THEME 3A- PEOPLE AND PROPERTY IMPACTS

Theme Leader: Katherine Haynes

Subproject: Probability of house destruction

Subproject lead: Owen Price

OVERVIEW

1. Theme

People and property impacts

2. Project question or problem statement

What are the determinants of losses and damage to houses?
We addressed this question by calculating the number of houses destroyed and damaged, as a proportion of the houses present in 100 ha hexagons. This proportion was statistically related to a range of potential determinants that describe the vegetation, fire history, weather, topography and built environment to explore the importance of these determinants.

3. Background

The 2019/20 fires were the worst in Australian history in terms of property damage (eclipsing the 2009 Victorian Black Saturday fires (Teague *et al.* 2010)). It is vital that we learn from this disaster, both so that risk mitigation strategies can be optimized and to inform the national debate around the causes and solutions. It is an unfortunate truth that the bigger the disaster, the more we can learn.

Improving our understanding of impact requires measuring risk factors in and around the affected communities, and determining how they influenced house destruction via statistical modelling.

Similar studies have been conducted in Australia (mostly into the Black Saturday fires, (Gibbons *et al.* 2012; Price and Bradstock 2013)) and overseas (e.g. (Alexandre *et al.* 2016), which have broadly identified the main risk factors, which are various aspects of weather, fuel and topography. However, the complexity of bushfire impact means that much uncertainty remains.

4. Geographic Location

This study encompasses the entire fire-affected parts of NSW.

