Managing Bushfire in a Biodiversity Hotspot

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Abstract
The south-west of Western Australia is recognised as a global hotspot of biodiversity and one of the world's most fire-prone regions. Ecosystems and organisms have evolved in this fire prone-environment and have developed adaptive traits that enable them to persist with, and in some cases, depend upon a variety of fire regimes. No regime is optimal for all organisms and communities, but fire diversity is essential for maintaining biodiversity, although some fire regimes can threaten biodiversity. Bushfires can also threaten people and property so fire management is necessary to both conserve biodiversity and to reduce the damaging impacts of bushfires on community assets. This paper describes a management framework that is being developed in the south-west for planning and implementing fire regimes to conserve biodiversity at the landscape scale and at the local patch scale. The framework utilises GIS as a tool for assembling relevant and often complex ecological and biological information including the distribution and location of plants, animals and fire sensitive ecosystems. Scientific knowledge of life histories and of the responses of sensitive ecosystems and organisms to fire is used to set fire regime bounds and to devise diverse regimes and create fire-induced mosaics at appropriate scales. The threat that these regimes pose to community assets is assessed and where it is deemed unacceptable, appropriate adjustments to fire management are made.

Introduction
The subdued natural landscapes of the south-west of Western Australia belie a diversity of life so remarkable that the region is now recognised as one of the world's twenty five biodiversity hotspots – the only one in Australia. It is primarily the great diversity and endemism of plants that has earned the region this recognition. Flammable vegetation and hot, dry summers have ensured that fire is a natural environmental factor in the region, which together with climate, landform and soils, has operated over thousands of years to forge this biodiversity (Hallam 1975, Hassell and Dodson 2003). Prior to European settlement, lightning started fires but more frequently they were set by Aboriginal people who used fire with confidence and skill for a myriad of reasons. Plants, animals and ecosystems evolved in this fire prone-environment and developed a range of physical and behavioural traits that enabled them to persist with, and in some cases, depend upon a variety of fire regimes (Burrows and Wardell-Johnson 2003).

For many plant species, reproduction and regeneration are cued or enhanced by fire and for many plant communities, particular fire regimes are necessary for the maintenance of floristic and structural diversity. A particular sequence and scale of fires are necessary to provide habitat diversity and opportunity for animals. However, the way in which species and communities respond to fire is variable (see Burrows and Abbott 2003). Some assemblages are quite resilient to a range of fire regimes (fire regime resilient assemblages), including frequent fire, and recover to their pre-fire state relatively quickly, while others are more sensitive to fire regimes and can take many decades to recover (fire regime specific assemblages). There are 'natural bounds' in terms of the frequency of burning, spatial extent, season and intensity of fire beyond which the floral and faunal components of ecosystems are unable to sustain themselves. Thus, no fire regime, or history of fire interval, season, intensity, patchiness and scale is optimal for all species and communities and although fire diversity is important for promoting biodiversity, some fire regimes can also threaten biodiversity.

The damage potential and difficulty of suppression of a bushfire is determined by the amount of live and dead vegetation that burns (the fuel), its moisture content and the weather conditions. In the absence of fire, fuel accumulates to relatively high levels before stabilising, as the rate of accession equals the rate of decomposition (Peet 1971, Burrows 1995). Prior to European settlement, extensive burning by Aboriginal people probably maintained a small-grained mosaic of vegetation at different stages of post-fire development, which would have provided habitat diversity and limited the spread and intensity of fires (see Hallam 1975, Abbott 2003, Lamont *et al*. 2003).

Today, in fragmented, urbanised and settled landscapes, wildfires can threaten people, property and conservation values. The rapidly expanding rural-urban interface is most vulnerable, but even beyond this, wildfires threaten towns, farms and other industry and infrastructure. Two broad fire management objectives have been identified by conservation and land management agencies (Burrows and Abbott 2003): a) to conserve biodiversity; and b) to ensure an acceptable level of protection to human life, property, industry and cultural values. Strategies to achieve these objectives will invariably involve prescribed fire. Fire management is complex, potentially dangerous and often controversial, and requires the skilful combination of art and science.

