Fire management for minimising risk – what relationships apply?

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Abstract

One of the main objectives for fire management is to reduce the risk of negative impacts from unplanned fires on people, property, and ecological values. The present study uses the process based computer simulation model, FIRESCAPE, to identify the relationships between different amounts of management 'effort' and fire regime responses. This model has been designed to simulate fire behaviour and fire regimes over long temporal scales, and over topographically complex landscape containing a diversity of vegetation communities. Relationships between treatment unit sizes, the proportion of treatment units burnt annually, and their spatial array on reducing bushfire risk in the World Heritage Area in south west Tasmania were identified. Simulations demonstrated that the annual prescribed burning treatment level had the greatest influence on reducing fire size, fire incidence, and mean annual area burnt by unplanned fires. Both the spatial patterns of treatment units, and the treatment unit size, were significantly more influential on fire size distributions and mean annual areas burnt by unplanned fires than on the incidence of unplanned fires. Improved understanding of these relationships will assist in optimising the use of management resources in minimising the bushfire risk to identified values at a landscape scale.

Introduction

Each year unplanned fires are responsible for the loss of life, property and ecological values. The majority of these adverse outcomes occur during a small number of large, high intensity fires burning during extreme fire weather. The use of suppression strategies during these fires is either impossible or severely limited. Hence fire management frequently focuses on implementing precautionary strategies that limit the severity of these fires, increase the suppression potential, and limit the probability of adverse outcomes.

Weather, topography and vegetation are the key drivers of fire behaviour. Of these, vegetation is the obvious factor that can be actively managed, primarily through the manipulation of fuel loads and fuel spatial arrays. Consequently, prescribed burning is performed in an attempt to reduce the size, incidence and areas burnt by unplanned fires, and therefore reduce the fire risk to identified values in the landscape.

Numerous studies world wide have demonstrated reductions in fire severity (Pollet and Omi 2002; Finney *et al.* 2005), fire intensities and scorch heights (Stephens 1998), and areas burnt by unplanned fires (Shang *et al.* 2004; King *et al.* (submitted)) as a direct consequence of fuel treatments. These studies have utilised a range of methodologies, including informed observation (Finney *et al.* 2005), field studies (eg Pollet and Omi 2002), examination of post-fire satellite photos and databases (eg Weatherspoon and Skinner 1995; Finney *et al.* 2005), and computer simulation modelling (eg Stephens 1998; Finney 2001; Shang *et al.* 2004; King *et al.* (submitted)). Of these, computer simulation modelling is an appropriate methodology for exploring, over large temporal and spatial scales, the relative effectiveness of alternate prescribed burning options in reducing the risks from unplanned fires.

The effectiveness of prescribed burn treatments in reducing the incidence and extent of unplanned fires is dependent on complex spatial and temporal interactions between treatment unit sizes, spatial arrays of fuel and treatment units (Fernandes and Botelho 2003; Finney *et al.* 2005), and the proportion of the landscape treated annually. Optimal fire management, therefore, is dependent on an accurate understanding of the relative influences of each of these prescribed burning parameters on reducing fire risk.

However, to date there has been minimal research investigating these interactions. The present study uses the computer simulation model FIRESCAPE to investigate the relative importance of the spatial array, treatment unit

size, and proportion of landscape treated annually on abating unplanned fire risk in the landscape of south west Tasmania, Australia. Here fire risk is defined as the probability of burning fire intolerant rainforest and alpine species. In particular, the effects of varying these variables on the fire size distribution of unplanned fires, the mean annual incidence of unplanned fires, and the mean annual area burnt by unplanned fires was explored.

