The Invisible Mosaic: Fire Regimes in One of NSW's Most Iconic Conservation Areas

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Abstract

We showcase the culmination of a number of years' research examining the fire regimes of the Greater Blue Mountains World Heritage Area (GBMWHA). The area is among the most fire-prone on earth, and there is a lot at stake: World-Heritage-listed ecosystems, threatened species, wild rivers, wilderness, and countless adjoining private properties and urban centres. In recent years, the Commonwealth Government recognised the importance of fire in the GBMWHA by funding work to better document its fire regimes. This information is key to ecologically-sustainable and strategic fire management.

We compiled existing fire records held by NPWS, and generated new fire severity maps based on satellite imagery, to produce a comprehensive, multi-decadal picture of the area's fire regimes. We found that by far the greatest proportion is within acceptable ecological thresholds in terms of fire frequency, but certain places and ecosystems have experienced a disproportionate dose of 'too frequent' fire. In a first for south east Australia, we also identified areas affected by repeated high-severity fires. How do these different combinations of fire frequency and severity actually affect GBMWHA ecosystems? We selectively examined the 'sensitive' wet sclerophyll forests and rainforests of Blue Mountains and Yengo National Parks using a targeted field survey, and present some preliminary findings.

Our work highlights the importance of keeping track of 'invisible' fire patterns as they accumulate across the landscape over time and shows how existing technology i.e. remote sensing enables us to do so. Ultimately, this information is for fire managers, for use in planning future fire operations and in informing immediate post-fire rehabilitation. We highlight that the NPWS has recently used this approach as part of the management of the major Warrumbungle-Coonabarabran fires, in which satellite-based fire severity maps were produced and used to support the response operations.

INTRODUCTION

The Greater Blue Mountains World Heritage Area (GBMWHA) is an iconic conservation area of approximately 1.03 million hectares, consisting of eight separate reserves: Yengo (YNP), Wollemi (WNP), Blue Mountains (BMNP), Gardens of Stone, Kanangra-Boyd, Nattai (NNP) and Thirlmere Lakes (TLNP) national parks and Jenolan Karst Conservation Reserve. It is situated in a highly fire-prone landscape and protects internationally significant biodiversity and ecosystems.

Fire regimes in the area consist of prescribed burns and unplanned bushfires of varying size and intensity. Over time, the 'invisible mosaic' (Gill, Allan and Yates, 2003) of fire frequency, intensity, and season varies under the influence of the diverse terrain, vegetation and weather conditions. The combination of large bushfires, internationally-significant biodiversity, vast remote areas, and an extensive urban and rural interface presents an ongoing challenge for fire management in the region.

This paper describes work completed over the last few years to enhance the fire regime information for the GBMWHA. We analyse existing fire history data, create new maps of fire severity, and complete a review of the suitability of fire regimes for the broad vegetation formations in the GBMWHA, including identifying locations that may have experienced adverse fire frequencies and intensities. Note that aspects of the project are the subject of ongoing analyses and will be published in the near future elsewhere (target journals include *Ecological Management and Restoration* and *Biological Conservation*).

PROJECT OBJECTIVES

The objectives of the project were to:

- examine the existing fire history data for the GBMWHA (fire perimeter maps and other information recorded routinely by Office of Environment and Heritage - OEH) and the status of vegetation with respect to the recommended fire intervals for maintaining species diversity;
- produce new maps of fire severity, which provide information on the intensity component of fire regimes in the GBMWHA;
- identify areas that have been subjected to too-frequent and repeated high-intensity fires in the GBMWHA; and
- complete a field survey of the responses of 'sensitive' wet sclerophyll forest ecosystems to fire regimes.

FIRE MANAGEMENT CONTEXT

Major fire seasons in the region usually occur during the drier *El Niño* periods (once or twice per decade) and have been known to affect as much as 25% of the GBMWHA (e.g. during the 1993–94 and 2001–02 fire seasons). However, there are also many years where there is little fire activity. Records of unplanned fires in the BMNP for the period from 1957 to 2003 indicate that 32% of fires are caused by lightning, 36% by arson, 23% by escaped burn-offs and campfires and 10% by unknown sources (DEC, 2004). Collectively over time, fires produce complex patterns of fire frequency, intensity, and season—the 'invisible mosaic' (Gill et al., 2003). These patterns are 'invisible' because burnt vegetation is rapidly replaced by regeneration, and the impacts of the most recent fires replace much of the evidence of earlier fires. The complexity of these patterns in the GBMWHA is influenced by the variable weather conditions, rugged terrain, diverse vegetation (Hammill and Bradstock 2009; Bradstock, Hammill, Collins and Price, 2010). In turn, fire contributes to the diversity of the ecosystems in the area.

