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Characterising and managing fire risks to plantations under changing climates

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Abstract

Wildfires are a common threat to the sustainability of commercial plantations in fire-prone regions. Large losses of plantations from wildfires can lead to the disruption of forest yield, with flow-on impacts to downstream industries, resulting in significant social and economic impacts to local communities. Future climate projections indicate an increase in wildfire activity, including increases in fire extent, severity or frequency in many fire-prone ecosystems. Land and fire management agencies around the world invest significant resources to reduce the likelihood and impact of future fires and increase the capacity for fire suppression. However, we currently know very little about how commercial plantations will be impacted by fire as the climate changes, or if strategic management can mitigate some of these risks into the future.

In this study we sought to 1) quantify fire risks to plantations and nearby community assets under current and changing climates; and 2) evaluate the effectiveness of management options for mitigating some of these risks under changing climates. This research included the customisation of a fire simulation tool (PHOENIX RapidFire) for use in plantation landscapes by developing plantation-specific fuel functions (derived from field-sampling in hardwood and softwood plantations around Australia) that were integrated into fire spread models. To quantify longer-term risks, these advancements were also integrated into a stochastic fire regime simulator (FROST– Fire Regimes and Operation Simulation Tool). Fire risks to both environmental and community assets were evaluated under current and changing climates to support evidence-based management to help guide investment, insurance negotiations, and fire mitigation in the plantation sector. The fire regime simulator (FROST) was also used to evaluate a range of different management options for reducing risk as a basis for efficient allocation of fire prevention and response resources both by plantation growers and by broader fire management agencies.

We found that reducing suppression response times (to 15 minutes or less for all ignitions) and the current approach to management (a construction rate of 2km/h for suppression and 15-minute response times, with 4000ha/year of prescribed burning) were consistently the best management strategies for reducing fire risks to plantations and adjacent communities, regardless of the climate model used. These strategies offer the greatest scope for reducing future wildfire risks to plantation assets and adjacent communities as the climate changes. High pruning in strategic locations may also be worthy of future investment but should be considered in combination with more rapid suppression and prescribed burning. Plantation owners currently have little influence over the amount and location of prescribed burning adjacent to plantations, and fuel reduction burning is not regularly undertaken in Australian plantations. Therefore, rapid suppression response times was found to be the single best investment for minimising impact to plantation assets under a hotter or drier climate.

1. Background & Introduction

Wildfires are a common threat to the sustainability of commercial plantations in fire prone regions. Wildfire is considered one of the main threats to plantations in many countries including Australia, Brazil, Indonesia, Chile and Portugal (Matthews et al. 2012; Booth 2013; Galizia & Rodrigues 2019), with an increased frequency of incidents in recent years (Bartlett 2012). In Australia, vast areas of hardwood and softwood plantations were burnt by the devastating 2019/2020 Black Summer wildfires, with more than a quarter (26%) of commercial plantations burnt in New South Wales alone (Cruz, Alexander & Plucinski 2017). The growth characteristics of plantations can be highly flammable, especially at key stages in their growth cycle. Severe wildfires may result

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in high economic losses if burnt trees are not salvageable due to their age profile, or when high-severity fire results in whole-of-stand losses. Wildfires that impact plantations can have flow-on effects for other parts of the wood products industry, potentially resulting in significant negative economic and social impacts to regional communities (Cruz, Alexander & Plucinski 2017). Understanding changes in fire regimes and the associated impacts in plantation landscapes will be key to adequately managing risks to both plantation and community assets in coming decades.

Future climate projections indicate an increase in wildfire activity, including increases in fire extent, severity or frequency in many fire-prone ecosystems (Bowman et al. 2009; Flannigan et al. 2009). Land and fire management agencies around the world invest significant resources to reduce the likelihood and impact of future fires and increase the capacity for fire suppression (Calkin et al. 2005; Berry, Donovan & Hesseln 2006). However, we currently know very little about how commercial plantations will fare as the climate changes, nor how management may be able to mitigate some of these risks into the future. Plantation forestry involves relatively long time scales, with 30-year rotations common. Therefore, improved prediction of fire risk over decade long time-scales is crucial to the industries sustainability.

