Welcome from Editor

It is my pleasure to bring to you the compiled papers from the Science Day of the AFAC and Bushfire CRC Annual Conference, held in the Sydney Convention Centre on the 1st of September 2011.

These papers were anonymously referred. I would like to express my gratitude to all the referees who agreed to take on this task diligently. I would also like to extend my gratitude to all those involved in the organising, and conducting of the Science Day.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Science Day ran four steams covering Fire behaviour and weather; Operations; Land Management and Social Science. Not all papers presented are included in these proceedings as some authors opted to not supply full papers.

The full presentations from the Science Day and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Richard Thornton

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Fire Regimes and Vegetation in the Greater Blue Mountains World Heritage Area

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Abstract

The Greater Blue Mountains World Heritage Area (GBMWHA) covers just over a million hectares, and comprises eight national parks. It is one of the most fire-prone regions on Earth, has extensive adjoining urban areas and contains internationally significant ecosystems and biodiversity. These features present significant management challenges, and increase the need for good science to underpin decision-making.

We carried out a synthesis of fire regime information for the GBMWHA, calculated fire frequencies for the four decades to 2010 and determined the status of area in relation to ‘fire-biodiversity thresholds’ that are suggested for the maintenance of plant species diversity. We found current fire frequencies across the GBMWHA are broadly appropriate, with approximately 76% of the landscape within threshold.

In addition, we generated fire severity maps for the GBMWHA for all five major bush fire seasons since 1990, using two different satellite image types (Landsat, SPOT) and two different approaches (pre/post-fire image differencing and single post-fire image analysis). Both image types and approaches produced useful fire severity maps, but image-differencing with Landsat produced the best cost-effective results. The resulting maps show the patterns of fire intensity for each of the bush fire seasons and provide new broad-scale information on this less-commonly documented component of fire regimes.

The comprehensive fire history now available for the GBMWHA is one of the most detailed in Australia, and is being used for fire planning and management, as a baseline against which to assess climate change impacts, and in further research.
Introduction
The Greater Blue Mountains World Heritage Area (GBMWHA) in eastern New South Wales covers an area of approximately 1.03 million hectares, and includes eight conservation reserves (Blue Mountains, Gardens of Stone, Kanangra-Boyd, Nattai, Thirlmere Lakes, Wollemi and Yengo national parks and Jenolan Karst Conservation Reserve). It stretches almost 250 kilometres from the southern edge of the Hunter Valley to the Southern Highlands of NSW. The Blue Mountains National Park (commonly thought of as “the Blue Mountains”) makes up just 25% of the Greater Blue Mountains World Heritage Area.

The World Heritage Area is an ideal location to study bush fires for a number of reasons. The region is highly fire-prone, experiencing large bush fire seasons one to two times per decade: since 1970 there have been ten major bush fire seasons. There are also good basic fire history records available, because the New South Wales National Parks & Wildlife Service (NPWS) has kept perimeter maps of both bush fires and prescribed fires for most of the land now in the GBMWHA since 1970 (for some areas more recently gazetted as national parks, the fire history only goes back to their date of gazettal). The region has an extensive bushland-urban interface and substantial numbers of people and assets embedded within a rugged and highly flammable landscape. The area has suffered substantial losses of property in the past, such as in the 1957-58 fires (Cunningham 1984) and the 1993-94 fires. It also has very high conservation values (NPWS and Environment Australia 1998), being one of the three most diverse areas of sclerophyll vegetation on Earth, with 114 endemic species, approximately 100 species of eucalypts, 400+ species of vertebrates, and rare and ancient Gondwanan species of world significance, such as the Wollemi Pine (Wollemia nobilis) and Blue Mountains Pine (Pherosphaera fitzgeraldii).

Recent climate change modelling suggests that the region is likely to experience more high to extreme fire danger (FFDI > 40) days, an earlier start to the fire season, and potentially more frequent fires of high intensity in the future (Hennessy *et al.* 2006; Clarke *et al.* 2011). Extrapolation from these models (Bradstock *et al.* 2008) suggests that the area, intensity and frequency of bush fires may increase in the future. The forecasts from these studies add urgency to the need to better understand, predict and manage the impacts of fire regimes in the region.

