A BIOLOGICAL BASIS FOR PLANNED BURNING

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Fires in Victoria have shaped the vegetation for many millennia. Anthropogenic fires have been used to manage the landscape, initially as an agricultural tool, latterly for ecological reasons and as a means of minimizing the damage done by wildfires. Some characteristics of Victoria's fire planning and management processes are discussed, such as the requirement for maintenance of biodiversity values and the Adaptive Experimental Management approach being followed. Similarly, some of the most critical regeneration characteristics of plants and vegetation types are highlighted and how these affect burning plans. Given the lack of fully-populated data sets various synthetic whole-of-ecosystem approaches are necessary and the derivation and application of one of these (establishment of Maximum and Minimum Tolerable Fire Intervals) is presented. Ecological constraints on existing (fire and fuel) management are discussed and directions for future research and on-going management considered, including the gaps in our current knowledge base.

Key words: Biodiversity values, fire management, ecological constraints.

PLANNED BURNING (also known as 'fuel reduction burning', 'prescribed burning', 'hazard reduction burning' and 'control burning') is a standard technique used by land managers around Australia, to manage wildfire in the landscape and to reduce the adverse impacts of wildfires on both the human built environment and the natural environment (Andersen 1999; Esplin et al. 2003; Lamb 2004; Sandell et al. 2006; Sneeuwjagt 2008; Whelan 2002). The rationale and many of the approaches initially adopted were originally derived from overseas (Attiwill 1994a; Bock and Bock 1978; Gill 1975; Glitzenstein et al. 1995; Komarek 1971; Kruger and Bigalke 1984; Midgley 1989; van Wilgen and Viviers 1985) but the continuing rationales and approaches are now largely endogenous (Andersen et al. 2005; Ecological Society of Australia 1997; Bell et al. 1984; Dyer et al. 2001; Friend et al. 2004; Gill 1975, 1977; Leonard 2004; Lunt 1995; Tran and Wild 2000; Williams et al. 1994).

Planned burning is a complex process that defines and balances the objectives and constraints for applying an intentional fire to part of the landscape, within an over-arching framework usually determined by a state or territory government agency under direction from the relevant government minister(s) (Bell et al. 1984; Friend et al. 2004; Russell-Smith and Bowman 1992). As in other jurisdictions, Victoria's policy framework for planned burning includes consideration of reduction of hazardous fuels (which exacerbate the dangers presented by wildfires and impede their control) and maintenance of essential ecological processes in the landscape (Friend et al. 2004).

Planned burning is a very difficult process due to the many, often competing, priorities that must be accommodated. One of those priorities is the maintenance of essential ecological processes and patterns. Biological / habitat maintenance is part of the process for determining and implementing planned burns on public land in Victoria (Friend et al. 2004; Leonard 2004). Very little of Victoria's bushland is private land (Mansergh et al. 2006). Hence, the management of fire on public land is virtually synonymous with the management of fire in bushland and native habitats.

MANAGEMENT OF FIRE ON PUBLIC LAND IN VICTORIA

Maintenance of essential ecological processes is a critical objective in implementing Victoria's fire management planning on public land. 'Essential ecological processes' includes the maintenance of the spread, diversity and vigour of the state's habitats and species. Species' requirements are intended to be incorporated using the 'Vital Attributes' model of Noble & Slatyer (1980, 1981). 'Vital Attributes' are those physiological or developmental characteristics of plant and animal species that determine how the species recover from fire in the landscape. Such attributes include time to first reproduction after the fire, time to maximum reproduction after the fire and how individuals survive the fire.

The ecological goal is to maintain all (pre-burn) indigenous species at the site(s) proposed for planned burns, without irretrievable adverse impacts from planned burning, and whilst minimizing adverse impacts from wildfires (Friend et al. 2004; Leonard 2004). This policy goal may include the application of planned fires to maintain or recover species whose local populations are shrinking or individuals senescing as a result of infrequent fires (Frood 1979; Hocking 1998; Vaughton 1998; Witkowski et al. 1991).

Ideally, the Vital Attributes of all species at a locality proposed for planned fire should be stored in an accessible dataset, so that these data may be interrogated to determine which (if any) species may be adversely affected by a planned burn (or by the absence of a proposed fire) (Noble 1985; Noble and Slatyer 1980). The proposed burn may then be modified to reduce or remove these potential adverse effects, or to enhance a species' recovery (Friend 2004; Friend et al. 1999; Friend et al. 2004; Tolhurst and Friend 2001). A Vital Attributes dataset for vascular plant species has been established in Victoria (McCarthy et al. 2003; Tolhurst and Friend 2001) and is being maintained and curated by the author. Vertebrates are intended to be incorporated into this Vital Attributes approach soon (Machunter et al. 2009).

ADEQUACY OF EXISTING DATA

A fully-populated Vital Attributes dataset was recommended as a **minimum** requirement to enable the Vital Attributes approach to effectively model plant species and vegetation and thus incorporate plant species' and vegetation requirements into fire management and planning (Noble 1985; Noble and Slatyer 1980, 1981). Acquisition of the relevant data involves a determined commitment to data collection (Gill and Bradstock 1992; Whelan et al. 2006) and often involves expert inference of the existing and somewhat scant data (McCarthy et al. 2003; McCarthy et al. 2001). Collection of field data on Vital Attributes is a long-term exercise. For example, even after a decade of data collection and curation, the Victorian Vital Attributes dataset has only scored 1711 taxa (32% of the state's flora) for their Key Fire Responses, leaving 3692 taxa (68%) not assessed (data extracted from the Vital Attributes dataset of 11th November 2011).

Lack of a fully-populated dataset will not prevent the application of a régime of applied fires and will not prevent control of wildfires. Planned fires will still be applied, and wildfires will still be controlled by back burns, fuel reduction, application of suppressants and other means (State of Victoria 2009). The recommendations from the 2009 Victorian Bushfires Royal Commission (www.royalcommission.vic.gov.au), which the state government has largely accepted, included a continuation of the former practice of using planned burns to manage hazardous fuel levels and greatly increased targets of hectares to be burnt in planned fires each season.

