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The influence of planting size and configuration on landscape fire risk

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Abstract

Revegetating cleared land with native trees and shrubs is increasingly used as a means of addressing loss of biodiversity, degraded soil and water resources and sequestration of carbon. However, revegetation also brings a potential to alter fire risk due to changing fuel types across the landscape. Previous research has found that increasing the area of revegetation does not increase the risk of fire at a landscape scale, but it remains unclear whether the design of revegetation can be optimised to minimise risk. We evaluated if size and arrangement of revegetation affects fire size and intensity within an agricultural setting using a simulation modelling approach. Three revegetation planting designs were assessed, including small (3.2 ha) dispersed plantings, small (3.2 ha) plantings clustered into one third of the landscape, and large (29.2 ha) dispersed plantings, all resulting in the same overall percentage of revegetation (approximately 10% of the landscape). We simulated fires using Phoenix Rapidfire under varying planting design, weather, surrounding pasture conditions, and fire suppression. Planting design had little effect on fire sizes across the landscape, with larger plantings resulting in slightly larger fire sizes. Fires were smaller in landscapes with all planting designs compared with current landscape patterns. There was no significant influence of planting design on fire intensity. Weather and suppression had the strongest influence on both fire size and intensity, with larger and more intense fires under extreme weather conditions, with higher adjacent pasture loads and with no simulated suppression. Management of fuel loads in the pasture surrounding revegetation, weather and suppression are far greater risk factors for fire in these landscapes than planting design.

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Title: The influence of planting size and configuration on landscape fire risk

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Abstract

Revegetating cleared land with native trees and shrubs is increasingly used as a means of addressing loss of biodiversity, degraded soil and water resources and sequestration of carbon. However, revegetation also brings a potential to alter fire risk due to changing fuel types across the landscape. Previous research has found that increasing the area of revegetation does not increase the risk of fire at a landscape scale, but it remains unclear whether the design of revegetation can be optimised to minimise risk. We evaluated if size and arrangement of revegetation affects fire size and intensity within an agricultural setting using a simulation modelling approach. Three revegetation planting designs were assessed, including small (3.2 ha) dispersed plantings, small (3.2 ha) plantings clustered into one third of the landscape, and large (29.2 ha) dispersed plantings, all resulting in the same overall percentage of revegetation (approximately 10% of the landscape). We simulated fires using Phoenix Rapidfire under varying planting design, weather, surrounding pasture conditions, and fire suppression. Planting design had little effect on fire sizes across the landscape, with larger plantings resulting in slightly larger fire sizes. Fires were smaller in landscapes with all planting designs compared with current landscape patterns. There was no significant influence of planting design on fire intensity. Weather and suppression had the strongest influence on both fire size and intensity, with larger and more intense fires under extreme weather conditions, with higher adjacent pasture loads and with no simulated suppression. Management of fuel loads in the pasture surrounding revegetation, weather and suppression are far greater risk factors for fire in these landscapes than planting design.

Keywords: Revegetation, Planting Design, Fire Behaviour, Fire Suppression, Connectivity, Fire Management.

Introduction

Revegetation or restoration of the landscape through planting of native trees and shrubs provides an important tool for increasing biodiversity and ecosystem services (Benayas et al., 2009; Kavanagh et al., 2007; Law et al., 2011; Munro et al., 2009), rehabilitation of soil and water resources (Yates and Hobbs, 1997) and mitigating against climate change (Jonson and Freudenberger, 2011; Roxburgh et al., 2006; Silver et al., 2000; Summers et al., 2015). Globally, a net annual decrease in forest area of 3.3 million hectares has been observed from 2010 to 2015, in spite of substantial reductions in deforestation and increased revegetation efforts (FAO, 2015). This has led to significant efforts and investments being made in revegetating and restoring landscapes globally (Campbell et al., 2017; Meli et al., 2017; Menz et al., 2013), with a range of different and often competing environmental, social and economic objectives. Plantings for carbon abatement objectives may target areas of high productivity, capable of sequestering large amounts of carbon (Nolan et al., 2018). Whilst, plantings with environmental objectives may target locations and designs that enhance connectivity between remnant patches of vegetation (Shanahan et al., 2011). Throughout Australia amount of revegetation (both temporally and spatially), the design (size and shape), species composition and management (Nolan et al., 2018; Paul et al., 2016) vary and have the potential to influence fire risk in a landscape context.

