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THE EFFECT OF HAZARD REDUCTION BURNING ON THE FUEL ARRAY IN NATURE RESERVES AND URBAN PARKS IN THE ACT

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ABSTRACT

Hazard reduction burning is a key component of the fuel management program in the Australian Capital Territory (ACT). Burning is used in a variety of situations depending on the applicable fuel standard, proximity to property, aims of land management and suitability of alternative methods. The main aim of this study was to characterise the changes in the fuel array due to the ACT hazard reduction burning program. We established 187 plots within 38 hazard reduction burns and adjacent unburnt areas. The fuel in all plots was characterised using the Overall Fuel Hazard Assessment (OFHA) method and then re-assessed following burning. Opportunistic assessments of four unplanned fires were also taken for comparison. The average OFHA prior to burning was High. This reflected the dense grassy fuels, relatively sparse shrub layer and abundance of smooth-barked gum trees in Canberra's nature reserves. Following burning the OFHA was reduced to an average of Moderate. The component of the assessment which exhibited the greatest change was the near-surface fuel which was usually consumed. Changes in bark fuel hazard and elevated fuel hazard were minimal. Surface litter had a minor effect on the OFHA because of the high grass cover in most systems and the incomplete combustion of litter. The sensitivity of the OFHA method to grass means that the OFHA may rapidly return to High – i.e. when the grass cover approaches 50 percent. In contrast, wildfires reduced the OFHA to Low, due to much greater consumption of the elevated, bark and surface litter fuels. We predict that the OFHA at sites burnt by wildfire will increase more slowly because of the slower pace of re-growth of woody vegetation.

INTRODUCTION

Hazard reduction burning is a key component of bushfire management in the Australian Capital Territory (ACT). The aim of burning is to reduce the fuel load and change the fuel structure so that unplanned fires that may occur in the future are more easily suppressed or mitigated. The aims of each burn are determined according to the standards set out in the ACT Strategic Bushfire Management Plan Version 2 (SBMP; ACT Government, 2009). The fuel standards for forest and shrubland are based on the Overall Fuel Hazard Assessment method (OFHA; Hines *et*. *al*. 2010). Vegetation in Outer Asset Protection Zones must be maintained at a rating ≤Moderate and in Strategic Fire Advantage Zones ≤High. Following each burn the fire ground is visually assessed by the Divisional Commander and a descriptive report of the fuel condition is included in a summary of the incident. The fuel standard achieved by the burn is then audited by the ACT Rural Fire Service.

The aim of this study was to improve understanding of the effects of the ACT Parks and Conservation Service burning program by conducting a systematic assessment. The study had three aims. 1) To investigate whether the fuel characteristics of different vegetation types varied systematically. This information could be used to refine the planning process and improve future outcomes. 2) To demonstrate the effect of the burning program in order to validate the present procedure or to determine what improvements are needed. 3) To characterise the response patterns of the components of the fuel array to understand how each contributed to the outcome.

METHOD

STUDY AREA

The study area was the nature reserves and urban parks of the ACT. Data were collected between December 2012 and April 2014. A total of 187 plots were established at 38 burns that were conducted to reduce fuel or meet ecological criteria as part of the ACT Parks and Conservation Service fuel management program.

EXPERIMENTAL STRATEGY

The preferred experimental procedure was to follow the Before-After-Control-Impact (BACI; Green, 1979) method using matched pairs of treatment and control plots. Sites were matched by proximity to each other, vegetation type, topography and aspect. At sites where matched pairs of plots could not be obtained, plots were surveyed before and after burning. Of the 38 planned burns, 31 proceeded on schedule. Of the 31 completed burns, the BACI method was followed at 25 burns and a before-after method was completed at six burns (Table 1). Twelve plots were surveyed from four wildfires for comparison.

Table 1. Summary of the number of burns and OFHA plots completed.

	Pre-burn Assessments	Post-burn Assessments		Wildfire
		Control	Impact	
Plots	187	69	96	12
Burns	38	25	31	4

