BUSH FIRE PATCHINESS

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Abstract

Bush fire patches are unburnt islands of vegetation within a fire boundary. They are an important part of the fire regime because they can affect ecological processes such as local extinction and recolonisation. The degree of patchiness is also measure of the effectiveness of a hazard-reduction burn.

Quantifying patchiness is no simple task, partly because of the continuous range of scales at which patchiness occurs and partly because patches cannot always be readily detected by remote sensing techniques. The aim of this study was to develop a field technique for the quantification of patchiness and estimation of overall patchiness in a site, using a simulation model derived from the environmental parameters that influence the patchiness of fires.

A transect method for sampling the bush fire landscape was used to produce a spatial model which was found to be an accurate and simple method of assessing the patchiness of a fire. This spatial model can also display the distribution and proportion of areas burnt within the landscape. There are many variables that may influence the patchiness. These can be divided into two main categories:

1. Areas that did not burn at the time of a fire because of the effect of barriers.
2. Areas that could not burn at the time of the fire because of the ability of the fuel to be ignited.

Introduction

The term fire regime as defined by Gill (1974) is now a commonly used concept to describe the key components of fire and its effects. The fire regime includes the frequency between successive fire events on the same area in the landscape, the season, or time of year in which a fire occurs, and the intensity of fire. Several authors have included spatial characteristics of a fire, such as total area or patchiness, as a fourth component of the fire regime (Tolhurst 1992 and Whelan 1995). The area of the fire could be defined as the total area within the perimeter of a fire and could be refined to include the proportion of that area burnt. The patchiness of a fire represents the area and arrangement of unburnt 'islands' within the fire perimeter.

The unburnt 'islands' within a fire can reduce the severity of the impact of that fire on the biota and environment (Christensen 1980). Fire-sensitive plants can survive in patches during a fire and therefore these patches then become important sources of seed for propagation of seedlings within the burnt area, especially when an area is being burnt frequently enough that local extinction of obligate-seeder plant species occurs in some parts of a landscape. They can be shelter sites for animals during the fire and sources of recolonisation after a fire. Patches also have implications for watershed hydrology and fire ground operations and management. Unburnt patches can also improve soil stability.

The perception that a heterogeneous fire landscape benefits plants and animals, although based on very little empirical evidence, has led to fire management prescriptions of mosaic burning or patchy fires. There has been a need for some time to have a greater understanding of the patchiness of fires. Many management prescriptions refer to patch or mosaic burning although the causes of patchiness are poorly understood (Keith et al 2002). Furthermore, there is no consistency in how patchiness is reported and, most significantly, the nature of the spatial relationship of patchiness is poorly defined.

For clarity, I identify the various components of the spatial arrangements of unburnt vegetation to be defined as follows:

- **Bush fire <u>patches</u>** (Fig 1) are unburnt islands of vegetation within a fire boundary.
- **Bush fire <u>spatial heterogeneity</u>** (Fig 2) of a fire relates to the variability in intensity of a fire and the strata of vegetation consumed in the fire. For example, a single fire may have some areas that burn with a relatively low intensity only consuming the leaf and grass layer and scorching the shrub layer, whereas other areas may burn with a greater intensity removing the shrub layer and scorching the canopies of the trees.
- **Bush fire <u>mosaics</u> of age classes** (Fig 3) are areas within a landscape which have been or are planned to be burnt at different times.
- **Bush fire <u>mosaics</u> of fire regimes** (Fig 4) are areas within a landscape of the same vegetation type which have been or are planned to be burnt under different fire regimes.

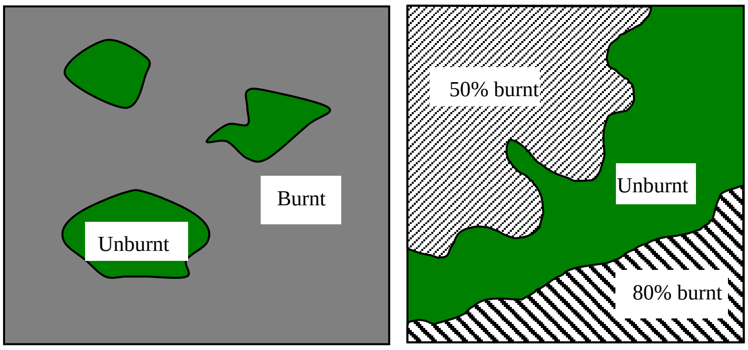

Figure 1 Examples of patchy fire maps.
The map on the left represents a fine scale description of individual unburnt patches within the perimeter of a burnt area. The map on the right represents a description of the distribution of different levels of patchiness within the landscape.

