S. Burns, N. Tapper, D. Packham. The spatial and temporal distribution of dry season fires on indigenous lands of
North-Central Arnhem Land: A feasibility study using MODIS satellite imagery.
Proceedings of SSC 2005 Spatial Intelligence, Innovation and Praxis: The national biennial Conference of the Spatial Sciences Institute, September, 2005.
Melbourne: Spatial Sciences Institute. ISBN 0-9581366-2-9

THE SPATIAL AND TEMPORAL DISTRIBUTION OF DRY SEASON FIRE ON INDIGENOUS LANDS OF NORTH-CENTRAL ARNHEM LAND: A FEASIBILITY STUDY USING MODIS SATELLITE IMAGERY

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KEYWORDS: MODIS, burn scar, Traditional burning, dry season, ignition points

ABSTRACT

Extensive regions of savanna in northern Australia burn each year. This has implications for global greenhouse gas emissions and ecological sustainability. To gain a greater understanding of the impact fire has on the environment, this project uses remote sensing to analyse the spatial and temporal distribution of fire on indigenous land. This feasibility project focuses on Maningrida, a remote aboriginal community in Northern Territory, Australia. The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard TERRA was selected for this project using bands 1 and 2 at 250-metre resolution. MODIS was chosen because it has free archived data, constant coverage and moderate resolution. Images were downloaded between March and October 2004 (dry season) and were then processed. Burn scar detection techniques (semi-automatic, change detection and visual identification) were performed to create a burnt/ unburnt mosaic of the area. Results showed that 60% of the region was burnt, with the most burning occurring in larger fires during the middle to late dry season. Early in the dry season fires were smaller and more numerous. A large proportion of fire ignition points were found in close proximity to roads and outstations. These results show the potential for MODIS to analyse spatial and temporal distribution of fire using MODIS to gain more accurate estimates of greenhouse gas emissions and provide information for land managers to use fire regimes for greater ecological sustainability.

BIOGRAPHY OF PRESENTER

- Bachelor of Science (Environmental) 1998-2001, Specialising in Geography and Atmospheric Science.
- Master of Science (Preliminary) 2004, Research focused on remote sensing in which the thesis has the same working title and is the research basis for this paper.
- Currently doing Postgraduate research that uses satellite imagery and weather station data to analyse interannual-climate variability and anthropogenic influences on fire regimes.

INTRODUCTION AND RATIONALE FOR RESEARCH

The role of fire is important at a number of scales, from local fires affecting vegetation, hydrology and microclimates, to global impacts such as emissions affecting atmospheric chemistry, air quality, radiation balance and biogeochemical cycling [Andreae and Merlet, 2001, Justice *et al.*, 2003, Roy *et al.*, 2002]. Previous studies suggest that up to 50 percent of some regions of Northern Australia's savanna lands are burnt each year during the dry season [Russell-Smith *et al.*, 1997, Press, 1988]. With this magnitude of burning and with the importance of the atmospheric, climatic and ecological impacts of tropical savanna fires, the need for accurate monitoring of spatial and temporal patterns of fire occurrence is apparent [Pereira, 2003]. There is an important human dimension to biomass burning, with approximately 90% of fires globally started from an anthropogenic source [Levine, 2000]. In Australia land managed by Indigenous communities are extensive and are expanding through native title claims and with the purchase of pastoral leases [Dyer *et al.*, 2001] Clearly it is important to have an understanding of land management techniques used in these regions. Indigenous people have used fire in the savannas for thousands of years, and people continue to use fire for many types of land management purposes and a variety of reasons including ease of travel, communication, hunting and regeneration of plant and food [Dyer *et al.*, 2001]. However, there have been many changes to the fire regimes - the extent, frequency, severity and timing of fires, through the evolutionary, prehistoric and now modern time scales. These communities have a profound knowledge of fire management that has economic, cultural and spiritual significance. However, this knowledge is becoming increasingly uncertain as traditional elders age and pass away [Dyer *et al.*, 2001].

Traditional fire practices involve small patches of grassland being burned throughout the year as people migrated throughout the country. It is argued that smaller, less intense fires of traditional regimes, would maintain a more diverse habitat than large late fires [Dyer *et al.*, 2001, Yibarbuk *et al.*, 2001]. Yibarbuk *et al.,* [2001] found this when they compared the fire behaviour and fire management in a region managed by traditional aboriginal owners using aerial surveys, fauna inventory and detailed ecological assessment of the location of fire-sensitive vegetation, and established that burned sites did attract important animal food resources and maintained plant food abundance along with the diversity of vertebrate fauna.

It is generally accepted that "fire is one of the key ecological processes in the world's tropical savannas" [Preece, 2002 p330]. "Fire is both a determinant of and a factor influenced by the vegetation" [Haynes *et al.*, 1991 p39]. Fire affects "individual plants, plant communities, animals and their habitats, nutrients, water catchments and down-stream hydrology" [Dyer *et al.*, 2001 p29]. Although tropical savannas have a simple structure, they are rich in species, communities of plants and animals, and habitats [Dyer *et al.*, 2001]. Burning is considered to be an important agent in the succession and rejuvenation of savannas [Zhan *et al.*, 2002]. Fires of varying size, intensity and frequency affect the landscape differently. Some plant species increase in abundance with annual burning, and some are more abundant after long fire intervals [Williams *et al.*, 2003].

Biomass burned annually not only affects ecological sustainability but also produces large amounts of trace gases and particulates that play important roles in atmospheric chemistry and climate [Crutzen and Andreae, 1990]. It is now well accepted that burning from savanna fires is a major proportion of global biomass burning and a source of associated greenhouse gas emissions [Russell-Smith *et al.*, 2003a]. Greenhouse gases have significant implications for the global climate through the release of emissions such as; carbon monoxide, carbon dioxide, methane, non-methane hydrocarbons, nitrous oxide, nitrogen oxides, halogenated and oxygenated compounds, and aerosol particles [Beringer *et al.*, 1995, Crutzen and Andreae, 1990, Levine, 2000, Russell-Smith *et al.*, 2003b]. Some of these effects include; carbon monoxide and methane affecting oxidation efficiency; nitric oxide and hydrocarbons leading to high ozone concentrations, and aerosols acting as cloud condensation nuclei, that can affect the radiation budget and hydrological cycle in these regions [Crutzen and Andreae, 1990]. The Australian contribution of biomass burning and thereby greenhouse emissions from savannas, is ranked third after Africa and America [Hao and Liu, 1994 cited in Russell-Smith *et al.*, 2003a]. Spatial and temporal data can reveal the amount of the chemical species released per mass of biomass burned and can be used to establish a world emissions record [Andreae and Merlet, 2001]. Therefore quantitative data about spatial and temporal distributions of burning events and burned areas is important, not only for ecological sustainability and land resource management, but also for atmospheric chemistry and climatic change studies [Zhan *et al.*, 2002].

