportional to the amount of deviance explained at each branch. The total deviance explained was 24%. Terminal branches (“leaves”) show the mean FF within that branch. ‘N’ is the number of pixels (50% of the total) at each leaf. ‘Droad’ is distance from the pixel to the nearest road in kilometers, ‘MBTA’ is the Mount Bundy defense training area and ‘KNP’ is Kakadu National Park.

Within lowland savannas, tenure was the strongest factor in predicting fire frequency. Kakadu and Mount Bundy had the highest mean number of fires per pixel (2.6) while pastoral properties had the lowest (1.1). Oenpelli, Maningrida, and Mary River National Park were not separated on the basis of tenure, but across all three regions fires were more frequent within 13 km (8 mi) of a road.

Timing of Burns

Within the regression tree model of the proportion of early season burns, thirty-six percent of the deviance between predicted and actual values was explained by partitioning the data into two groups based on management regions: 1) pastoral properties, Mary River and Kakadu National Parks, and Mt. Bundy Training Area; and 2) Oenpelli and Maningrida. These groups correspond exactly to European and Aboriginal tenure types, respectively. The strong seasonal signal in the data is highlighted by Figure 4 where we show the percentage of EDS fires from 2002 – 2005.

Figure 5 shows the GLM derived probability of a fire occurring within a given month. Again, segregation by tenure is apparent, with fire most likely to occur in European lands in a single month (May). By contrast, the probability of fire on Aboriginal lands was dispersed throughout the dry season, but less likely before June. Model error was also higher within Aboriginal lands, implying greater interannual variability in fire timing. Distance from road was negatively correlated with fire activity, but most strongly early in the dry season.

DISCUSSION

Our findings on short-term fire frequency compare with longer term findings using Landsat derived fire scars in Kakadu National Park (Russell-Smith *et al*. 1997, Gill *et al*. 2000). Press (1986) records that fires on average burnt 50% of lowland systems annually in Kakadu from 1980 through 1985, while Russell-Smith (1995b) estimates that 40-45% Kakadu burnt annually from 1990 through 1995. We found that on average 66% of the area of lowland savannas burned annually, which is close to the maximum frequency reported by Russell-Smith *et al.* (1997) and Gill *et al.* (2000) for lowland savannas. This is possibly due to higher dry season fuel loads as a result of higher than above average wet season rainfall (Australian Bureau of Meteorology: http://www.bom.gov.au/climate/averages/tables/ca_nt_names.shtml).

Unfortunately, we lack a similar historical perspective on the regions outside of Kakadu, although Bowman *et al.* (2004) report comparable fire frequencies to those reported here from a ten-year analysis of fire patterns in central Arnhemland. During the relatively short time period of our study, Mary River National Park and the Aboriginal lands of Oenpelli and Maningrida had a distinctly lower four-year fire frequency compared to Kakadu (Figure 3). The lowest fire frequencies overall were on pastoral stations adjacent to Kakadu where most areas had no fires over four years and the mean number of fires was 1.1. This is probably due to reduced grass fuel loads from grazing and few intentional ignitions.

The contrast in timing of burns between Aboriginal and European lands is stark (Figure 4). This pattern encapsulates a suite of changes in fire management in northern Australia during the past century, including Aboriginal depopulation and resettlement (Russell-Smith *et al*. 2003 and references therein), the implementation of a campaign of early-season burning on European controlled lands (Price *et al*. 2003, Bowman *et al*. 2007a), and changes in grass layer composition initiated following the de-stocking of feral and domesticated grazers (Petty *et al*. 2007, Werner *et al.* 2006).