Method

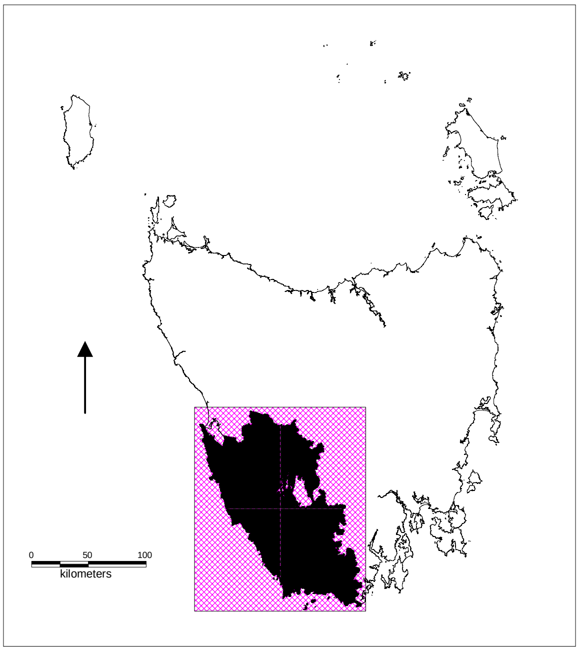

Figure 1 *– Location of the study area (box), and the World Heritage Area (grey) in south west Tasmania, Australia.*

Study site

The study site in south west Tasmania consists of the World Heritage Area (WHA) and the Southwest Conservation Area, containing two large man-made hydro-electric lakes (study area approximately 1.8 million hectares) (Fig. 1). This region contains a diversity of vegetation communities, including highly flammable buttongrass moorland (*Gymnoschoenus sphaerocephalus)* communities (~23%), less fire-prone wet scrub communities (predominantly *Leptospermum spp.*, *Melaleuca spp.*, and *Banksia marginata)* (~11%), wet sclerophyll and mixed forests dominated by *Eucalyptus nitida* (~32%), in addition to rainforest (~19%) and alpine (~2.3%) vegetation (Reid *et al.* 1999). The remainder of the landscape contains agricultural lands (~6%) and dry sclerophyll forest (~6%). A number of rainforest species (eg Huon pine (*Lagarostrobos franklinii)*, King Billy pine (*Athrotaxis selaginoides*)) and alpine species (eg Alpine gymnosperms (*Microcachrys tetragona, Microstrobos niphophilus, Podocarpus lawrencei, Diselma archeri, Athrotaxis cupressoides*, and deciduous beech (*Nothofagus gunnii*)) are killed by single fires, and possess ineffective post-fire regeneration strategies. Consequently, it is common for these species to become locally extinct following fire.

Modelling

For this study, the process-based computer simulation model FIRESCAPE (Cary and Banks 1999; Cary 2002; McCarthy and Cary 2002; King 2004) was used to investigate management treatments super-imposed on a representation of natural landscape fire regimes. This model was designed to simulate fire behaviour and fire regimes over long temporal scales, and, in the form used here, over the topographically complex landscape of south west Tasmania containing a diversity of vegetation communities. The model represents the 1.8 million hectare landscape as a grid of one hectare square pixels, and incorporates a landscape fire regime simulator and a dynamic vegetation model. In its present form FIRESCAPE does not simulate spotting, and therefore potentially under-predicts the spread rate and potential of some fires.

In this investigation prescribed burning treatments varied in the proportion of the landscape treated annually, the mean treatment unit size, and the spatial pattern of treatment units. To remain consistent with the present practice in south west Tasmania of prescribe burning only in buttongrass moorland communities, simulations depicted treatments only in this vegetation, with annual proportions treated being either 0%, 2%, 5%, 10%, 20%, 33%, or 50%. The treatment unit size was determined by dividing the buttongrass moorland in the study area into blocks of approximately the mean simulated treatment unit size (1 ha, 250 ha, 1000 ha, 2000 ha, or 4000 ha). Either a deterministic or random spatial selection pattern for treatment units was simulated. For those simulations with a deterministic spatial pattern, adjacent blocks exhibited a one year difference in their time since treatment. Conversely, random spatial selection patterns involved the random selection of a pre-defined proportion of treatment units each year, again assuming all buttongrass was burnt in selected blocks. Consequently the distribution of inter-fire intervals was relatively uniform under a deterministic spatial strategy, but more diverse using a random spatial strategy.