Remote sensing in the form of satellite imagery enables us to gain quantitative data to monitor fire regimes and their ecological responses on a number of scales. This imagery is combined with computer mapping software known commonly as Geographical Information Systems (GIS), to document modern fire regime patterns and identify land management issues [Dyer *et al.*, 2001]. Results of such analyses offer the opportunity to study past patterns and address further work that is needed in assessing burning practices [Russell-Smith *et al.*, 2003b]. Currently there are numerous remote sensing products available to assess burning although all have their limitations. These problems include the accessibility and cost of the data products, the need to obtain information on how to access, read and interpret the products, and the fact that data from different systems are provided by different means and in different formats, meaning that accessing and manipulating some data requires a whole new methodology. In addition, different satellite systems provide different information on fires for different groups and agencies and the continued flow of information to operational users cannot be guaranteed [Justice *et al.*, 2002b]. This project attempts to overcome these issues by creating a methodology using readily available data from the sensor MODIS (Moderate Resolution Imaging Spectroradiometer). MODIS is carried on board the NASA Terra and Aqua spacecrafts [Li *et al.*, 2004], which was launched in December 1999 as part of NASA's Earth Observing System (EOS), and began collecting images by February 2000 [Justice *et al.*, 2002a]. MODIS has thirty-six spectral bands with resolution ranging from 250 to 1000 metres. MODIS bands are also particularly sensitive to fire. Bands one and two are at 250 metre resolution. Although limited they fall into the range of red and near-infrared wavelength which are among the most important spectral regions for remote sensing of vegetation [Zhan *et al.*, 2002]. MODIS produces full global coverage everyday for all areas except the equatorial region, where the repeat frequency is approximately 1.2 days. This is important for burn scar detection in cloudy regions as it provides many alternative days for analysis. The images are archived from 2001 and available free from the Earth Observing System (EOS) Data Gateway, Land Processes Distributed Active Archive Centre, USGS (United States Geological Sciences) website owned and operated by NASA.

There are many fire monitoring systems set up already in Australia, including Sentinel (www.sentinel.csiro.au), North Australia Fire Information (www.firenorth.org.au) and that of the Western Australian Department of Land Information (www.dli.wa.gov.au). These systems are appropriate for quick examination of the overall burnt area and for making communities aware of the risks, but do not allow detailed analyses of the spatial and temporal distribution of fire (although Sentinel has recently made burnt area downloads available for 2004 and 2005). These organisations often use a combination of active fire detection and burn scar detection. Active fires detected by satellites provide a good indication of the spatial and temporal patterns of global fire incidence, but are inadequate to estimate the area burned, [Pereira, 2003]. This is because the satellite may not pass when burning occurs or clouds may cover active fire detection [Roy *et al.*, 2002]. Area burned is an important factor in estimating the impacts of fire on the atmosphere and on the ecosystem [Pereira, 2003]. Burned areas are characterised by deposits of charcoal and ash, by the removal of vegetation, and by changes in the structure of vegetation [Roy *et al.*, 2002], therefore they generally last for weeks to several months, allowing more reliable detection through satellite remote sensing [Li *et al.*, 2004]. Several factors can interfere with using burn scar detection in the identification of burnt and unburnt regions including cloud shadows, water surfaces with sun glint, and very bright land surfaces, all of which confuse the classification [Li *et al.*, 2004]. This can be overcome by individually identifying the interfering factors and excluding them from the images. There are many algorithms and models designed for classification and detection of burn scars. Bowman *et al.,* [2003b] studied four techniques using Landsat TM imagery; systematic visual, semi-automated, automated and change detection. It was found that regardless of which technique was used, none identified 100% of the burn scars. The visual method appeared to identify burn scars for the longest time period with fewer falsely burn scars than the automated method [Bowman *et al.*, 2003].

Although not perfect at detecting burn scars, remote sensing has greatly advanced our understanding of fire regimes in northern Australia in a short period of time [Russell-Smith *et al.*, 2003b]. While many of these studies analyse the total area burnt and differences between early and late dry season burning their main focus is often on ecological impacts (as can be seen in Williams *et al.,* [2003] and Yibarbuk *et al.,* [2001]). The small-scale spatial and temporal distribution of fires, for example on Indigenous land, has been less studied. Bowman *et al*., [2004] pointed out that the research conducted by O'Neill *et al.,* [1993] was groundbreaking because of its use of satellite imagery, GIS and interviews with local people over a three year period to analyse variations in landscape burning over a dry season, both spatially and temporally. Bowman *et al.,* [2004] continued similar research using cloud-free Landsat imagery, GIS and GPS (Global Positioning Systems) to measure spatial and temporal change in fire patterns and relationship to major vegetation types.

This project shows that burn scar mapping on indigenous lands using MODIS 250 metre resolution imagery can be used to identify the spatial and temporal distribution of fire. This project uses a combination of semi-automated classification, total visual identification and change detection to distinguish the burn scars. The specific aims of the research were to create a feasible methodology to establish spatial and temporal distribution of fire in the study site, to calculate the area burnt in the study site and the month to month variability of this and compare these results with other papers. And finally to locate the ignition points (start point areas) and analyse their temporal and spatial distribution. By quantifying these results this project enables a clearer understanding of the fire regime within this region, which then can be engaged to tackle the land management and ecological sustainability issues.