The Vital Attributes dataset is not fully populated and there are significant knowledge gaps in how species and communities respond to fires (discussed below). Despite these deficiencies, we must use these data to incorporate ecological considerations into planning burns. Otherwise, there would be no defined process for inclusion of ecological considerations into planned burns, and these would be drafted and applied with scant ecological input. The current zoning scheme for fire planning (DSE 2004) and its proposed update and replacement (DSE 2011) specify that ecological considerations are part of the planning for each zone and prime in some of the specified zones.

ECOSYSTEM APPROACH

In the absence of a fully-populated Vital Attributes dataset and of empirical research and data on the individual responses of all species to fire, it may be legitimate to adopt a whole-of-ecosystem approach (Anderson and Inouye 2001; Bohning-Gaese 1997; Kruger 1981; Lamont 1992; May et al. 2003; Norton 1996; Sattler and Williams 1999). The base vegetation unit for ecological fire planning in Victoria is the Ecological Vegetation Class (EVC) (Friend et al. 1999; Friend et al. 2004; Lamb 2004; Tolhurst and Friend 2001; Wouters 2002), for which a statewide data layer is accessible to the public (Table 1). Each EVC is backed up with a web-based (www.dse.vic.gov.au) benchmark, that describes 'typical' condition for the vegetation unit. Ideally, ecological fire planning should be based on the time since fire of the EVC(s) in the subject landscape unit and the presence of Key Fire Response Species

(KFRS; as determined from their Vital Attributes, and as identified in the Vital Attributes dataset). Key Fire Response Species are defined as those species which are particularly sensitive to changes in the fire régime and are thus most suitable as indicators of past régimes and as monitoring subjects in relation to future fires.

There are problems with some of the assumptions behind this approach (Cheal 2004; Robinson 2006; Wallis et al. 2007), but it is comprehensive across the state and its procedures and basic tools are explicit and accessible to the public. A summary of EVC data sets developed by DSE is provided in Table 1.

However, there are over 300 vegetation units in the NV2005_EVCBCS data layer; a prohibitively large number for individual consideration in fire planning. There was sense in aggregating these map units into fewer but larger, ecologically based groupings. The existing schemes for major vegetation groups were surveyed. Around 30 units was thought useful for large-scale uses in relation to fire management. A previous project for Parks Victoria (Long et al. 2003) erected 32 larger-scale vegetation units. This project, which focused on the impact of rabbits on vegetation and habitats in the reserves system at a statewide scale, included the recognition of large-scale vegetation units termed 'Ecological Vegetation Divisions'. The unit 'EVD' was named in analogy with the formal system of botanical nomenclature, in which the next major taxonomic unit above 'Class' was termed 'Division'.

Each EVD is a grouping of more than one EVC. This approach enables EVDs to be mapped using the NV2005_EVCBCS data layer. Some of the EVDs devised by Long et al. (2003) were renamed to avoid confusion with similarly named EVCs in the NV2005_EVCBCS data layer (refer Table 2 for name changes). These larger units (ie. EVDs) were at a feasible scale for assigning fire responses (fewer EVDs than EVCs and thus EVDs encompassed a larger area). Of course, smaller scale units (such as a group of EVCs) would better represent local variability and landscape specificities than a broad scale unit such as an EVD. However, there is neither the data nor the staff to support fire planning and application at such fine scale sensitivity.

TOLERABLE FIRE INTERVALS

The assignment of minimum and maximum tolerable fire intervals (TFIs) to EVDs was an important component of the project to provide fire management information integrated with the existing native vegetation data sets. TFIs give fire managers information on the ecological adaptation of EVDs to fire (régimes), so that the frequency, severity and intensity of planned fires can be scheduled and conducted in ways that ensure the ecological sustainability of native vegetation communities and their constituent species (Cheal 2010).

The ideal interval between fires for any given vegetation community is determined by the time taken by the constituent species to flower and set seed, the time taken to accumulate an adequate seed bank and the time to extinction in the absence of fire. If fire is too frequent, species that are not able to reproduce may be lost from the community (Enright et al. 2011; Morrison et al. 1995; Vaughton 1998). If the interval between fires is too long, species that depend on fire for regeneration may become locally extinct (Keith 1996; Williams 2006).

Detailed research on the fire ecology of Australian native vegetation communities is patchy (Tran and Wild 2000). Some vegetation communities, such as basalt grasslands, heathlands and mountain forests, have been well studied (Ashton 2000b; Attiwill 1994a; Gill 1975; Gill and Groves 1981; Whelan et al. 2006). However, even for these vegetation communities, information on the long-term influences of fire is still incomplete. Therefore, the ecological futures of most vegetation communities under various fire régimes were estimated using expert knowledge and opinion (Ashton 2000b; Cheal 1994). In the context of adaptive management, it was thought acceptable to use information based on the best available knowledge, provided that the uncertainties in using assumed data were recognized (Cheal 2010).

Adaptive experimental management (Oglethorpe 2000) provided a theoretical framework for incorporating unreliable and uncertain data into applied fire management, on the assumption that experience gained while applying a fire management plan feeds back into the planning process, enabling later plans to be more soundly based. This 'learning by doing' has been recognized as an integral part of the Fire Ecology Program for the past 10 years (Friend et al. 1999; Friend et al. 2004). Ultimately, long-term data (derived from research and survey) will provide for greater certainty and strengthen assumptions.

In spite of these uncertainties and assumptions, a process was undertaken to assign maximum and minimum TFIs for each EVD. The process

Table 1 Summary of DSE's native vegetation data sets* at 2007. Data set names are in the form NV(Year)_(attribute), where NV stands for native vegetation, (Year) is the year to which the data applies, e.g. 1750 is just prior to the first European settlement in Australia and 2005 is the year of the modelled current extent (the next year may be 2010 or 2015, depending on monitoring frequency), and (attribute) is the type of information stored in the data set (EVC, EVCBCS, QUAL, etc.).