Planning at a landscape level could allow for broad strategies to be implemented, such as restoring habitat and carbon abatement. Plantings provide increased structural complexity when compared to agricultural land (i.e. pasture or crop) and have been associated with increased resources and in turn increased biodiversity (Kavanagh et al., 2005; Kavanagh et al., 2007; Michael et al., 2011; Yates and Hobbs, 1997). The most common forms of planting in agricultural regions are narrow linear belts (Smith, 2008) and block-style planting, with an average area of 5.1 hectares for tree blocks (Kimber et al., 1999). Linear belts can create corridors which improve connectivity between remnant native vegetation and other plantings, reducing the isolation of patches in a landscape (Cunningham et al., 2015). Block-style plantings aim to increase the amount of habitat in the landscape, with larger blocks tending to have greater benefit for birds, arboreal mammals, reptiles and bats (Munro et al, 2007; Law et al 2011). Compared to block planting, linear belts have a larger perimeter to area ratio, resulting in less competition for resources such as light, water and nutrients (Paul et al., 2016), and hence several studies have shown linear plantings increase above ground biomass (i.e. carbon sequestration) compared with block planting (Henskens et al., 2001; Paul et al., 2016; Paul et al., 2015).

Positive outcomes associated with plantings may come at a cost of increased risk of fire and the associated negative social and environmental costs (Benayas et al., 2007). The amount and spatial distribution of vegetation types will have important implications for fire propagation and behaviour across landscapes (Duguy et al., 2007; Penman et al., 2014). Where revegetation consists of adding shrubs and trees to grassland or pasture, there will be an increase in biomass and vertical continuity of fuels, thereby creating potential for higher intensity fires and greater ember production in plantings compared to pastures. Conversely, plantings may reduce the rate of fire spread due to the interception of wind by woody vegetation (Jenkins et al., 2016; Sullivan et al., 2012). For example, Collins et al. (2015) demonstrated through landscape fire simulation, that the amount of revegetation (as a percentage of the total landscape) had a increased fire size and intensity when the pasture being replaced had a low fuel load (2 t ha^{-1}). However, when the pasture had higher fuel loads ($\geq$ 4.5 t ha^{-1}) revegetation reduced fire size and intensity. Therefore, research examining the effect of planting configuration on fire risk at a landscape level is currently lacking.

Fire management agencies undertake activities to minimise the impact of bushfires, this is collectively referred to as suppression. The likelihood of effective fire suppression is dependent upon time since ignition, fire intensity, fire rate of spread and spotting (Alexander, 2000; Cheney and Sullivan, 2008; Gould et al., 2007). Grass fires tend to have faster rates of spread than forest fires (Cheney, 1990), potentially reaching large sizes in short time frames (Sullivan et al., 2012). However, a recent study showed 95% of grass fires are contained within 2 hours whilst compared with only 50% of forests fires being contained within the same time period (Collins et al., 2018). Forest fires burn at greater intensity than grassfires and are more likely to exceed the threshold of suppression capabilities (2000 Kw/m; Cary et al., 2017). The presence of trees in the landscape increases the potential for ember production and can reduce the likelihood of fire suppression (McCarthy and Tolhurst, 1998). Revegetation alters the spatial distribution of trees and potential fuels in the landscape and therefore may reduce the effectiveness of fire suppression.

Simulation studies can provide valuable insight into the effects of landscape change on fire risk, as they allow for examination of a large range of environmental conditions and management actions (Duguy et al., 2007; Penman et al., 2013). The aim of this study is to examine whether the arrangement and size of plantings influences the size and intensity of wildfires in an agricultural landscape. We used fire simulation models to address the following questions: i) do large (29.2 ha) plantings result in larger more intense fires than small (3.2 ha) plantings? ii) do spatially clustered plantings result in smaller less intense fires than spatially dispersed plantings? and iii) does the size and arrangement of plantings alter the effectiveness of fire suppression at reducing fire size?

Methods

Study Area

The simulation study focussed on a 40 x 40 km area in the Albury/Wodonga region (36.0806° S, 146.9158° E), New South Wales, Australia (Figure 1; Jenkins et al., 2016). The area has been largely cleared of native vegetation and the dominant land-use is grazing by sheep and cattle (DECCW, 2009). Since the 1970's, the study area has been the focus of numerous revegetation programs that include a diverse array of shapes and sizes. Recent programs have focussed on putting trees and shrubs into critical landscape areas like creeks and roadsides to create wildlife corridors, whilst older plantings tended to be large blocks of tree replanting (Datson, G. pers comm., Kavanagh et al., 2005). The region was chosen for the simulation study as it is representative of the types of landscapes undergoing transformation as a result of revegetation in temperate regions of Australia.