Fuel management is the primary means for land and fire managers to reduce the occurrence, size and severity of future fires while also having the co-benefit of increasing the capacity for suppression during an active fire (Agee & Skinner 2005; Wilson & Wiitala 2005; Finney, Grenfell & McHugh 2009; Penman et al. 2011). Fuel management in and around plantations is regarded as being important for reducing the likelihood of future impacts from wildfires. Fuel management within plantations primarily focuses on modifying or reducing the amount of fuel in key strata. The modification or removal of surface fuel and increasing the gap between the canopy base height and the ground (through removal of elevated fuels) is known to reduce the overall flammability (Burrows et al. 1989; Agee & Skinner 2005; Johnson & Peterson 2005; Fernandes et al. 2008). However, the effectiveness of different types of management under a changing climate is not yet well understood.

In this study, fire risks to both environmental and community assets were evaluated under current and changing climates to support evidence-based management to help guide investment, insurance negotiations, and fire mitigation in the plantation sector. A fire regime simulator (FROST - Fire Regimes and Operation Simulation Tool) was also used to evaluate a range of different management options for reducing risk as a basis for efficient allocation of fire prevention and response resources both by plantation growers and by fire management agencies.

This research had two key objectives:

1. To quantify fire risks to plantations and nearby community assets under current and changing climates;
2. To evaluate the effectiveness of management options for mitigating fire risks to plantations and nearby community assets under changing climates.

2. Approach

This research included the customisation of a fire simulation tool (PHOENIX RapidFire) for use in plantation landscapes by developing plantation-specific fuel functions (derived from field-sampling in hardwood and softwood plantations around Australia, see Figure 1A) that were integrated into fire spread models. To quantify longer-term risks, these advancements were also integrated into a stochastic fire regime simulator - FROST, that is proposed for future use in operational risk assessments.

2.1. Quantifying fuel accumulation in plantations over time

Prior to this study, plantation fuels were represented in fire-behaviour simulators by Olson fuel accumulation curves based on native vegetation. These curves are characterised by a rapid and steady increase in fuel load in young age classes (~5 to 8 years) followed by a progressive stabilisation to loads of ~16 Mg ha^{-1} in the surface/near-surface stratum and 2 Mg ha^{-1} in the elevated stratum. However, the accuracy of these fuel functions for plantations has not been fully assessed. As a result, fuel hazard has been poorly estimated in plantations, resulting in sub-optimal predictions of fire behaviour and risk in plantation areas.

To address this, we undertook a series of field-based vegetation surveys, to quantify how fuel accumulates over time in hardwood and softwood plantations. The project involved six study landscapes (each roughly 80 km^2) across Australia (Figure 1A). In each study landscape a series of field-based fuel accumulation surveys were conducted. *Sampling of surface, near-surface, elevated and ladder fuels occurred across five different plantation species from immediately post-harvesting (0 years) through to just prior to harvesting (~30 years). These data were used to develop fuel accumulation curves for each species, per region.* Polynomial regression analyses were used to fit functions to the fuel load by age data, using an iterative approach that increased the order of the polynomial to optimise R-squared values.

2.2. Fire regime modelling

The newly developed fuel accumulation curves were integrated into a stochastic fire regime simulator – FROST. FROST is an innovative model that uses available environmental data to spatially and temporally predict current and future trends in fire regimes and can simulate fire regimes over decades and centuries (Penman et al. 2015). It uses PHOENIX RapidFire as the fire behaviour simulator, and uses empirical ignition and fuel models based on biophysical data to allow for realistic estimates of future fire risk. FROST also uses Bayesian Networks to capture uncertainties in risk estimates and produces reliable simulations by integrating dynamic relationships associated with past fires (Penman et al. 2015).

The major components of FROST are termed ‘machines’. The primary machines include a weather machine, an ignition machine and a fuel machine. These machines provide the input data for the fire behaviour simulator (in this case PHOENIX RapidFire) to run fires for each day. FROST also includes a fuel treatment manager, a disruption machine and a suppression machine. These machines allow the user to test various operational scenarios and can be used to simulate management strategies and their impact on fire behaviour. These machines were used to evaluate management options for mitigating fire risks to plantations and nearby community assets under changing climates.