OVERALL FUEL HAZARD ASSESSMENT

An OFHA was conducted at each study plot following the method of Hines *et*. *al*. (2010). The location of the plots within the burn site varied depending on the size of the burn. At small urban reserves, plots were preferentially located in the centre of the largest sectors of the burn. Unburnt control sites were located close-by. At large rural sites, plots were located around the edge of the burn to facilitate matching of treatment and controls. Each plot was classified to one of eight vegetation types: dry schlerophyll forest; Yellow Box (*Eucalyptus melliodora*) grassy woodland; sub-alpine woodland; wet schlerophyll forest, eucalypt plantation; native grassland, exotic grassland and pine plantation (Table 2). Bark fuel hazard was assessed from a plot of 20m radius, classified to one of three types; 'stringybark', 'ribbon bark' or 'other bark' and assigned a bark hazard rating using the OFHA field guide (Hines *et.al.* 2010). Elevated fuel hazard, near-surface fuel hazard and surface litter fuel hazard was assessed from a plot of 10m radius. Elevated fuel hazard was defined as fine fuel (<6mm thick) within the layer of vegetation from 0.5m – 2m in height. Near-surface fuel was defined as fine fuel (<6mm thick) within the layer that was <0.5m in height and attached to the ground but not lying on it. Surface litter fuel was defined as the leaves, twigs, bark and other fine fuel (<6mm thick) lying on the ground (litter layer). To determine the fuel hazard for the elevated and near-surface layers, we estimated the percentage cover of fuel, percentage of the fuel that was dead and fuel height (m). To determine the surface litter fuel hazard, we estimated percentage cover and depth (mm) of the surface litter (Hines *et.al*. 2010). The rating scale for fuel hazard was: Low; Moderate; High; Very High and Extreme. 'Low' represented a light fuel load which was vertically and horizontally discontinuous and with high fuel moisture. 'Extreme' represented a heavy fuel load with excellent vertical and horizontal continuity and little fuel moisture.

Table 2. The number of plots assessed by treatment and vegetation type.

Vegetation type	Pre-burn	Control	Impact	Wildfire	Total
Dry Schlerophyll Forest	92	36	56	6	190
Eucalypt Plantation	16	3	1		20
Exotic Grassland	8	3	5	3	19
Native Grassland	4	2	2		8
Pine Plantation	18	6	12		36
Sub-alpine Woodland	4	2	2		8
Wet Schlerophyll Forest	8	4	4		16
Yellow Box Grassy Woodland	37	13	14	3	67
Total	**187**	**69**	**96**	**12**	**364**

STATISTICAL ANALYSIS

Plots were treated as independent because each burn was subject to detailed planning and the effects of fire were largely determined by management decisions and actions. Burn management included: 1) assessment of fuel load to determine whether a burn was required; 2) definition of the aims of each burn in relation to fuel management and conservation outcomes; 3) monitoring of variation in fuel moisture content and changes in it; 4) definition of suitable weather conditions for ignition and continuation of burning; 5) continuous monitoring of the weather prior to and during the burn; 5) pre-burn works to manipulate fuel and establish control lines for lighting and containment; 6) planning of an ignition strategy in relation to topography and pre-determined suitable weather conditions; 7) manipulation of lighting patterns; 8) suppression of fire when behaviour (flame height, rate of spread or intensity) exceeded prescriptions; 9) postponement of burning when fire behaviour failed to meet prescription; 10) monitoring of the fire ground until no smoke had been detected for 48 hours.

The fuel hazard ratings were converted to an ordinal scale for all analyses: Low = 1, Moderate = 2, High = 3, Very High = 4 and Extreme = 5.

MULTIVARIATE ANALYSES

Multivariate analyses were conducted in CANOCO 4.5 following procedures of Ter Braak (1986) and Ter Braak & Smilauer (2002). Each dataset was subjected to a Detrended Correspondence Analysis (DCA) to determine the lengths of gradient of the first four axes of variation. The DCAs were conducted using untransformed data, no downweighting of rare species and detrending by segment. If the lengths of gradient were <4 then the final analysis was conducted using Principle Components Analysis (PCA). PCAs were conducted using untransformed data, with scaling focussed on inter-species correlations, species scores divided by the standard deviation of the data and with centring by species.

We tested for patterns in the fuel array associated with different vegetation types using all the pre-burn data collected – including from sites that were not burnt during the study. Each plot was classified to a vegetation type with a score for stringybark hazard, ribbon bark hazard, other bark hazard, elevated fuel hazard, near-surface fuel hazard and surface litter fuel hazard. A DCA conducted on the dataset returned gradient lengths <4 so the final ordination was conducted using a PCA. Envelopes were fitted around each classification. The ordination containing all data was dominated by plots from the two most common ecosystem types, so a second ordination was prepared following the same procedure but with these two classes removed.