Analysis

All combinations of treatment levels (0%, 2%, 5%, 10%, 20%, 33% and 50%), mean treatment unit sizes (1 ha, 250 ha, 1000 ha, 2000 ha and 4000 ha), and the spatial distribution of treatment units (deterministic and random) were simulated for 250 years, each with ten replicates. Analyses excluded the first fifty years of simulated data, so that all outputs reflected the response to the simulated annual prescribed burning treatments, rather than the intact starting conditions.

Simulations investigated the relative importance of varying treatment level, treatment unit size, and spatial pattern on the resultant distribution of unplanned fire sizes, their mean annual incidence, and the mean annual area burnt. Initially, log-likelihood methods were used to fit log-Normal distributions to each replicate of the fire size distribution data, with a likelihood ratio test verifying that all replicates of the same simulated combination of variables came from the same distribution. Replicates were then pooled for subsequent analyses of fire size distributions. Cochran's tests were initially performed to test for heterogeneity of variance, with heterogeneity of variances remaining non-significant following log transformation for fire size distributions, and square root transformations for the remaining data sets. Two-way analyses of variance (ANOVA) tests, and multiple comparisons using Tukey tests, were then used to test the effects of different simulated treatment parameters on the fire size distributions, the mean annual incidence of unplanned fires, and the mean annual area burnt by unplanned fires.

Results

Comparison of replicate simulations

Simulated fires that were one hectare in size were eliminated from the data sets, as a truncated data set commencing at two hectares was shown to be more accurate for analyses (Hutchinson 1995; King *et al.* (submitted)). A likelihood ratio test showed that fire size data for replicates of the same simulated prescribed burning treatment combination came from the same log-Normal distribution, and goodness of fit tests showed the log-Normal distribution described the data well.

Fire size distributions

Replicates for each combination of prescribed burning treatment (treatment level, spatial pattern and treatment unit size class) were pooled for comparisons of fire size distributions. Logarithmic cumulative frequency plots were used to compare the probability distributions of fire sizes (areas burnt) between all simulated treatment combinations (Fig. 2). These illustrate the proportion of fires (ordinate) that are as large, or larger, than a given area in hectares (abscissa).