2.3. Scenario modelling

The FROST simulation modelling tested the effects of climate change on the fire regime across the six study landscapes. We selected two global climate models:

1. ECHAM5 (*hotter*), submodel 1 – characterised by a relatively large increase in annual temperature over south-eastern Australia (of about 2.5 ºC) with little change in annual precipitation (0%), and,
2. CSIRO Mk3 (*drier*), submodel 1 – characterised by an increase in average annual temperatures over south-eastern Australia (of about 1.6 ºC) and a decrease in average annual precipitation (-7%).

We ran simulations for current (1990-2009) and far-future (2060-2079) climate epochs. Planning for a changing climate with associated higher future fire risk will enable plantation owners to assess and undertake management options that will have the greatest reduction in risk under a changing climate. The 20 years of climate data were looped five times to allow the fire regime to play out over 100 years. Each scenario was replicated 25 times to cover variation in the runs given that many of the conditions are probabilistic.

2.4. Management strategies

In consultation with plantation owners from the six study landscapes, a series of potential management strategies were identified. Management strategies were designed around the themes of fire preparedness, fire response or fire prevention. A set of four potential management scenarios were defined for each region. These scenarios were compared to a ‘current management’ option and a ‘no-management’ option. Current management reflected a construction rate of 2 km/h and response time of between 15-45 mins for all ignitions, depending on the region, with prescribed burning (outside of plantations) set at a 5-year interval within Strategic Fire Advantage Zones and at minimum tolerable fire intervals based on the native vegetation in landscape burning areas. Each of these scenarios were explored for current (1990-2009) and far-future (2060-2079) epochs, and using the two global climate models (ECHAM5 and CSIRO Mk3).

3. Key findings & recommendations

3.1. Fuel curves for plantations

3.1.1. Softwood plantations (Pinus radiata)

We found that fuel curves derived from field data collected in plantations around Australia (hereafter termed ‘new plantation’ fuels) were much more nuanced than the ‘traditional’ fuel curves. Surface/near-surface fuel loads were consistently higher in the new plantation fuel curves (particularly in the first year or two of a rotation) suggesting that traditional fuel curves used in Phoenix may be under-predicting fuel accumulation, and therefore fire risk in plantations.

New plantation fuels for softwood plantations indicated that combined surface/near-surface fuel loads peak at age 0 at around 25 Mg ha^{-1}. This was followed by a sharp decrease to a low point of 5 Mg ha^{-1} at 5 years, followed by a near-linear growth until 14 years (to 15 Mg ha^{-1}) and a decrease in load until 24 years (12 Mg ha^{-1}). When compared to the traditional fuel function currently implemented in PHOENIX this translates to an increase in surface/near-surface fuels load under 5 years, and lower or similar loads from 5-30 years.

Elevated fuel loads for *P. radiata* peaked at 2.5 Mg ha^{-1} at around 8 years in the new plantation curve, followed by a steady decrease to approximately 0.5 Mg ha^{-1} at 20 years. While fuel loads are in the same range as the traditional fuel curve, the new plantation fuels were found to predict higher elevated fuel loads at younger ages than the traditional fuels, which predict a maximum of 1.8t/ha at approximately 15 years.

3.1.2.Hardwood plantations (Eucalyptus globulus)

Similar to the softwood plantation fuel curves, we found that fuel accumulation curves in hardwood plantations also differed from the traditional fuel curves, indicating more variability in the curves than previously suggested. For hardwood plantations, the new plantation fuel curves demonstrated that the combined surface/near-surface fuels started at ~6 Mg ha^{-1} and remained relatively stable until 10 years, before reaching a peak of 16 Mg ha^{-1} at 18 years. These values were higher than the traditional fuel curve which starts at 1.7 Mg ha^{-1} before reaching a maximum of 13.9 Mg ha^{-1} at 15 years.

Elevated fuels in the new plantation curves for *E. globulus* were found to be very low immediately post-harvest before reaching a peak of ~2.5 Mg ha^{-1} at 3 years. This was followed by a decrease to almost 0 Mg ha^{-1} from 7 years from which point fuel loads remained largely stable at less than 1 Mg ha^{-1}.