Analyses comparing the fuel array between burnt and unburnt plots were prepared using data only from the 31 sites that were burnt. The variables tested were bark fuel hazard, elevated fuel hazard, near-surface fuel hazard, surface litter fuel hazard, OFHA and fire severity. The severity classes were defined as: 1) ‘burnt’ in which fire had burnt across the plot; 2) ‘partially burnt’ in which less than half the ground fuel in the plot area was burnt; and 3) ‘unburnt’ in which no ground fuel was burnt and there were no ignitions in the plot. DCAs of the pre-burn and the post-burn data returned gradient lengths <4 so the final ordinations were conducted using PCAs. The pre-burn plots were all classified as unburnt. The post-burn plots were classified as either: 1) unburnt controls; 2) treated by hazard reduction burns or, 3) burnt by wildfires. A second ordination of the post-burn data was prepared in which the classification was modified so that unburnt controls and plots that were within the burn area but did not burn were both classified as unburnt.

UNIVARIATE ANALYSES

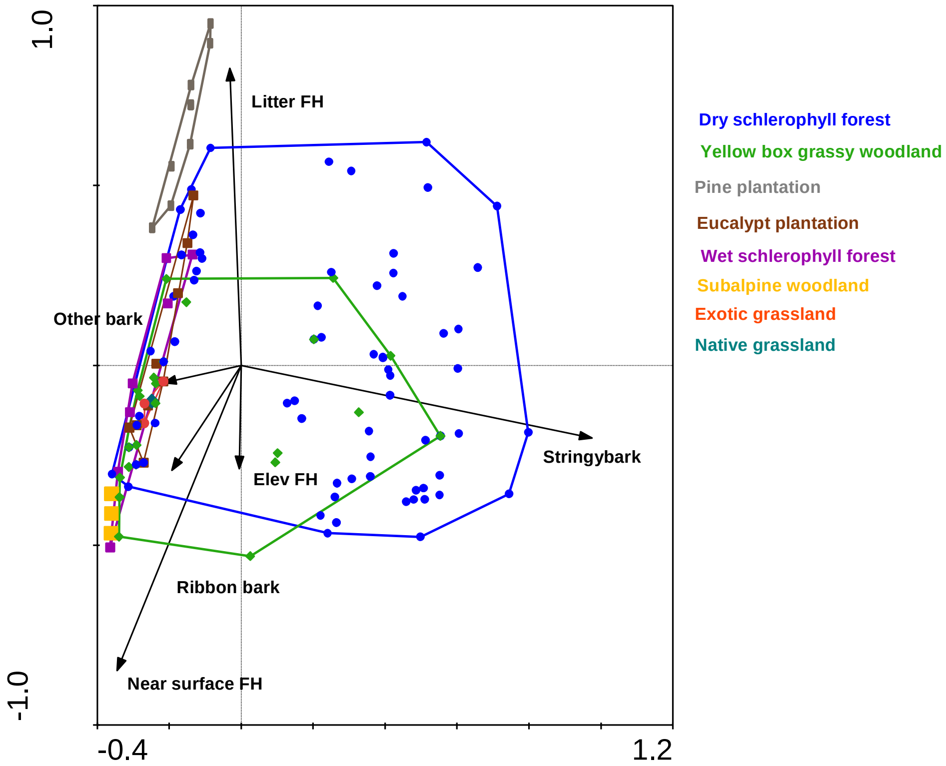
Tests for the effect of burning were conducted using General Linear Models in SPSS 11 (SPSS Inc., 2002). The model was run with two fixed terms. 1) The fixed term ‘treatment’ represented the effects of burning and consisted of the levels: a) ‘pre-burn’, including controls and planned treatments; b) ‘HR burn’, an abbreviation of hazard reduction, including plots that were part of the scheduled burn but may not have actually burnt; c) ‘unburnt controls’; and d) ‘wildfire’. 2) The fixed term ‘burn’ represented each incident and these were separated from each other by either space or time. The final model contained the main effect ‘treatment’ and ‘burn’. The dependent variables were bark hazard, elevated fuel hazard, near-surface fuel hazard, surface litter fuel hazard and OFHA. The results were reported using an F-statistic and p-value ($\alpha = 0.05$).