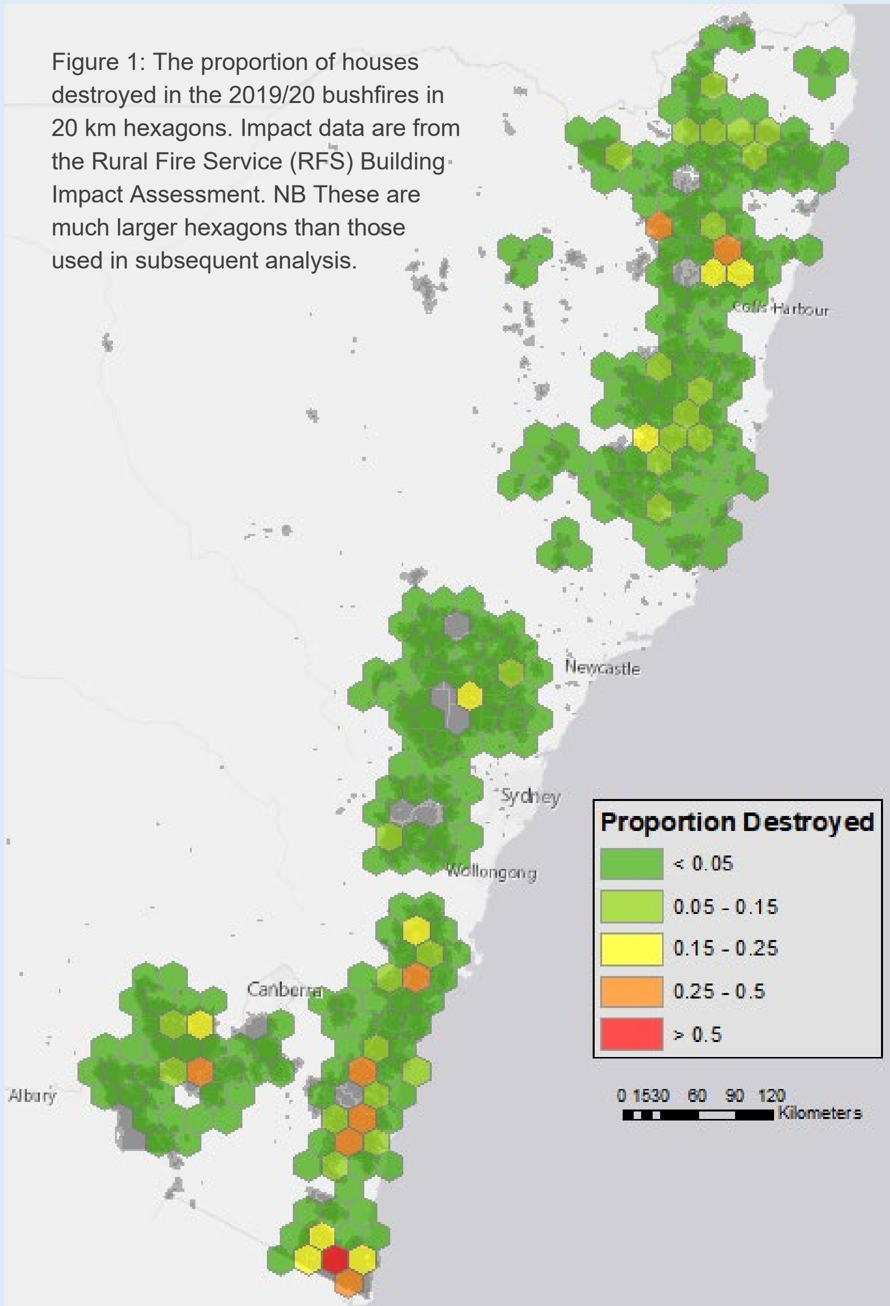


Figure 1: The proportion of houses destroyed in the 2019/20 bushfires in 20 km hexagons. Impact data are from the Rural Fire Service (RFS) Building Impact Assessment. NB These are much larger hexagons than those used in subsequent analysis.

5. Key Findings

- There were strong geographic patterns in the proportion of houses destroyed within a hexagon, with hotspots of >25% destruction in the northern (Liberation Trail and Kangawalla fires) and southern NSW fires (Dunns Road, Clyde Mountain and Badja fire) (Figure 1).
- There was a peak in house destruction in the north of the state in early November 2019 and in the south of the state in early January 2020, with deaths occurring in both peaks (Figure 2). The central fires had much lower levels of house destruction.
- The proportion of a hexagon burnt at high severity (crown scorch or consumption) had a strong positive effect on house loss (Figure 3).
- There were also strong effects of fire weather (FFDI) both on the proportion of high severity and on house loss. Nevertheless, 20% of the house loss occurred under more moderate fire weather (FFDI <Very High, 25) (Figure 3).
- There was little prescribed burning either within hexagons or in the landscape around them (Figure 4). Nevertheless a modest effect of recent prescribed burning on house destruction was detected (Figure 3). Statistical models developed to identify the independent effects of various determinants fount that treatment of 50% of hexagons within the past five years reduced the probability that any house destruction would occur in a hexagon by approximately 0.15 (e.g. from 40% to 25%), but had no influence on the proportion of houses destroyed (Figure 5). There was some indication that prescribed burning in the broader landscape had the opposite effect (slightly increased destruction).
- The extent of forest or long unburnt forest had modest effects on destruction. For example, 20% of hexagons had less than 10% forest, but the proportion of houses destroyed in these was only slightly lower than those with >50% forest (0.070 v 0.082). The models revealed modest positive effects of the amount of forest (both within and in the landscape) and long unburnt forest on house destruction (Figure 3, 5), but a countervailing effect of long unburnt forest in the hexagon and broader landscape on the proportion of houses destroyed (a higher proportion of long unburnt in the hexagon increased destruction but in the broader landscape it decreased destruction).

- Topography had only minor effects, with higher slope slightly increasing destruction (Figure 3, 5).
- Wind direction did not influence house destruction (Figure 3)
- Measures of urbanisation had a complex relationship with house destruction. The number of buildings was negatively associated with the proportion of housed destroyed but positively with the probability of any destruction, while the amount of road had a positive effect on house destruction (Figure 3, 5).
- There was some evidence that defence was an important factor in limiting destruction. The proportion of effected houses that were damaged had negative association on the proportion of houses destroyed (Figure 3, 5). It can be assumed that damaged houses were defended.
- Statistical modelling exploring the combined effect of the predictors confirms these effects, but has modest predictive accuracy, correctly identifying 59% of impacted suburbs and leaving >60% of the variation in impact unexplained (Figure 5).
- The relative importance of determinants of house losses varied geographically, as shown by case study landscapes (Figure 6).
- The results conform to previous studies of impact that weather is the most important driver of fire behaviour and impact, followed by fuels and topography.