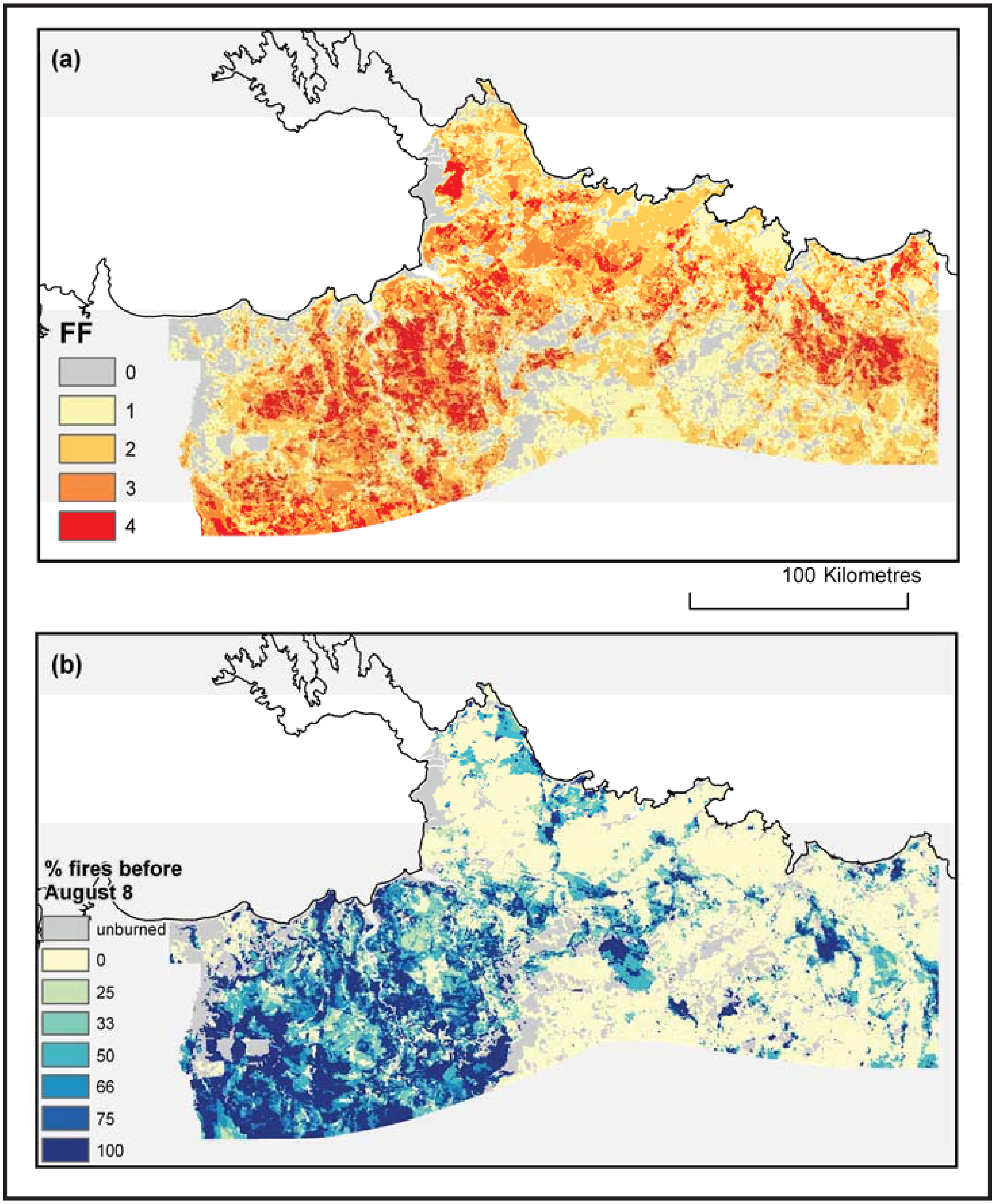

Figure 4: (a) Map of Fire History Index: The number of fires from 2002-2005 across the study area. (b) The percentage of fires from 2002-2005 detected before August 8 (early dry season fires). Fires were mapped from MODIS satellite data by the Bushfires Council NT. Colors were selected with the help of the Color Brewer: www.colorbrewer.org

For example, on Aboriginal lands, fire probability rises in July and remains relatively constant until October (Figure 5). Fire probability on Aboriginal lands and elsewhere declines sharply with distance from road early in the dry season, reflecting management in inhabited areas (Bowman *et al.* 2004). Late-season fires, which often travel tens of kilometres, reduce the effect of proximity to roads as the late season progresses. However, overall, the probability of fire on Aboriginal lands remains relatively constant throughout the dry season, and the number of return fires to the same area is lower. This is consistent with the contemporary and historical Aboriginal practice of multiple small, patchy burns throughout the dry season, starting on the upland areas and hills and moving towards lower lying (and hence wetter) areas as grass cures (Yibarbuk *et al*. 2001, Vigilante 2001, Preece 2002, Bowman *et al*. 2007b).