In this paper, we outline an integrated fire planning framework being developed in the south-west of Western Australia to conserve biodiversity, but which also provides for the land management and strategic asset protection outcomes required of land managers. The framework based on twelve key scientific principles, consists of five basic processes; (1) specifying fire management objectives for various spatial scales, (2) mobilising and applying the substantial body of biophysical and fire ecology knowledge using GIS, (3) incorporating other land management objectives and activities such as timber harvesting, (4) carrying out a risk analysis (wildfire threat analysis) and adjusting prescribed fire regimes to accommodate community asset protection obligations, and (5) continuously improving fire management through uptake of new knowledge gained from experience, research and monitoring (adaptive management). Although not specifically identified in this planning framework because it is generic to all land use planning in the modern era, community consultation and participation is essential for successful outcomes.

Key Fire Planning Principles

Knowledge to underpin fire management has advanced as a result of experience and ongoing research undertaken by a range of organisations over the last 40 years or so. Although incomplete, there is a substantial body of science that has not been fully utilised in fire planning processes. Knowledge of fire in south-west ecosystems has been synthesised in a book recently published following a fire symposium held in Perth in April 2002 (Abbott and Burrows 2003). From this synthesis, and drawing on the experiences of other land management agencies (Parks Victoria 1999), Burrows and Abbott (2003) have proposed 12 key principles to guide fire planning.

Principle 1: The vegetation and climate of the south-west region make it highly prone to bushfire. Fire should be regarded as an environmental factor that has and will continue to influence the nature of south-west landscapes and biodiversity and is integral to natural resource management.

Principle 2: Species and communities vary in their adaptations to, and reliance on, fire. Knowledge of the ways in which species and communities respond to fire, and of the temporal and spatial scales of fires in relation to the life histories of organisms or communities involved underpins the use of fire.

Principle 3: Following fire, environmental factors such as landform, topography and species' life history attributes, and random events such as climatic events, often drive ecosystems towards a new transient state with respect to species composition and structure. This may preclude the identification of changes specifically attributable to fire.

Principle 4: Fire management is required for two primary reasons, which are not necessarily mutually exclusive: a) to conserve biodiversity and b) to reduce the impact of wildfires on life, property and industry.

Principle 5: Fire management should be both precautionary and adaptive, considering ecological and protection objectives in order to optimise outcomes.

Principle 6: Fire diversity promotes biodiversity at both the landscape scale and the local scale. At the landscape scale, a mosaic of patches of vegetation representing a range of biologically-derived fire frequencies, intervals, seasons, intensities and scales will provide diversity of habitats for organisms that are mobile and can move through the landscape. At the local scale, appropriate fire regimes based on biological attributes are necessary to ensure the persistence of sessile organisms and structures.

Principle 7: Avoid applying the same fire regime over large areas for long periods of time and avoid seral and structural homogenisation by not treating large areas with extreme regimes such as sustained very frequent (<4 years) or very infrequent (>20 years) fire intervals (see Burrows and Abbott 2003 for biological characterisation of fire intervals).

Principle 8: The scale, or grain-size, of the fire-induced mosaic should a) enable natal dispersal b) optimise boundary habitat (interface between two or more seral states) and c) optimise connectivity (ability of keystone fauna to migrate between seral states).

Principle 9: All available knowledge, including life histories, vital attributes of the flora and fauna, fire history and knowledge of Aboriginal fire regimes should be utilised to develop ecologically-based fire regimes.

Principle 10: Fire history, vegetation complexes and landscape units should be used to develop known and ideal fire age class distributions at the landscape scale.

Principle 11: Wildfire can damage and destroy both conservation and societal values including life, property and industry. Risk management must be based on a systematic, structured and transparent approach to identifying, ameliorating and managing the consequences of such an event.