6. Significance of findings in context of previous studies

The results conform broadly to previous studies which indicate that:

- Weather is the most important driver of fire behaviour and impact, followed by fuels and topography. This has been found in many previous studies of several aspects of fire behavior and impact (Cary *et al.* 2009; Bradstock *et al.* 2010; Price and Bradstock 2012; Storey *et al.* in press).
- Prescribed burning in the vicinity of the houses can substantially reduce risk of house loss without eliminating it, while prescribed burning in the broader landscape has limited benefit. This is in accord

with previous studies addressing the optimal location of prescribed burning treatment (Price and Bradstock 2010; Penman *et al.* 2014).

- Fire severity has been found to be a good predictor of house destruction in the past (Price and Bradstock 2013).

7. Limitations and remaining knowledge gaps

There are a number of data limitations in this analysis. Primary among them is weather attribution, caused by uncertainty in when the fires arrived at each hexagon and the distance to the nearest weather station. This is described in more detail in Price (2020). There are also uncertainties in mapping the extent of forest into suburban areas, in missing fires in the fire history database, in the number of houses in RFS BIA data.

There are limitations with the chosen hurdle model method, which does not reveal non-linear relationships (though preliminary analysis suggested this was not a serious problem), or formally incorporate spatial autocorrelation.

The method applied does not address certain aspects of risk nor response that are known to be important (Gibbons *et al.* 2012; McNamara *et al.* 2019; Price *et al.* in review). This includes features of the house and garden, the occurrence of house-to-house transmission, the cause of ignition (ember, flame or radiant heat), and formal data on suppression. A detailed house by house analysis is a priority but cannot be conducted without extensive new data collection.

8. Implications for fire management

Weather (FFDI) was the strongest determinant of house destruction. Management has no control over fire weather, while the frequency of severe fire weather conditions is projected to increase in the future.

Prescribed burning (fuel management) within the suburb has a substantial benefit, but treatments in the landscape had no detectable effect.

Management that reduces fire severity will be beneficial. Since severity was a stronger predictor of destruction than was fire history, preventing high severity may not be achievable using prescribed burning as the only strategy.

Areas that are dominated by forests or long unburnt forests suffered only slightly higher destruction than areas with a small proportion of forest, so extensive forest is not a pre-requisite for impact.

Most of the variation in house destruction remained unexplained. Therefore, much uncertainty remains about how best to protect communities. Much of the explained variation could be due to factors such as suppression, resident actions during the fires, building design and age etc. as explored in other published studies.