In this paper we describe the enhancement of existing fire history information for the GBMWHA into a fire regime analysis of outstanding spatial and temporal coverage and resolution. Specifically, in this study we: (1) combined existing fire perimeter maps from various NPWS records and analysed the fire frequency patterns; (2) compiled a single seamless vegetation map from ten existing source maps to cover the entire GBMWHA; (3) combined the fire frequency and vegetation maps, and compared the output against suggested biodiversity fire thresholds for New South Wales vegetation; and (4) prepared fire severity maps for the five major bush fire seasons in the last 20 years for the region.

Fire Frequency Analysis
Maps of the occurrence and perimeter of all fires (including prescribed burns) in the GBMWHA were sourced from existing digital geographic information system layers held by the NPWS. These were available back to the 1960s for most of the GBMWHA, but only back
to the 1980s for Gardens of Stone National Park— the most recently gazetted park. This provided a fire history analysis period of between 49 and 29 years to 2010, depending on the reserve (49 years for Blue Mountains, Kanangra-Boyd and Nattai national parks and Jenolan Karst Conservation Reserve; 43 years for Yengo National Park; 39 years for Wollemi National Park and 29 years for Gardens of Stone National Park). During the study period there have been a number of major fire seasons in the region (that is, years with multiple large fires requiring multi-agency fire-fighting), including 1977-78, 1979-80, 1980-82, 1982-83, 1984-85, 1993-94, 1997-98, 2001-02, 2002-03 and 2006-07. The large fires during these seasons have essentially determined the fire regimes of the region (Fig 1a). For example the 1993-94 and 2001-02 fires each burnt 25% of the GBMWHA and the 2002-03 fires burnt 19%.

Analysis of these fire maps revealed that the most common time-since-fire values in the GBMWHA (at 2010) were 9 years post-fire (23% last burnt in the 2001-02 fires), 8 years post-fire (19% last burnt in 2002-03), 4 years post-fire (10% last burnt in 2006-07) and 13 years post-fire (8%). More than half (58%) the GBMWHA is currently less than ten years post-fire age (Fig 2).

However, because successive big fire seasons have predominantly burnt different parts of the landscape, the majority of the GBMWHA has been burnt by just one (26%), two (29%) or three (20%) fires during the study period, with an additional 18% unburnt (Fig 1b). Less than 10% of the GBMWHA was burnt more often than this (four fires 5%, five fires 1%, six fires 1%, seven fires 1%). The areas of more frequent fire are concentrated in Yengo and (eastern) Wollemi national parks – which have lower average annual rainfall and higher temperatures than other parts of the GBMWHA – and in the Grose Valley in Blue Mountains National Park. Many parts of the cool and moist south-west of the GBMWHA (Kanangra-Boyd National Park and Jenolan Karst Conservation Reserve) have not been burnt since 1970. The major fires of the summer of 1957-58 affected some parts of Kanangra-Boyd, however reliable spatial information for these fires is not available.

**Biodiversity Fire Threshold Analysis**

Broad-scale fire management for the conservation of native vegetation in New South Wales makes use of the concept of ‘thresholds of potential concern’ (*sensu* van Wilgen and Scott 2001). These are defined as the minimum and maximum intervals between fires predicted to maintain floristic diversity (Noble and Slatyer 1980; Kenny *et al.* 2004), and are based on known plant species responses to fire. Different intervals are defined for each of the twelve broad vegetation formations in New South Wales (Keith 2004), based on analysis of their component plant species, as recorded in the New South Wales Flora Fire Response Database (OEH 2010). The database currently includes information for 3088 species, including type of response to fire (e.g. seeder or resprouter), method of persistence at a site (e.g. soil seedbank), primary juvenile period (i.e. number of years from germination to first flowering), maximum lifespan (of individual plants) and longevity of the seed-bank.

The *minimum* interval threshold (for any given vegetation formation) is determined by the slowest-maturing species in that formation that is killed by fire and depends on seed to regenerate. This is the longest time to maturity of species sensitive to frequent fire. The *maximum* interval is determined by the shortest-lived of the species in that formation that
needs fire to germinate, flower or release seed. This is the shortest time to extinction for species sensitive to infrequent fire.