By contrast, on European tenures, which in this study are dominated by Kakadu National Park and the Mount Bundy Training Area, well resourced land managers have implemented widespread fire management campaigns even in otherwise inaccessible areas. These fires are intentionally lit as early as possible, and are often difficult to start because grass still retains moisture from the end of the wet season—a desirable condition for European land managers as it inhibits the spread of these fires and increases internal heterogeneity. This has led to a spike in fire activity in the month of May (Figure 5), and one unintended consequence has been an overall increase in temporal fire frequency (Figure 3).

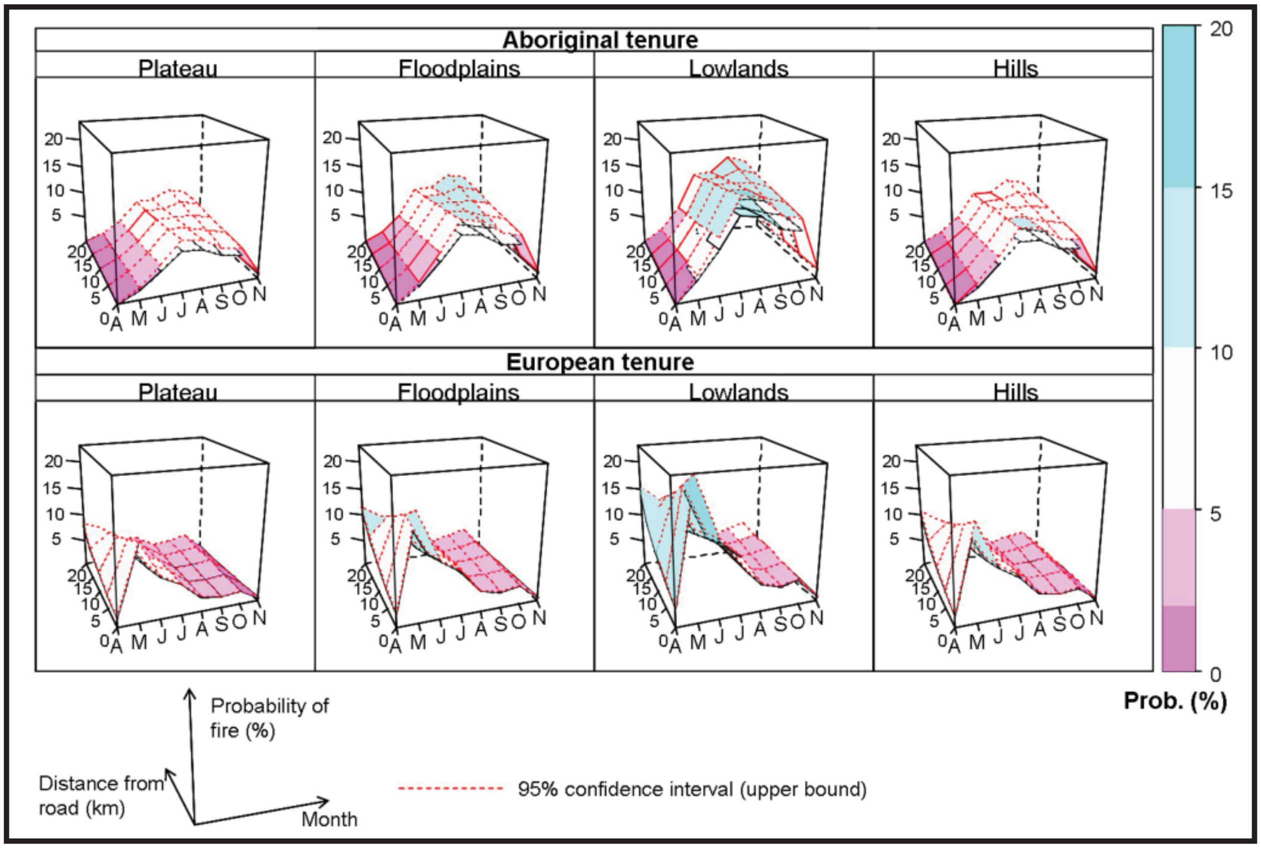

Figure 5: Predicted probabilities of a fire occurring on any given 250-m pixel within Aboriginal and European tenures stratified by vegetation type. Shown are prediction surfaces based on the averaged parameters and associated standard error of ten independent binomial GLM models derived from MODIS fire scar data. Only the upper bound of the standard error estimates is visible (in red) because the lower bound is very close to the mean value. The mean total deviance explained was 19.4%.

Entangled within these different management approaches is an increasing east-west gradient of annual sorghum (*Sorghum intrans* and *S. timorense*) cover (Bowman *et al*. 2007b, Franklin *et al*. in press), a fire tolerant and fire promoting native annual grass that cures about two months earlier than perennial grasses (Williams *et al.* 2002). The notable exception to this gradient is Mary River National Park, where sorghum levels, and fire frequency, remain mysteriously low (Franklin *et al*. in press). Sorghum levels may have increased in Kakadu National Park as a result of using fire to reduce fuel loads after the removal of feral Asian water buffalo within the park led to a pulse of annual grasses (Petty *et al*. 2007). Indeed, it is likely that increased sorghum cover has simultaneously increased the perceived need for early season burning to prevent conflagrations later in the dry season and, by curing earlier, created the conditions that make early burning possible. High fire frequency, in turn, confers a competitive advantage to sorghum (Mott and Andrew 1985) potentially locking landscapes into a “grass-fire cycle.”