Principle 12: Fire management should adapt to new knowledge gained through research, monitoring and experience and take account of changing community expectations.

Fire management objectives for different scales

Having clear fire management objectives for the conservation of biodiversity is of key strategic and operational importance. They assist with the development of fire management plans and standards, with determining strategies and tactics and with assessing the acceptability or otherwise of the environmental impacts of fire as they are understood from research and monitoring (risk analysis).

The following hierarchical set of broad fire management objectives and strategies attempts to encapsulate the spatial and temporal scales important for maintaining biodiversity. Setting objectives for different scales reflects the reality that ecosystems and organisms within them are dynamic and ever changing, rather than static and fixed in space and time.

At the bioregional scale (tens of thousand of square kilometres).
A bioregion is a large geographic area that is similar with respect to climate, geology, landforms, broad vegetation types, flora and fauna and land use (Thackway and Creswell 1995). There are seven bioregions in the south-west. The fire management objective is to protect and maintain the environmental, social and economic values of the bioregion.

Broad strategies include:
Undertaking a risk analysis to determine the strategic importance of assets in various bioregions and where resource allocations are most needed to protect assets. Such decisions are usually made at political and senior levels in management agencies. Operational strategies include cataloguing key environmental, social and economic assets within the bioregion and assessing how they may be impacted by fire. Other strategies include identifying landscapes within bioregions and using landscape biological and physical characteristics to devise appropriate fire management strategies (see below).

At the landscape scale (tens of thousands of hectares).
There are likely to be many landscapes within a bioregion. A landscape can be conceptualised (and mapped) as being a mosaic where the mix of local ecosystems and landforms is repeated in a similar form over a kilometres-wide area within a bioregion (after Forman 1995). Several attributes, including climate, landforms, soils, assemblages of local flora and fauna and disturbance regimes tend to be similar and repeated across the area. Mattiske and Havel (2002) have recently defined and mapped Landscapes Conservation Units (LCUs) for the forest areas of the south-west.

Fire management objectives at this scale are: to maintain biodiversity and a diverse range of ecosystem structures, seral states and habitats through space and time; to protect relatively fire sensitive and fire regime specific ecosystems and niches such as riparian zones, aquatic ecosystems, peat wetlands (Horwitz *et al.* 2003), some swamps, some valley floors, rock outcrops and young regrowth forests from frequent fire or large and intense wildfire. Fire regime specific ecosystems are usually characterised as those that contain plant species that are obligate seeders with long juvenile periods, fauna that are habitat-specific, have low fecundity and dispersal capacity and prefer late mature or mid-late successional stage vegetation, communities that take a relatively long time to recover to their pre-fire state and vegetation types that are less flammable because they either occupy mesic habitats or have sparse ground fuels.

Broad strategies to achieve these objectives include:
Maintaining an interlocking mosaic of patches of vegetation at different seral states including recently burnt and long unburnt states, and patches burnt in different seasons. The mosaic should have at least three biologically significant phases, being a) time since last fire, b) fire frequency and c) fire season. Phases should be determined from knowledge of the fire ecology and life histories of taxa occurring within the landscape.

Using vital attributes of plants and animals such as: juvenile period (age to first flowering) of plants that depend on seed for regeneration after fire (obligate seeders); the life span of serotinous species (obligate seeders with seed stored in woody capsules in the canopy): and habitat requirements of key fauna (especially fauna that require mature, late successional state vegetation and rare and endangered taxa) to estimate the range of desirable seral states (time since last fire) and fire frequencies within a landscape.

Favouring small to medium fire management units (not burnt patch size) within the range of a few hundred to a few thousand hectares. Scale, grain size or patch size of the mosaic is important in determining boundary habitat (or area of edge effect or interface between different seral states) and connectivity (dispersal and hence recolonisation). There may need to be a trade-off with what is practical and cost effective to implement. The mosaic should be dynamic by varying the fire regime at the local or patch scale (see below). Design and juxta-position of fire management units within the landscape should be such that boundary habitat is optimised, or avoid linking units with the same or similar post-fire state. Retain manageable and representative "no planned burn" scientific reference areas where possible as part of the mosaic.