OEH is a key agency in cooperative fire management arrangements in NSW, including in the Blue Mountains region, and is a fire authority under the *Rural Fires Act 1997*. OEH typically implements the first response to fires in national parks, especially in remote locations. Most fires (over 90%) are extinguished within park boundaries (OEH, 2012). Capabilities include helicopters and specialist crews, 4WD fire fighting vehicles, highly trained remote area fire fighters and incident management teams. Many fires in the GBMWHA ignite from lightning strikes in remote locations and most are extinguished by OEH rapid response teams before they spread. However, on 'extreme' or 'catastrophic' fire danger days, ignitions spread rapidly and can quickly become uncontrollable. Often there are multiple, dispersed ignitions on such days following, for example, a band of dry storms, and fire fighting resources can become stretched with priority given to fires close to assets. In such situations even remote fires are a threat if the fire spreads toward assets or towns and spot fires can occur many kilometres ahead. These situations become multi-agency incidents and are ultimately under the lead of the NSW Rural Fire Service.

Fire management involves a response component and a planning component. Part of the latter involves keeping records of all fires. There are between 20 and 50 years of fire records for the GBMWHA, depending on the gazettal date of the reserves when NPWS began managing the area. This is extremely valuable information. The maps are used by fire managers to plan the timing of prescribed burns (hazard reduction), by determining the number of years elapsed since the last fire—an indication of fuel accumulation as well as the regenerative capacity of the vegetation. The latter is summarised in the form of the fire interval guidelines for broad vegetation types across NSW (Kenny, Sutherland, Tasker and Bradstock, 2003). These maps can also be used at a landscape scale to determine wider patterns in fire frequency.

However, in contrast to our knowledge about fire frequency, information on the intensity component of the fire history is often lacking, especially for large unplanned bushfires that cover vast areas and burn at variable intensities. This is an important limitation in our capacity to analyse and understand the impacts of the complete fire regime. In our project we have placed considerable focus on filling this gap for the GBMWHA.

METHODS

Fire Frequency Analysis

We obtained fire perimeter maps for the GBMWHA from the OEH fire history database. The length of the available fire history varied from approximately 20 to 50 years, depending on when OEH management and record keeping commenced for each of the reserves. A vegetation map for the GBMWHA was derived by joining a number of existing maps covering smaller areas. Vegetation communities (the most detailed level of classification) in the maps were assigned to a state-wide vegetation formation (broad structural types; Keith, 2004), so that the recommended fire intervals could be assessed against them (Table 1).

We then implemented a GIS analysis using Fire Tools (Version 1, Release 5; DECCW, 2010a)—a specialised ArcGIS tool developed to support ecologically sustainable fire management in national parks. Fire Tools first computes maps of fire frequency and inter-fire intervals for a study area based on the overlay of fire perimeter maps. These outputs are cross-referenced with the vegetation formations and associated recommended minimum and maximum fire intervals (Table 1) to determine the biodiversity threshold status of the landscape (Table 2).

Table 1: State-wide vegetation formations and the recommended fire intervals for maintaining species diversity (Kenny et al., 2003; Keith, 2010; DECCW, 2010).

State-wide vegetation formation	Minimum interval (years)	Maximum interval (years)
Rainforests	Fire should be avoided	
Alpine Complex	Fire should be avoided	
Saline Wetlands	Fire should be avoided	
Wet Sclerophyll Forests (shrubby sub-formation)**	25	60
Wet Sclerophyll Forests (grassy sub-formation)**	10	50
Forested Wetlands	7	35
Grassy Woodlands	5	40
Dry Sclerophyll Forests (shrub/grass sub-formation)	5	50
Dry Sclerophyll Forests (shrubby sub-formation)	7	30
Semi-arid Woodlands	6*	40*
Arid Shrublands	6*	40*
Heathlands	7	30
Grasslands	2	10*
Freshwater Wetlands	6	35
Intervals for endangered ecological communities in the Blue Mountains (Keith, 2010)		
Blue Mountains Shale Cap Forest	11	30
Blue Mountains Swamps in the Sydney Basin Bioregion	12	20
Cooks River/Castlereagh Ironbark Forest in the Sydney Basin Bioregion	11	20
Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps	8	22
Newnes Plateau Shrub Swamp in the Sydney Basin Bioregion	11	25
River-Flat Eucalypt Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions	11	35
Shale-Sandstone Transitional Forest	13	20
Sun Valley Cabbage Gum Forest in the Sydney Basin Bioregion	11	25
Sydney Turpentine-Ironbark Forest	11	22

An asterisk (*) indicates intervals are tentative due to insufficient data.

