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Research Paper

Countervailing effects of urbanization and vegetation extent on fire frequency on the Wildland Urban Interface: Disentangling fuel and ignition effects

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HIGHLIGHTS

- Wildfire frequency at the urban interface is negatively related to the amount of cleared land.
- Fire frequency is positively related to the amount of urban land.
- Wildfire is particularly high in urban land retaining substantial native vegetation.
- Urban development is a double-edged sword with respect to wildfire.

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ABSTRACT

Fire activity has been found to follow a humped relationship with population density, but the countervailing drivers and scale effects in this relationship have not previously been teased apart. This is important because it helps us to understand which aspects of fire risk are amenable to management. The likelihood of a fire occurring at the Wildland Urban Interface (WUI) can be broken into two components: that of ignitions occurring and that of the fire spreading from the ignition to the interface. We hypothesize that urbanization is a double-edged sword because it both increases the likelihood of ignition but also protects areas from fire spread. We investigated this hypothesis for Sydney Australia using 38 years of historical fire mapping by examining statistical relationships between wildfire count at 1250 points in the WUI and measures of vegetation clearing and urbanization at multiple scales (1 km and 10 km radii around sample points). The number of fires at a point was influenced negatively by the amount of un-vegetated land at both 1 km and 10 km radii and positively by urban land within 10 km radii. There was also an interaction between un-vegetated land and urbanization such that fire activity is particularly high where some urban development has occurred but a considerable amount of vegetation remains. As predicted, urban centres provide both sources of ignition and a degree of protection from fire spread. Fire risk could best be reduced either by reducing fuel near the WUI or by reducing ignitions from city dwellers.

1. Introduction

Human settlements act both to increase wildfire ignition rates and to remove fuel required for fire spread as postulated by Syphard (Syphard, Radeloff, Hawbaker, & Stewart, 2009; Syphard et al., 2007) who found a humped relationship between population density and wildfire activity in Mediterranean biomes around the world. Likewise, Westerling et al. (2011) found a positive relationship between fire activity and population density in California, but in some particularly densely populated areas, fire activity was particularly low. This dual effect of human populations requires further exploration because quantifying the roles of the two effects would help us to understand how fire frequency (and consequent risk) varies across a region and how it could be reduced. Optimization of wildfire management requires a cost-benefit analysis of all management strategies, for which the first prerequisite is quantifying the independent effects of risk factors such as these. Since the impact of wildfire on human values is greatest at the Wildland Urban Interface (WUI) (Mell, Manzello, Maranghides, Butry, & Rehm, 2010; Safford, Schmidt, & Carlson, 2009), this zone should be a priority for this research.

The likelihood of a wildfire occurring at any site is determined by a complex array of factors: those that influence fire ignition and

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those that influence its subsequent spread. If humans act in countervailing ways as Syphard et al. (2009) suggest, both to increase ignition rates and to remove fuel, then it should be possible to separate these effects using measures that reflect one or other of them. For example, the extent of un-vegetated land (as measured in most vegetation maps) describes the degree of permanent fuel removal and so affects fire ignition and spread, while property density measures the potential source of ignitions. These two measures are somewhat related: vegetation clearance usually accompanies high-density development, but there are situations where the two are disconnected. For example on most farming land there are low levels of vegetation and low property density and in amenity-led rural communities where people are escaping cities to live closer to the natural environment there can be high levels of native vegetation coverage and high property density. If Syphard et al. (2009) are correct and other factors are held constant, then farming landscapes should have the lowest fire frequency and amenity-led communities the highest.

Because wildfires come in a range of sizes and people (who start many fires) are mobile, some of these factors may operate at different scales. For example, since fire-starters are mobile, we may expect the effect of urbanization on ignition to be experienced over many kilometres, but since it is the fuel at the exact site that determines whether a fire starts, un-vegetated land will influence ignition over small scales. On the other hand, large fires have to spread through extensive fuels, so spread may be influenced by the extent of un-vegetated land at a much larger scale than ignition. These matters are important: if we want to reduce the risk from wildfire we need to know whether it is better to manage fuels, people or both and whether the local, landscape or both scales are most influential.