RESULTS

VEGETATION TYPES

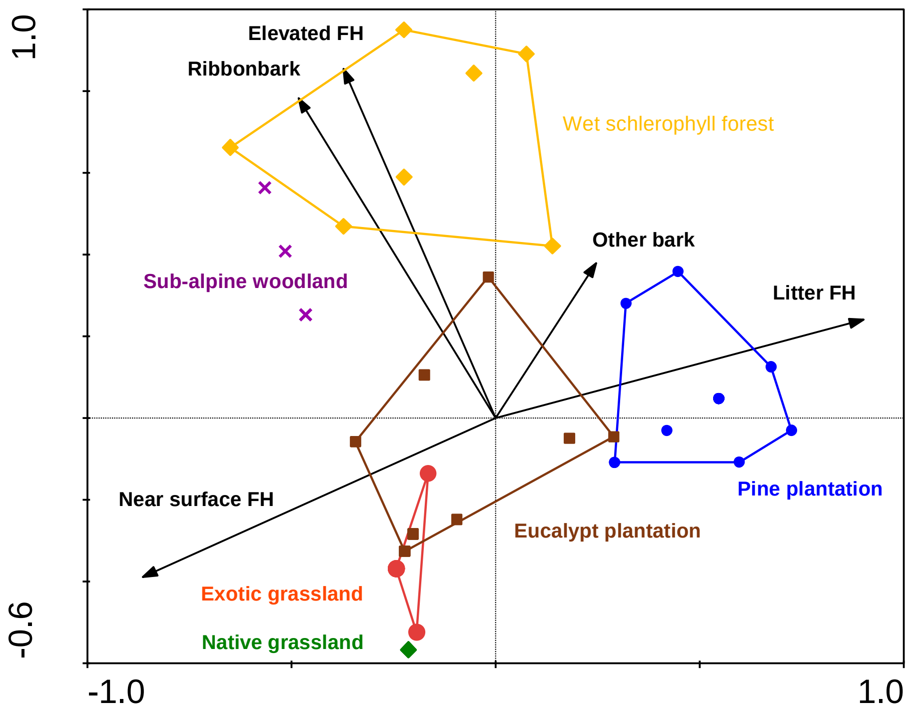
The fuel array within each vegetation type exhibited distinct patterns (Figures 1, 11, 12). The two main axes of the ordination were stringybark (*Eucalyptus macrorhyncha*) fuel hazard and ground fuels (a combination of the negatively correlated variables, near-surface fuel hazard and surface litter fuel hazard which represent grass and litter). Ordination space was dominated by the vegetation types which were surveyed most frequently; dry schlerophyll forest, and Yellow Box grassy woodland. The prominence of the stringybark fuel hazard variable in the ordination is due to its abundance in the most commonly surveyed fuel type, dry schlerophyll forest. The fuel array in Yellow Box grassy woodland is similar to dry schlerophyll forest except that the bark hazard and surface litter fuel hazard tends to be lower. Eucalypt plantations were similar to the dry schlerophyll forest except they did not contain any stringybark and were therefore distributed along the ‘other bark’ axis.

Figure 1. Ordination from a Principle Components Analysis on pre-burn plots using OFHA data with envelopes around plots from different vegetation classes.



The vegetation types that did not support stringybark were concentrated in a small area of ordination space so a second ordination was prepared with the two most common vegetation types removed (Figure 2). The two main axes represent ground fuels and two strongly correlated variables ribbon bark and elevated fuel hazard. Sub-alpine woodland supporting *Eucalyptus dalrympleana* and wet schlerophyll forest supporting *Eucalyptus viminalis* had higher ribbon bark hazard than the other fuel types. These vegetation types also had higher elevated fuel hazard due to dense re-growth of Bitterpea (*Daviesia* spp.), Dogwood (*Cassinia* spp.) and *Acacias* following the intense wildfires of 2003 (McLeod, 2003). Pine plantations differed from the other fuel types due to a greater coverage of litter fuels. Eucalypt plantations occupied the centre of ordination space indicating that the bark hazard was relatively low while the other variables tended to be at intermediate levels. Grasslands occupied space with higher near-surface fuel hazard values and low elevated fuel and bark hazard values.

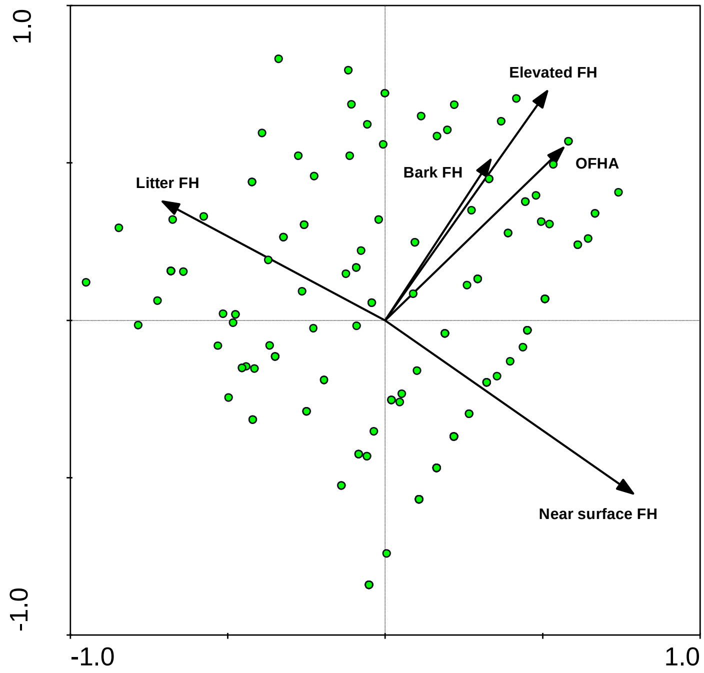
Figure 2. The ordination from a Principle Components Analysis performed using OFHA data from pre-burn plots with the two most commonly surveyed vegetation types removed. Envelopes have been placed around plots from each vegetation type.