Table 2: Biodiversity threshold categories defined in the Fire Tools analysis (see DECCW, 2010; DECCW, 2010a).

Biodiversity threshold category	Guidelines for interpreting fire regime threshold status
'Too Frequently Burnt'	These areas have experienced sustained (two or more) consecutive intervals between fires shorter than the recommended minimum interval for this vegetation type. Any Rainforest / Mangrove/ fire exclusion vegetation that has been burnt will be in this category. Areas of vegetation that are repeatedly burnt at intervals shorter than recommended for the vegetation type may experience a decline in the abundance of plant species sensitive to frequent fire. If inter-fire intervals shorter than the recommended minimum continue, these sensitive species are at risk of local extinction. Attempts should be made to minimise fire occurrence in these areas.
'Vulnerable to Frequent Fire'	These areas have already experienced one inter-fire interval less than the shortest (minimum) interval recommended for this vegetation type and/or the current time-since-fire is less than the minimum recommended interval. All unburnt Rainforest/ Mangrove/ fire exclusion vegetation is in this category.
'Within Threshold'	The time-since-fire age of the vegetation is greater than the shortest recommended inter-fire interval and less than the longest recommended inter-fire interval, and the vegetation has not previously experienced any intervals shorter than the minimum recommended. If a fire occurs before the number of years specified as the minimum interval has been reached it will move into the 'Vulnerable to Frequent Fire' category. If three or more fires occur in close succession the area will move into the 'Too Frequently Burnt' category.
'Long Unburnt'*	The post-fire age of the vegetation is greater that the recommended longest inter-fire interval for this vegetation type*. If fire continues to be absent from the vegetation for a prolonged time, it is anticipated that plant species that require fire to stimulate flowering or seed production (and their seed banks) may begin to senescence. Long unburnt areas in some vegetation types are very rare and therefore significant. Long unburnt vegetation may also have other ecological values that make it important habitat for certain species in a given area. Careful consideration should be given before burning these areas, and wherever possible the decision should be based on a scientific assessment and/or recommendation prior to burning.
'Unknown'	Areas where the fire history is not long enough to calculate whether an area is 'within threshold' or 'long unburnt'.

An asterisk (*) indicates intervals are tentative due to insufficient data.

Table 3: Fire severity categories mapped in this study, typical post-fire vegetation characteristics, indicative fire behaviour and likelihood of suppression in forest vegetation types.

Severity category	Typical post-fire vegetation characteristics	Indicative fire behaviour	Likelihood of suppression
Low-moderate	Ground and shrub layer scorched; majority of tree canopy unburnt	Low intensity, patchy fire in ground and shrub layer; flame height <4 m	High
High	Ground and shrub layer scorched or consumed; majority of tree canopy scorched	High intensity shrub fire; flame height 4-10 m	Low
Extreme	Ground and shrub layer consumed; majority of tree canopy also consumed	Crown fire; flame height >8 m	Nil

Fire Intensity Mapping

We derived fire intensity records for the GBMWHA by mapping patterns in the 'severity' of fires that occurred during five major fire seasons in recent decades: 1993-94, 1997-98, 2001-02, 2002-03, and 2006-07. Severity is defined here as the level of vegetation scorch and consumption caused by the fire, which is a good indicator of intensity due to the relationship between vegetation scorch and consumption and flame height/heat generated by the fire. We used an established remote sensing method for detecting temporal change in vegetation (e.g. Hammill and Bradstock 2006). The method is based on the Normalised Vegetation Greenness Index (NDVI), which is a ratio of reflected near infra-red and visible red wavelengths recorded in satellite imagery. Changes in this index between a pre-fire and an immediate post-fire image can be calculated, and then referenced to the field to produce a classified map of fire severity/intensity. We used the fire severity categories set out in Table 3.

We obtained pre-fire and post-fire Landsat image pairs covering all of the fire in each season (with the exception of two fires in the 2006-07 seasons, for which we only had single post-fire images available). The NDVI (or equivalent Normalised Burn Ratio) was computed for each image, and then used to determine the change in vegetation greenness caused by the fire (i.e. by calculating pre-fire NDVI minus post-fire NDVI). The resulting NDVI difference image was classified into broad fire severity categories on the basis of validation points identified in the field by on-ground survey or from post-fire aerial or oblique photographs (the latter were taken from vantage points above the burnt area). The accuracy of the maps for each fire and for each season differed depending on the extent of validation and the dates of the best, cloud-free imagery available.

We also generated a cumulative, multi-season fire severity map to identify areas affected by different combinations of severity over the years. The preliminary results are presented here, while further analyses are underway to examine these patterns in more detail.