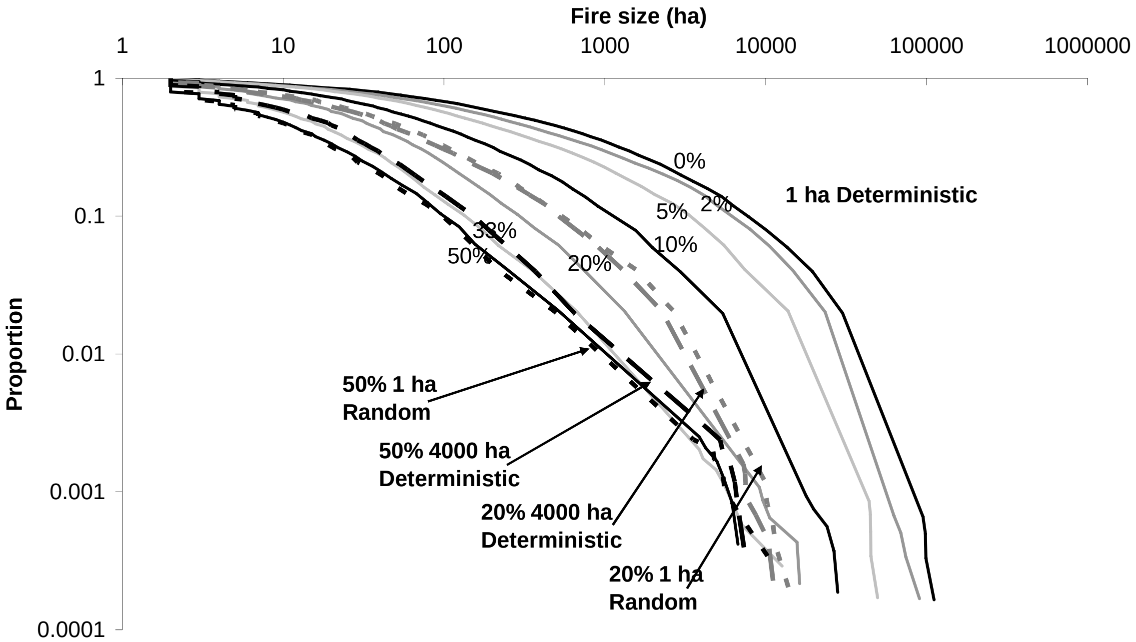

Figure 2 *– An example of the fire size distributions for different prescribed burning treatments, showing the proportion of all unplanned fires as large, or larger, than a given size. Solid lines are for simulations performed where prescribed burning treatment units were 1 hectare, and distributed in a deterministic spatial pattern. Additionally, results for the 20% and 50% treatment levels both for a 1 ha treatment unit size and random selection pattern (dotted lines), and for a 4000 ha treatment unit size and deterministic spatial pattern (dashed line) are shown for comparison.*

Table 1: Significant differences between treatment unit sizes for each treatment level and spatial pattern. Boxes denote those treatments with non-significantly different likelihood ratio test results.

	Deterministic	Random
2%	No significant differences	No significant differences
5%	Some significant differences. No discernable pattern	No significant differences
10%	1 250 1000 2000 4000	1 250 1000 2000 4000
20%	1 250 1000 2000 4000	1 250 1000 2000 4000
33%	1 1000 250 2000 4000	1 250 1000 2000 4000
50%	1 250 1000 2000 4000	1 250 2000 1000 4000

Significant differences in fire size distributions between all treatment levels were evident for each combination of treatment unit size and spatial pattern. In all but one instance, fire sizes were significantly larger for a random spatial selection, rather than a deterministic spatial pattern, for each treatment unit size and for all treatment levels of 10% or greater, and for the 5% treatment level for treatment unit sizes of 1000 ha and 4000 ha.

Likelihood ratio testing identified significant differences between treatment unit sizes within treatment level, in each spatial pattern for treatment levels of 10% or greater, with larger fires occurring with larger treatment unit sizes (Table 1).

Mean annual incidence of unplanned fire

ANOVA tests demonstrated that the percentage of buttongrass treated annually, if over 5%, had a significant effect on the mean annual incidence of unplanned fires (Fig. 3). Tukey tests demonstrated that spatial pattern was significant only at the 33% and 50% treatment levels, and only for some treatment unit sizes (1ha, 1000ha and 4000ha), with significantly more fires burning under a random spatial regime than a deterministic one. Further analysis identified that, in the majority of cases, treatment unit size and spatial pattern were non-significant at the same treatment level.