METHODS AND DATA ANALYSIS

Study Site

Location, Community, Vegetation and Climate

Maningrida is located 500 km east of Darwin and 300 km north east of Jabiru and is on the North Central Arnhem Land coast of the Arafura Sea in the Northern

Figure 1. Study Site distinguished by box. [GA, 2005]

Figure 2. Study Site. Available from: **http://www.firenorth.org.au/nafi/init.jsp** Accessed: 09/02/05

Territory [Maningrida Council Incorporated, 2004] at latitude of -12.04 S and longitude of 134.22 E [BOM, 2005] (figures 1 and 2). The town of Maningrida supports a population of approximately 2600 people, which includes those who live on the 25 - 30 outstations around Maningrida, [Carew *et al.*, 1996, Maningrida Council Incorporated, 2004] It is a remote community that is thought to have retained a more traditional burning regime.

The area covered in this research project was determined by the location of the outstations, totalling a land area of approximately 10555 km^2. Bawinanga Aboriginal Corporation services the outstations; the name Bawinanga comes from the three major language groups of the region which are: Bararra, Kunwinkju and Rembaranga [Hall, 2004]. Bawinanga was formed in 1970 as an outstation resource centre, established a formal land management program in the early 1990's, and successfully sought resources and training for community rangers [Shain, 2005]. The outstations in this region each vary in facilities that can include airstrips, schools, bores, telephones, or can minimally be campsites [Carew *et al.*, 1996]. Topographical 1:50000 digital data sets (maps) for the region were obtained from the Department of Defence (Imagery and Geospatial Organisation) in cooperation with Geoscience Australia. These maps were used to determine roads, waterways, infrastructure and vegetation and were important for overlaying burn scars found by satellite imagery and enabled analysis of fires in proximity to infrastructure with a high degree of accuracy. The bounding coordinates used for the project were upper left latitude –11.83 and longitude 133.96 and lower right latitude –12.81 and longitude 135.06 using datum; WGS 1984 in UTM Zone 53S.

According to the Maningrida Council Incorporated (2004), the Kunbidji people are the traditional landowners of this region. The other main tribal groups who live in the area are Kunbarlang, Nakkara, Burarra, Gunnartpa, Gurrgoni, Rembarrnga, Eastern Kunwinjku, Djinang, Wurlaki and Gupapuyngu [Questacon, 2005, Maningrida Council Incorporated, 2004]. The concern to establish Maningrida came about after the Second World War when Aboriginal people were moving to Darwin and other nearby towns [Doolan, 1989]. A Patrol Officer working for the Commonwealth Department of Native Affairs established Maningrida as a trading post and rations depot in 1947 [Maningrida Council Incorporated, 2004]. Maningrida become a permanent Welfare Department settlement from 1958 and is now the second largest Aboriginal community in the Northern Territory after Port Keats (Wadeye) [Maningrida Council Incorporated, 2004].

The landscape consists of coastal region, extensive floodplains, undulating lowland plains and a rugged sandstone plateau [Alix, 2001]. Griffiths *et al.,* [2000] provided a broad description of the diversity of the vegetation of Maningrida. This showed that the diversity of flora in Maningrida is high. Herbs are the most abundant form of all plant species (30%) and trees, mainly savanna Eucalypts, are also a major component (20%) [Dyer *et al.*, 2001]. Griffith *et al.,* [2000] suggests that the Eucalypt open forest comprises 37% of the study area. Swamps, saline wetlands, mangroves and floodplains, although less extensive than the Eucalypt woodland, play a large role in the hindrance of fire.

The region has a tropical climate influenced by its proximity to the coast and is characterised by hot, wet, humid summers and drier winters [Dyer *et al.*, 2001]. The wet season occurs between November and March when the north-west monsoons delivers much of the area's rainfall of 800 mm to 1600 mm [TSCRC, 2004]. The wet season is characterised by high atmospheric instability, occasional tropical cyclones, tropical depressions and thunderstorms [Sturman and Tapper, 1996]. The median maximum temperature of the wet season is 33°C [TSCRC, 2004]. The dry season occurs between April and October with the onset of prevailing south-easterly trade winds. The dry season sees minimum temperatures of 15°C to 21°C in July [TSCRC, 2004]. This dramatic seasonal variation in climate has a great impact on fire weather through the year, and hence on fire regimes [Dyer *et al.*, 2001]. Maningrida is also affected by a daily sea breeze which generally starts late morning and proceeds into the evening [Sturman and Tapper, 1996]. The sea breezes can often be seen affecting fire shapes near the coast, whereas inland fires are dominantly affected by the south-easterly trade winds. The dry season fire regime was selected for this study as almost all burning in the region occurs during this period. Daily maximum temperatures are over 30°C, and the drying of grassy fuels provides an area of highly flammable conditions annually [Beringer *et al.*, 1995, Yibarbuk *et al.*, 2001].

Indigenous Use of Fire at the Study Site

The indigenous people in this region use an alternative calendar to the European calendar that better suits their requirements. These seasonal calendars are generally derived from local weather and vegetation conditions. Seasonal calendars found include those of the Gunei people, the Burarra people and the Jawoyn people**.** The seasons are created from the naturally occurring variations in time at which a season's change is clearly recognised by the traditional owners [Haynes, 1985]. These changes may be marked by a natural sign such as the first storm of the wet season, or the onset of flowering of certain species rather than by a measured calendar [Haynes, 1985]. The Gunei people burn different biomes at varying times with most burning occurring June to August [Haynes, 1985](Table 1). The Jawoyn people also do most burning during June to August [BOM, 2005] (Table 2). The seasonal calendar used by the Burarra people [Questacon, 2005] is created from varying winds that blow at different times of the year, also with indications from other weather activity, plant growth and animal life and death cycles. Two examples of using natural indicators to understand and manage the region provided by the Burarra people are 1. When a yam plant changes colour it is time to burn (this burning will clear the bush for new growth) and 2. When a butterfly becomes active indicates monsoon rains are about to begin [Questacon, 2005].

Table 1. Gunei seasonal names located within Maningrida region Reproduced from Haynes [1985 pp206].