Reducing the likelihood of events such as large, intense and damaging wildfires by incorporating risk mitigation strategies such as fuel reduction burning into the overall mosaic.

At the Fire Management Unit (FMU) scale (a few hundred to a few thousand hectares).
A fire management unit is a spatial element within a landscape unit. It is an area that has a manageable boundary in terms of fire security (roads, tracks or natural fuel breaks) that lends itself to burning, or partial burning, as a unit. It could contain a representation of landforms, ecosystems and vegetation complexes (Mattiske & Havel 1998) common to the landscape unit. Fire management units can be sinks or sources of recolonisation.

Fire management unit scale objectives are to:

- conserve biodiversity through time (recognises temporal fluctuations associated with disturbances such as fire, and other natural phenomena).
- implement diverse and dynamic fire regimes varying in season, frequency and interval of fire.
- provide a variety of habitats, seral states and structures through time.
- protect relatively fire sensitive and fire regime specific ecosystems and niches such as riparian zones, aquatic ecosystems, peat wetlands, granite outcrops and new growth forests from frequent fire or large and intense wildfire.

Broad strategies to achieve these include:
Varying the fire regime applied to an FMU. This involves varying the season, frequency and interval of fire using knowledge of fire responses, vital attributes and life histories of key taxa to circumscribe regime bounds for each vegetation complex or ecosystems where the ecosystem can be discriminated, or recognised by fire at some point in time (differentially flammable). Unless there is a substantial reason to do otherwise, fire should be excluded or used very cautiously in small patches of remnant vegetation (say <500 ha). Experience has shown that small remnants can be vulnerable to post-fire degradation due to weed invasion, feral animal invasion and heavy grazing pressure by invertebrates, feral herbivores and macropods following fire.

Implementing mostly low intensity, patchy burns within the FMU to create a fire-induced mosaic at the FMU scale is desirable (creating patchiness within patches). Small-grained fire-induced mosaics (patchiness) can be achieved a number of ways, including using natural and artificial physical fire barriers, burning when moisture differentials exist across the landscape, introducing fire into the landscape frequently when fuel flammability (quantity and cover) differentials exist, using wind-driven strips in heath vegetation and regulating the lighting/ignition pattern. Occasional moderate intensity fires under summer/autumn conditions are desirable to regenerate vegetation and habitats.

Burning flammable, drier vegetation assemblages or habitats at intervals ranging from frequent to infrequent, based on vital attributes and life histories of key taxa (see Burrows and Friend 1998, Burrows and Abbott 2003). Burning less flammable (fire sensitive and fire regime specific) habitats (e.g. riparian zones, some swamps, valley floors, granite outcrops) less frequently, the interval determined by vital attributes and life histories of key taxa. Selective burning of adjacent flammable assemblages by exploiting flammability differentials also provides protection to fire sensitive habitats.

Assembling datasets: planning considerations

Planning to achieve the objectives outlined above should commence at the landscape scale and due to the complexity of the information involved can only be undertaken in a GIS environment. Some of the themes for which data need to be assembled and utilised in this process are summarised in Table 1. Having identified and mapped the various planning scales (described above), the next task is to assemble all available biological and ecological knowledge to assist with decision making. Considering the vital attributes and life histories of key flora and fauna species occurring within the Landscape Conservation Units, especially of "fire sensitive taxa", enables the identification of the appropriate 'bounds' for the fire regimes in those habitats, particularly the return period between fire events, the season and intensity of fire, and the scale or size of burnt patches. "Fire sensitive" flora, or flora with specific fire regime requirements, are those that are readily killed by fire, that depend upon seed stored in the canopy for regeneration (serotinous) and that have relatively long juvenile periods. However, these taxa usually require fire at some stage in their life cycle for regeneration. "Fire sensitive" fauna are those taxa that have specific habitat requirements with respect to the structure and seral state of the vegetation and have low dispersal capacity (Burrows and Friend 1998).