Table 4: Experimental design for the floristic sites surveyed in the Grose and Govett gorges. Fire severity combinations for the 2006-07 and 1993-94 fires ('experimental treatment') are listed with the corresponding number of replicate sites surveyed.

Fire severity 2006-07	Fire severity 1993-94	Fire severity 2006-07/1993-94 'experimental treatment'	Number of replicate sites
High severity	High severity	High/High	3
High severity	Low severity	High/Low	1
Low severity	High severity	Low/High	1
Low severity	Low severity	Low/Low	5
High severity	Unburnt	High/Null	7
Low severity	Unburnt	Low/Null	8
Unburnt	Unburnt	Null/Null	1

FIELD SURVEY OF FIRE IMPACTS

Using the maps described above, we designed a field survey to examine the impact of multiple high-severity fires on 'sensitive' wet sclerophyll forest of the shrubby subformation. We targeted two locations: the upper Grose Gorge and Govett Gorge (often referred to as the Grose Valley) of BMNP and southern YNP, however we present only the preliminary results from the Grose and Govett gorges survey here. These sites were located in wet sclerophyll forests (shrubby subformation), all burnt in 1982-83. Most sites were also burnt in 2006-07 (two fires), at either low/moderate or high/extreme severity, and some sites were also burnt in 1993-94 (three fires) at either low/moderate or high/extreme severity. We used the severity mapping described above to select sites burnt at the different levels of severity (Table 4).

Full floristics (cover-abundance scores) data were collected at a total of 26 sites using 20 m x 20 m quadrats. Consistent detailed data collection was undertaken, for a period of approximately 2-3 hours per site. Data on vegetation structure, habitat condition and fire severity were also collected, however this information remains to be fully analysed and is not presented here. The sites were located near (usually within 200 m of) walking tracks within the Grose and Govett gorges, between Victoria Falls, Burra Korrain, Blue Gum Forest and Hayward Gully. Steep terrain and dense regrowth following the November 2006 fire made access to more remote sites impractical. The floristic data were analysed in relation to fire history (frequency and severity) using multidimensional scaling and the results are presented here as MDS plots.

RESULTS AND DISCUSSION

Fire Frequency Analysis

Our analysis of fire frequency reveals that the vast majority (74%) of the GBMWHA has been burnt by 1-3 fires since records began (in most case, since the 1960s), less than 10% has been burnt more than three times, and a large proportion (17%) has remained unburnt during this time (Fig. 1). Areas with the lowest fire frequencies (0-1 fire) occur mostly in the western parts of the GBMWHA, while areas with highest fire frequencies (four or more fires) occur scattered in different parts of the GBMWHA, but most notably in the Grose Gorge of BMNP, YNP and northeast WNP, and in localised patches in NNP and southern BMNP (Fig. 1).

When combining these fire frequency/interval results with the vegetation formations and recommended minimum and maximum intervals between fires, our analysis revealed that the majority of the GBMWHA is currently (as of the 2012-13 fire season) within acceptable 'biodiversity thresholds': 56% is 'within threshold' and 18% is 'vulnerable to frequent fire'. The latter is still technically within threshold, but needs protection from fire until the minimum recommended interval between fires has been reached, usually within the next few years.

Areas of most concern from a fire frequency perspective, however, are the 5% 'too frequently burnt' and 12% 'long unburnt'. Higher than recommended frequencies include parts of the BMNP (upper Grose Gorge and Govett Gorge, YNP (near Colo/Putty), northeast WNP and TLNP (near Picton) (Fig. 2). Wet sclerophyll forests in the shrubby subformation have a disproportionate amount with 25% of these forests being 'too frequently burnt'. These forests have a particularly long recommended minimum interval between fires (25 years; Table 1), and are thus more 'sensitive' to fires recurring at typical *El Niño* occurrence rates (of about one per decade).