Month	**Name of Season**	**Translation**
Oct - Dec	Duludu	Early Storms
Nov - March	Gadjagdung	Monsoon
Mar - April	Ganirringgon	“knock em down” storms
May	Yegerr	Cool (dry season)
Jun – Aug	Wurrgeng	Cold weather (dry season)
Sep- Oct	Walirr	Hot weather (dry season)

Table 2. Jawoyn calendar from the Katherine Region Reproduced from IWK page ([BOM, 2005].

Month	**Name of Season**	**Translation**
Jan - Feb	Jiorkk	Main part of wet rains
March – April	Bungarung	Last rains, drying out
April – May	Jungalk	Early hot dry
Jun – Aug	Malaparr	Middle dry, Cooler, Burning time
Sept – Oct	Worrwopmi	Early build-up, hot and sticky
Nov - Dec	Wakaringding	The build-up, first rains

Many people in the Maningrida region continue to rely on the surrounding land to supplement their income and food. It is in the communities’ best interest to maintain biological diversity through best land management practices. Subsistence is vital as many communities can become isolated in the wet season, making it difficult and expensive to either travel to Maningrida and/or order aircraft deliveries. Hall [2004] revealed that ownership of land usually comes from the paternal side and land and resource management comes from the maternal side, suggesting a traditional regime passed down over a long time period. These traditional practices are important for ecological sustainability and as pointed out by Hall [2004] the most important traditional management practice that is applied to help maintain the existing environment is fire. As mentioned earlier traditional management in this region is to burn fuel load for a variety of reasons and especially to avoid late dry season burning caused by lightning strikes or accidental lightings (out of control campfires) which can have devastating effects on flora and fauna. These late dry season fires can also affect the carbon cycle; with the release of high amounts of carbon and very little retained, compared with early dry season fire [Hall, 2004]. Another important use for fire in this region is for hunting especially for wallabies and goannas. This is sometimes known as a “fire drive” [Hall, 2004, Yibarbuk *et al.*, 2001, Bowman *et al.*, 2001].

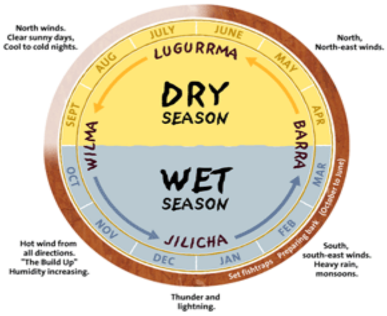


Figure 3. Burrara people seasonal calendar. Diagram by L, Cooper, P, Danaja & Questacon [Questacon, 2005]

The location of the study site (proximity to the north tropical coast), its occupancy (spread of outstations, required economic travel), subsistence requirements, climate (south easterlies, sea breezes) and vegetation (Eucalypts, swamps, etc) all significantly influence fire regimes, and therefore it is important to have an extensive knowledge of these factors to gain a complete picture of the fire regimes.

Detecting burn scars

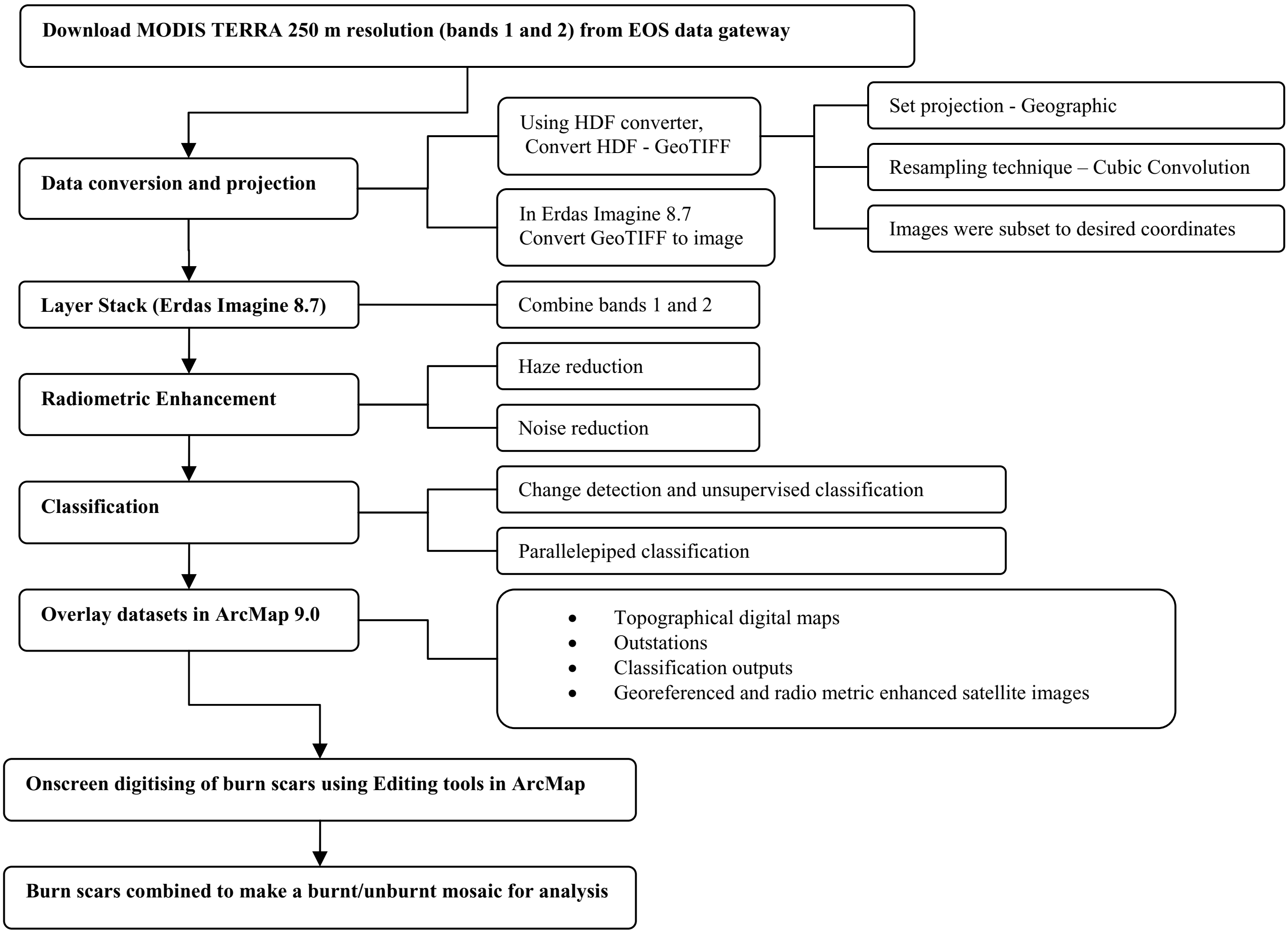
The most useful bands for mapping different vegetation communities, (in this case differentiating between burnt and unburnt areas) is a combination of visible red and infrared, hence this project uses MODIS 250m band 1 (visible red) and band 2 (infra red) at a spectral resolution of 620 nm-670 nm and 841 nm-876 nm respectively [O'Neill *et al.*, 1993]. The images were downloaded from the Earth Observing System (EOS) Data Gateway, Land Processes Distributed Active Archive Centre, USGS (United States Geological Sciences) website owned and operated by NASA. The shorter the inter image period the more effective the method is, as there is less background change or fading of burnt areas. This was accomplished by downloading images from March to October avoiding images that were distorted, where the swath missed the study site (1.2 day coverage), or in most cases where there was high degree of cloud cover.