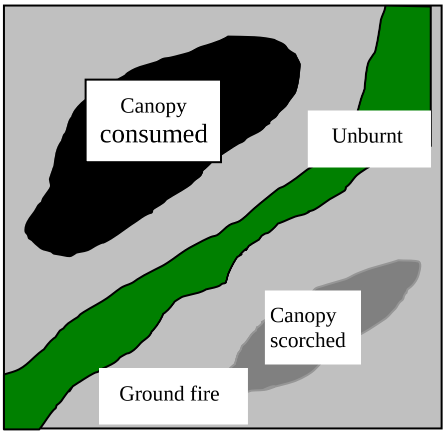

Figure 2 Example of a spatially heterogeneous fire.

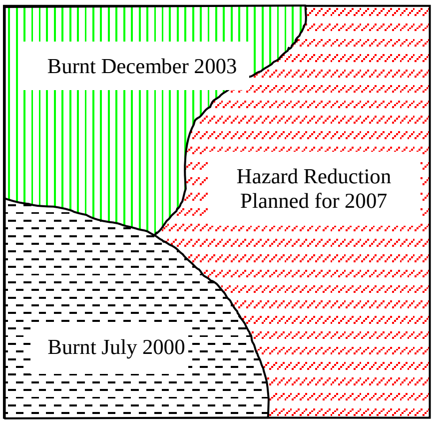

Figure 3 Example of bush fire mosaics of different fire age classes.

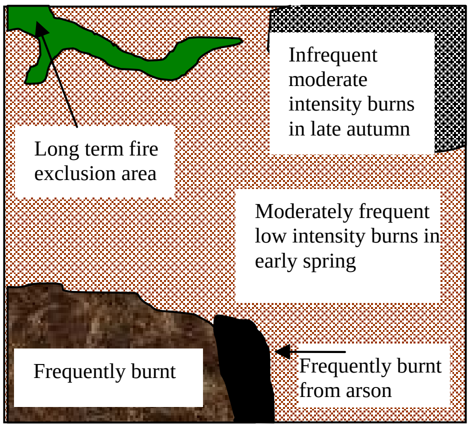

Figure 4 Example of bush fire mosaics of different fire regimes.

Some attempts have been made to assess and quantify the spatial variability and patchiness of fires (Rolf et al. 2005). This has included aerial photo interpretation, satellite image analysis, direct fire intensity measurement, infrared scanning and visual estimation. The methods investigated are too costly, complex, time-consuming or have low accuracy, particularly in forested landscapes with low intensity prescribed fires. There is a need for a consistent and reliable method of assessment of bush fire patchiness that is cost effective and enables field staff to be easily trained. The overall aim of this study was to devise and test techniques for measuring patchiness in the field and then to use this method in a number of fires to assess the correlates of patchiness, thus enabling construction of a predictive GIS model for fires in the coastal forest of NSW. To do this I identified three specific tasks, as follows:

1. Develop a way of describing the patchiness that is useful for land managers.
2. Ensure that the method of assessing patchiness is accurate for fires that are of low intensity under a thick canopy.
3. Investigate the correlates of patchiness of fire and determine the relative influence of environmental and other parameters on a particular fire.

Methods

In the initial stage of my study, I started by directly mapping the patchiness of small fires by walking the boundaries using GPS. This method was extremely labour-intensive and time-consuming and this trial demonstrated that this was not a viable method of measuring the patchiness due to the large amount of boundaries that would need to be surveyed.

I investigated the use of transects to sample a patchy landscape. Traditionally, sampling heterogeneous landscapes is performed using random point sampling (Thompson 1992). First, I wanted to test whether transect sampling is generally more efficient than random point sampling. To investigate this I calculated the Coefficient of Variation (CV) values for a range of idealised patchy maps. It was found that the CV values for point sampling were much greater than for transect sampling (Steel and Heemstra unpublished). The number of transects required to obtain a given accuracy will be between four and sixteen times less than the number of points required in a random point sampling scheme depending on the arrangement of patchiness.