Revegetation design

The revegetation scenarios considered in this study focused on the effect of varying design configurations (size and dispersion), whilst holding the amount of revegetation constant at approximately 10% of landscape, with the caveat that revegetation cannot be located on existing forested areas (less than15 % of the landscape was forested). The area was reforested at a rate of approximately 10% which was chosen as conversations with land management agencies and recent quantification of revegetation activities (Kyle and Duncan, 2012; Smith, 2008) suggest that revegetating at rates greater than 10% area seem unviable. The four revegetation scenarios examined were: i) 5000 small plantings (3.2 ha) dispersed across the entire study area; ii) 5000 small plantings clustered within sections of the study area; iii) 525 large plantings dispersed across the study area (29.2 ha); and iv) the current landscape (control; Figure 1).

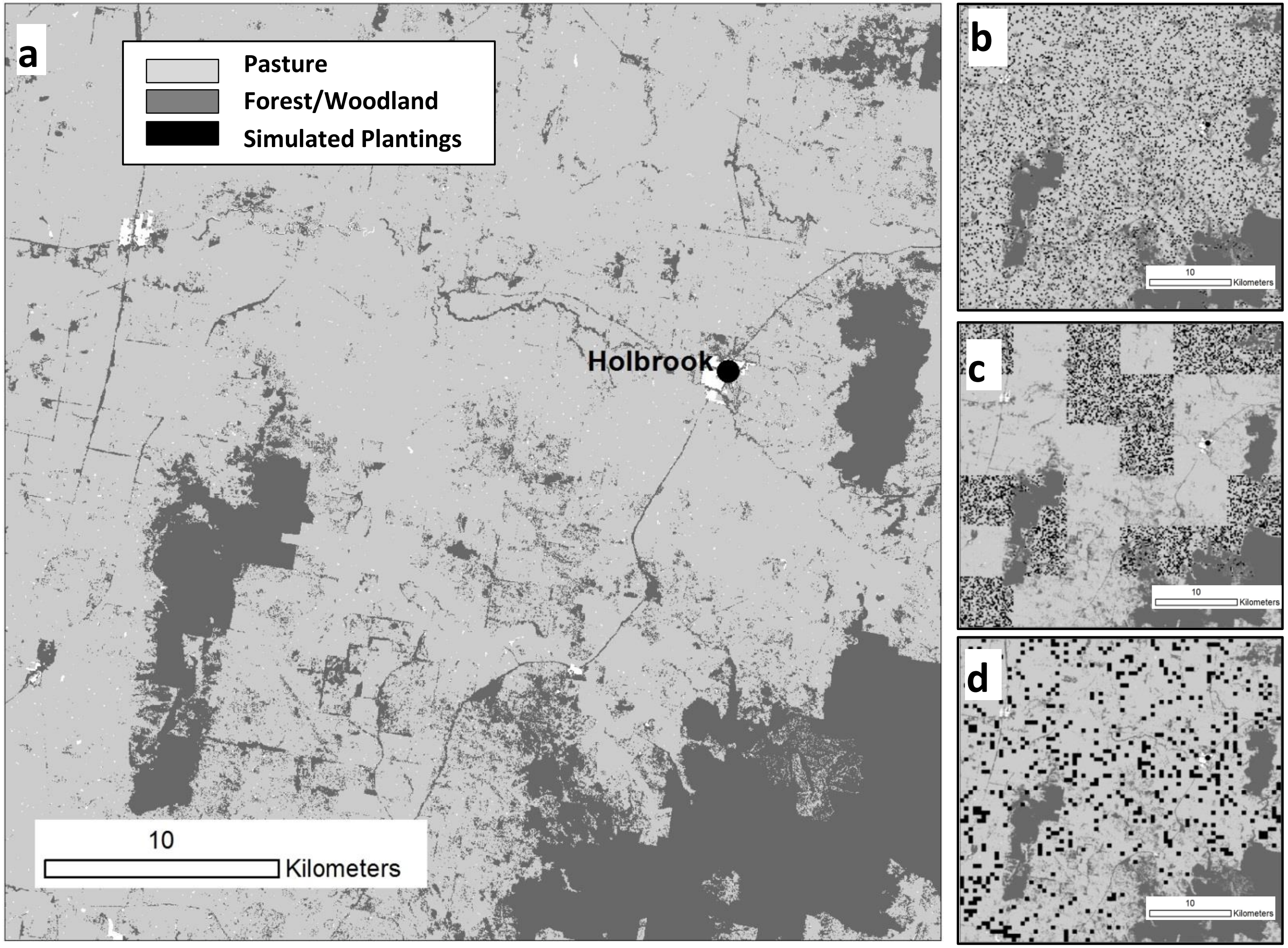

Figure 1: The study area for the Phoenix simulation showing a) The distribution of existing pasture and forest/woodland vegetation; b) small simulated plantings (3 ha); c) clustered plantings (3 ha) and d) large plantings (29.2 ha).