The data were received in a Hierarchical Data Format (HDF), thus the data were converted into a GIS useable form using a HDF converter tool. The most appropriate converter for this project was HEG (HDF-EOF to GIS Conversion Tool 1.0). This was also downloaded from the EOS data gateway. This tool enables the user to subset the image, assign a projection and choose a resampling type (in this case cubic convolution). This technique was chosen to avoid the disjointed appearance that nearest neighbour technique often causes, and to provide a slightly sharper image than bilinear interpolation [Lillesand and Kiefer, 1994]. Images were further geometrically rectified and radiometrically calibrated; this included using WGS 84 datum and performing haze and noise reduction on every image. Following pre-processing the images prepared for the identification of burn scars. This project used a combination of semi-automated classification, change detection and total visual analysis. Three detection techniques were chosen to gain an understanding of the varying benefits of each method in detecting burn scars.

Change detection was a repeatable and time-efficient method of delineating burnt area patches, and was performed in ERDAS Imagine 8.7. Following change detection an unsupervised classification was applied to the images and 5 classes were assigned; this efficiently delineated newly burnt areas. The results were then imported into ArcMap and converted into polygons to analyse each individual scar. This caused considerable error as the output was extremely angular. It was also extremely difficult to distinguish start points and fire spread using this method.

The next method used was parallelepiped classification; this was useful, especially when there were no other images to compare with. In parallelepiped classification an unknown pixel is classified according to the category range, or decision range in which it lies [Lillesand and Kiefer, 1994]. The pixels were nominated using the seed pixel approach; the ‘region grow’ tool was set with the spectral Euclidean distance of 100 – 500 depending on the requirements for the individual burn scar. This identified surrounding pixels with the same spectral range within a chosen variance. The result of training was a set of signatures that defined a training sample. Each signature corresponded to a class, and was used with a decision rule to assign the pixels in the image file to a class [Smith and Brown, 1999]. Separate signature files were created for each image as no one signature file would detect the necessary pixels. The change in spectral signatures was often attributable to revegetation on the burnt area [O'Neill *et al.*, 1993]. Also factors such as change in time of day, brightness and bad/corrupted images all caused variations to the spectral reflectance.

Visual identification of burn scars with the assistance of parallelepiped classification and change detection (where outputs were both imported into ArcMap) were performed in ArcMap 9.0 where they were visually analysed in conjunction with the original image. The burn scars were identified and their boundaries digitised on screen using the editing tools of ArcGIS [ESRI, 2004]. It was necessary to independently digitise so that areas of clouds, cloud shadows and contaminated pixels could be avoided. The digitised outline of the burn scars enabled the user to distinguish the start point, area covered per day (of the days that imagery was available), the direction travelled by the fire and the length and width of the burn scar. The processing of the images is displayed in the following flowchart.



Creating a burnt/unburnt mosaic

A mosaic of burnt and unburnt areas was created by combining the burn scars in ArcMap with the outstations and the 1:50000 topographical digital data, which included sealed roads, unsealed roads and tracks. Colours were assigned to each month to display changes in month-to-month burning (figure 4). Tools in Arc toolbox were used to measure and gain spatial statistics of the burn scar. The purpose was to collect information about the spatial and temporal distribution of fire within this region and how it related to meteorological conditions, vegetation and anthropogenic effects.

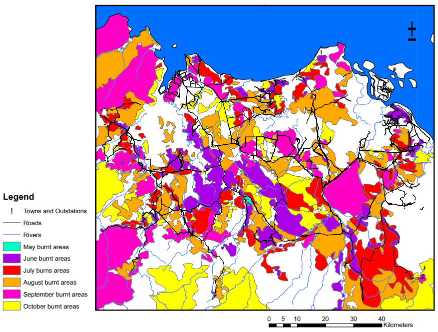


Figure 4. Cumulative map of burn scars in study site May to October 2004

Identifying start points

Start points were located in this study by focusing on the burn scars over the season, and working back through the images to see where they originated. In most cases these areas are not the exact start points, but a small area. The small region was then digitised and a central point was assigned. The distance from this central point to the nearest road and outstation was then measured using tools in Arc toolbox. These points do not cover all fires as not all start points were located due to intermittent images, thus is only a general spatial and temporal overview of start points. The identified start point areas and the assigned central points are shown in figure 5.

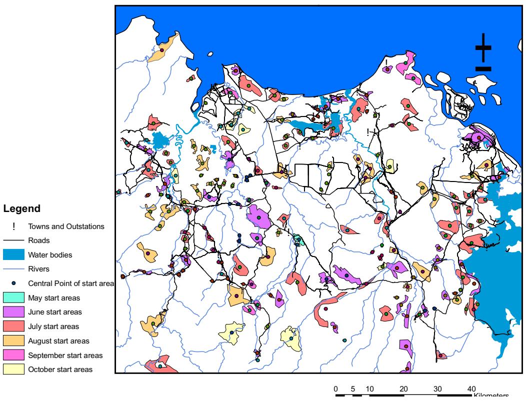


Figure 5. Start points identified in the study site May to October 2004 in the month they were identified and their assigned centre point. These points were used to measure the proximity of start points to roads and outstations

RESULTS AND DISCUSSION

Analysis has a range of associated errors (satellite resolution, mapping errors, etc) and they are discussed in detail in Burns [2004]. A combination of higher resolution imagery (Landsat) and ground truthing was used for validation of the methodology; this was also covered in Burns [2004].