To investigate the number of transects that would be required to sample patchiness at a given accuracy level, forty five different types of patch distributions were constructed with a range of patch numbers and sizes. Using a set of derived statistical formulae (Steel and Heemstra unpublished) it was determined that a sample size of between 10 and 20 transects will give an estimate of the proportion of area burnt (±10%). The number of transects required would be less where attempts are made to maximize landscape heterogeneity by choosing transects that cover the range of environmental variables such as slope, aspect and vegetation type.

The transect sampling method was applied to twelve sites in south eastern NSW. The vegetation within each of the sites was predominantly the Shrubby Dry Sclerophyll Forest sub-formation of the Sydney Coastal and South East Vegetation classes as described by Keith (2004), encompassing a range of fire sizes from small hazard reduction blocks (5ha) to large wildfires covering more than 1000ha.

For each fire, the first step was to determine the fire boundary. This was derived from maps, particularly where the hazard reduction burn boundaries were roads. In some cases, further plotting of the perimeter was conducted using GPS, by walking or driving to produce a more precise assessment. A transect sampling pattern was chosen, from a topographic map, to cover the range of slopes and aspects within the area. These transects were navigated using compass bearings and GPS “Way Points”. The presence/absence of burnt ground along this transect was recorded using a GPS line feature data capture. This data was then transferred into a GIS to calculate the area and proportion of the unburnt vegetation within the fire boundary. Further, a frequency histogram was produced from the length of the burnt and unburnt segments within each transect to give a representation of the relative abundance patches of different sizes. I chose the following segment length categories: 0-20m, 20-50m, 50-200m and greater than 200m. These categories were used because they spanned the range of patch areas that I considered to be ecologically relevant and related to the habitat requirements of a range of species. These patch-size frequency distributions can be compared between different fires.

The transect data for each site was then analysed to produce a map representing the patchiness in the whole area burnt. First, the transect data of burnt and unburnt areas was converted to raster format, with a one metre grid. Further layers that were added to the GIS database included roads, creeks and a Digital Elevation Model (DEM). Both the road and creek overlays were used to create distance contour overlays. Elevation, slope and aspect overlays were created from the DEM. Grid data layers, containing the x and y coordinates were also produced for the analysis. These data layers provide a landscape scale representation of variables that influence fire behaviour.

All of the data layers described above were then intersected and converted into table format for analysis. The data was analysed using a logistic regression model to determine the influence of each of the landscape factors on the patchiness of the fire. The rules derived from this analysis were used within the GIS to produce a map of the predicted patchiness for the specific landscape sampled.

Maps were produced to display the spatial arrangement of the predicted patchiness derived from the logistic regression. The percentage burnt colour ranges were chosen at 10 percentage intervals to allow for a comparison of the proportion of patchiness between maps such as in Figure 7. The standard error for each transect patchiness was determined using the formulae from Steel and Heemstra (unpublished). Further the accuracy of the logistic regression model was tested by conducting a linear regression of the percentage burn classes for the predicted percentage burnt values against the observed values.

Results

For the twelve fires that were examined the proportion of area burnt ranged from 47% to 100%. For small fires that have a complete burn, such as Anderson at less than 6ha, the entire fire area could be observed from the boundary and no further transects need to be used. The number and type of transects were varied in developing the methods for this study. Standard error values, though a very conservative estimate of error, vary from less than 5% to 25%. Testing of the logistic regression generally demonstrated a strong correlation between the model and the observed bush fire patchiness. A full summary of the results from the study is provided in Table 1 below.

For this paper the output from the Boyne hazard reduction has been presented. The transect paths are displayed in Figure 5 and the patch size distribution histogram demonstrates that the patch size distribution was very variable and many patches exceed a transect width of 200m (Figure 6). The patchiness distribution map produced from the logistic regression identifies that patchiness is strongly correlated with distance from creeks as well as an east/west influence, probably due to the effect of the weather (Figure 7). Linear regression of the patch classes demonstrates a very good fit to the model with an r^2 value of 9.1 (Figure 8).