Plantings were allocated randomly and only to pre-existing pasture (i.e. not on already forested land). Clustering was achieved by only allocating plantings in randomly selected subdivisions of the study area (12 of the 36 squares in a 6 x 6 grid), which is a common scenario as some landholders are more amenable to having plantings on their property (Jellinek et al., 2013). The design scenarios were each replicated three times in order to minimise the effect of specific planting arrangement on the results.

Simulation study

The Phoenix Rapidfire (v 3.9) simulator (Phoenix; Tolhurst et al., 2008) was used to examine the effects of planting design on fire size and intensity. Phoenix is a dynamic fire behaviour simulator that uses two basic fire behaviour models: the CSIRO southern grassland fire spread model (Cheney et al., 1998) and a modified McArthur Mk5 forest fire behaviour model (McArthur, 1967; Noble et al., 1980). Numerous studies have utilised Phoenix to examine the effects of factors such as weather, fuel management strategies, suppression and fire behaviour (Collins et al., 2015; Duff et al., 2013; Penman et al., 2013). Fire agencies in eastern and southern Australia routinely use Phoenix for operational predictions of fire behaviour and risk assessments and are considered to provide an adequate representation of fire behaviour in these areas (Bentley and Penman, 2017). Inputs for Phoenix include fuel wind reduction factors, topography, built assets, road proximity, disruption (breaks in the continuity of fuel), and weather and suppression resources (Chong et al., 2013).

Fuel treatments

Fuel load in Phoenix is estimated from fuel accumulation curves predicting fuel hazard as a function of time since fire for each vegetation type, using a negative exponential function (Olson, 1963). Parameters include surface (forest litter fuels), elevated (shrub fuels) and bark fuels as described by Gould et al. (2011).The fuel type was adapted from a state-wide fuel layer developed by the New South Wales Rural Fire Service (unpublished data) based on vegetation mapping (Keith, 2004). There were 17 fuel types in the study area, dominated by Cropland (65.7% of the area), Grassland (11.6%), Upper Riverina dry sclerophyll forests (7.5%) and Remnant woodland (6.9%). For the purposes of this study, cropland and grass fuel types were grouped together (as pasture) based on our knowledge of the study area. Since, revegetation in this area has focussed on planting locally indigenous species, we populated a new vegetation type "plantings" using the most common pre-existing forest type (Upper Riverina dry sclerophyll forest). Average fuel hazard ratings from 20 year old eucalypt plantings were used to parameterise the "plantings" fuel type, as previous work has shown that this is when fuel hazard first reaches a steady state in plantings (Jenkins et al. 2016). The "plantings" fuel type was then used for all revegetation designs used in fire simulations. All other fuel types were populated with data for the major vegetation formation in the study area (Watson, 2011). Dry sclerophyll forests experience mixed severity wildfire (Bradstock, 2009; Collins et al., 2014), whereby fire behaviour is determined by both a combination of fire weather conditions, topography and fuel characteristics (Bradstock et al., 2010; Storey et al., 2016). The dry sclerophyll communities are dominated by eucalypt species that resprout epicormically in response to high severity canopy fires (Fairman et al., 2016), with understoreys that are typically dominated by resprouting shrubs and herbs (Hammill et al., 2016).

Pasture fuel loads fluctuate annually with climate as well as with management i.e. grazing and cropping (Gill et al., 2010) and have been shown to have a strong effect on fire behaviour (Cheney et al., 1998). In this simulation we examined two levels of pasture fuel load: Low, using parameters from Grassland (2 t ha^{-1}) for all areas mapped as pasture, and; Moderate, using parameters set for Grassland (4.5 t ha^{-1}) for all areas mapped as pasture (following Collins et al., 2015).