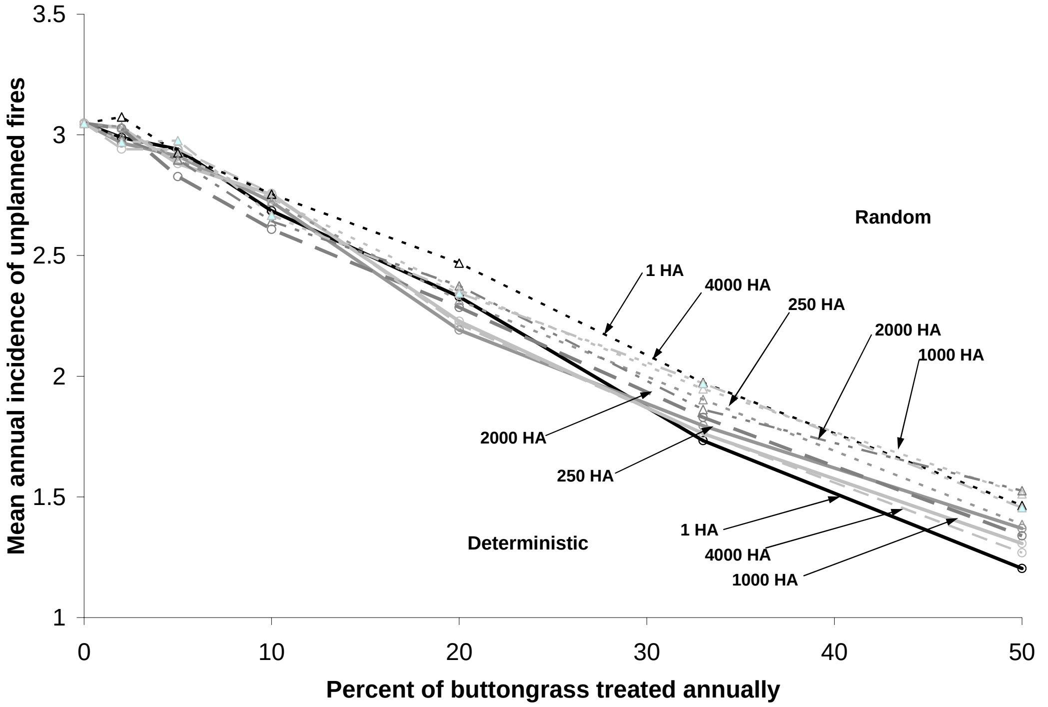

***Figure 3** – The mean annual incidence of unplanned fires for all simulated treatment levels (x axis), spatial patterns (deterministic – circles, random – triangles), and treatment unit sizes (shown).*

Mean annual area burnt by unplanned fires

The mean annual area burnt by unplanned fires exhibited an approximate negative exponential decline with increasing treatment levels for all treatment unit size classes and both spatial patterns (Fig. 4). ANOVA results and Tukey tests demonstrated that significant differences were evident between almost all treatment levels and both spatial patterns for each treatment unit size. Exceptions, where they occurred, were between the 33% and 50% treatment levels. Further analysis demonstrated that, for the same treatment level, in some instances treatment unit

size was significant for treatment levels of 5% or greater, and spatial pattern was significant for treatment levels of greater than 10%. Where multiple comparisons using Tukey tests identified significant differences, the mean annual area burnt by unplanned fires was greater where random spatial patterns were simulated, and where treatment unit sizes were large.