THE FUEL ARRAY

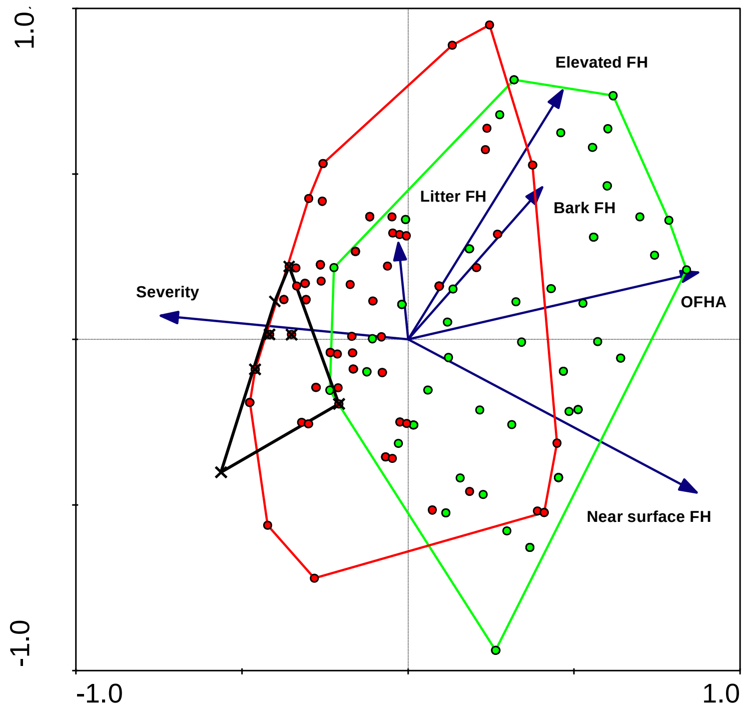
Unburnt vegetation in the ACT was distributed in ordination space along two main axes of variation (Figure 3). One axis represented ground fuels with two strongly negatively correlated components grass and litter. The other axis represented two strongly correlated variables, bark fuel hazard and elevated fuel hazard. OFHA increased as bark hazard or elevated fuel hazard increased.

Figure 3. An ordination of a PCA performed on OFHA data from pre-burn plots at locations where burning proceeded. Variables were the inputs to the OFHA, so this ordination is a representation of the fuel array in the ACT at sites prior to burning. The two main axes represent ground fuels and two strongly correlated variables, bark fuel hazard and elevated fuel hazard.



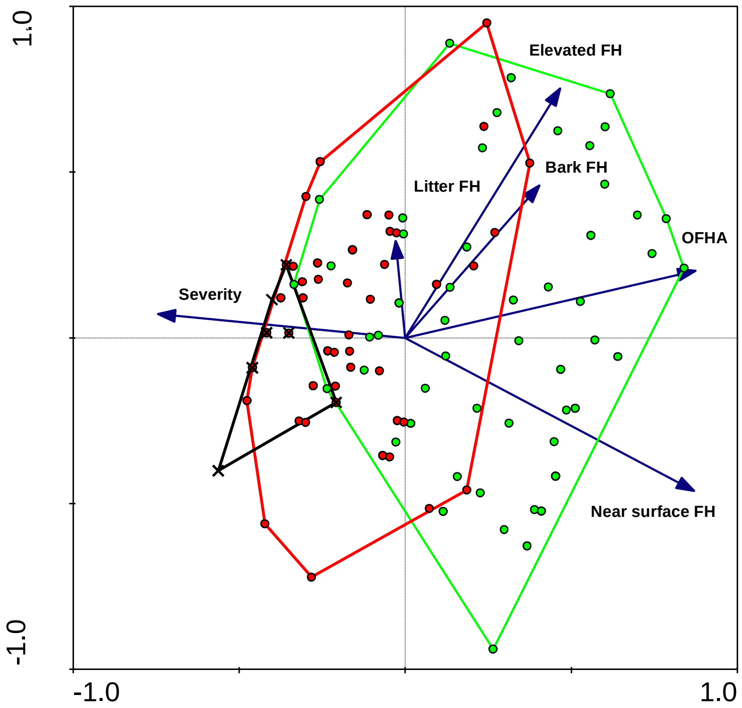
The ACT hazard reduction burning program reduced the OFHA by reducing the grass cover, shrub cover and the amount of combustible bark (Figures 4, 13, 14, 15, 16). Most of the OFHA variables were negatively correlated with fire severity; the strongest relationship was with near-surface fuel hazard which represented grass. Therefore reduction in grass cover was the main driver of the reduction in OFHA. The other main axis of variation represented two strongly correlated fuel hazard parameters, bark fuel hazard and elevated fuel hazard. The wildfire plots were clustered around the axis representing increasing fire severity (Figure 17). Plots treated in hazard reduction burns were also clustered in this region but tended to radiate out into space that was occupied by unburnt control plots. This reflects the incomplete consumption of fuel that occurred during hazard reduction burning and within burn patchiness (some treated plots were only partially burnt or not burnt at all). The ordination represents the change in the fuel array at treated sites due to the ACT hazard reduction burning program.