Suppression

The scenarios were run with and without active fire suppression. The suppression module included in Phoenix allows the user to define the time taken for resources to reach the fire (response time) and the number and type of resources. The suppression module progressively extinguishes the fire perimeter starting from the rear, progressing along the flanks toward the head (Penman et al., 2013; Tolhurst et al., 2008), which is common practice operationally (Plucinski, 2013). The rate of line construction follows expert estimates of fire line construction rates as a function of the number and type of resources available, topography (slope), distance from road (road proximity), fuel load and fire intensity (McCarthy and Tolhurst, 1998). In this study, suppression response time was fixed at 30 minutes after ignition and six tankers were deployed to each fire, until the end of each simulation (the average number of appliances deployed for initial response for fires in the Albury region during 2013-2014 was 5.3; NSW Rural Fire Service Situation Report, unpublished data). Resources were added to the flanks in a 60:40 ratio, favouring the leeward side of the fire. Suppression rates for tankers in Phoenix are reduced to 0 at 2500 (kW m^{-1}). As wind changes are characteristic of fire weather in southern Australia, the distribution of resources between fire flanks can be modified (Duff and Tolhurst, 2015). The suppression module by default has a road proximity value of 350 m for tankers, as tanker suppression rates are reduced to zero if the distance from the fire to the road is greater than 350 m. In agricultural landscapes access through pasture (i.e. off road) is likely, so we reduced the road proximity to zero (in the suppression function) to allow suppression resources to access fires within both pasture and plantings equally.

Weather

The Forest Fire Danger Index (FFDI) is a measure of the potential for fires to escape initial attack using the fire weather variables; wind speed, temperature and relative humidity (Noble et al., 1980). FFDI was determined using hourly weather observations obtained from the Australian Bureau of Meteorology, Albury Airport automated weather station (AWS 72160). Three levels of FFDI were examined as part of this study. To reduce the number of simulations required High and Very high FFDI were combined, as were Extreme and Catastrophic FFDI to give: High/Very high (12-49), Severe (50-74) and Extreme/Catastrophic (>75). Five replicate weather streams of each level of FFDI were taken from months/years when historical wildfire events had occurred in the region. Simulations were run for 12 h after ignition. All weather streams consisted of hourly observations and covered a 24 h period, commencing from 10 h prior to fire ignition (i.e. midnight as ignition was set at 10:00 h) to allow for equilibrium of fuel moisture and radiation levels (Penman et al., 2013) and concluded 12 h after ignition (i.e. 22:00 h). Grass curing was set to 100% for all simulations, which is the worst possible scenario in the summer bushfire season (Gill et al., 2010; Luke and McArthur, 1978).

A total of 600 scenarios were run: 9 revegetation designs (clustered, small and large plantings each with 3 replicates) x 2 pasture levels x 2 suppression levels x 3 FFDI x 5 replicate weather streams, and the current landscape (control) x 2 pasture levels x 2 suppression levels x 3 FFDI x 5 replicate weather streams. A 2 km gridded ignition pattern was used giving 272 ignition points within the study area for each scenario. Each ignition was simulated independently (as if the others had not occurred) and allowed to run for 12 hours, resulting in a total of 163,200 simulated fires.

Analysis

Two simulation outputs were used for comparisons of the simulated scenarios: fire size (ha) and fire intensity (kW m^{-1}), for each planting design n = 272 fires. Linear mixed models fitted by maximum likelihood (Bates et al., 2015) were used to test for the effect of design on fire size and intensity. A Gaussian distribution was used in these models with the response variables being log-transformed to meet the assumptions of normality. Models representing all one way and two way interactions with design were considered. The results from the control (current state) simulations were not included in the model fitting analysis as the objective of the study was to compare designs with the same total planting area. Planting scenario (1-9) and ignition points (1-272) were included as random terms. Model selection was undertaken using Akaike's Information Criteria (AIC). Models with ΔAIC < 4 points of the top model (i.e. with the smallest AIC) were considered as being strongly supported (Burnham and Anderson, 2003). Statistics were conducted using R 3.5.1 (R Core Team, 2018) and the lme4 package (lmer; Bates et al., 2015).

Results

There was a very small effect of planting design on fire size (Table 1 & Figure 2) when compared to the effects of weather, pasture fuel loads and suppression. Scenarios including plantings resulted in smaller fires than the controls (current state) in all four combinations of suppression and pasture load, only slightly so with low pasture and with suppression, but between 1.2 – 2.3 times larger for the other combinations (Figure 2). Fire sizes were approximately 1.1 times larger in scenarios with the large and clustered planting designs compared to those scenarios with small planting designs (Figure 2, Table 1). Weather had a strong effect on fire size, where the greater the FFDI the larger the fire size (Figure 2, Table

1). Suppression had the greatest effect on reducing fire size and was most effective when pasture fuel load was low (Figure 2, Table 1).