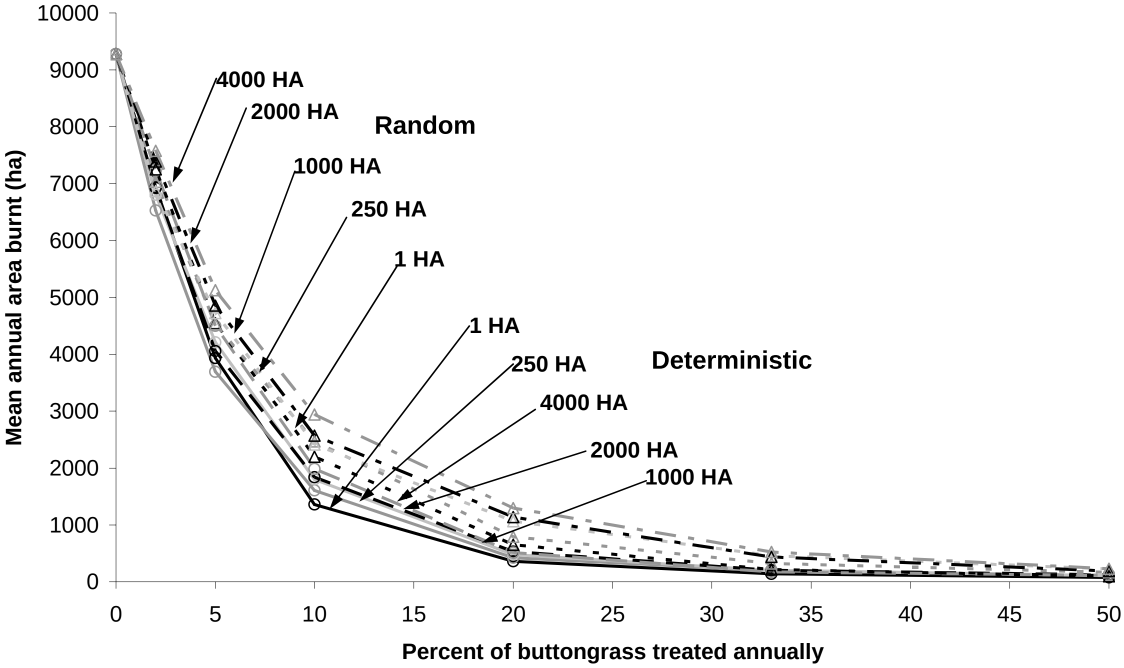

Figure 4 – *The mean annual area burnt by unplanned fires for all simulated treatment levels (x axis), spatial patterns (deterministic – circles, random – triangles), and treatment unit sizes (shown).*

Discussion

This study predicts that certain prescribed burning strategies may reduce unplanned fire sizes, their mean annual incidence and the mean annual area burnt by unplanned fires. Simulations indicated that, in south west Tasmania, the proportion of the landscape annually prescribe burnt (treatment level) had the greatest influence on these three fire behaviour parameters, with all three declining with increasing treatment level. Treatment levels are inversely proportional to the time between fires, and hence to fuel ages and loads. Therefore, shorter fire intervals that resulted from higher treatment levels, had a greater effect on the measured fire behaviour parameters. This observation is consistent with evidence from a variety of landscapes around the world (eg Fernandes and Botelho 2003; Finney *et al.* 2005), all of which indicate a diminishing effect of prescribed burning treatment with time.

In the majority of instances, and unlike the effects of treatment level, both the spatial pattern and treatment unit size did not significantly influence the incidence of unplanned fires in this landscape. These two factors had little impact on the probability of unplanned fires igniting. However, both treatment unit size and spatial pattern did influence the rate of propagation of unplanned fires across the landscape, as was evident from the analyses of both the fire size distributions and mean annual areas burnt by unplanned fires. This finding is consistent with Cary *et al.* (2006). The effects of spatial pattern and treatment unit size on fire sizes and areas burnt were shown to be least significant where treatment levels were 5% or below, as in these cases the majority of fuels were at levels sufficient to propagate fire. Where spatial pattern was shown to be significant, larger areas were burnt under random, rather than deterministic, selection strategies. This reflected the increased spatial and temporal variability in fuel ages, and therefore the increased potential for fire propagation with random spatial patterns. Where treatment unit size was shown to be significant, greater areas were burnt where larger treatment unit sizes were simulated, again reflecting the level of heterogeneity within the spatial fuel array.

This study has demonstrated that, in south west Tasmania, increased fuel heterogeneity, which is promoted by higher treatment levels, deterministic spatial patterns, and smaller treatment unit sizes, reduces the potential for fire propagation. Reductions in the incidence of unplanned fire are primarily driven by the treatment level. It is important to note that deterministic spatial patterns, which dictate relatively uniform fire intervals, are not always congruent to the optimisation of biodiversity, especially where a number of species with a diversity of life attributes are present (Morrison *et al.* 1995; Gill and McCarthy 1998). Consequently, a compromise between deterministic burning practices immediately surrounding defined values, and more variable burning intervals elsewhere, may need to be implemented if both asset protection and biodiversity values are to be simultaneously optimised. Further,

despite the spatial pattern and treatment unit size being shown to be significant only at treatment levels of greater than 5%, both logistic and opportunistic constraints may prevent these levels being consistently achieved in practice.

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