Journal of Environmental Management 150 (2015) 196–205

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Adding fuel to the fire? Revegetation influences wildfire size and intensity

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ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form
4 November 2014
Accepted 7 November 2014
Available online

Keywords:
Ecological restoration
Woodland
Forest
Phoenix rapidfire
Australia

ABSTRACT

The regrowth of woody vegetation in cleared landscapes (i.e. revegetation) has the potential to dramatically alter the spatial characteristics of vegetation and fuels, which will potentially alter fire characteristics. Understanding how revegetation alters fire size and intensity will be critical in determining the social and environmental value of revegetation. We used simulation modelling to examine (i) whether increasing native woody vegetation extent across landscapes cleared for pasture (i.e. revegetation) affects fire size and median fireline intensity and (ii) whether fuel load in the pasture matrix, the initial extent of land clearing and weather conditions during a fire alter the direction and/or magnitude of the relationships between revegetation and fire size or intensity. Simulations revealed that fire size and intensity were altered by increasing woody vegetation extent, though the direction of change was dependent upon landscape context. Increased woody vegetation extent led to (i) increased fire size in landscapes with low pasture fuel load (2 t ha^{-1}) regardless of the extent of land clearing, (ii) decreased fire size in highly cleared landscapes with moderate (4.5 t ha^{-1}) and high (7 t ha^{-1}) pasture fuel load, and (iii) little change to fire size in landscapes subjected to low levels of clearing when pasture fuel load was moderate or high. Similar patterns were observed for fireline intensity. The magnitude of change in fire size and intensity was greatest under extreme fire weather conditions. Revegetation rarely increased median fireline intensity beyond suppressible levels (i.e. 4000 kW m^{-1}), with fire weather and pasture fuel load being the main determinants of suppression potential. Our findings show that the response of fire size and intensity to revegetation will depend on landscape scale pasture management.

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1. Introduction

Revegetation involving the conversion of agricultural land (i.e. pasture, cropland) to woody vegetation has been occurring in many landscapes worldwide (Kyle and Duncan, 2012; Moreira et al., 2011). Passive revegetation, due to land abandonment and the removal of agricultural pressures (e.g. grazing stock), and active revegetation (i.e. deliberate planting), for the purpose of environmental restoration, carbon sequestration and timber production, have largely facilitated these transformations (Kyle and Duncan, 2012; Moreira et al., 2001; Romero-Calcerrada and Perry, 2004; Rudel et al., 2005; Smith, 2008; Zhang et al., 2000). Revegetation has a number of benefits for biodiversity (Kavanagh et al., 2007; Munro et al., 2007; Rey Benayas et al., 2009) and can increase carbon storage across landscapes (Laganière et al., 2010; Marín-Spiotta et al., 2007). Consequently, significant investment in revegetation is being made via initiatives aimed at increasing carbon sequestration to mitigate climate change impacts and restoring habitat to combat biodiversity losses (e.g. Plants for the Planet, www.plant-for-the-planet.org, accessed 24 February 2014; Carbon Farming Initiative, www.cleanenergyregulator.gov.au/Carbon-Farming-Initiative/Pages/default.aspx, accessed 24 February 2014; Biodiversity Fund, www.environment.gov.au/cleanenergyfuture/biodiversity-fund/index.html, accessed 24 February 2014).

The importance of planting design in maximising carbon sequestration and biodiversity has been established (e.g. Kavanagh et al., 2007; Laganière et al., 2010; Munro et al., 2009, 2007), however, the effect of landscape-scale revegetation on fire has been largely overlooked (with the exception of the Mediterranean

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http://dx.doi.org/10.1016/j.jenvman.2014.11.009
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biome; Moreira et al., 2011; Pausas and Fernández-Muñoz, 2012; Rey Benayas et al., 2007). Fire regimes, which encompass the spatial (fire size and intensity) and temporal (fire frequency and season) characteristics of fire within a landscape (Archibald et al., 2013; Gill, 1975), are influential in shaping ecosystem carbon balances (Collins et al., 2014b; Ryan and Williams, 2010; Williams et al., 2012), habitat (Collins et al., 2012a, 2012b) and biological diversity (Bradstock et al., 2002; Keeley et al., 2012). Consequently, the environmental benefits of revegetation will in part be determined by the effect revegetation has on fire regimes. Furthermore, changes to fire behaviour arising from revegetation may alter the risk fire poses to people and property, which will have implications for the social benefits of revegetation. Understanding the likely impact revegetation will have on fire will be an important step in determining the social and environmental value of this restoration practice (Rey Benayas et al., 2007).

The establishment, growth and development of vegetation following revegetation will alter vegetative composition and structure at a local scale, as well as the spatial arrangement of vegetation types at the landscape scale (Moreira et al., 2001; Romero-Calcerrada and Perry, 2004; Viedma et al., 2006). At the local scale, conversion from pasture to woody vegetation communities (i.e. shrubland, woodland, forest) will result in a shift from a community dominated by herbaceous vegetation to one comprising herbs, shrubs and/or trees (Munro et al., 2009; Vesk et al., 2008). The transition from grassland to woody vegetation will simultaneously reduce grass fuels and increase leaf litter fuels, altering potential fire behaviour and fire regimes (Archibald et al., 2013; Bradstock, 2010; Sullivan et al., 2012). Overall fuel biomass and the number of distinct fuel strata is greater in woody vegetation communities than grasslands and pastures (Sullivan et al., 2012), resulting in greater potential maximum fire intensity in the former. However, the vertical arrangement of grass fuels and absence of trees to reduce wind speed leads to greater rates of spread in grasslands than forests, allowing grass fires to reach larger sizes in shorter periods of time (Catchpole, 2002; Luke and McArthur, 1978; Sullivan et al., 2012).