Fire intensity was not significantly influenced by planting design (Table 2). Lower fire intensity was shown in scenarios with low pasture fuel loads with suppression for all planting designs and weather combinations (Figure 3 & Table 2), such that it was less than the upper fire intensity limits for fire suppression by ground-based forces (~3000–4000 kW/m; Cary et al., 2017). However, fire intensity was much higher in the other combinations, especially with more severe weather and without suppression (Figure 3). Weather had a strong significant influence on intensity whereby increasing FFDI resulted in greater fire intensity (Figure 3, Table 2).

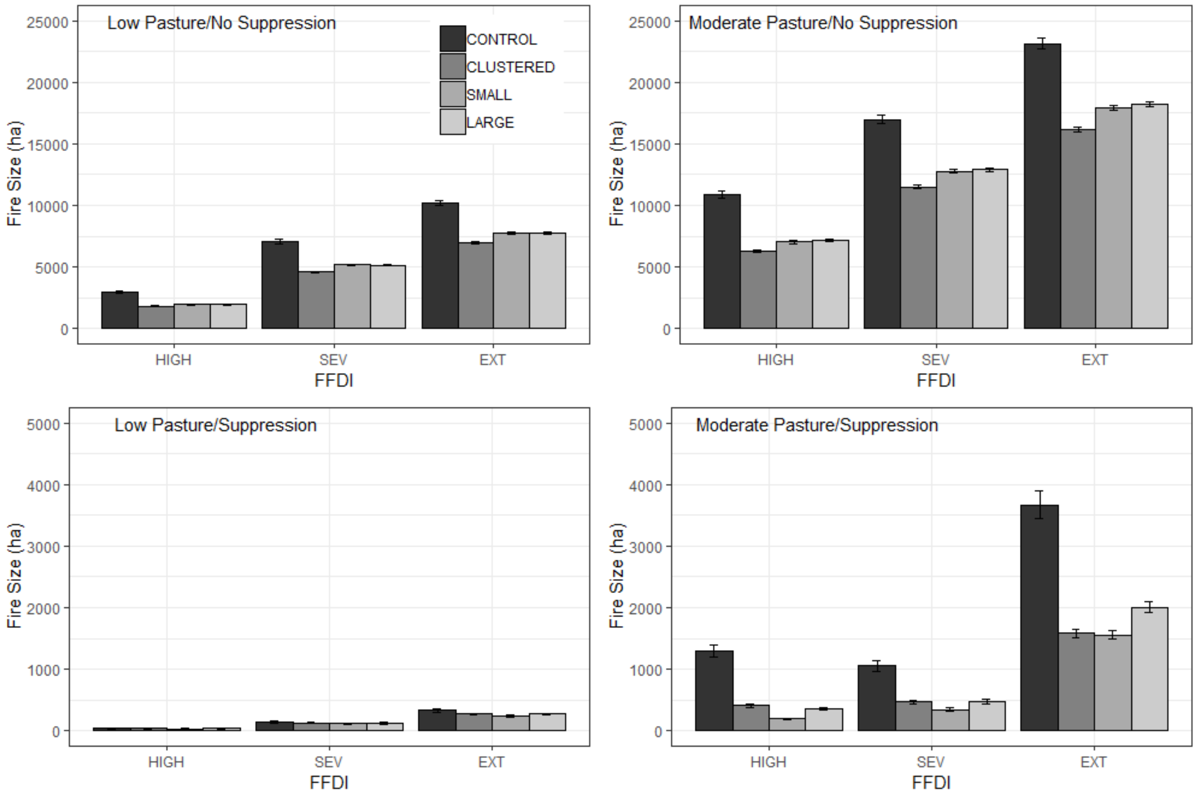

Figure 2: Mean fire size (ha) from Phoenix predicting the effect of planting design on fire size classified according to weather (forest fire danger index, FFDI), suppression and adjacent pasture condition (error bars represent standard error).