Table 1 Results of transect surveys

Study Site	Total burn area (ha)	No. of transects	Transect length (m)	% Burnt	Standard Error	Regression correlation coefficient
Anderson	5.9ha	0	NA	100%	NA	NA
Boyne	504ha	7	9,500m	47%	13.5%	0.91
Blackbutt	1130ha	8	28,613m	94%	2.8%	NA
Buxton	Unknown	4	6,700m	46%	NA	NA
Clyde	645ha	5	10,668m	75%	6.0%	0.88
Kioloa East	176ha	4	4,003m	49%	12.7%	0.90
Kioloa West	362ha	5	6,069m	54%	24.7%	0.93
Kioloa North	960ha	13	3,210m	84%	6.8%	0.43
Kioloa 98	1260ha	9	26,278m	78%	17.9%	0.23
Oakdale	5.6km	16	5,818m	80%	9.6%	0.12
Thirilmere	124ha	19	11,091m	85%	6.7%	0.87
Shallow crossing	30ha	1	1,294m	97%	NA	NA

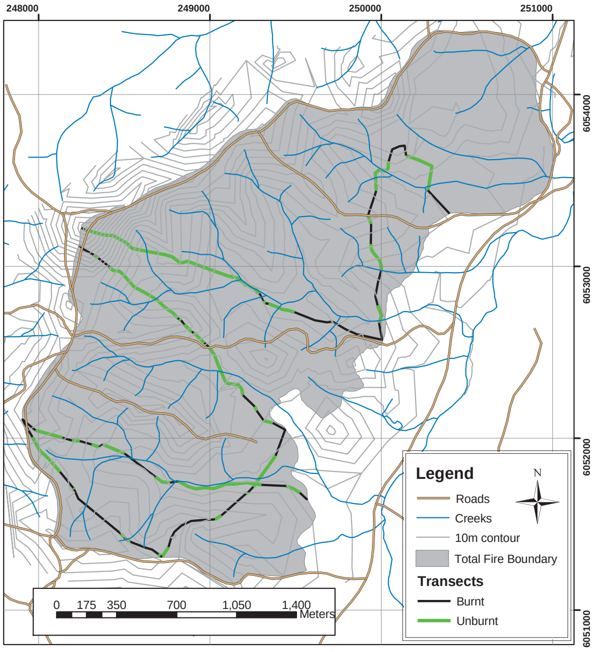

Figure 5 Transect paths through complex patch shapes from Boyne

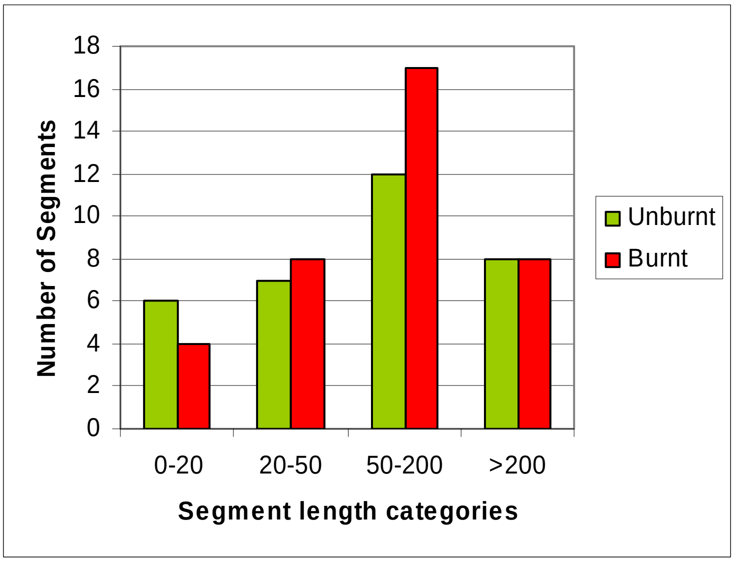

Figure 6 Sample histogram of transect segment lengths from Boyne

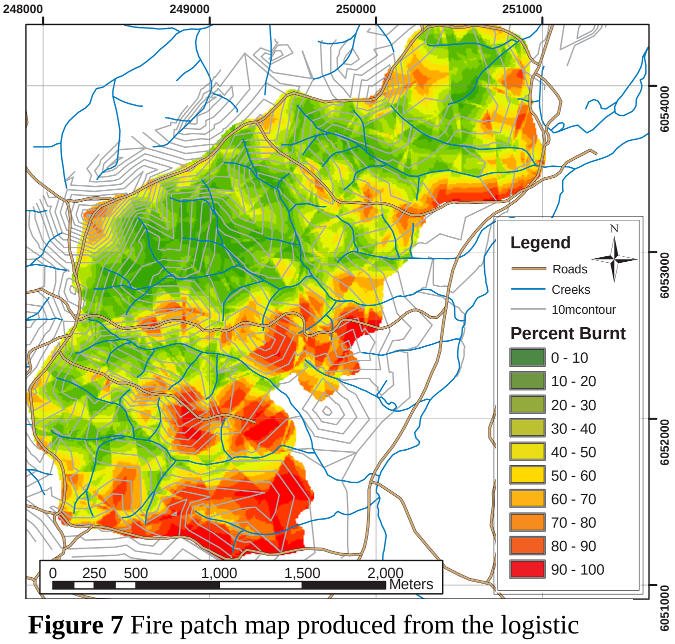

Figure 7 Fire patch map produced from the logistic regression model from Boyne.

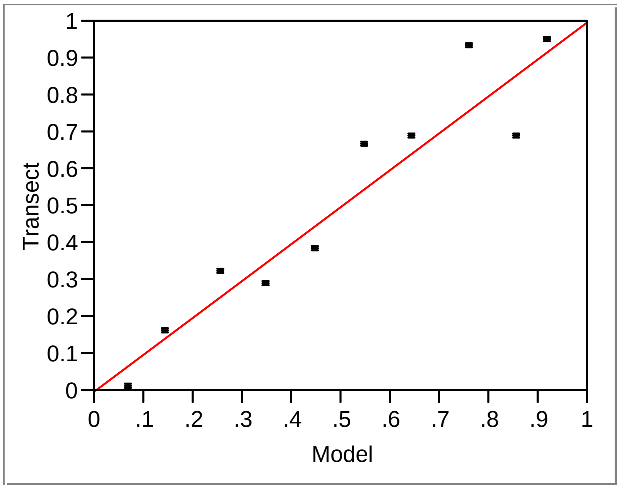

Figure 8 Plot of observed and predicted values from the logistic regression model for Boyne.

Discussion

From this study I have observed that there are two distinctly different types of unburnt patches that can be found after a fire has passed through the landscape:

1. Areas that could have burnt at the time of the fire but did not burn because fire did not get to it, primarily due to the effect of barriers; and
2. Areas that did not burn because they could not burn at the time of the fire, due to the ability of the fuel to be ignited.

Landscape features with no fuel can act as barriers and stop the progress of the fire line. These can be human-made features including fire trails and walking tracks or natural landscape features such as animal tracks, rock ledges, ridgelines and cliffs. On a smaller scale, logs, large tree trunks and cleared areas from animal activity can result in small unburnt patches. Water bodies, such as rivers, lakes, creeks, wetlands and dams, can be very effective barriers. As well as blocking the fire progress, proximity to water also has an effect on the flammability of the fuel.

The nature of the fuel has a large impact on fire behaviour. If conditions are poor for burning, most of the landscape will not burn and patchiness will be low. If conditions are extreme and fuels are very high then all of the landscape may burn. The interrelation of many environmental parameters will determine how flammable different areas of the landscape are.

Patchiness can be caused by extinction of the fire line due to changes in the arrangement of combustible biomass (fuel) in the landscape. However, low fuel loads may be caused by a variety of factors. Fuel level may relate to the time since an area was last burnt. Lower levels because of a recent fire may increase patchiness. Previous hazard reduction works as observed in this study can also act as barriers to fires.

Ignition method can also have an influence on patchiness. During a summer wild fire, most fires originate from a point source of lightning strike or arson and develop an intense head in the direction of the wind. Under this scenario the fire front's progress is influenced by large landscape barriers.

Prescribed fires are usually conducted during the cooler months and fire is applied to many more points in the landscape. The two main methods of igniting a fire for a hazard reduction involve lighting a line of fire around the perimeter from roads and/or aerial ignition by dropping incendiaries through the interior of the burn boundaries. Under aerial ignition (depending on the lighting pattern) the effect of barriers on the patchiness of a fire will be reduced due to high ignition intensity through the landscape.