9. Figures

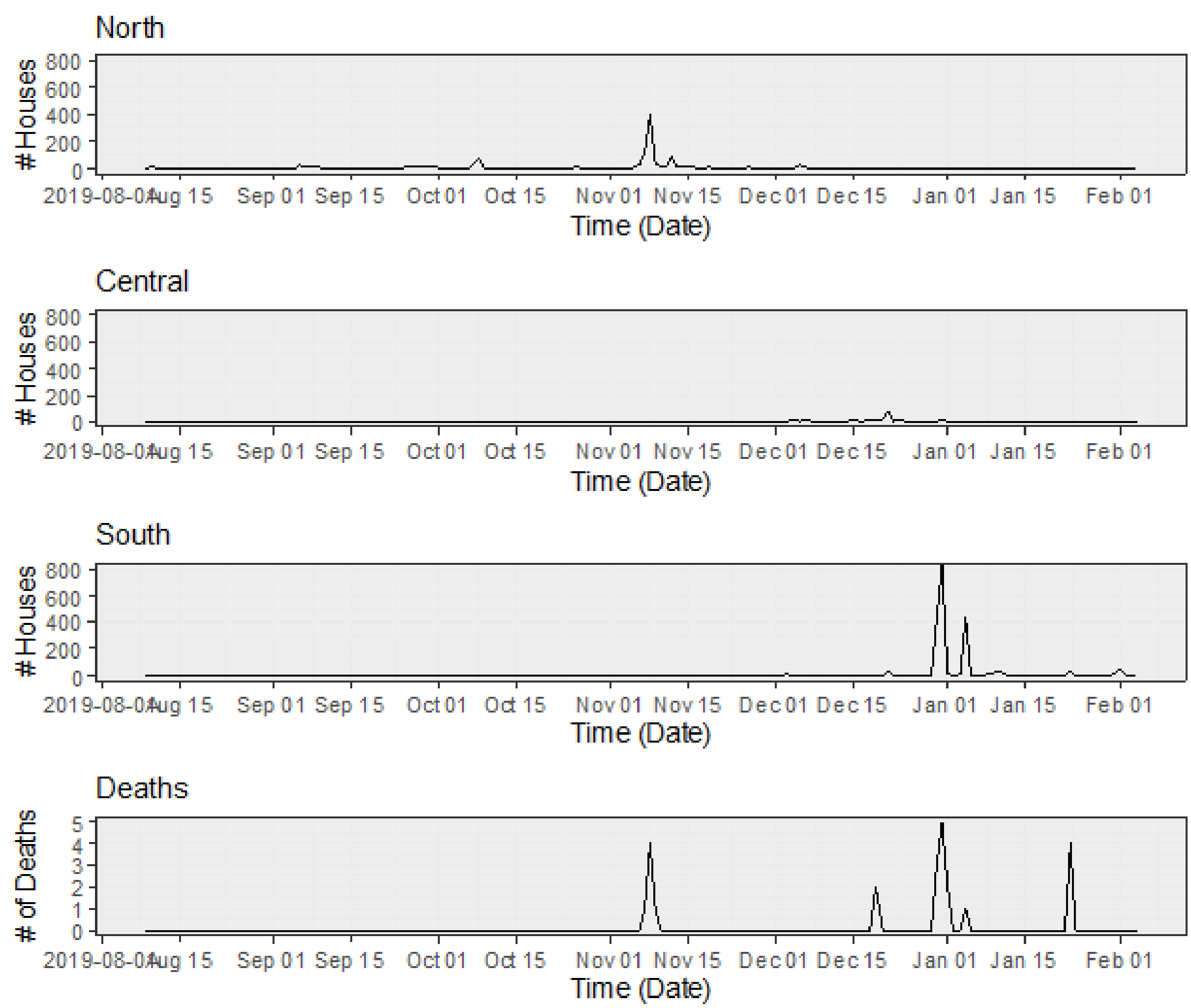


Figure 2: Time trace of house destruction for the three regions (northern, central and southern), plus the number of deaths for all regions combined. The timing for the house loss plots are from the reconstruction of fire progressions.