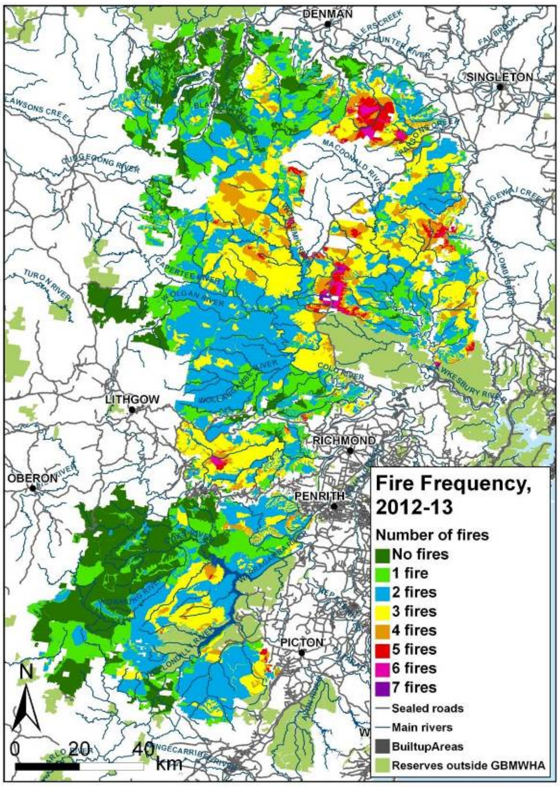

Fig. 1: Fire frequency patterns in the GBMWHA at the end of the 2012-13 fire season, as indicated by the number of fires in recorded history.

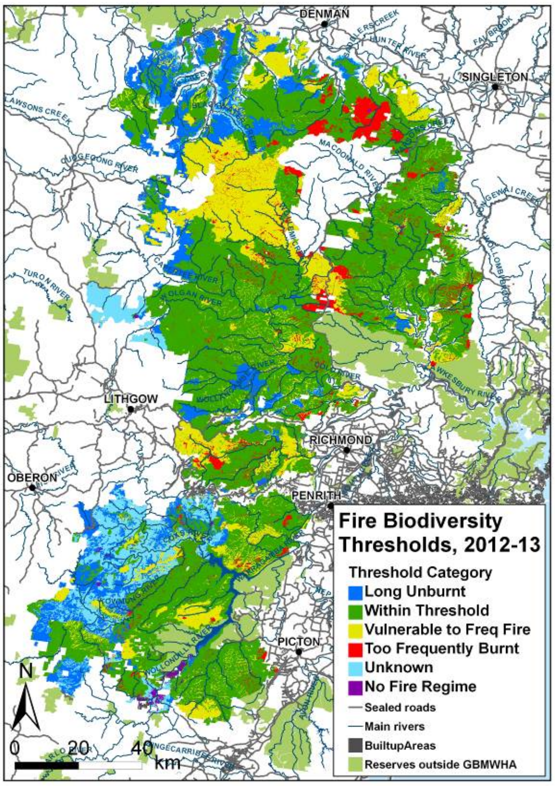

Fig. 2: Fire biodiversity thresholds in the GBMWHA at the end of the 2012-13 fire season, as indicated by the threshold categories: 'long unburnt', 'within threshold', vulnerable to frequent fire', 'too frequently burnt' and 'unknown'.

Fire Severity Mapping

The fire severity maps reveal highly-variable fire behaviour within the fire perimeters for each season (Fig. 3). Patches of low, high and extreme severity often occur within close proximity and are likely to be highly influenced by terrain effects. Low fire severity is more common in moist, forested gullies that are protected from high winds, while higher severities are more common on ridges with drier heaths and low forests. Variations in fire severity at this terrain scale (within hundreds of metres) are likely to be of great importance for the survival of many fauna species during large fires.

Broader patterns in fire severity are also evident in many of the fires. In particular, there are some large areas (kilometres across) that are dominated by high to extreme fire severities (Fig. 3). These areas correspond to days of adverse weather when the fires spread rapidly and at high intensities under strong winds (unpublished weather and fire spread data).