Total area burnt over the 2004 dry season

Using the burn scar detection methods described earlier, this study found that approximately 60% of the land area of this region was burnt between May and October in 2004 .There are many variations in results between studies and this is likely to be due to site variations and methodological differences. Russell-Smith *et al.*, [1993] found that approximately 50% of the tropical savanna in some regions is burnt each year during the dry season, although there were large variations according to location, climate and vegetation. Russell-Smith *et al.,* [2003] used both hot spot detection and burn scar analysis with NOAA AVHRR to derive maps of the entire Northern Australia over a five-year period. They found that 19.3% of the tropical savanna region was burnt each year. However the Russell-Smith *et al.,* [1997] study of Kakadu National Park over a 15-year period using Landsat MSS showed that 46% of the park was burnt each year. Haynes *et al.,* [1991] had the opportunity to interview the Gunei people and study their dry season fire regimes in 1976 without satellite imagery. The outstation was located close to Maningrida and the focus of the study was a small area. They found that 70% of the area was burnt that year. Clearly fire regimes are very diverse reflecting variations in management, vegetation, soil structure, rainfall and other meteorological conditions.

Month-to-Month variability of burning

For additional analysis the dry season is often split into two periods, the early dry season, May to July and the late dry season August to October. It is usually expected that the majority of planned Indigenous burning occurs in the early dry season to avoid a build up of biomass which often leads to high intensity late dry season fire that is damaging to species richness in late dry season [Williams *et al.*, 1999]. Whether the burning is seen to be occurring in the early or late dry season varies from study to study. Haynes *et al.,* [1985], Bowman *et al.,* [2004] and Russell-Smith *et al.,* [2003] found that a larger percentage of burning occurred in the late dry season, whereas Russell-Smith *et al.,* [1997] in a study of Kakadu national park demonstrated that greater burning occurred in the early dry season. Bowman *et al.,* [2004] believe these results may have occurred due to cultural differences. This study supports the findings from Bowman *et al.,* [2004] in that more burning occurred in the late dry season, as shown in figure 6, however, these results differ from many other studies, namely O'Neil *et al.,* [1993] who suggested that most aboriginal burning occurred in the early dry season. These results reveal burnt area, not the amount of burning activity. A method required to compare the amount of burning activity is to locate the origin of the fire.

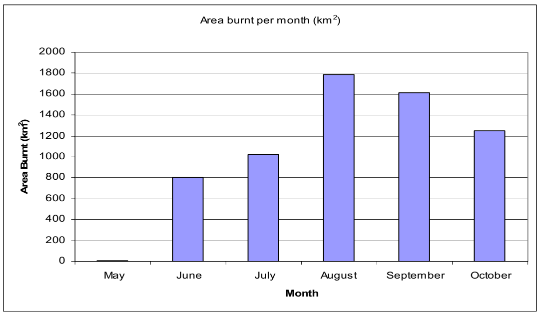


Figure 6. Calculated total new area burnt per month in study site May to October 2004

Temporal and spatial distribution of start points

For an analysis of these fires it is important to look at when and where these fires are being started especially since the majority of fires are started anthropogenically. Studies such as O'Neill *et al.,* [1993] make mention of the start points occurring along roads, but have not quantified it. Russell-Smith *et al.,* [1997] found a correlation of fire starts close to roads during the early dry season but could not find any correlation for late dry season. Bowman *et al.,* [2004] also found that the majority of burning occurred close to outstations and roads whereas in the late dry season there was much more burning in uninhabited land.

Spatial distribution of start points

Fires were started close to roads in almost all analysed cases as shown in figure 7. There was also a close correlation shown to proximity to outstations (figure 8). This reinforces the idea that the burning in these regions is due to intentional fire starts, and also shows that fires are not started as they were historically by communities travelling on foot throughout the country; fire is now occurring close to outstations and via vehicles along roads. It is therefore important to gain an understanding of the current movement within the region, including such things as football matches, jobs and cultural activities, as movement within region could correlate with when and where the fires are started. This is beyond the scope of this preliminary research, although is certainly an area of interest for future studies.

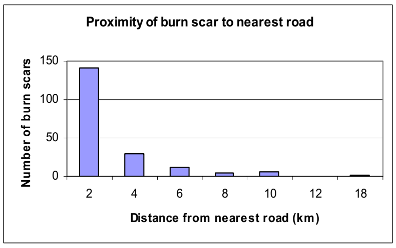


Figure 7. Proximity of fire start to roads (km) in study site from May to October

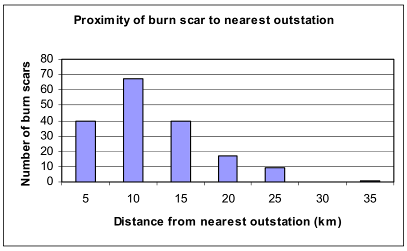


Figure 8. Proximity of fire starts to Outstations (km) in study site from May to October

Temporal distribution of start points

There were 197 start points identified, 138 in the early dry season and 59 in the late dry season. If we include our knowledge of known burnt area over the dry season we can conclude that many small fires were occurring during the early dry season with few large fires in the late dry season. The results of ignition points temporally would be better to correlate with the aboriginal seasonal calendars than the total area burnt for early and late dry season as Dyer *et al.,* [2001] suggests that traditional aboriginal practices have a peak in burning activity during June and July and very little in August and September.