Altering the connectivity of grass and woody fuels at the landscape scale will have important implications for fire regimes. However, making simple generalisations about the relationships between fire and fuel types may be difficult due to the complex interplay between vegetation, climate and human intervention (Archibald et al., 2013). For example, evidence from Mediterranean ecosystems reveals that the abandonment of farming activities and subsequent revegetation of agricultural land with shrublands and forests is leading to increased fuel biomass and connectivity of these vegetation types (Moreira et al., 2011). This has been accompanied by increased fire occurrence, annual area burnt and fire size in some landscapes (Pausas and Fernández-Muñoz, 2012) as shrublands and certain forest types (e.g. pine forests) are more fire prone (i.e. the proportion of the vegetation type burnt exceeds its proportional coverage in the landscape) than agricultural land (Moreira et al., 2011). However, evidence from South African savannahs suggests that annual area burnt is reduced when tree cover exceeds 40%, presumably in response to a reduction in the amount and connectivity of highly flammable grass fuels (Archibald et al., 2009). The management of grass fuels may be particularly important in determining these fire – fuel type relationships, as intensively managed grasslands (e.g. heavily mown or grazed) can present an impediment to fire spread, while unmanaged grasslands may enhance the spread of fire (Archibald et al., 2009; Cheney and Sullivan, 2008).

Fire simulation models provide a means for exploring how landscape scale changes in fuel structure, amount and spatial arrangement alter components of the fire regime (Bradstock et al., 2012; Finney, 2007; Finney et al., 2007; Penman et al., 2013). In this study we simulated fires at a landscape scale to examine how revegetation will affect fire size and intensity under a range of pasture conditions. We predict that in landscapes with unmanaged pastures, increasing the extent of predominantly woody native vegetation will typically reduce fire size and increase fireline intensity. However, in landscapes with intensively managed pastures we expect revegetation will lead to an increase in fire size and intensity.

2. Methods

2.1. Study area

The study focused on a 1,600,000 ha area in the southern and western regions of the Hawkesbury-Nepean catchment, located near Sydney, New South Wales in south-eastern Australia (Fig. 1). The study area was defined by placing a 10 km buffer around any land with an agricultural use in these regions (Fig. 1). The 10 km buffer was included as part of the study area to allow fires to enter agricultural land from adjacent native vegetation, softwood plantations or areas outside of the catchment. The study area was broken up into six sub-regions (Fig. 1), based primarily on the amount of existing native vegetation, as well as other environmental factors (i.e. topography, geology, soils). This allowed us to examine whether changes to fire size and intensity due to increasing native woody vegetation cover were dependent upon existing woody vegetation extent.

Land cover within the study area is predominantly a complex mosaic of native vegetation and land modified for agriculture (Fig. 1, Table 1). Approximately 50% of the study area is covered by native vegetation, most of which is mapped as dry sclerophyll forest (~35% of the study area) (Keith, 2004). Native non-woody vegetation communities (i.e. grasslands, freshwater wetlands) occupy less than 0.5% of the study area. Remnant native vegetation is predominantly located within rugged terrain or on soils with low fertility in the eastern and southern fringes of the study area (Fig. 1). The majority of the remaining land cover is pasture (~45% of the study area), reflecting extensive past and present agricultural land use. Agricultural land use typically occurs in areas of higher soil fertility and low topographic relief (i.e. valleys and plains). Exotic softwood plantations (predominantly *Pinus radiata*) cover approximately 3% of the study area, while urban areas make up less than 1%. Prior to agricultural conversion approximately 80% of the cleared land within the study area was either grassy woodland or dry sclerophyll forest (Keith, 2004; D. Keith, unpublished data) (Table 1). These woodland and forest communities are dominated by canopy species from the genus *Eucalyptus* (e.g. *E. agglomerata*, *E. blakelyi*, *E. globoidea*, *E. melliodora*, *E. piperita*) which typically have a strong capacity to resprout following high severity fire (Bradstock, 2008).

2.2. Modelling

2.2.1. Fire behaviour

Phoenix Rapidfire (Phoenix) was used to simulate the effects of revegetation on fire size and intensity across the study area. Phoenix is a dynamic fire simulator (Tolhurst et al., 2008) that uses grassland (Cheney et al., 1998) and forest fire behaviour models (Noble et al., 1980) to simulate surface fire behaviour. These models predict flame height, fireline intensity and ember density based on a range of input data relating to topography, fuels and weather. Fire propagation is simulated using Huygen's algorithm (Tolhurst et al., 2008). Input environmental data used in Phoenix includes grids (30 m resolution) of topography, fuel type, time since fire and fuel

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