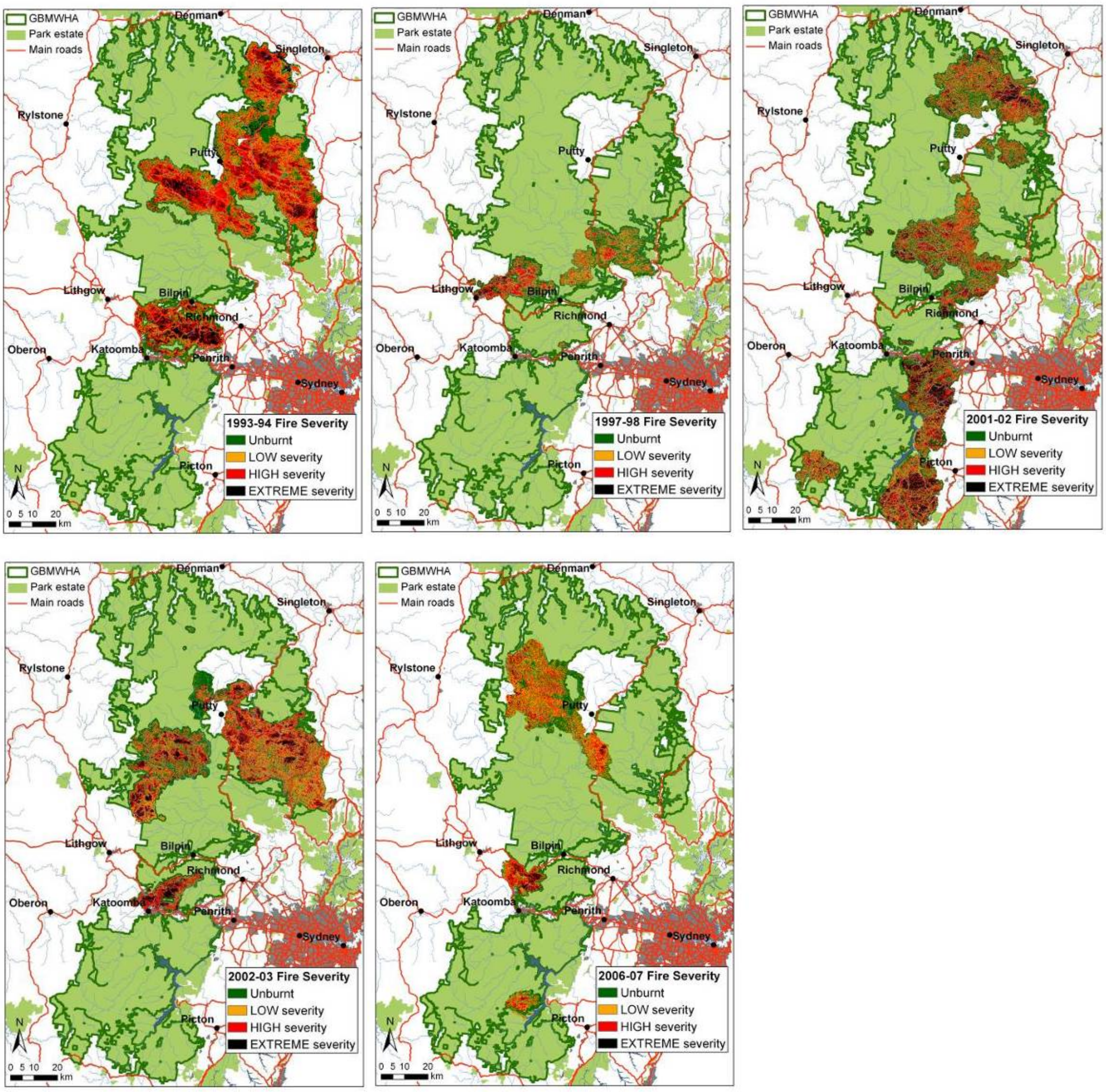

Fig. 3: Fire severity maps derived in this project for five major seasons affecting the GBMWHA (1993-94, 1997-98, 2001-02, 2002-03, and 2006-07) during the last two decades.

The cumulative fire severity analysis reveals patterns produced over multiple fire seasons (Fig. 4). Of particular interest are areas affected by multiple ‘extreme’ severity fires, i.e. multiple crown fires. Crown fires arguably have the greatest potential environmental impact in terms of vegetation structural change in the short-medium term (e.g. loss of canopy cover and tree death, especially of tall forest dominants such as *Eucalyptus oreades* and *Eucalyptus deanei*), reduced survival of animals especially arboreal mammals and others with limited dispersal/flight capacity, and increased soil impacts such as sediment movement and loss of organic matter.

Our cumulative fire severity map reveals for the first time the invisible mosaic of fire severity/intensity in the GBMWHA. We reveal that significant parts of the Grose and Govett gorges, localised areas in WNP (south of the Wolgan River and between the Capertee and Wolgan rivers) and YNP have been affected by multiple ‘extreme’ severity fires in the last two decades (Fig. 4). Certain vegetation communities and fauna populations could possibly be adversely affected in these areas; however this remains to be seen subject to robust and detailed assessment in the field.