The average of start point proximity to roads and outstations found that there was burning occurring closer to roads and outstations in the early dry season than the late dry season. This is similar to Russell-Smith *et al.,* [1997], Bowman *et al.,* [2004] and Haynes *et al.,* [1991] who were all able to conduct interviews and ground-truthing to support the findings that early dry season saw more fires occurring closer to the infrastructure. This could be because all regions close to this area were being burnt first and then expanding out to more uninhabited lands later in the season when they had no where else to burn off and other areas have dried out becoming more accessible, this is suggested as being 'traditional burning' Yibarbuk *et al.,* [2001]. This may also indicate that this study site has such a large coverage of roads and outstations that there is little area that is needed to travel into to burn later in the season. Although the coverage is not complete it still gives an indication of the fire regime and some theory of burning practices being used in this region.

CONCLUSION

Approximately 60% of the study site was burnt in the dry season of 2004 with most of this burning occurring late dry season although majority of start points occurred in the early dry season. Vegetation and meteorology played a large role in the spatial and temporal distribution of fire but anthropogenic factors were vital to the timing and whereabouts of the fire. This was shown in a correlation of start points and the proximity to roads and outstations in the study site. Maningrida and surrounds proved to be an appropriate choice for this study due to its remoteness, spread of outstations and high use of fire. The study site has a classic savanna environment with dominant eucalypts, annual high rainfall in the wet and little or no rainfall in the dry. It is affected greatly by southeasterly trade winds and a daily sea breeze. Traditional burning practices have been suggested to be occurring in this region. To analyse these burning practices MODIS proved to be a very suitable option for burn scar detection. Bands 1 and 2 working in red and near infrared respectively was utilised, which made burn scar detection simpler with a resolution of 250 metres. The constant coverage of every 1.2 days gave a choice of images, which was vital with the number of cloud cover days that was experienced over this dry season. The data were archived, easily accessible and free of charge. With a combination of techniques used to detect the burn scars including semi-automated classification, change detection and visual identification this paper was confident in accurately identifying the majority of burn scars. It is clear none of these techniques are 100% accurate. Although not perfect this research proves the usefulness of MODIS in detecting burn scars. This project provides a methodology for new users, small communities and individuals to create their own burnt/unburnt mosaics affordably and practically. The findings will assist in giving greater understanding of fire regimes and the major factors influencing the regimes.

The findings of this research suggest that further work is required. Initially establishing a study site that can utilise a number of methods including high resolution imagery, aerial photos, vegetation assessment, ground truthing and most importantly interviews with locals should be conducted to gain a greater understanding of their traditional burning practices. Additionally a savanna wide assessment using MODIS satellite imagery should be implemented, primarily creating a feasible yet efficient burn scar detection technique which can be validated using the ground truthing and higher resolution analysis of the smaller study site. This analysis could also be done in conjunction with an analysis of weather station data as MODIS data is available from 2001 this will provide a greater understanding of the effect of inter-annual climate variability on fire regimes. And finally to improve the analysis and representation of the proximity of fires occurring to roads and outstations it would be appropriate to implement buffer zones as Bowman *et al.,* [2004] and also analyse the percentage of burnt area occurring near roads using various statistical methods.

Despite the need for further analyses this paper shows a feasible approach that is sufficient for finding the spatial and temporal distribution of fire.

ACKNOWLEDGMENTS

We thank Professor Ben Olove from the University of California at Davis, USA, and all the Academic and Administration staff and students of SGES Monash University for their comments and support and finally the NOAA Climate and Global Change Program for research funding.

REFERENCES

Alix, C. (2001) **Australian Tropical Savanna**. Available: http://www.blueplanetbiomes.org/savanna_australia.htm Accessed: 25th August 2004

Andreae, M. O. & Merlet, P. (2001), "Emission of trace gases and aerosols from biomass burning", **Global biogeochemical cycles***,* 15 (4)**,** 955-966.

Beringer, J., Packham, D. & Tapper, N. (1995), "Biomass Burning and Resulting Emissions in the Northern Territory, Australia." **International Journal of Wildland Fire***,* 5 (4)**,** 229-235.

BOM (2005) **Bureau Of Meteorology**. Available: www.bom.gov.au Accessed: 2nd February 2005

Bowman, D. J. M. S., Garde, M. & Saulwick, A. (2001), **Kunj-ken Makka Man-wurrk Fire is for Kangaroos: Interpreting Aboriginal Accounts of Landscape Burnsing in Central Arnhem Land**. IN Anderson, A., Lilley, I. & O'connor, S. (Eds.) Histories of old ages, Essays in honour of Rhys Jones*.* Australian National University, Canberra: ANH Publications.

Bowman, D. M. J. S., Zhang, Y., Walsh, A. & Williams, R. J. (2003), "Experimental comparison of four remote sensing techniques to map tropical savanna fire-scars using Landsat-TM imagery", **International Journal of Wildland Fire***,* 12 341-348.

Burns, S. L. (2004),**The temporal and spatial distribution of dry season fires on indigenous lands of North-Central Arnhem Land: A feasibility study using MODIS satellite imagery.** School of Geography and Environmental Science, Monash University, Melbourne.

Carew, M., Handelsmann, R. & Garde, M. (1996), **Maningrida Area Outstations**. Bawinanga Aboriginal Corporation.

Crutzen, P. J. & Andreae, M. O. (1990), "Biomass Burning in the Tropics: Impacts on Atmospheric Chemistry and Biogeochemical Cycles", **Science***,* 250 1669-1678.

Doolan, J. K. (1989), **The founding of Maningrida**, Darwin: Northern Territory Library Services.

Dyer, R., Jacklyn, P., Partridge, I., Russell-Smith, J. & Williams, D. (Eds.) (2001), **Savanna Burning Understanding and using fire in northern Australia**, Darwin: Tropical Savannas CRC.Pages

ESRI (2004), **ArcGIS Version 9**, Redlands, CA, USA: Environmental Systems Research Institute Inc.

GA (2005) **Geoscience Australia**. Available: www.ga.gov.au Accessed: 2nd February 2005

Griffiths, T., Bowman, D. J. M. S., Cowie, I. & Fensham, R. (2000), "Vegetation of the Maningrida Region, North-Central Arnhem Land", **Technical Report No.1**, 1-6.