There is immense concern for the impact of Aboriginal depopulation and the breakdown of traditional fire management regimes on native plants and animals, particularly on the virtually uninhabited Arnhemland Plateau (Bowman *et al*. 2001, Price *et al.* 2003, Yates and Russell-Smith 2003). By contrast, the ecological effect of the extreme early-season burning regime currently favored by European land managers in northern Australia is not well understood. There is ample evidence that, given equal understory composition, early-season fires are of lower intensity (Russell-Smith and Edwards 2006, Gill *et al.* 1996), and some evidence that understory diversity increases with early dry-season fires (Edwards *et al*. 2003). However, plant species in the Australian monsoon tropics evolved to survive the very late dry-season fires that would have prevailed prior to the arrival of humans (Bowman 2002), and there are indications that growth in juvenile eucalypts is hampered by early-season fires (Prior *et al.* 2004). The conventional wisdom among European land managers is that decreased fire intensity at the expense of increased fire frequency is an acceptable trade-off, however recent research suggests that fire frequency has a more significant impact than fire intensity on floral and faunal assemblages (Woinarski *et al.* 2004, Andersen *et al*. 2005).

The pattern reported here is an exception to most of northern Australia, where over half of all fires occur after August (Russell-Smith *et al*. 2003). This is a consequence of a sparse population and a lack of resources, both Aboriginal and European, to implement early-season burning. However, as awareness of the immense carbon sequestration potential of tropical savannas grows (Williams *et al*. 2004), pressure is building to more intensively manage Australia’s north. At present, such management will likely emulate the European model of burning as much as possible as early as possible. This is not entirely without merit, but we urge careful consideration of the impact of this paradigm on savanna systems adapted to a more heterogeneous fire regime.

Fire is a ubiquitous feature of the Australian tropical savannas. Unlike the mixed success of land managers in the western United States and southern Australia (Pyne 1991, 1997), land managers have never reduced fire frequency in Australia’s far north. Nevertheless, the imprint of differing “cultural paradigms” (Pyne 2007) on the timing of fire in northern Australia is clear. Given the importance of fire in shaping savanna ecosystems (Higgins 2000), the decision of when to burn may have ecological consequences as profound as the decision made in temperate ecosystems almost a century ago not to burn.

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