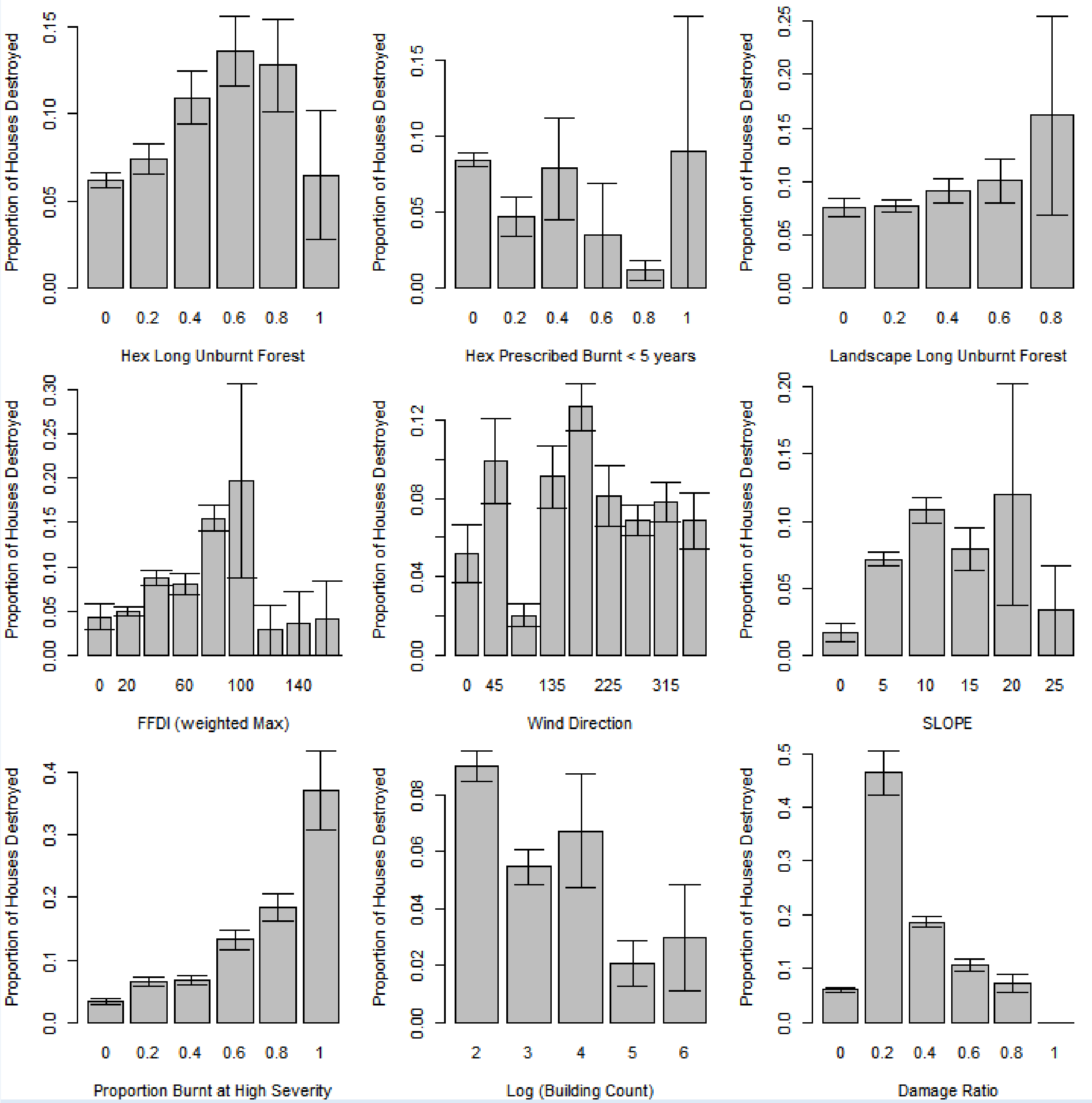


Figure 3: The proportion of houses destroyed in suburbs according to levels of nine predictors. ‘Hex’ refers to forest within the 100 ha hexagons and ‘Landscape’ to all areas within 5 km of the centre of the hexagon. Damage Ratio is damaged houses as a proportion of all damaged and destroyed houses and is a proxy for defense. These are raw data plots (not modelling results).

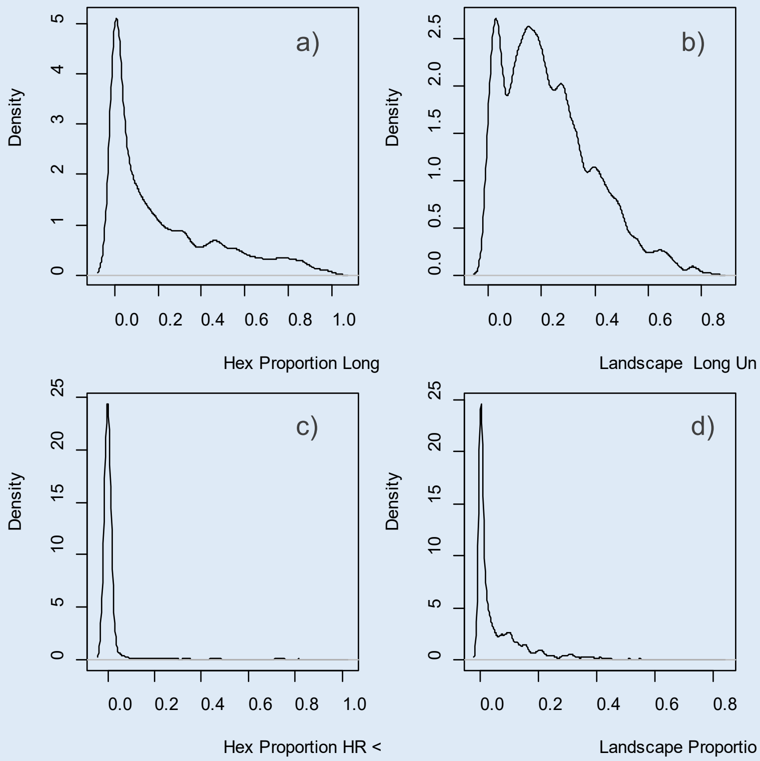
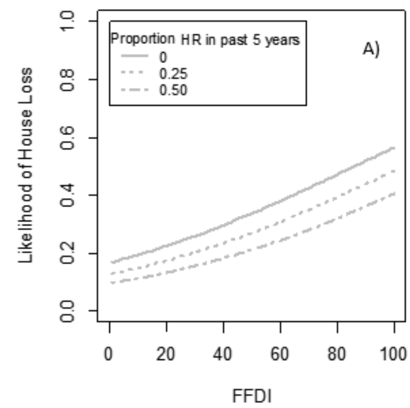