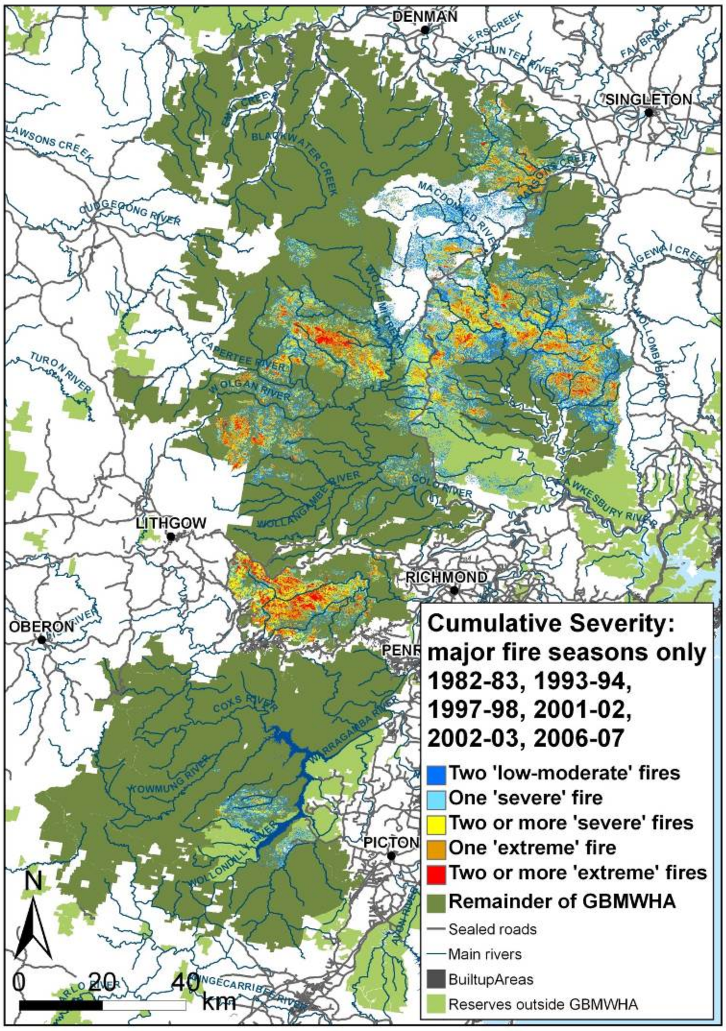

Fig. 4: Cumulative fire severity map for the GBMWHA derived by combining the severity maps for each season. The categories depicted in this map are for areas burnt by two or more fires of different combinations of severity (see map legend). Note that areas burnt in 1982-83 were included in this analysis; however this data is not described elsewhere in this paper due to the data needing refinement.

FIELD SURVEY OF FIRE IMPACTS

Multidimensional scaling of floristic data is used to explore floristic similarity between quadrat data. The distance between points indicates relative similarity, so that points closer together are floristically more similar than those further apart. In the MDS plot of the Grose and Govett gorges survey data (Fig. 5), sites burnt twice (in 1982-83 and 2006-07) are more similar (clustered lower left) than those burnt three times (in 1982-83, 1993-94 and 2006-07) (clustered upper right), indicating a possible effect of number of fires on wet sclerophyll forests composition. This difference is also likely to be influenced by geographic location—the twice-burnt sites were located near Victoria Falls Creek in an uppermost part of Grose Gorge and the thrice-burnt sites were located further downstream in the Grose and Govett gorges (a difference that was unavoidable due to the differing extents of the fires).