There have been many studies that develop spatially explicit empirical models of ignition, which generally find measures related to human population to be important predictors (Liu, Yang, Chang, Weisberg, & He, 2012; Penman, Price, & Bradstock, 2013; Romero-Calcerrada, Novillo, Millington, & Gomez-Jimenez, 2008). However, the protection offered by un-vegetated land has received little empirical attention. Rather, simulation has usually been used to model fire spread towards the WUI (Atkinson, Chladil, Janssen, & Lucieer, 2010; Bradstock et al., 2012; Chuvieco et al., 2010; Keane, Drury, Karau, Hessburg, & Reynolds, 2010; Stockmann, Burchfield, Calkin, & Venn, 2010). These methods implicitly include the effects of un-vegetated land on fire spread through the use of fuel maps, but do not quantify those effects. Bradstock, Gill, Kenny, and Scott (1998) used a more simple approach, applying the McArthur fire behaviour equation to predict the frequency of days in which fires would be uncontrollable if they occurred under different hypothetical fuel reduction treatments. Most importantly, none of the methods is able to discriminate the countervailing effects of un-vegetated land or urbanization or identify scales of effect. It is possible to do this empirically, using historical fire mapping and statistical modelling.

We hypothesize that ignitions are positively related to human population density and the tendency to spread is negatively related to the amount of un-vegetated land. In other words, fire frequency associated with human development is in tension between the positive effect of population size (starters of fires) and the negative effect of un-vegetated land (removal of fuel). We expect the most effective way of reducing fire is to match high levels of un-vegetated land with low levels of urbanization, such as occurs in farming landscapes, and on the other hand, the most fire prone landscapes will be where there is high level of urbanization but relatively little un-vegetated land, such as in amenity-led communities within forests. Note that this expectation does not consider the cost effectiveness of the measures (e.g. cost per home protected) or the ecological values of native vegetation. Moreover, we predict that there are multi-scale effects such that the local extent of un-vegetated land reduces fire occurrence (ignition and spread) around houses, but there is an additional benefit from un-vegetated land at larger scale because this can protect houses from the spread of even the largest fires.

In this study, we investigate the fire frequency experienced at points in the WUI in the Sydney region of Australia. We focused on the WUI rather than the entire region because the WUI is both the area where impacts on human values are most acute and also where the tension between un-vegetated land and population is most likely to be manifest. Sydney experiences damaging fire seasons that cause house loss once or twice per decade (Bradstock et al., 1998), and in this respect is similar to many other cities in Australia and elsewhere in the world (Keeley, Fotheringham, & Morais, 1999). We sampled points in the WUI and constructed statistical models of fire count against a range of spatial predictor variables. The primary objective was to understand how the spatial pattern of un-vegetated land and urbanization influences fire frequency. In order to do so, we also explored and controlled for other potential drivers such as geology, vegetation type, and topography.

2. Methods

2.1. Study area

Sydney is a city of 4 million people, lying in a highly developed coastal lowland plain (the Cumberland Plain) surrounded by dissected sandstone tablelands (Fig. 1). The native vegetation in the tablelands is largely intact and is dominated by a diverse dry and wet sclerophyll eucalypt forest, with a total area of approximately 20,000 km^2. Rainforests, wetlands, heathlands and grasslands represent only minor components of the vegetation (<2% each, Tozer et al., 2006). Urban development abuts the forest around the edge of the city and there are fingers of development into the tablelands. There are also many forested patches within the city, usually associated with steep and rugged drainage lines. The WUI in the Sydney region has a length of approximately 7000 km (from the data derived in this study). The climate is warm and temperate, and the rainfall total of 1200 mm is evenly distributed through the year (Bureau of Meteorology data). Approximately 5% of the forest is burnt by unplanned fires each year, and another 1% is burnt by prescribed burning (Price & Bradstock, 2011).

2.2. Data

We used the 2007 New South Wales Digital Cadastral Database to define urban areas as those where there were more than two properties per ha (using a 1 ha grid size). Then we defined the WUI to be a 500 m buffer around the urban areas. The total perimeter of the urban area thus defined was 7672 km, or 6303 km if only urban patches larger than 10 ha are included. This urban layer has a major concentration in the city of Sydney, with smaller urban centres in Wollongong and Newcastle (Fig. 1). Notice that WUI exists within the city area due to the prevalence of retained forest in some suburbs, and also the presence of small or linear urban areas away from the coastal area (e.g. Katoomba).

To create a sample for analysis, we created points every 500 m along a line 250 m outside the urban lands (i.e. at the mid-point of the WUI). These points were all 250 m from urban land, but could be located among low-density housing or farming land. Alternating points were used for model development (n = 633) and for model validation.

An historical fire-mapping database produced by the Office of Environment and Heritage was used to calculate the number of fires experienced at each point over a 38 year period (1970–2008).