These fire biodiversity guidelines are used in New South Wales for planning and management of all fire-prone national parks, as well as outside national parks in areas of native vegetation to which the Bush Fire Environmental Assessment Code (RFS 2006) applies, in accordance with the *Rural Fires Act 1997*.

**Fig 1:** (a) Time of last fire, and (b) number of fires, for the Greater Blue Mountains World Heritage Area for the period of available fire history to 2010. Note that only fires within the GBMWHA reserves are shown and the length of fire history varies for the different reserves (see text).
To apply the thresholds, we used the following method. Fire perimeter maps were combined with a digital vegetation map using geographic information system software ArcGIS (v. 9.3, ©ESRI 2008). The fire maps were used to derive fire frequency and fire interval data and the vegetation map was re-classified at the broad level of formation (e.g. rainforest, heathland; Keith 2004). Combinations of fire and vegetation were analysed using a customised spatial analysis tool Fire Tools (OEH 2011) that runs within the ArcGIS platform. This compares the actual fire frequencies and sequences of inter-fire-intervals with the suggested minimum and maximum thresholds for each vegetation formation (Table 1), producing an output map with areas assigned to a series of fire-biodiversity frequency categories. These are: 'too frequently burnt' (inter-fire-intervals shorter than recommended), 'within threshold'; 'vulnerable to frequent fire' (areas that are 'within threshold' but recently burnt, and which if burnt again in the near future would become 'too frequently burnt'); 'long unburnt' (inter-fire-intervals longer than recommended); and 'unknown' (areas where there is insufficient fire history available to assess the status of the vegetation).
<table>
<thead>
<tr>
<th>Vegetation formation (Keith 2004)</th>
<th>Minimum interval</th>
<th>Maximum interval</th>
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</thead>
<tbody>
<tr>
<td>Rainforests</td>
<td>Fire should be avoided</td>
<td></td>
</tr>
<tr>
<td>Alpine Complex</td>
<td>Fire should be avoided</td>
<td></td>
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<tr>
<td>Saline Wetlands</td>
<td>Fire should be avoided</td>
<td></td>
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<tr>
<td>Wet Sclerophyll Forests (shrubby subformation)</td>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td>Wet Sclerophyll Forests (grassy subformation)</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Forested Wetlands</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>Grassy Woodlands</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>Dry Sclerophyll Forests (shrub/grass subformation)</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>Dry Sclerophyll Forests (shrubby subformation)</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>Semi-arid Woodlands</td>
<td>6</td>
<td>40</td>
</tr>
<tr>
<td>Semi-arid Shrublands</td>
<td>6</td>
<td>40</td>
</tr>
<tr>
<td>Heathlands</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>Grasslands</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Freshwater Wetlands</td>
<td>6</td>
<td>35</td>
</tr>
</tbody>
</table>

The analysis revealed that the majority of the landscape (74%) is currently within the suggested thresholds (i.e. ‘within threshold’ or ‘vulnerable to frequent fire’), while 12% is ‘long unburnt’, 5% is considered ‘too frequently burnt’ and a further 8% is ‘unknown’ (Fig 3). The ‘too frequently burnt’ category coincides with areas burnt by five or more fires since the 1960s or with vegetation for which any fire is considered ‘too frequent’ (i.e. rainforest) or with vegetation for which the suggested minimum interval is very long (i.e. wet sclerophyll forests; see Table 1). ‘Too frequently burnt’ areas are of particular concern because of the potential for loss of floristic diversity and/or changes in vegetation structure. Some of the areas in this category identified by this study have been targeted for field-based surveys as part of ongoing work (not reported here).