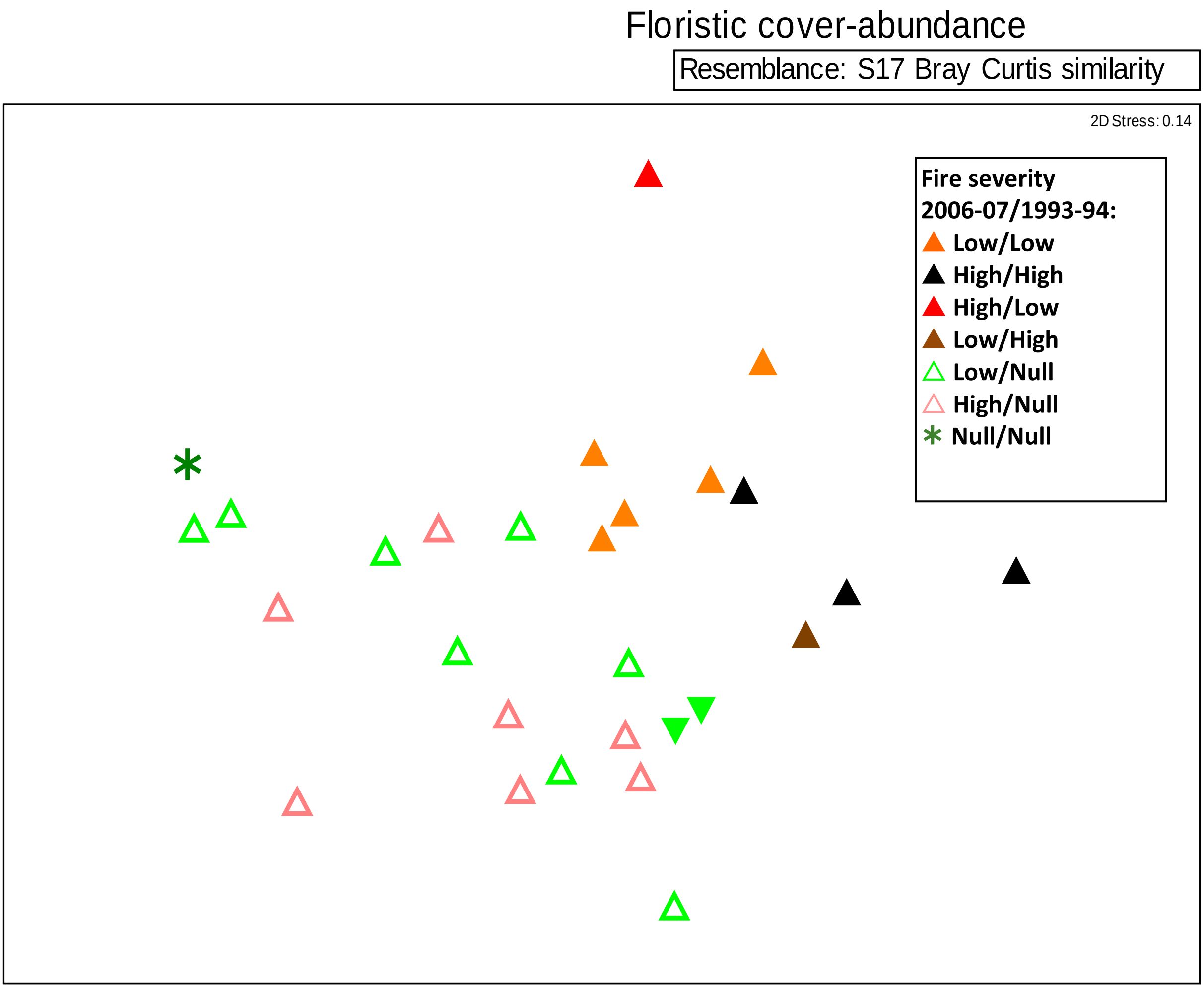

Fig. 5: Multidimensional scaling (MDS) of floristic cover-abundance data from the Grose and Govett gorges field survey sites. All sites were burnt in the 1982-83 season. Hollow symbols represent sites also burnt in the 2006-07 season and solid symbols represent sites burnt in both the 2006-07 and 1993-94 seasons. The different coloured symbols represent different combinations of fire severity for the 2006-07 and 1993-94 fires respectively (see legend).

Within the sites burnt three times (Fig. 5; solid symbols), those that had experienced repeated low severity fires are clustered separately to those that experienced repeated higher severity fires, (e.g. Low/Low vs. High/High). This indicates a possible effect of fire intensity on the composition of the wet sclerophyll forests of the Grose and Govett gorges. Further, the sites burnt by repeated higher severity fires (High/High) are least similar to those burnt less often (i.e. positioned further from the twice burnt sites; Fig. 5). We are currently exploring these data in more detail to determine the nature of these floristic differences, as well as any differences in vegetation structure and habitat condition, which is important for fauna. An equivalent analysis of the Yengo data is also being undertaken and will explore whether these effects are similar in the wet sclerophyll forests in different parts of the GBMWHA.

CONCLUSION

The GBWHA is one of the most fire-prone regions on earth. This project has significantly enhanced the scope of the fire history information available for the area. We identify where potentially adverse regimes of too-frequent and repeated high intensity fires have occurred. The maps should prove useful in many kinds of studies of fire behaviour and fire regime impacts on biodiversity and as an additional resource for fire managers in the region.

Overall, our results show that the invisible mosaic of fire frequency and intensity varies greatly across the GBMWHA. The vast majority of the GBMWHA is within acceptable limits of fire frequency for maintaining species diversity, although there are some areas where this is not so, including in the iconic Grose and Govett gorges. Fire behaviour has been highly variable within the boundaries of large unplanned bushfires in the GBMWHA. This is already known to fire managers; however our maps provide a record for the entire landscape and should be useful in future fire planning.

The cumulative fire severity patterns reveal that certain areas have experienced multiple high-extreme severity fires and it is possible that certain ecosystems and species in these areas could have been adversely impacted.

The targeted survey of wet sclerophyll forest ecosystems in this project has shown that a recent regime of multiple high-extreme severity fires has impacted on the floristics of these kinds of forests, although we are still analysing the particular nature of these impacts.

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BIOGRAPHY

Dr Kate Hammill has worked for over 12 years in bushfire research with OEH and NPWS on fire severity mapping and fire impacts on native vegetation. Her work has been supported by research grants from the NSW Environmental Trust and more recently the Commonwealth Government *Caring for Our Country*. As well as working with the co-authors of this paper, she has collaborated with Prof Ross Bradstock and Dr Owen Price (University of Wollongong). She now works as a bushfire ecology consultant, including with Transfield Services Pty Limited.