The new field-derived plantation fuel accumulation curves demonstrated that fuel loads in hardwood plantations were considerably higher than previously indicated by traditional Olson curves, especially in the surface/near-surface stratum between 0-7 years from planting.

Information about when fuel loads are at their highest will be important for plantation owners. This knowledge may help guide fuel management within plantations in an attempt to reduce future fire risk to their assets.

3.2. Fire risk profiles

Overall, impacts were greatest under the hotter (ECHAM5) climate prediction. Annual area burnt, annual area burnt by high intensity fire, and burn frequency were consistently higher under this model, and these effects were more pronounced in the northern study landscapes. This indicates that future climate predictions that are characterised by a larger increase in temperatures (i.e. >2.5 ºC) with little change in annual precipitation, are likely to result in higher future fire risks for both plantation and other human assets.

In terms of the best management scenarios for reducing risks to plantation assets and adjacent communities, our results were largely consistent across the study landscapes. Increased suppression effectiveness (characterised by early detection and a response time of <15 minutes for all ignitions) and the current approach to management (a construction rate of 2km/h for suppression and 15-minute response times, with 4000ha/year of prescribed burning) were consistently the best management strategies (Figure 1B). Our results indicate that improving suppression response times and continuing the current rate of fuel management outside of plantations will offer the greatest scope for reducing future wildfire risks to plantation assets and adjacent communities. High pruning in strategic locations may also be worthy of future investment but should be considered in combination with more rapid suppression and prescribed burning.

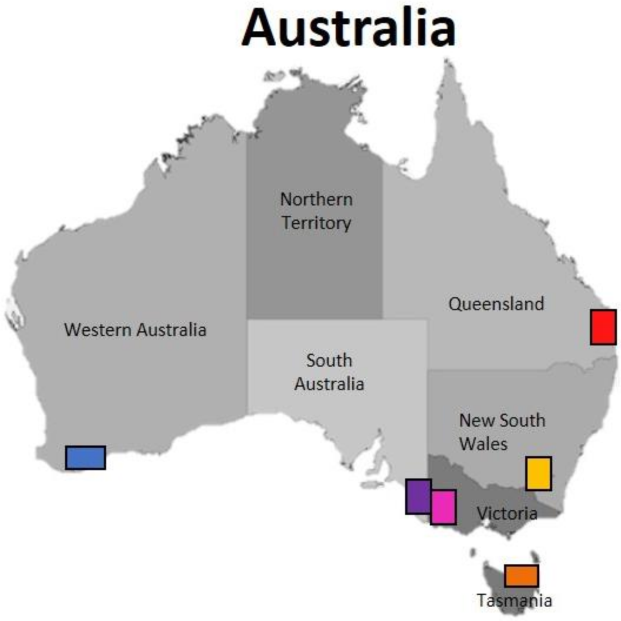
4. Conclusions

In this study we found that fuel curves derived from field data collected in plantations around Australia were much more nuanced than traditional fuel curves. Surface/near-surface fuel loads were consistently higher in the new plantation fuel curves (particularly in the first few years of a rotation) indicating that traditional fuel curves used in PHOENIX may be under-predicting fuel accumulation, and therefore fire risk in plantations. We therefore recommend that the traditional Olson curves be replaced with the new plantation fuel curves for future fire risk modelling where plantations are present in the landscape of interest.

We found that future climate predictions characterised by larger increases in annual average temperatures with little change in annual precipitation were more likely to result in increased fire risks for both plantation and other human assets. This knowledge, combined with a new understanding of how fuel accumulates in plantations over time will help guide strategic fuel management in plantations.

Regarding the best use of resources for reducing fire risk to plantations under a changing climate, we found that increasing suppression response times and continuing the current approach to fuel management outside of plantations were the best strategies for reducing future impacts to plantations, regardless of the climate model used. Therefore, additional suppression resources and strategic positioning of these resources throughout the landscape (i.e. based on burn frequency maps and areas of high-risk plantations) will be an important area for future investment. Focusing on increasing early detection may also help reduce the risk of future losses. Plantation owners currently have little influence over the amount and location of prescribed burning adjacent to plantations, and fuel reduction burning is not regularly undertaken in Australian plantations. Therefore, rapid suppression response times is the single best investment for minimising impact to plantation assets under a hotter or drier climate.