Figure 4: The distribution of long unburnt forest and recent prescribed burning within hexagons and in the broader landscape (5 km radius). The y axis is a relative count of hexagons. For example, c) shows there were very few hexagons with more than 0.1 (10%) of their area burnt by prescribed burning, while d) shows the landscape prescribed burning was more extensive.

A) Statistical model for whether house destruction occurred (binomial GLM, n = 1186, accuracy 58.5% on test data, 6.4% of Deviance captured).

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
(Intercept)	-3.532	0.393	-8.981	< 2e-16
FFDI	0.017	0.003	5.631	0.000
Proportion Forest	-1.209	0.332	-3.645	0.000
Landscape Proportion Forest	1.187	0.389	3.055	0.002
Proportion Long Unburnt Forest	1.154	0.306	3.769	0.000
Proportion Prescribed Burnt Within 5 Years	-1.344	0.620	-2.168	0.030
Landscape Prescribed Burnt Within 5 Years	1.950	0.733	2.659	0.008
Proportion Road	2.333	0.560	4.167	0.000
Building Count (log)	0.330	0.104	3.192	0.001
Slope	0.040	0.021	1.910	0.056



B) Statistical model for proportion of houses destroyed (log GLM, n = 402, rms error on test data = 0.064 (5%), 43.0% of Deviance captured).

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
(Intercept)	1.488	0.085	17.460	< 2e-16
FFDI	0.003	0.001	3.950	0.000
Long Unburnt Forest	0.264	0.066	4.024	0.000
Landscape Long Unburnt Forest	-0.240	0.099	-2.427	0.016
Landscape Forest	0.179	0.064	2.807	0.005
Building Count (log)	-0.247	0.020	-12.148	< 2e-16
Slope	0.013	0.005	2.829	0.005
Damage Ratio	-0.168	0.060	-2.782	0.006
Proportion Road	0.189	0.117	1.615	0.107

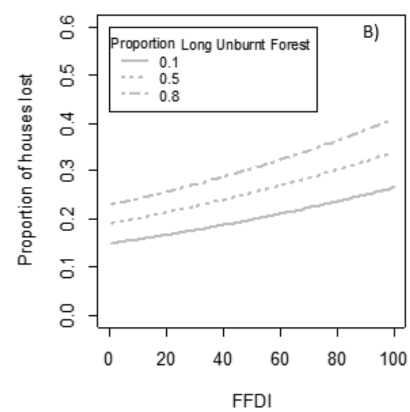


Figure 5: Results of the statistical modelling of impact within a 1 km suburbs, as a two-step process: A) occurrence of house loss and B) the proportion of houses lost in suburbs that lost houses. The estimate column identifies the slope of the relationship and the t-value indicates the relative strength of the effects. On the right is a graph of each model showing the most important effects (with all the other variables held constant at their average values).