Hall, R. (2004) **Use of forests in the Blyth and Liverpool Rivers catchments, Arnhem Land NT.** Available: http://www.affa.gov.au/content/publications.cfm?ObjectID=6CF1AE5A-079E-460D-89D8249BD2486305 Accessed: 7th February 2004

Hao, W. M. & Liu, M. H. (1994), "Spatial and Temporal distribution of tropical biomass burning", **Global Biogeochemical Cycles**, 8 495-503.

Haynes, C. D. (1985), "The pattern and ecology of munwag: traditional Aboriginal fire regimes in north-central Arnhemland", **Proc. Ecol. Soc. Aust.**, 13 203-214.

Haynes, C. D., Ridpath, M. G. & Williams, M. A. J. (Eds.) (1991), **Monsoonal Australia**, Rotterdam: A. A. Balkema.Pages

Justice, C. O., Csiszar, I. A., Goldammer, J. M. & Lee, B. (2002a), **GOFC/GOLD-Fire: a program for international coordination of fire observations**. *Bushfires:managing the risk 2002.* Camperdown, Sydney, Nature Conservation council of NSW Inc.

Justice, C. O., Giglio, L., Korontzi, S., Owens, J., Morisette, J. T., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F. & Kaufman, Y. (2002b), "The MODIS fire products", **Remote Sensing of Environment**, 83 244-262.

Justice, C. O., Smith, R., Gill, A. M. & Csiszar, I. (2003), "A review of current space-based fire monitoring in Australia and the GOFC/GOLD program for international coordination", **International Journal of Wildland Fire**, 12 247-258.

Levine, J. S. (2000), **Global Biomass Burning: A case study of Gaseous Particulate Emissions Related to the Atmosphere During the 1997 Fires in Kalimanta and Sumatra, Indonesia In Biomass Burning and Climate**. IN Innes, J. L., Beniston, M. & Vertrete, M. (Eds.) An Introduction in Biomass Burning and it's Inter-Relationship with the Climate System. Dordrecht: Kluwer.

Li, R. R., Kaufman, Y. J., Hao, W. M., Salmon, J. M. & Gao, B. C. (2004), "A Technique for Detecting Burn Scars Using MODIS Data", **IEEE Transactions on Geoscience and Remote Sensing**, 42 (6)**,** 1300-1308.

Lillesand, T. M. & Kiefer, R. W. (1994), **Remote Sensing and Image Interpretation**, Canada: John Wiley & Sons.

Maningrida Council Incorporated (2004) **Maningrida Council Incorporated**. Available: http://www.maningrida.nt.gov.au/ Accessed: 29th March 2004

O'Neill, A. L., Head, L. M. & Marthick, J. K. (1993), "Integrating remote sensing and spatial analysis techniques to compare aboriginal and pastoral fire patterns in the East Kimberley, Australia", **Applied Geography**, 13 (1)**,** 67-85.

Pereira, J. M. C. (2003), "Remote sensing of burned areas in tropical Savanna", **International Journal of Wildland Fire**, 12 259-270.

Preece, N. (2002), "Aboriginal fires in monsoonal Australia from historical accounts", **Journal of Biogeography**, 29 321-336.

Press, A. J. (1988), "Comparisons of the extent of fire in different land management systems in the Top End of the Northern Territory", **Proceedings of the Ecological Society of Australia**, 15 167-175.

Questacon (2005) **Burarra Gathering**. Available: http://burarra.questacon.edu.au/pages/welcome.html Accessed: 2nd February 2005

Roy, D. P., Lewis, P. E. & Justice, C. O. (2002), "Burned area mapping using multi-temporal moderate spatial resolution data - a bi-directional reflectance model-based expectation approach", **Remote Sensing of the Environment**, 83 263-286.

Russell-Smith, J., Ryan, P. G. & Durieu, R. (1997), "A LANDSAT MSS-derived fire history of Kakadu National Park, monsoonal northern Australia, 1980-94: seasonal extent, frequency and patchiness", **Journal of Applied Ecology**, 34 748-766.

Russell-Smith, J., Whitehead, P. J., Williams, R. J. & Flannigan, M. (2003a), **Fire and savanna landscapes in northern Australia: regional lessons and global challenges**, CSIRO Publishing.

Russell-Smith, J., Yates, C., Edwards, A., Allan, G. E., Cook, G. D., Cooke, P., Craig, R., Heath, B. & Smith, R. (2003b), "Contemporary fire regimes of northern Australia, 1997-2001: change since Aboriginal occupancy, challenges for sustainable management", **International Journal of Wildland Fire**, 12 283-297.

Shain, K. (2005) **Bawinanga Aboriginal Corporation**. Available: http://www.atns.net.au/biogs/A000677b.htm Accessed: 2nd February 2005

Smith, C. & Brown, N. (Eds.) (1999), **ERDAS Field Guide**, USA: ERDAS inc.Pages

Sturman, A. P. & Tapper, N. J. (1996), **The Weather and Climate of Australia and New Zealand**, Melbourne: Oxford University

TSCRC (2004) **Arnhem Land**. Available: http://savanna.ntu.edu.au Accessed: 16th June

Williams, R. J., Congdon, R. A., Grice, A. C. & Clarke, P. J. (2003), "Effect of fire regimes on plant abundance in a tropical eucalypt savanna of north-eastern Australia", **Austral Ecology**, 28 327-338.

Williams, R. J., Cook, G. D., Gill, A. M. & Moore, P. H. R. (1999), "Fire regime, fire intensity and tree survival in a tropical savanna in northern Australia", **Australian Journal of Ecology**, 24 50-59.

Yibarbuk, D. M., Whitehead, P. J., Russell-Smith, J., Jackson, D., Fisher, A., Cooke, P., Choquenot, D. & Bowman, D. J. M. S. (2001), "Fire ecology and Aboriginal land management in central Arnhem Land, northern Australia: a tradition of ecosystem management", **Journal of Biogeography**, 28 325-343.

Zhan, X., Sohlberg, R. A., Townshend, J. R. G., DiMiceli, carroll, M. L., Eastman, J. C., Hansen, M. C. & Defries, R. S. (2002), "Detection of land cover changes using MODIS 250m m data", **Remote Sensing of the Environment**, 83 336-350.