2007 Data set	Data set name
NV1750_EVC	Native Vegetation, 1750 – Ecological Vegetation Classes
NV1750_EVCBCS	Native Vegetation, 1750 – Bioregional Conservation Status of EVCs
NV2005_EXTENT	Native Vegetation, 2005 – Extent
NV2005_EVCBCS	Native Vegetation, 2005 – Bioregional Conservation Status of EVCs
NV2005_QUAL	Native Vegetation, 2005 – Quality

followed by Wouters (2002) was used where data were available.

Flora records were accessed using the Flora Information System (FIS) (Gullan 2009) and KFRS were identified using DSE's Vital Attributes dataset. Vascular plant species with the longest juvenile period were identified, concentrating on those with a propagule bank that is exhausted immediately after fire and those with the shortest time to senescence and local extinction. In each EVD the long juvenile period species were utilized as the prime determinants of the minimum tolerable fire interval (MinTFI), and the short senescence/local extinction species were the prime determinants for the maximum tolerable fire intervals (MaxTFIs).

For EVDs with limited species-based data, TFIs were assigned by using expert knowledge, experience and modelling to derive reasonable approximations of the maximum and minimum TFIs (Cheal 2010). A continuing commitment to adaptive management using data derived from ongoing monitoring and research will enable these assumptions to be refined in the future when specific data are available.

FIRE SEVERITY

Many vegetation communities experience little variation in fire severity between repeat fires at a single site – either the vegetation community burns or it does not. This is commonly the situation where vegetation is not strongly stratified – where the strata are physically close, so that the flames may easily reach them all, or where intensities and fuel levels are usually so high that no stratum easily escapes the flames, no matter what distance or height separates it from other strata. An example of effectively unstratified vegetation is Basalt Plains Grassland (Lunt 1991; Stuwe 1994). An example of vegetation that usually experiences only high severity fires in which all strata are burnt is the tall wet forests of the Central Highlands (Ashton 1976, 2000a; Attiwill 1994b).

However, in other vegetation communities it is possible to have fires of different severity at one site because of local variations in characteristics such as season of burn, weather conditions when the fire front arrives and topography (Harris 2002; Morrison and Renwick 2000; Prober and Thiele 2004). In these communities fire behaviour and severity are less predictable and it is possible for the same site to experience fires of different severities at different times, depending on the local conditions (Catchpole 2001; Gill 1975; Whelan et al. 2006; Whelan and York 1998). This can be a common pattern in vegetation composed of different strata that are separated to an extent that flames in less intense fires have little prospect of reaching other strata.

When fires are of low intensity (or severity), small fuel discontinuities or localized topography or weather conditions may (temporarily) extinguish the fire, creating unburnt islands in a sea of burnt habitat (Bradstock et al. 1996; Russell-Smith et al. 2002; Thomas et al. 2003; Wiltshire and Lord 1997). In higher intensity fires, such small fuel discontinuities are less likely to (locally) extinguish the fire and there are fewer unburnt refuges left after the fire front has passed (Bradstock et al. 1996; Gill and Bradstock 1995; Whelan 1995).

In the TFI process, two broad intensity/severity classes were recognized; one where (moderate or patchy) scorching resulted in rapid resprouting without a significant impact on vegetation structure, and one where full scorching resulted in a structural change that took a significantly longer time from which to recover.

It is the patchiness of less severe fires that particularly affects the survival and regeneration of many plant species at a site. A highly patchy fire (e.g. where 40% or more of the land within the fire perimeter remains unburnt) retains a substantial

Table 2 EVD name changes, from Long et al. (2003) to current report.

EVD No.	EVD Name (Long et al. 2003)	EVD renamed
4	Swampy Scrub	Damp Scrub
7	Lowland Forest (eastern)	Tall Mixed Forest (eastern)
10	Damp Forest	Moist Forest
12	Wet ForestTall	Mist Forest
13	Rainforest	Closed-forest
18	Rocky Outcrop Shrubland	Rocky Knoll
22	Semi-arid Woodland (non-eucalypt)	Dry Woodland (non-eucalypt)
23	Alluvial Plains Woodland	Inland Plains Woodland
29	Chenopod Mallee	Saltbush Mallee

area of refuges in which obligate seed-regenerating species (those killed by fire) survive, at the same time providing regeneration opportunities for seedling regeneration on nearby burnt ground. A second fire in close succession could be presumed to kill all the new seedlings and produce a local extinction (Bradstock et al. 1996; Macfarlane 1994; Manders 1987). However, if both fires were of low severity (and hence very patchy) then patches unburnt by both fires would remain. Thus, two high-severity fires in close succession may lead to local extinctions, but two low-severity (patchy) fires in close succession are far less likely to lead to local extinctions (Thomas et al. 2003). As a result, the minimum tolerable inter-fire intervals for low severity fires were set lower than for high severity fires in the same vegetation community (Smith et al. 2000). Patchiness may provide some insurance against local extinctions of fire-sensitive species (Whelan 1995), but further work is required to flesh out the importance of patchiness and the relevance of different patterns of habitats in space and time.

Nevertheless, and at the same time, less intense fires may adversely affect survival chances for fire sensitive species, by killing some parent individuals and yet not providing the relevant fire-related cues for seed release nor establishment (Archer 1984; Brits et al. 1993; Smith et al. 2000).

Maximum tolerable fire intervals did not usually vary with fire severity, as these intervals were substantially determined from the longevities of species in the absence of fire. However, in some vegetation communities the minimum tolerable fire intervals varied with severity. High-severity fires (sometimes referred to as 'stand replacement fires') in such communities were often wildfires, and low-severity fires were often planned burns (mainly ecological or fuel reduction burns, Table 3). The correlations of high severity with homogeneity of burn (and the contrary situation of low severity with heterogeneity or patchiness) are weak and far from universal, but may be reliable enough to justify this distinction in the Minimum Tolerable Fire Intervals. Using these data, in conjunction within the vegetation (spatial) data set, maps can be produced to assist ecological fire planning, Figures 1 and 2 (Cheal 2010). These maps may also be produced at a variety of scales, to assist ecological fire planning. Cheal (2010) includes discussion of other aspects of ecological fire planning, such as the derivation of explicit growth stages and comparison of growth stages across a variety of EVDs.