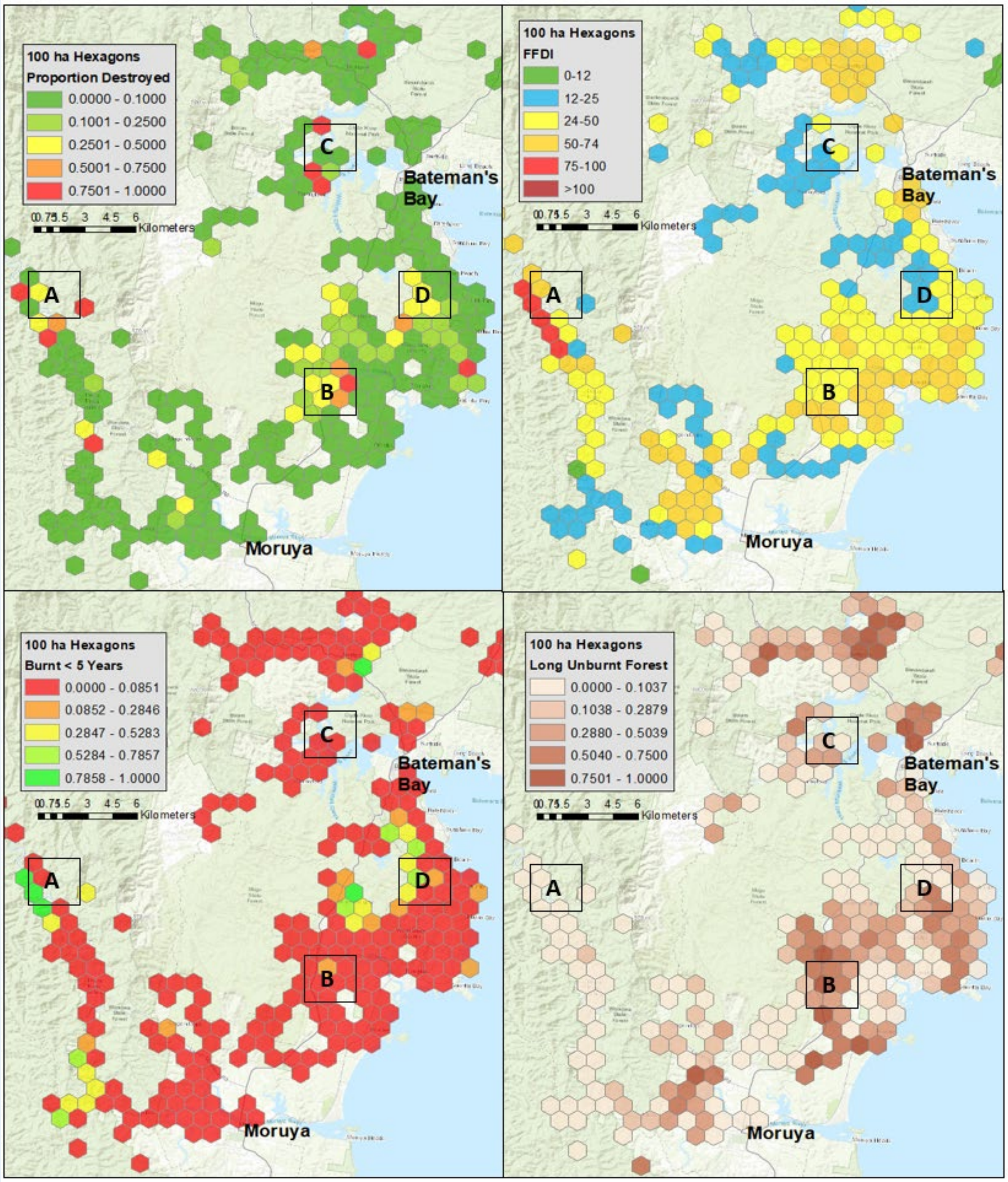


Figure 6: Patterns of house loss and major determinants in 100 ha hexagons around Batemans Bay, one of the most heavily impacted areas. High rates of house destruction around location A seem to be associated with extreme FFDI (>75). Around location B the weather was Very High but there was also a lot of long unburnt forests and no recent prescribed burning. At C, the weather was High and the most affected suburbs had moderate levels of long unburnt forest. In D there was considerable recent prescribed burning, the weather was High to Very High and the proportion of long unburnt forest was moderate.

10. Key reference list

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11. Appendix

Methods

- The aim was to quantify the influence of determinants known to affect impacts in previous fires on the proportion of houses destroyed in suburbs exposed to the 2019/20 bushfires. This is different to examining each exposed house individually and is for two reasons. Firstly, we currently have little information about individual houses (e.g. construction, garden layout, preparedness, defence) that would be needed for such a fine-scale analysis. Second, suburb-scale is more appropriate for examining landscape-scale determinants such as the layout of forests and fuel management that are hard to identify in individual house analysis. This scale also reduces the statistical problem spatial autocorrelation which can artificially inflate the importance of some determinants due to the fact that neighbouring houses are not truly independent of each other. For this report, we created 100 ha wide hexagons across NSW and analysed only those which contained more than five houses and were more than half burnt, for which there are 1186.