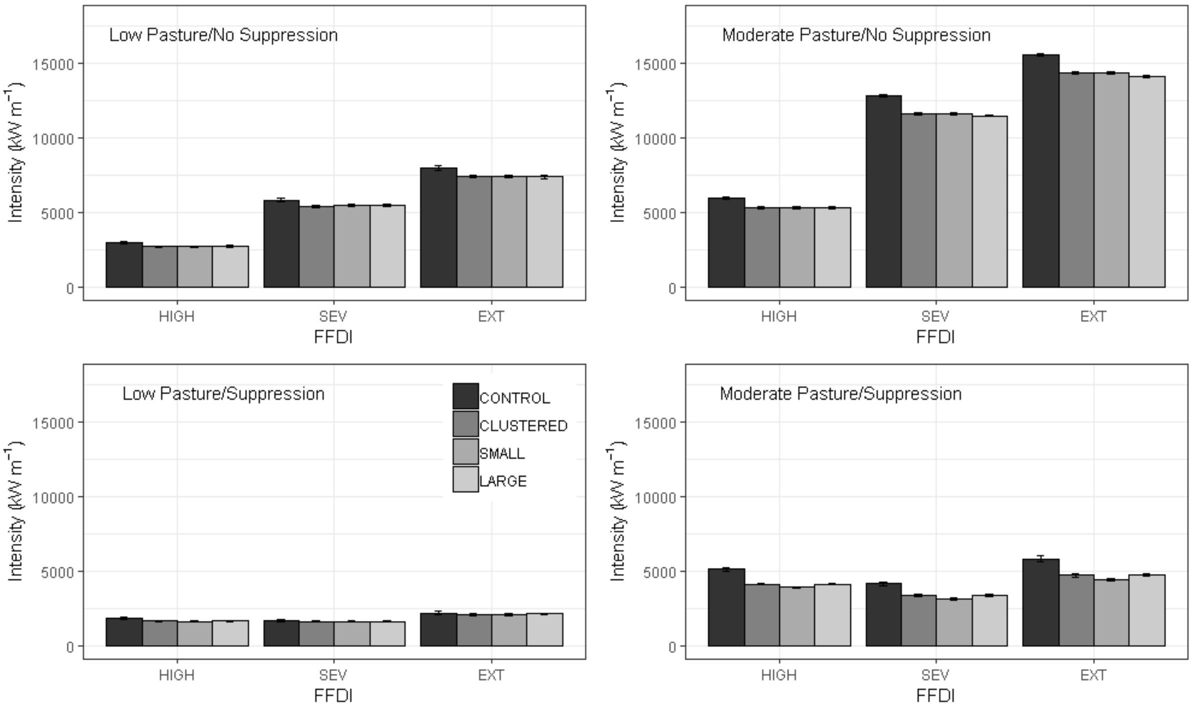

Figure 3: Mean fire intensity (kW m^{-1}) from Phoenix predicting the effect of planting design on fire intensity classified according to weather (forest fire danger index, FFDI), suppression and adjacent pasture condition (error bars represent standard error).

Table 1: Summary statistics for the selected linear mixed model for fire size in the Albury/Wodonga region of New South Wales, Australia.

logfsz ~ design * pasture + design * weather + design * suppress + (1 | designid) + (1 | fireid).

	Estimate	Std. Error	T value	P-value
Intercept	3.225	0.077	41.901	<0.001
Design Large	0.039	0.036	1.078	0.288
Design Small	-0.193	0.036	-5.395	<0.001
Pasture Low	-1.385	0.019	-74.513	<0.001
Weather High	-0.993	0.023	-43.611	<0.001
Weather Sev	-0.452	0.023	-19.847	<0.001
Suppression No	5.560	0.019	299.052	<0.001
Design Large: Pasture Low	-0.008	0.026	-0.308	0.758
Design Small: Pasture Low	0.101	0.026	3.833	<0.001
Design Large: Weather High	0.005	0.032	0.157	0.875
Design Small: Weather High	-0.038	0.032	-1.180	0.238
Design Large: Weather Sev	-0.021	0.032	-0.638	0.524
Design Small: Weather Sev	0.004	0.032	0.112	0.910
Design Large: Suppression No	0.063	0.026	2.403	0.016
Design Small: Suppression No	0.270	0.026	10.278	<0.001

Table 2: Summary statistics for the selected linear mixed model for fire intensity in the Albury/Wodonga region of New South Wales, Australia.

LogInt ~ design + weather + pasture + suppress + (1 | design) + (1 | fireid) (note: there was no significant interaction between design and weather, pasture or suppression).