KNOWN UNKNOWNS

Despite the advances discussed above, there are gaps in our knowledge base – ecological problems that have, as yet, been addressed in only a cursory or preliminary way. These include:

1. **Seed Bank Longevities** – Seed bank studies are notoriously difficult and it is generally accepted that the soil seed bank as determined from conventional methods only 'correlates' with the true soil seed bank (Brown 1992; Pierce and Cowling 1991; Ramp 1994). Nevertheless, it is critical to understand the longevity of seed in the soil in order to differentiate between the 'life span' of photosynthetic plants at a site from the life span of a species at a site. Many plants die within a few years of fire-cued germination. This does not mean that they are locally extinct, as viable seed may survive for many decades in the soil (Ballairs et al. 2006; Bossard 1993; Holmes and Cowling 1997; Keeley 1986; Ramp 1994)
2. **Death of resprouters in fires** – Many models of fire in vegetation assume that all individuals of species able to resprout post-fire do resprout. This is

Table 3 Maximum and minimum Tolerable Fire Intervals for 3 example EVDs

EVD no.	Ecological Vegetation Division	Max Fire Interval	Min Interval for high intensity fires	Min Interval for low intensity, patchy fires
2	Heathland (sands)	45 years	12 years (all except Little & Big Deserts)	8 years (only where Xanthorrhoea resinosa dominant)
				12 years (all except X. resinosa dominant or Little & Big Deserts)
			15 years (Little & Big Deserts only)	15 years (Little & Big Deserts only)
8	Foothills Forest	100 years	25 years	10 years
20	Basalt Grassland	7 years	3 years	2 years

clearly not the case. There is always a (small?) proportion of resprouters that is killed by the fire (Benwell 2007; Enright and Lamont 1992; Nicolle 2006; Rice and Westoby 1999; Tolsma 2002; Wright and Clarke 2007).

3. Differential effects of planned fires vs. wild fires – There are many differences between planned fires and wild fires, including season of burn, heterogeneity (patchiness), on-site intensity, fuel moisture content, weather on day(s) of burn and many more (Sneeuwjagt 2008; Whelan 2002; Wuerthner 2006). Some research has focused on understanding and quantifying these differences (McCarthy et al. 2001; Tolhurst and Friend 2001; Watson 2001), but we still know very little about these differential effects in most ecosystems.

4. Seasonal effects immediately after fires – Recovery post-fire is influenced by many factors, but

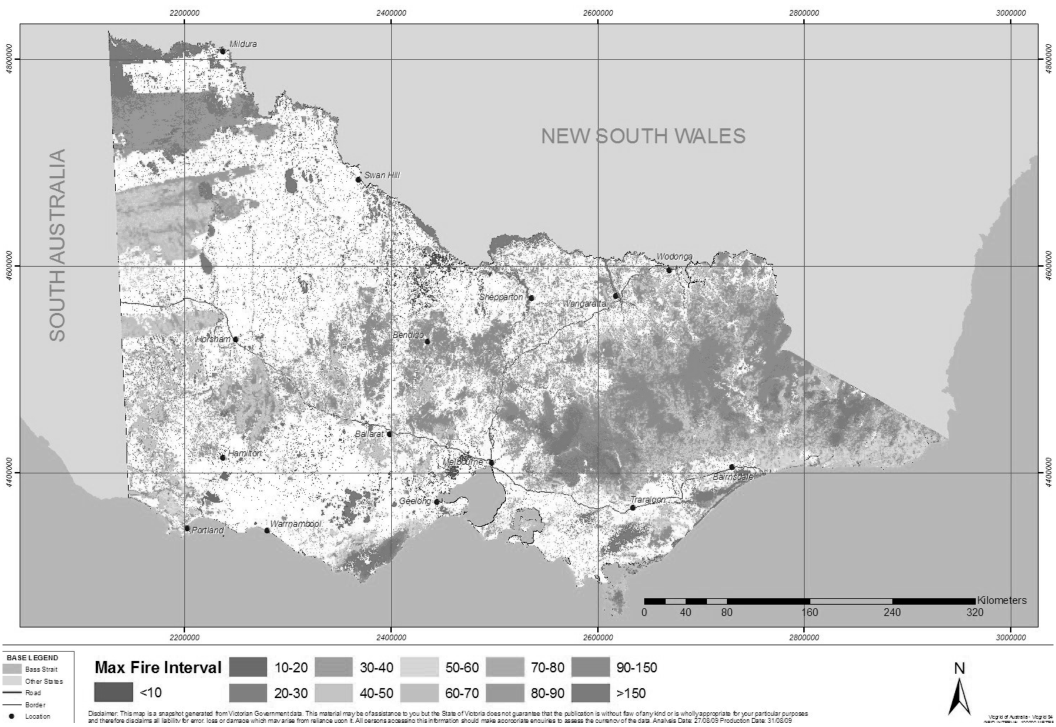
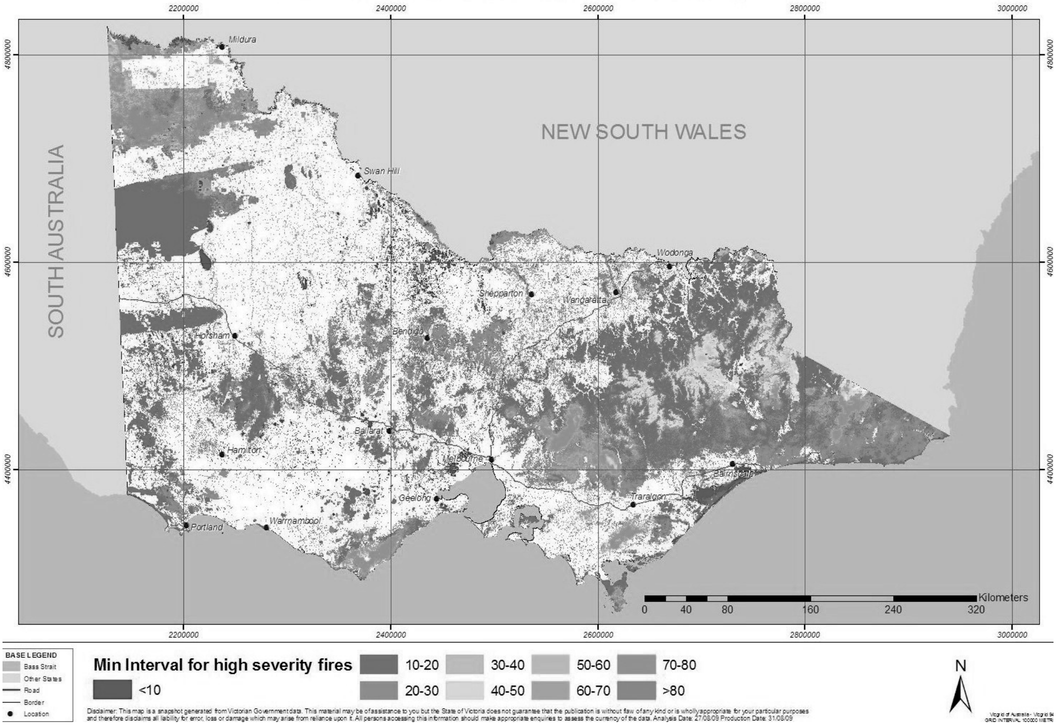