Landscape Conservation Units are the basic planning units within which to consider management and asset protection considerations. Biodiversity, land management and asset protection must be considered at a landscape scale and at a localised fire management unit scale. Constant iteration between these two scales is necessary to optimise the outcomes at both scales.

The next step is to incorporate other land management considerations into the planning process. These themes are associated with the requirements of activities such as timber harvesting, silviculture and scientific study and usually have a short to medium term impact on fire regimes. These themes are considered within the bounds of each Land Conservation Unit. After their inclusion the indicative burn plan is adjusted to ensure that the biodiversity outcomes are still achievable whilst optimising other management objectives.

The third step is to consider the strategic protection requirements for both tangible assets (those with a commercial value such as town sites, infrastructure, timber and other industries) and intangible assets (those that are not able to be valued commercially such as ecologically threatened communities and cultural heritage values). This is undertaken utilising a Wildfire Threat Analysis approach that takes into account the spatial distribution of these assets and their value; potential fire behaviour, suppression capacity and risk of ignition (Muller 1993). After the inclusion of asset protection requirements, the indicative burn plan is adjusted to ensure that the biodiversity outcomes are still achievable whilst optimising management objectives and the asset protection obligations.

Planning the Landscape Scale Mosaic

Identify areas that are not to be burnt, i.e., set aside from burning for a period of time. These may include areas that are identified in statutory management plans for reservation from burning for some specified purpose and period, areas that have been identified as scientific reference areas for the study of fire effects or other research plots, areas that contain a value that is sensitive to fire such as fire sensitive regrowth or a declared rare flora site, areas that are subject to a land management constraint such as an area required to remain unburnt for a period of time long enough to enable the use of flora to interpret the distribution of dieback disease.

Identify the areas that must be burnt within the planning period. These may include:
areas that need to be burnt as a high priority to provide strategic protection to assets such as fire sensitive regeneration, infrastructure, life and property values, areas that are subject to disturbance by timber harvesting and require a pre or post harvesting fire treatment for operational or silvicultural reasons; and areas that are subject to fire research.

Table 1. – Some of the information themes that are manipulated in a GIS environment in the development of indicative burning programs.

Biodiversity Inputs	**Description**
Vegetation Complex	A biogeographical unit derived by considering vegetation as a reflection of the underlying geology, soils, landscape and climate
Land Conservation Unit	An amalgam of Vegetation Complexes into broadly homogeneous landscape units
Diverse Ecological Zones	Areas of localised diversity such as rock outcrops, swamps, peat wetlands and riparian zones
Fauna habitat types	An amalgam of vegetation complexes based on fauna habitat use and vegetation structure
Fire regime specific flora	Flora species with vital attributes that make them dependent on a particular fire regime; usually susceptible to very frequent or very infrequent fire.
Fire regime specific fauna	Fauna species with life histories that make them dependent on a particular fire regime; usually susceptible to very frequent or very infrequent, large and intense fire.
Fire regime specific fauna habitats	Fauna habitats that are dependent on a particular fire regime.
Fire history	Information on the season and periodicity of past fire events
Management Inputs	
For example, timber harvesting plan	Identifies areas scheduled for timber harvesting operations that require pre-harvest fire treatments
For example, silviculture plans	Identifies areas disturbed by timber harvesting that require fire treatments to promote regeneration or to protect fire sensitive regrowth
Scientific reference areas	Areas identified as long term study areas for fire effects research
No plan burn areas	Areas identified in statutory management plans that are not to be burnt
Asset Protection Inputs	
Wildfire Threat Analysis	Information on wildfire risk zones that result form consideration of risk of ignition, potential fire behaviour, suppression response capability, and the location and value of assets at risk

Conservation assets	Information on the spatial distribution, conservation status and fire sensitivity of conservation assets such as Declared Rare Flora, threatened fauna, threatened ecological communities and fauna re-introduction sites etc.