Figure 4. Ordination of a Principle Components Analysis performed using OFHA data and an index of fire severity.



When unburnt plots within treated sites are re-classified as 'unburnt' (Figure 5), the envelope representing OFHA of burnt plots shrinks along the axis of near-surface fuel hazard. The ordination suggests that incomplete combustion of fuel maybe a more important contributor of within burn patchiness than unburnt patches.

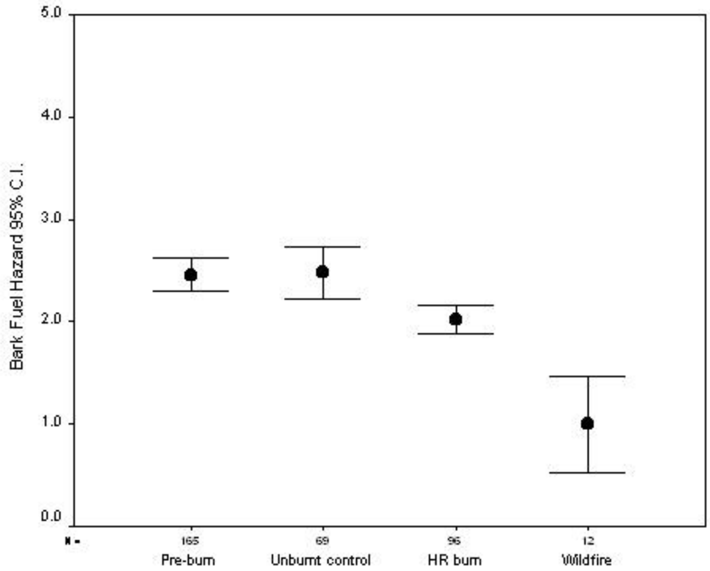
Figure 5. Ordination of a Principle Components Analysis performed using OFHA data and an index of fire severity. The ordination was performed using the same data as figure 4, but with a different classification of plots. Plots that were within the treatment area but did not burn have been classified with the unburnt control plots. The ordination therefore represents the effect of fire on the fuel array due to the ACT hazard reduction burning program.



COMPONENTS OF THE FUEL ARRAY

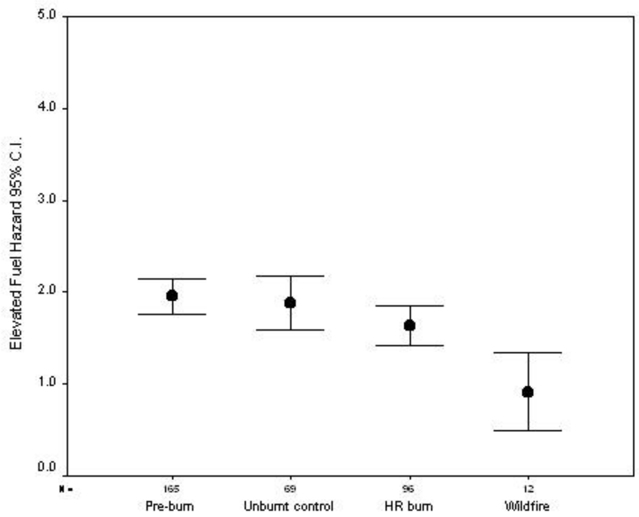
Bark hazard was reduced by hazard reduction burning (F = 22.3, p <0.001) but the effect was small such that the pre-burn plots, unburnt controls and fuel reduced sites were all classified to Moderate (Figure 6). Plots burnt by wildfire were reduced to Low.