A)



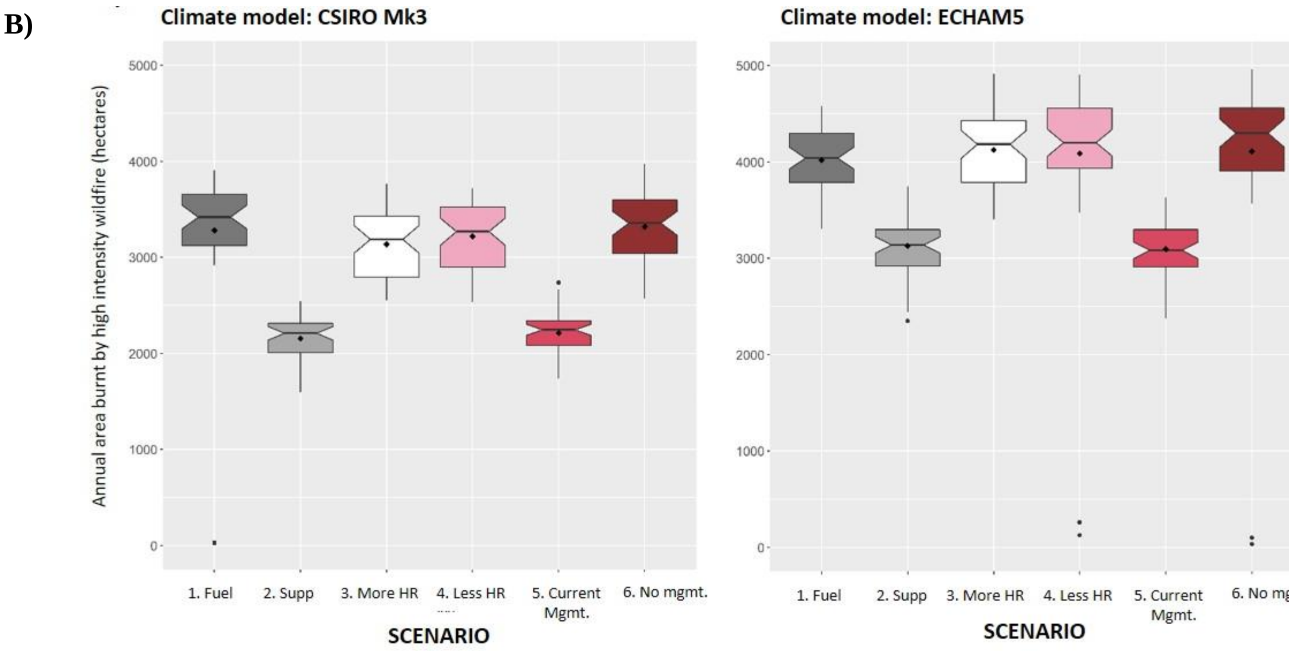


Figure 1- A) Map of Australia with the six study regions indicated by coloured boxes. B) Simulated future annual area burnt by high-intensity wildfire by management scenario and under two climate models (CSIRO Mk3 left; ECHAM5 right). Values are based on 25 replications over a 100-year simulation period and are presented as notched box plots with the mid-line indicating the median and non-overlapping notches indicating significant differences. Modelled scenarios were: 1. Fuel – surface/near-surface fuel loads reduced to 10t/ha throughout rotation and elevated fuels reduced within 1km of towns to reflect high pruning practices. 2. Reducing suppression response time (to an average of 10 minutes throughout each plantation region). 3. Increasing the amount of annual area burnt by prescribed fire outside of plantations (from 4000ha/year to 6000ha/year). 4. Reducing the amount of annual area burnt by prescribed burning outside of plantations (from 4000ha/year to 2000ha/year). 5. Current management approach (suppression resources set to reflect a construction rate of 2km/h and response time of 15 minutes for all ignitions, and prescribed fire outside of plantations at 4000ha/year). 6. No management – a 'do-nothing' approach (no fuel management within or outside of plantations).

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