Fig. 1. Maximum TFIs for native vegetation. (spatial data prepared by Andrew Blackett, DSE)

Fig. 2. Minimum TFIs (for high severity and low severity fires) for native vegetation. (spatial data prepared by Andrew Blackett, DSE) (facing page)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SOUTH AUSTRALIA
Mildura
Swan Hill
Wodonga
Shepparton
Wangaratta
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Bendigo
Ballarat
Hamilton
Melbourne
Bairnsdale
Traralgon
Geelong
Portland
Warrnambool
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BASE LEGEND
Bass Strait
Other States
Road
Border
Location
Min Interval for high severity fires
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10-20
20-30
30-40
40-50
50-60
60-70
70-80
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N
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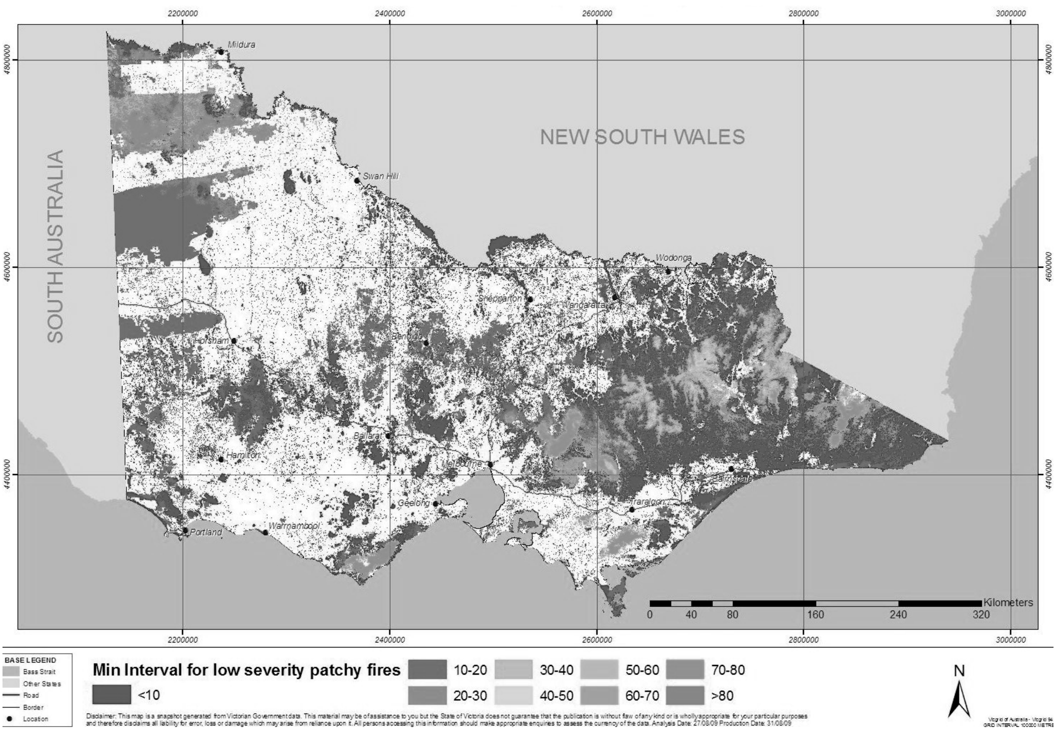
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notably important is the seasonal conditions in the first season after fires (Hill and French 2004; Lamont and Groom 1998; Moreno and Oechel 1992; Whelan and York 1998; Wright and Clarke 2007). Nevertheless, there have been few correlative studies characterizing the effects on regeneration of post-fire seasonal conditions.

5. **Effects of fires on weeds** – Weeds are often highly visible in the first few seasons post-fire. Whilst we have some studies investigating the impacts of fires on a few high profile environmental weeds (Bachmann and Johnson 2010; Ingamells 2007; Leach 2011; Moore and Thomas 2011; Williams and Wardle 2007), there are so many environmental weed species in so many different ecological systems that the effects of fires on weeds remains substantially uninvestigated.

6. **Effects of fires on introduced vertebrate pests** – Similarly, very little is known of the impacts of introduced vertebrate predators on the indigenous fauna and how these impacts change with, and are dependent on, the fire régimes (Gill and Catling 2002).

7. **Effects of fires on flammability of the local vegetation – do fires increase flammability of the regrowth, and, if so, by how much?** – There are numerous anecdotal observations that post-fire regrowth may be more flammable than the local vegetation was before the fire (wild or planned) in some vegetation communities (Barnett 2007; Green 2003; Russell-Smith *et al.* 2002). Nevertheless, this aspect of applied fire régimes is largely uninvestigated.

8. **Fire in select communities (eg. Box-Ironbark)** - We are yet to identify a burning régime which might enhance (rather than simply maintain) biodiversity of Box-Ironbark remnants. Many other habitats have been only cursorily investigated.

Until many outstanding issues can be resolved we must tread warily with our use of fire in a depleted and fragmented landscape.