Figure 6. The effect of hazard reduction burning on bark fuel hazard, showing mean and 95% confidence intervals. Low = 1, Moderate = 2, High = 3, Very high = 4 and Extreme = 5.



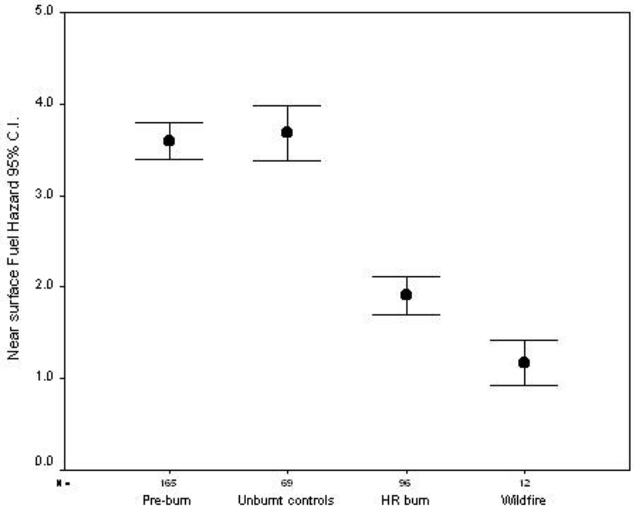
Elevated fuel hazard was lower following wildfire than it was in pre-burn plots and unburnt controls (F = 4.6, p = 0.01; Figure 7). Pre-burn plots, unburnt controls and fuel reduced sites were all classified Moderate, while plots burnt by wildfire were classified Low.

Figure 7. The effect of hazard reduction burning on elevated fuel hazard, showing mean and 95% confidence intervals. Low = 1, Moderate = 2, High = 3, Very high = 4 and Extreme = 5.



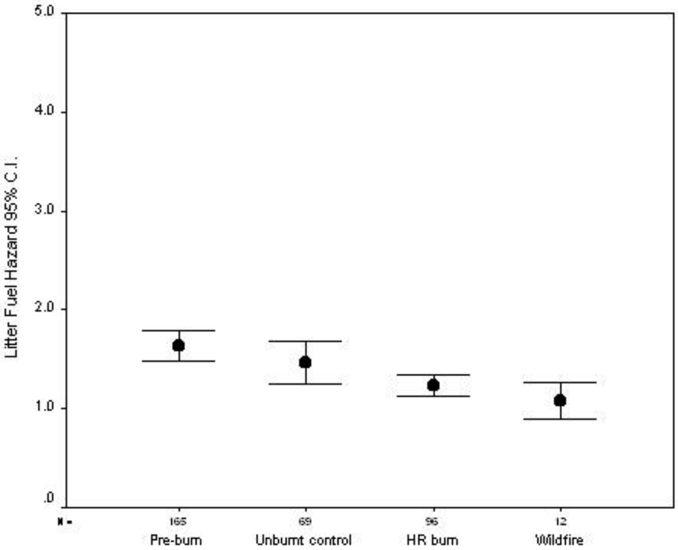
Near-surface fuel hazard was reduced from Very high to Moderate following hazard reduction burning (F = 132.0, p <0.001; Figure 8). Plots burnt by wildfire were classified Low.

Figure 8. The effect of hazard reduction burning on near-surface fuel hazard, showing mean and 95% confidence intervals. Low = 1, Moderate = 2, High = 3, Very high = 4 and Extreme = 5.



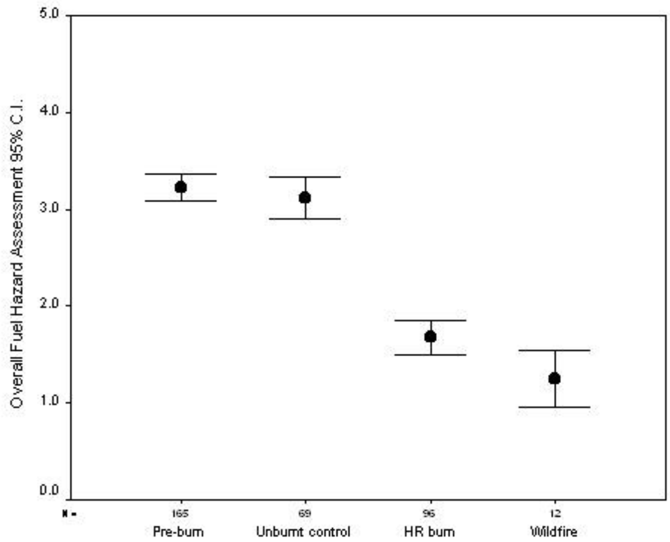
Surface litter fuel hazard was reduced following hazard reduction burning and wildfire (F = 14.6.0, p <0.001), but the parameter did not contribute much to the OFHA and the effect was small (Figure 9). Surface litter fuel hazard was classified Low for all treatments.