Data

- The number of houses destroyed and damaged was obtained from the Rural Fire Service Building Impact Assessment, which surveyed 44000 structures including 18000 houses. We restricted this analysis to houses (not sheds, outbuildings or commercial property). The ratio of houses damaged/destroyed was used as an index of suppression effort. Researchers at the USA National Institute of Standards and Technology consider that once ignited, an undefended house will always be destroyed, so by definition a damaged house must have been defended (McNamara et al. 2019).

- A list of fatalities and dates was obtained from media reports, most importantly the Daily Telegraph report on January 22nd.

- The extent of forests was extracted from the Keith vegetation formation layer at 50 m cell size (Keith 2004). Overall Fuel Hazard is a measure of the combined amount of litter, grass, shrub and bark fuel layers (Hines et al. 2010). RFS uses this measure to map fuel hazard across NSW at 50 m cell size, and it is the input layer to their PHOENIX fire spread simulations. RFS supplied this data as the OFH as of July 2019 (i.e. taking account of fire history that reduces different fuel layers) and also as the maximum possible value (if there had been no past fires). We calculated the mean values of OFH and OFHmax in each settlement hexagon.

- Fire history was provided by RFS and this was used to calculate the proportion of each settlement that had been prescribed burning in the past five years and the proportion that consisted of forest unburnt for at least 50 years. Five years approximates how long it takes for litter fuel hazard to return to near pre-fire levels (Watson 2011) and has proven a useful measure of the influence of past burning on subsequent bushfire impacts (Price and Bradstock 2011; Price and Bradstock 2012). Both measures were also calculated in the surrounding landscape (proportion prescribed burnt < 5 years and long unburnt within 5 km of the settlement). Notice these measures include non-forest vegetation and urban land. For example, if 50% of the hexagon was forest and 50% of that had been burnt in the past five years, the resultant value is 0.25.

- Topographic variables elevation, slope, and the standard deviation of elevation (across the whole hexagon) were derived from the 30 m Shuttle Radar Digital Elevation Model.
- The weather at the time of impact was estimated by reconstructing the progression of the fires combining the RFS progression archive, aerial linescan archive, and satellite hotspot information to map and time 5000 polygons and then match them with weather data from the Bureau of Meteorology and RFS. This process is described in more detail in report Price (2020).
- Road density was estimated by generalising the NSW road network to a 100 m grid of presence absence, and calculating the proportion of the hexagon occupied by road.
- The GEEBAM fire severity map was supplied by the Department of Planning, Industry and Environment. This mapped severity at a resolution of 10 m.

Analysis

- The progression mapping was used to plot the daily number of houses destroyed in the northern, central and southern regions of the bushfires and also the daily fatalites for the whole state.
- Variables were not used if they showd a high correlation with others (OFHmax and OFH19 were both correlated with Forest and themselves ($r>0.78$) and so were removed.
- The primary dependent variable was the proportion of houses destroyed in each hexagon. The individual affect of each determinant on that proportion was explored graphically.
- The independent effect of the determinants (controlling for the others) was examined by developing statistical models. Due to the non-normal distribution of the dependent variable, the analysis was conducted in a two-step ‘hurdle’ process. First a model of the best combination of determinants on whether or not any house was destroyed. This was a binomial model, with the best set of determinants selected on the basis of AIC, and pairwise interactions among the terms in the best model added if they reduced AIC. The second model used those hexagons where at least one house was destroyed ($n = 483$) and the dependent variable was the proportion of houses destroyed (natural log to normalise the data) but otherwise developed in the same way as the binomial model. In both models, the data was randomly split 80% to develop the model and 20% to test it’s accuracy.
- The degree of spatial autocorrelation was examined by calculating the Moran’s I index for the dependent variable and the residuals from the best model. This revealed a low level of spatial correlation ($I = 0.115$).