The effect of fuel moisture is very strongly correlated to the effect of topography. This includes the effect of elevation, slope and aspect. Elevated areas on ridges receive more drying winds than in gullies and valleys. On a course scale, gullies and valleys will have higher patchiness as the moisture levels are very high. Flat areas will pool water and the distribution of moisture will be more variable whereas, on steep slopes, moisture will often be concentrated along drainage lines.

Areas with steep slopes receive less solar radiation and therefore fuels retain moisture longer after a rainfall event and will more likely have unburnt patches. Similarly, aspect has an effect. Southerly slopes are shaded for a greater proportion of the day. Season has an effect as the solar path is much lower particularly during winter and during this time, distribution of fuel moisture will be more variable. Due to high moisture levels, southerly and easterly slopes may have higher decomposition rates and therefore lower fuel levels. The regression models from this study found pronounced effects of topographic features in all of the fires examined.

The patchiness of a fire can also be influenced by the weather. The spatial variability in rainfall can result in higher moisture levels in particular pockets of the landscape. Prevailing winds result in drier fuels on particular slopes within the landscape. Wind gusts during the fire can change the direction of a fire front and result in the flanks being extinguished. Cooler air temperatures and/or high humidity during a fire increase the likelihood of the fire being extinguished. Strong winds during a fire increase fire intensities and potential areas burnt. Strong winds also increase the distance of spotting and the probability of a fire line crossing barriers.

The effects of wind can act as a barrier and lead to the formation of patches. Light variable winds can cause a slow moving fire to travel sporadically and extinguish in areas. Strong winds can also act as a barrier, by blowing out the heel and flanks of fires. Wind effects from spotting can also carry fire into patches of vegetation that would otherwise have been protected by landscape features over barriers and this will reduce the patchiness.

Conclusions

The three overall aims of this project were to develop a method of assessing the patchiness of bush fires, to produce a method of describing patchiness that is useful to land managers and to investigate the causes of patchiness. Overall, the project was very successful. A practical and useful method of assessing patchiness has been developed. Table 2 summarises the outcomes of the study in relation to each of these aims.

Table 2 Outcomes of aims of study.

Aim	**Outcome**
1. Method of assessing patchiness	
Effective under thick canopy	- GPS can work effectively under canopy. - Continual improvements with this technology are producing lighter and more powerful receivers and data loggers.
Detects low intensity fires	- As the assessment is done on the ground, it is very effective at detecting low intensity fires.
Detects patches less than 5m diameter	- Unburnt patches are best seen on the ground. - It is important to survey within a short time of the fire as leaf litter fall and grass growth can quickly obscure boundaries.
Can be determined in a short time	- This method can easily be implemented in a short time. - Pre-existing base datasets also improve efficiencies.
Cost Effective	- Takes time for field staff to access but little subsequent cost.
Easy to train field staff	- The field assessment is relatively easy. - Data analysis requires an experienced operator or more time training.
Be an accurate estimate of patchiness	- The transect model showed that between 10 and 20 transects will give at least a 90% accuracy of an estimate of patchiness. - Logistic regression modelling to produce the patchiness map is accurate for the eight fires tested.
2. Description of patchiness useful to land managers	
Understanding of spatial extent of fire	- Maps produced give a good representation of patchiness.
Description of arrangement of patches	- From the maps, it is easy to see the areas on the landscape that are patchier than others. - Good to compare between fires.
Description of size of patches	- Plotting of a frequency histogram is useful for managers to gain an understanding of the minimum diameter of patches.
3. Investigation of cause of patchiness	
	- Logistic regression is a good tool to investigate the effects of the parameters. Topography was very significant. - This method can be applied for further investigation and ground truthing of remotely sensed data.

This study required liaising with most of the major land managers in NSW. There is considerable variability in the standards of mapping fires between and even within organisations in different areas. There is often a lack of adequate records of the extent of prescribed burning. Land managers need to appreciate the value of accurately mapping fires. Improved mapping that includes the patchiness of fires will benefit the long term management of the risk of fire to human life, property and the natural environment.

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