CONCLUSIONS

There have been substantial advances over the last decade that have enabled ecological considerations to become part of fire planning. Processes for fire planning that include ecological considerations have been developed and are gradually assuming their place as essential to informed application of fire management. Nevertheless, we remain largely ignorant of many aspects of fire in native landscapes and can only incorporate ecological considerations by extrapolation from existing data and by inference within our current knowledge base.

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REFERENCES

Andersen, A.N., 1999. Fire management in northern Australia: beyond command-and-control. *Australian Biologist* 12: 63-70.

Andersen, A.N., Cook, G.D., Corbett, L.K., Douglas, M.M., Eager, R.W., Russell-Smith, J., Setterfield, S.A., Williams, R.J. & Woinarski, J.C.Z., 2005. Fire frequency and biodiversity conservation in Australian tropical savannas: implications from the Kapalga fire experiment. *Austral Ecology* 30: 155-167.

Anderson, J.E. & Inouye, R.S., 2001. Landscape-scale Changes in Plant Species Abundance and Biodiversity of a Sagebrush Steppe over 45 Years. *Ecological Monographs* 71: 531-556.

Archer, W.R., 1984. Thesium australe R. Brown (SANTALACEAE) – Field Notes and Observations. *Victorian Naturalist* 101: 81-85.

Ashton, D.H., 1976. The Development of Even-aged Stands of *Eucalyptus regnans* F. Muell. in Central Victoria. *Australian Journal of Botany* 24: 397-414.

Ashton, D., 2000a. The Environment and Plant Ecology of the Hume Range, Central Victoria. *Proceedings of the Royal Society of Victoria* 112: 185-278.

Ashton, D.H., 2000b. The Big Ash Forest, Wallaby Creek, Victoria - changes during one lifetime. *Australian Journal of Botany* 48: 1-26.

Attiwill, P.M., 1994a. The disturbance of forest ecosystems: the ecological basis for conservative management. *Forest Ecology and Management* 63: 247-300.

ATTIWILL, P.M., 1994b. Ecological disturbance and the conservative management of eucalypt forests in Australia. *Forest Ecology and Management* 63: 301-346.

BACHMANN, M. & JOHNSON, R., 2010. Distribution, outbreak observations and implications for management of Bluebell Creeper *Billardiera heterophylla* (Lindl.) L. Cayzer & Crisp, in the Green Triangle region of south-eastern Australia. *Victorian Naturalist* 127: 137-145.

BALLAIRS, S.M., BARTIER, F.V. & GRAVINA, A.J., BAKER, K., 2006. Seed biology implications for the maintenance and establishment of *Tetratheca juncea* (Tremandraceae), a vulnerable Australian species. *Australian Journal of Botany* 54: 35-41.

BARNETT, J., 2007. Fire management gone berserk? In 'update'. pp. 1.

BELL, D.T., HOPKINS, A.J.M. & PATE, J.S., 1984. Fire in the Kwongan. In Pate, J.S. & Beard, J.S. (eds), *Kwongan Plant Life of the Sandplain*. University of Western Australia Press, Perth, pp. 178-204.

BENWELL, A. 2007. Response of rock-outcrop and fringing vegetation to disturbance by fire and drought. *Australian Journal of Botany* 55: 736-748.

BOCK, C.E. & BOCK, J.H. 1978. Response of Birds, Small Mammals, and Vegetation to Burning Sacaton Grasslands in Southeastern Arizona. *Journal of Range Management* 31: 296-300.

BOHNING-GAESE, K. 1997. Determinants of avian species richness at different spatial scales. *Journal of Biogeography* 24: 49-60.

BOSSARD, C.C. 1993. Seed Germination in the Exotic Shrub *Cytisus scoparius* (Scotch Broom) in California. *Madrono* 40: 47-61.

BRADSTOCK, R.A., BEDWARD, M., SCOTT, J. & KEITH, D.A., 1996. Simulation of the Effect of Spatial and Temporal Variation in Fire Regimes on the Population Viability of a *Banksia* Species. *Conservation Biology* 10: 776-784.

BRITS, G.J., CALITZ, F.J., BROWN, N.A.C. & MANNING, J.C., 1993. Desiccation as the active principle in heat-stimulated seed germination of *Leucospermum* R. Br. (Proteaceae) in fynbos. *New Phytologist* 125: 397-403.

BROWN, D., 1992. Estimating the composition of a forest seed bank: a comparison of the seed extraction and seedling emergence methods. *Canadian Journal of Botany* 70: 1603-1612.

CATCHPOLE, W., 2001. Fire properties and burn patterns in heterogeneous landscapes. In *Flammable Australia: The fire regimes and biodiversity of a continent*'. R.A. Bradstock, J.E. Williams & A.M. Gill, eds, Cambridge University Press, Melbourne.

CHEAL, D., 2004. A Consideration of Victoria's Proposals for Ecological Burning, using Mallee Heathlands as a case study. In *Bushfire 2004 Earth, Wind and Fire Fusing the Elements*. Department of Environment and Heritage, Adelaide.

CHEAL, D., 2010. *Growth stages and tolerable fire intervals for Victoria's native vegetation data sets*. Arthur Rylah Institute for Environmental Research 84, Heidelberg, Victoria.

CHEAL, D.C., 1994. Fire Succession in Heathlands and Implications for Vegetation Management. In *Fire and Biodiversity The Effects and Effectiveness of Fire Management*. Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra, p. 278.

DSE, 2004. Using Fire to manage our parks and forests. In (Ed. DSE Victoria) pp. 4. Department of Sustainability and Environment, Melbourne.

DSE, 2011. Fire Management Zones. In. (Ed. DSE Victoria) pp. 4. Department of Sustainability and Environment, Melbourne.

DYER, R., JACKLYN, P., PARTRIDGE, P., RUSSELL-SMITH, J. & WILLIAMS, D., 2001. 'Savanna Burning Understanding and using fire in northern Australia.' (Tropical Savannas CRC: Darwin)

ECOLOGICAL SOCIETY OF AUSTRALIA, 1997. The Use of Fire in Ecosystem Management. In *Bulletin of the Ecological Society of Australia*. pp. 160-163. (Ecological Society of Australia: Canberra, ACT)

ENRIGHT, N., FONTAINE, J., WESTCOTT, V., MILLER, B. & LADE, J. 2011. Effects of short interval fire on woody species biodoversity in kwongan (shrublands) of the Mid-West Region, SW Australia. In 'Western Australian Bushfire Research Forum 2011'. pp. 17. Department of Conservation and Environment, Perth.