Planning the Fire Management Unit (FMU) Scale Mosaic

The vegetation complexes within the FMU are mapped and linked to the biophysical and fire response databases. The fire-proneness and fire sensitivity of each vegetation complex is characterised as Low, Medium or High, based on the above information. Fire proneness is a measure of the flammability of the complex in terms of fuel quantity, structure and annual moisture content variation. For each FMU a known and inferred vascular flora and vertebrate fauna species list is generated from existing databases. From these, 'fire sensitive' or fire regime dependent taxa are identified by intersecting species lists with fire response databases and their vital attributes, especially juvenile period (time to first flowering after fire), longevity, post-fire regeneration response (flora) and post-fire state habitat preference and dispersal capacity (fauna). The known or inferred location of these taxa is mapped, as are the known locations of rare and threatened taxa. In most cases, "fire sensitive" taxa will occur in those parts of the landscape that are less prone to fire. Juvenile period and longevity (flora), and preferred habitat condition (fauna) with respect to the relationship between vegetation structural development and time since fire, are used to help set minimum and maximum fire intervals for the ecosystems or habitats in which they occur. Information about the distribution of flora in the south-west is readily accessible electronically as a result of advanced and innovative IT systems developed at the Western Australian Herbarium.

Research shows that late summer/early autumn fires optimise regeneration and survival from seed in Mediterranean ecosystems (e.g. Burrows and Wardell-Johnson 2003). However, fire severity and homogeneity (extent of the landscape burnt in a fire event) is proportional to fuel dryness and fuel quantity, so frequent summer/autumn fires are undesirable unless the frequency is such that the fires are patchy and low intensity (e.g., every 2-4 yrs in dry forests). Within an FMU, there is likely to be at least two broad habitat types that require different fire regimes. The drier, more flammable uplands will generally contain plant species that are mostly resprouters, have relatively short juvenile periods (<3-4 years) and which recover relatively quickly following fire, and fauna that do not require mature or medium to late successional state vegetation. On the other hand, the lowlands, creeks, swamps, rock outcrops etc. (less fire-prone parts of the landscape) will most likely contain one or more plant species that are fire sensitive with relatively long juvenile periods (>3-4 years), and animal species that prefer mature or medium to late successional stages of vegetation. Moisture and fuel flammability differentials across the management unit (between broad habitat types) can be exploited to differentiate the fire regimes applied to flammable and less flammable habitats within a FMU, using vital attributes and habitat requirements to set upper and lower limits of fire interval (as described above).

Monitoring and adaptive management

Monitoring is an important part of the Plan-Do-Check cycle of continuous improvement (adaptive management). Monitoring actual results against specified objectives or anticipated outcomes is critical to building knowledge and allowing adaptive management to occur over time. Burn prescriptions and objectives should realize the opportunity to undertake simple field experiments. All fires, either planned or unplanned, should be treated as opportunities from which to learn about fire behaviour and impacts. It is important that records of extent, date and timing of each fire continue to be meticulously maintained. Such assessments should involve both remote sensing and on-ground validation.

It is self-evidently impossible to monitor the impact of hundreds of fires each year on the thousands of species present in the south-west of WA. However, it is feasible to demonstrate the degree to which spatial heterogeneity of fire is achieved. More intensive on-ground monitoring of biodiversity at representative sites can complement this.

Conclusions

It is possible by using biogeographical partitioning of the landscape and the vital attributes and life histories of key taxa that occur within landscape units, to manipulate complex data sets within a GIS environment to develop and apply fire regimes that aim to conserve biodiversity. It is possible to achieve and maintain meaningful diversity at both the local and landscape scales using such an approach. In doing so it is also possible to optimise the fire management solutions for achieving land management and asset protection outcomes.

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