	Estimate	Std. Error	T value	P-value
Intercept	7.965	0.041	7.965	<0.001
Design Large	-0.014	0.015	-0.014	0.380
Design Small	-0.011	0.015	-0.011	0.492
Weather High	-0.500	0.006	-0.500	<0.001
Weather Sev	-0.203	0.006	-0.203	<0.001
Pasture Low	-1.042	0.005	-1.042	<0.001
Suppression No	1.269	0.005	1.269	<0.001

Discussion

The size and arrangement of plantings had a small effect on fire size and no effect on fire intensity. Simulations showed that fires occurring in a landscape revegetated with large plantings resulted in slightly larger fires than landscapes revegetated with smaller plantings, but smaller fires than landscape with no plantings. The tendency for fire size to decrease with the addition of revegetation is in agreement with previous simulation studies for temperate Australia (Collins et al. 2015). Our results suggest that faster rates of spread of fire in pastures surrounding plantings was more important than the design of the planting and that greater gaps between plantings in the large planting scenarios allowed for uninterrupted rates of fire spread through pasture than in the small and clustered planting design scenarios. This suggests that increased connectivity of forested areas (as shown in the smaller and clustered designs) is unlikely to lead to larger fire size in these systems. Slower rates of fire spread in plantings (or forested areas) than in surrounding pasture fuel, may ultimately make fires more easily suppressed and contained.

The effect of spatial arrangement of fuel types (pasture vs forest) on fire patterns in the landscape can be likened to percolation models that examine how entities (e.g. animals, fire) propagate through a lattice with more or less permeable members (Abades et al., 2014; Il Pak et al., 2011; Wiens et al., 1997; With et al., 1999). These models generally report a critical threshold of the proportion of permeable cells above which movement or spread is unhindered. In the case of fire, a figure of 60% has been reported (Abades et al., 2014), which implies that landscapes with less than 60% fuel coverage will impede fire spread. Previous work by Collins et al (2015) suggests that revegetation which increases forest and woodland cover to greater than 60% of the landscape is sufficient to impede rapid fire spread across high biomass pastures. The revegetation scenarios considered in our study only increased woody vegetation cover to ~25% of the total landscape, which may have been insufficient to invoke major changes to fire spread between designs. However, the slight decrease in fire size shown with small and clustered design suggest these may have been sufficient to impede rapid fire spread in pastures when compared to large planting, due to a larger areas of uninterrupted pasture fuel between large plantings.

Fire weather and suppression had the strongest effect on fire size and intensity, consistent with previous empirical and simulation studies (Bradstock et al., 2010; Cary et al., 2009; Penman et al., 2013). Phoenix simulates each suppression resource with a defined ‘base’ suppression rate, which is increased or decreased depending on landscape attributes (e.g. slope, road proximity, fuel type, time and fire intensity; Duff and Tolhurst, 2015). In our simulations we assumed suppression resources could operate within plantings and pastures equally via access through pasture, however in reality suppression is likely to be limited to the edge of plantings (e.g. typically a maximum 3 lengths of hose, or about 90 m) for safety purposes. However, even with the larger sized planting simulated in this study, suppression may have been effective at limiting fire size, if the fire was not allowed to escape the revegetated area into surrounding pasture.

Spotting behaviour and ember attack can significantly alter the rates of fire spread and suppression effectiveness (Sullivan et al., 2012). Spotting potential is strongly determined by bark characteristics of the dominant trees. Eucalypts exhibit a wide range of bark characteristics (Boland et al., 2006), which can influence both ember production of distance travelled. Fibrous bark (such as stringy bark) can produce intense short-distance spotting, whilst ribbon bark is known for occasional long distance (greater than tens of kilometres) spotting (Ellis, 2011; Hall et al., 2015). Conversely, species with smooth bark (i.e. gums) or firmly held and compact fibrous bark (e.g. ironbark, box bark) produce few embers (Hines et al., 2010). Revegetation within the study region has largely utilised ironbark and box bark species, resulting in planting communities with a moderate level of bark fuel hazard (Jenkins et al., 2016), and low amounts of spotting that will not hinder fire suppression (Hines et al., 2010). Revegetation with species with greater spotting potential (than used in this study) may be a potential mechanism by which fire risk posed by plantings is increased.

As with any simulation study, it is possible that the simulation does not represent the reality of fire spread in our study landscape. For example, Phoenix uses a deterministic spotting model based on bark fuel, the intensity of the fire and the convective updraughts (Tolhurst et al., 2008), which has a limited empirical underpinning. It is also possible that the revegetation, and hence the addition of bark fuels to the landscape, have the potential to increase fire spread through spotting to a greater extent than predicted by the simulation.

Our results suggest that fire risk will be relatively unaltered by planting arrangement and that pasture management and suppression are greater factors in reducing fire risk in these landscapes. Further studies focusing on the effects of planting design for increased connectivity (e.g. linking remnant vegetation), linear strip plantings and species composition (e.g. tree bark types) on fire behaviour are required. This research would provide greater insight into the extent to which planting design may influence fire risk and fire propagation across fragmented landscapes.

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