ENRIGHT, N.J. & LAMONT, B.J. 1992. Recruitment variability in the resprouting shrub *Banksia attenuata* and non-sprouting congeners in the northern sandplain heaths of southwestern Australia. *Acta Oecologica* 13: 727-741.

ESPLIN, B., GILL, A.M. & ENRIGHT, N.J., 2003. *Re-*

port of the Inquiry into the 2002-2003 Victorian Bushfires. Department of Premier and Cabinet, Melbourne.

FRIEND, G., 2004. Fire impacts on fauna. *Victorian Naturalist* 121: 116-121.

FRIEND, G., LEONARD, M., MACLEAN, A. & SIELER, I., 1999. Management of fire for the conservation of biodiversity: new initiatives in Victoria. In *Bushfire 99*. Charles Sturt University, Albury.

FRIEND, G., Leonard, M., Walker, I. & McHugh, P., 2004. *Guidelines and Procedures for Ecological Burning on Public Land in Victoria 2004*. Fire Ecology Working Group, Department of Sustainability and Environment, Melbourne.

FROOD, D., 1979. 'Dynamics of a post-1951 fire in heathland, Tidal Overlook, Wilsons Promontory, Victoria'. BSc (Hons) thesis, University of Melbourne.

GILL, A.M., 1975. Fire and the Australian flora: A review. *Australian Forestry* 38: 4-25.

GILL, A.M., 1977. Management of fire-prone vegetation for plant species conservation in Australia. *Search* 8: 20-26.

GILL, A.M. & BRADSTOCK, R.A., 1992. A national register for the fire responses of plant species. *Cunninghamia* 2: 653-660.

GILL, A.M. & BRADSTOCK, R., 1995. Extinction of biota by fires. In *Conserving biodiversity: threats and solutions*. R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney & D.P. Sivertsen, eds, Surrey Beatty & Sons, Chipping Norton, NSW, pp. 309-322.

GILL, A.M. & CATLING, P.C., 2002. Fire regimes and biodiversity of forested landscapes of southern Australia. In *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. R.A. Bradstock, J.E. Williams & A.M. Gill, eds, Cambridge University Press, Melbourne, pp. 351-372.

GILL, A.M. & GROVES, R.H., 1981. Fire regimes in heathlands and their plant ecological effects. In *Ecosystems of the World 9B Heathlands and Related Shrublands Analytical Studies*. R.L. Specht, ed, Elsevier Scientific, New York, pp. 61-84.

GLITZENSTEIN, J.S., PLATT, W.J. & STRENG, D.R., 1995. Effects of fire regime and habitat on tree dynamics in North Florida Longleaf Pine Savannas. *Ecological Monographs* 65: 441-476.

GREEN, K., 2003. Fires. *Victorian Naturalist* 120: 153-155.

GULLAN, P.K., 2009. *Flora Information System*. Viridans: East Bentleigh, Victoria.

Harris, M., 2002. Cypress Pine Forests. *Australian Plants* 21: 317-319.

HILL, S.J. & FRENCH, K., 2004. Potential impacts of fire and grazing in an endangered ecological community: plant composition and shrub and eucalypt regeneration in Cumberland Plain Woodland. *Australian Journal of Botany* 52: 23-29.

HOCKING, C., 1998. *Preliminary Report on the NRE-Funded Project Management of Senescent Themeda*. Victoria University, Melbourne.

HOLMES, P.M. & COWLING, R.M., 1997. Diversity, composition and guild structure relationships between soil-stored seed banks and mature vegetation in alien plant-invaded South African fynbos shrublands. *Plant Ecology* 133: 107-122.

INGAMELLS, P., 2007. Willows on the march. In *Parkwatch*. p. 21. Victorian National Parks Association, Melbourne.

KEELEY, J.E., 1986. Resilience of mediterranean shrub communities to fire. In *Resilience in Mediterranean-type Ecosystems - Tasks for Vegetation Science 16*. B Dell, AJM Hopkins & BB Lamont, eds, W. Junk: Dordrecht, pp. 95-112.

KEITH, D., 1996. Fire-driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. *Proceedings of the Linnean Society of New South Wales* 116: 37-78.

KOMAREK, E.V., 1971. Principles of fire ecology and fire management in relation to the Alaskan environment. In *Fire in the Northern Environment* pp. 3-19

KRUGER, F.J., 1981. Conservation; South African Heathlands. In Ecosystems of the World 9B Heathlands and Related Shrublands Analytical Studies'. (Ed. RL Specht). (Elsevier Scientific: New York)

KRUGER, F.J. & BIGALKE, R.C., 1984. Fire in Fynbos. In *Ecological Effects of Fire in South African Ecosystems*. Pd.V. Booysen & N.M. Tainton, eds, Springer-Verlag, Berlin.

LAMB, A., 2004. Use of fire in ecological management. In F*ield Nats News*, p. 10.

LAMONT, B.B., 1992. Functional interactions within plants - the contribution of keystone and other species to biological diversity. In *Biodiversity of Mediterranean Ecosystems in Australia*. R.J. Hobbs, ed, Surrey Beatty & Sons, Chipping Norton, pp. 95-127.

Lamont, B.B. & Groom, P.K., 1998. Seed and seedling biology of the woody-fruited Proteaceae. *Australian Journal of Botany* 46: 387-406.

Leach, D., 2011. Sunmary of fire suppressant impacts on flora of the Swan Coastal Plain. In *Western Australian Bushfire Research Forum*. R. Sneeuwjagt, R. Smith & P. Grierson, eds, Department of Environment and Conservation and University of Western Australia, Perth, p. 35.

Leonard, M., 2004. Victoria's parks, forests and fire. *Victorian Naturalist* 121: 122-128.