The suggested fire-biodiversity intervals are based on the principle of maintaining floristic diversity by minimising plant species extinctions in the long-term. While there are other important components of biodiversity, such as vegetation structure and faunal diversity, these are not explicitly considered in the current thresholds. Application of the thresholds also does not currently take into account fire season, patchiness or severity, all of which modulate the impacts. The levels of existing mapping and analysis to date have not allowed this to be done, however the current work and other ongoing projects will make this possible in the future.
Fire intensity (the amount of heat energy released by a fire) is one of the key attributes of fire regimes (Gill 1981) and is an important determinant of the impacts of fire, for biodiversity, human life and property. For example, high intensity fires are associated with a higher loss of biomass and slower subsequent fuel accumulation, changes in soil properties including deterioration of soil structure and porosity, increased propensity for post-fire erosion (Doerr et al. 2006) and increased loss of soil organic matter and nutrients (Certini 2005). High intensity fires are also associated with greater mortality of some plants and animals (e.g. Vivian et al. 2008; Newsome et al. 1975), but increased germination of many plants (e.g. numerous hard-seeded Acacia species and others in the Fabaceae family; Auld & O’Connell 1991). Trees can be lost through collapse after severe fires but there can also be increased production of hollows in remaining trees (Collins et al. submitted a, b).
Fire intensity is difficult to measure during large bush fires, however it is closely correlated with fire severity (the degree of loss or change in organic matter above- and below-ground; Keeley 2009). Remote sensing offers the opportunity to detect and map the latter following a fire and can be used to retrospectively infer the intensity of the fire.

Prior to this study fire severity maps were available only for one season (2001-02) and for only some of the parts of the GBMWHA (Hammill & Bradstock 2006; Bradstock et al. 2010). We prepared new fire severity maps to increase the coverage of the 2001-02 season and to cover the other major fire seasons (2006-07, 2002-03, 1997-98 and 1993-94) using the following approach.

We obtained post-fire satellite imagery, captured as soon as possible after the dates on which the fires of interest were out. Both Landsat and SPOT (Satellite Pour l’Observation de la Terre) imagery are suitable for fire severity mapping in south-eastern Australian landscapes, but for reasons of availability and cost (see below) we predominantly used Landsat. Wherever possible we also obtained pre-fire imagery of the area, captured as close in time before the fires as possible.

We used ERDAS Imagine (© 2009 ERDAS, Inc.) image processing software and ArcGIS to map the pixel values of the ratio between light wavelengths that show “greenness” (see example in. Fig 4). Two different ratios were commonly used (depending on suitability), the Normalised Difference Vegetation Index (NDVI) and the Normalised Burn Ratio (NBR). NDVI is the ratio of the visible red to near infra-red wavelength bands and is available for both Landsat and SPOT imagery. NBR is the ratio of the near infra-red to far infra-red bands and is only available for Landsat images. If paired pre- and post-fire images were available, then the difference in greenness before and after the fire was mapped (i.e. dNDVI or dNBR).

We used field-based assessments and post-fire photographs (where available) of fire severity to validate the remote sensing data. The degree of vegetation scorch and consumption of the canopy, understorey and ground-layer was identified as well as possible at numerous replicate sites (in different vegetation types and severity categories) at georeferenced point localities. Field-based assessments were not possible for the earlier fires, and in such cases the fire severity was estimated from historic aerial or ground-based photos taken shortly after the fire. The site assessments of severity were matched against the pixel value for each point location and used to determine the range of values representing different categories of fire severity, namely: ‘low’ (understorey scorched, canopy unburnt), ‘high’ (all or most vegetation scorched) and ‘extreme’ (all or most vegetation consumed; Hammill et al. 2010). Once the thresholds in pixel values were determined, the fire severity maps were generated using a tailored image classification decision tree (Fig 5).

Because of the limited availability of satellite imagery for some of the fire seasons, and the impossibility of carrying out detailed field-based assessments of fire severity for the older fires, a range of methods were used to prepare the fire severity maps (Table 2). While an image differencing approach (i.e. a pre/post-fire comparison) is the most widely-used method for fire severity mapping (Brewer et al. 2005; Lentile et al. 2006) and is generally accepted as the best method, single-image fire severity mapping is also common when the alternative is not feasible (e.g. Koutsias & Karteris 2000; Brewer et al. 2005).
Fig 4: Map and cross-section of pixel values of the Normalised Difference Vegetation Index for the 2006-07 Lawsons Long Alley Fire in the upper Blue Mountains and Grose Valley. The dark area in the image (at left) indicates the fire area. The histogram of pixel values (at right) shows the NDVI values along the cross-section across the fire area (see vertical line in the image at left)—the highest NDVI values indicate unburnt areas; lower NDVI values indicate higher severity).

Table 2: Methods used to map fire severity for the major bush fire seasons since 1990.