Figure 9. The effect of hazard reduction burning on surface litter fuel hazard, showing mean and 95% confidence intervals. Low = 1, Moderate = 2, High = 3, Very high = 4 and Extreme = 5.



Overall fuel hazard was reduced from High in pre-burn plots and unburnt controls to Moderate following hazard reduction burning (F = 149.7, p <0.001; Figure 10). Following wildfire, overall fuel hazard was Low.

Figure 10. The effect of hazard reduction burning on overall fuel hazard, showing mean and 95% confidence intervals. Low = 1, Moderate = 2, High = 3, Very high = 4 and Extreme = 5.



DISCUSSION

Our results suggest that the ACT hazard reduction burning program is achieving the fuel management standards set out for it by the ACT Government in the SBMP (ACT Government, 2009). The main driver of fuel hazard in the ACT is grass and this is augmented in some places by shrubs and combustible bark. Surface litter appears to be a minor component of the fuel array. The hazard reduction burning program achieves a reduction in the OFHA by removing the grass cover but it is not generally having such a strong effect on the other components of the fuel array.

Different vegetation types in the ACT were characterised by distinct fuel arrays and this information could be used to refine the aims of burning to better meet the objectives of the program. Fuel hazard in the two most commonly burnt vegetation classes, dry schlerophyll forest and Yellow Box grassy woodland was dominated by grass, however stringybark is also an important component where it occurs. Sample sizes of the other vegetation types were small, however the results suggest: 1) dense shrub cover and ribbon bark are key components of the fuel array in sub-alpine woodland and wet schlerophyll forest; 2) pine needle litter is the key component of the fuel array in pine plantations. Burning specifically focussed on reducing these fuel types may improve the fuel management program.

An issue that arises with use of the OFHA in grass-dominated systems is that the near-surface fuel hazard rating is strongly influenced by cover and grass cover usually accumulates more quickly than surface litter following hazard reduction burning (Tolhurst, 1996; Leavesley *et. al.*, 2013). This means that the OFHA may also rapidly increase as the grass coverage returns to 50 percent necessitating more frequent burning than would be required to maintain a given OFHA standard than in surface litter dominated systems.

Red Stringybark trees are a key component of the fuel array in dry schlerophyll forest and some Yellow Box grassy woodland. Following a low intensity hazard reduction burn, charring of stringybark is often restricted to the bottom 1m of tree trunks or if higher to one side of the tree. Previous work has demonstrated that consumption of bark increases with fire intensity (Gill et. al. 1986). Further work is needed to better understand bark consumption and charring in low intensity burns.

Figure 11. Dry schlerophyll forest at Googong Nature Reserve prior to burning. The reserve is a water catchment and the site was part of a Bushfire CRC study of the effects of prescribed fire on carbon (Volkova and Weston 2015).

Figure 12. A grass dominated understorey in dry schlerophyll forest at Black Mountain Nature Reserve prior to burning.

Figure 13. A hazard reduction burn at Black Mountain Nature Reserve. The fire is backing down the hill.

Figure 14. After a hazard reduction burn at Black Mountain Nature Reserve. Grass cover is greatly reduced, shrub cover has declined due to flame scorch and charring of stringybark is minimal.

Figure 15. After a hazard reduction burn at Black Mountain Nature Reserve. Grass cover is greatly reduced, eucalypt saplings have received some flame scorch and surface litter consumption is patchy.

Figure 16. Patchy consumption of litter; the Divisional Commander described the progress of this sector of the burn as ‘brutally slow’.

Figure 17. The site of a small wild fire in the ACT; charring of bark has carried to the top of the trees, shrub foliage has been consumed in some places and little grass or surface litter remains.

Figure 18. ACT Parks and Conservation fire crews skilfully planned and implemented the burning program.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the staff of Parks Brigade of the ACT Rural Fire Service who skilfully planned and implemented the burning program. They were ably assisted by New South Wales (NSW) Parks and Wildlife Service staff and volunteers from other ACT and NSW volunteer bushfire brigades. Special thanks to Scott Farquhar and Dylan Kendall for accommodating the project within the ACT Parks burning program. The comments of Daniel Iglesias and an anonymous reviewer greatly improved the manuscript.

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