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<tbody>
<tr>
<td>Landsat 7 (NDVI or NBR)</td>
<td>Y (part)</td>
<td>NBR</td>
<td>NDVI</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>SPOT 2 (NDVI)</td>
<td>Y (part)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pre-/post-comparison</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>Single post-fire image</td>
<td>Y</td>
<td></td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Validation data</td>
<td>Photos</td>
<td>Field</td>
<td>Field</td>
<td>Photos</td>
<td>Photos</td>
</tr>
</tbody>
</table>

The resulting fire severity maps show that even during the biggest of fires, a range of fire severities occur. More detailed analysis of the patterns and how they relate to weather at the time of the fire, topography and vegetation (Hammill & Bradstock 2006; Bradstock et al. 2010) reveal that weather can be the over-riding influence on severity in these landscapes, with topography and vegetation playing lesser roles and almost none on extreme fire weather days. While such detailed analyses have been completed on only a subset of fires from the 2001-02 season, using the new information produced by our current study, such analyses could now be extended to different fire seasons, and more broadly across the GBMWHA.
Both Landsat and SPOT have advantages and disadvantages (Table 3). While Landsat images are coarser resolution and are captured less frequently, they cover a bigger area (Fig 6), are less expensive, are available retrospectively and have wavelengths that enable them to penetrate light smoke. We found that Landsat images (including Landsat 5) are highly useful. Based on our analyses, we also confirm that the image-differencing approach is preferable since it is less sensitive to vegetation type and date of image capture. Nevertheless, if only a single post-fire image is available, a reasonable fire severity map can still be prepared if a vegetation map is available and particular effort is made to incorporate vegetation effects into the severity mapping. This is because there are strong differences in reflectance resulting from contrasting vegetation types (i.e. swamps and moist forests have inherently higher NDVI than dry heaths and woodlands). These difference need to be distinguished from differences due to fire severity.

Fig 5: Fire severity maps produced in this study for the five major bush fire seasons since 1990.
Table 3: Advantages and disadvantages of Landsat 7 versus SPOT 2.

<table>
<thead>
<tr>
<th>LANDSAT</th>
<th>SPOT</th>
</tr>
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<tbody>
<tr>
<td>NDVI and NBR</td>
<td>NDVI</td>
</tr>
<tr>
<td>Cheaper (~$1,700 per image)</td>
<td>More expensive ($2,500+ per image)</td>
</tr>
<tr>
<td>Available retrospectively</td>
<td>Imagery not archived</td>
</tr>
<tr>
<td>185 x 185 km scenes</td>
<td>60 x 60 km scenes</td>
</tr>
<tr>
<td>Multiple infra-red bands penetrate smoke</td>
<td>Cannot penetrate smoke</td>
</tr>
<tr>
<td>Lower resolution (30m)</td>
<td>Better resolution (10m)</td>
</tr>
<tr>
<td>Less frequent (16 days)</td>
<td>More frequent capture (2-3 days)</td>
</tr>
<tr>
<td>Images captured in eastern Australia midday so terrain shadows less</td>
<td>Images captured in eastern Australia approx 10am so greater terrain shadows</td>
</tr>
</tbody>
</table>

Fig 6: Comparison of image extent and coverage for Landsat and SPOT of the Greater Blue Mountains World Heritage Area.
Conclusions

As an increasing range of satellites become available over the next few years with a greater range of band widths and higher spatial and temporal coverage, the exact choice of satellite may not be the same as used here. However we suggest that as a general principal, a pre-/post-fire image comparison will remain more accurate for fire severity mapping. A single post-fire image supplemented by a vegetation map can produce acceptable results if the alternative is not feasible.

Keeping good fire history information is fundamental to be able to detect changes in fire regimes over time, predict patterns of fire occurrence and plan where to target fuel reduction activities. It is also fundamental for the study of fuel patterns, fire behaviour, impacts of fires on biodiversity, vegetation, erosion, soil nutrients and soil carbon.

The detailed fire history compiled in this study is already being used as a substantial input to a number of research projects. These include modelling of fuel accumulation rates and soil carbon, and testing impacts of repeated high-intensity and low-intensity fires on plant diversity and faunal habitat values. The fire history for the GBMWHA compiled in this study is one of the most comprehensive currently available in Australia, and provides invaluable baseline data against which to monitor future change in fire regimes.

References