Long, K., Robley, A., Cheal, D., White, M.D., Carter, O., Tolsma, A. & Oates, A., 2003. *Prioritisation of Rabbit Control within the Parks Victoria Estate; Reducing Risks to Environmental Values*. Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria.

Lunt, I.D., 1991. Management of remnant lowland grasslands and grassy woodlands for nature conservation: a review. *Victorian Naturalist* 108: 56-66.

Lunt, I.D., 1995. European management of remnant grassy forests and woodlands in south-eastern Australia – past, present and future? *Victorian Naturalist* 112: 239-249.

MacFarlane, K., 1994. Fire in mallee shrubland at Hattah: The effects of time since fire and a short fire interval. B. Sc. (Hons.) thesis, La Trobe University.

MacHunter, J., Menkhorst, P. & Loyn, R., 2009. *Towards a process for integrating Vertebrate Fauna into Fire Management Planning*. Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria.

Manders, P.T.,1987. A transition matrix model of the population dynamics of the Clanwilliam Cedar (*Widdringtonia cedarbergensis*) in natural stands subject to fire. *Forest Ecology and Management* 20: 171-186.

Mansergh, I., Anderson, H. & Amos, N., 2006. Victoria's living natural capital-decline and replenishment 1800-2050 (Part 1). *Victorian Naturalist* 123: 4-28.

May, T., New, T., Walsh, N. & Yen, A., 2003. The Victorian *Flora and Fauna Guarantee Act* and the Conservation of lesser known groups of biota. *Victorian Naturalist* 120: 248-260.

McCarthy, G., Tolhurst, K.G. & Chatto, K., 2003. *Determination of Sustainable Fire Regimes in the Victorian Alps using Plant Vital Attributes*. Department of Sustainability and Environment, Melbourne.

McCarthy, M., Possingham, H.P. & Gill, A.M., 2001. Using stochastic dynamic programming to determine optimal fire management for *Banksia ornata*. *Journal of Applied Ecology* 38: 585-592.

Midgley, J.J. 1989. Season of burn of serotinous fynbos Proteaceae: A critical review and further data. *South African Journal of Botany* 55: 165-170.

Moore, J. & Thomas, E., 2011. Fighting the willow menace on the Bogong High Plains. In *Parkwatch*. Victorian National Parks Association, Carlton, pp. 8-9.

Moreno, J.M. & Oechel, W.C., 1992. Factors controlling postfire seedling establishment in southern California chapparal. *Oecologia* 90: 50-60.

Morrison, D.A., Cary, G.J., Pengelly, S.M., Ross, D.G., Mullins, B.J., Thomas, C.R. & Anderson, T.S., 1995. Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: Inter-fire interval and time-since-fire. *Australian Journal of Ecology* 20: 239-247.

Morrison, D.A. & Renwick, J.A., 2000. Effects of variation in fire intensity on regeneration of co-occurring species of small trees in the Sydney region. *Australian Journal of Botany* 48: 71-79.

Nicolle, D., 2006. A classification and census of regenerative strategies in the eucalypts (*Angophora, Corymbia* and *Eucalyptus* – Myrtaceae), with special reference to the obligate seeders. *Australian Journal of Botany* 54: 391-407.

Noble, I.R., 1985. Fire effects, vital attributes and expert systems. *Technical Memorandum - CSIRO, Australia, Division of Water and Land Resources* 85: 96-103.

Noble, I.R. & Slatyer, R.O., 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* 43: 5-21.

Noble, I.R. & Slatyer, R.O., 1981. Concepts and models of succession in vascular plant communities subject to recurrent fire. In *Fire and the Australian Biota*. A.M. Gill, R.H. Groves & I.R. Noble, eds, Australian Academy of Science, Canberra, pp. 311-335.

Norton, T.W., 1996. Conservation of biological diversity in temperate and boreal forest ecosystems. *Forest Ecology and Management* 85:, 1-7.

Oglethorpe, J.A.E., 2000. *Adaptive Management : From Theory to Practice*. IUCN, Gland, Switzerland.

PIERCE, S.M. & COWLING, R.M., 1991. Dynamics of soil-stored seed banks of six shrubs in fire-prone dune fynbos. *Journal of Ecology* 79: 731-747.

PROBER, S.M. & THIELE, K.R., 2004. *Fire recovery vegetation monitoring in White Box - White Cypress Pine woodlands of East Gippsland*. Department of Sustainability and Environment, Melbourne.

RAMP, D., 1994. Seed-bank dynamics and germination ecology in Mediterranean Heathland, Wyperfeld National Park. BSc (Hons) thesis, University of Melbourne.

RICE, B. & Westoby, M., 1999. Regeneration after fire in *Triodia* R. Br. *Australian Journal of Ecology* 24: 563-572.

ROBINSON, R., 2006. Ecological vegetation classes - an over-simplification? *Indigenotes* 17: 3-4.

RUSSELL-SMITH, J. & BOWMAN, D.M.J.S., 1992. Conservation of monsoon rainforest isolates in the Northern Territory, Australia. *Biological Conservation* 59: 51-63.

RUSSELL-SMITH, J., RYAN, P.G. & CHEAL, D.C., 2002. Fire regimes and the conservation of sandstone heath in monsoonal northern Australia: frequency, interval, patchiness. *Biological Conservation* 104: 91-106.

SANDELL, P., TOLHURST, K., DALTON, J., SCOTT, B. & SMITH, M., 2006. Fire management prescriptions for the Victorian Mallee Parks. *Proceedings of the Royal Society of Victoria* 118: 395-412.

SATTLER, P. & WILLIAMS, R., 1999. *The Conservation Status of Queensland's Bioregional Ecosystems*. Environment Protection Agency, Brisbane.

SMITH, M.A., LONERAGAN, W.A., GRANT, C.D. & KOCH, J.M., 2000. Effect of fire on the topsoil seed banks of rehabilitated bauxite mine sites in the jarrah forest of Western Australia. *Ecological Management and Restoration* 1: 50-57.

SNEEUWJAGT, R., 2008. 'Prescribed burning: how effective is it in the control of large forest fires. In *International Bushfire Research Conference*'. Department of Environment and Conservation, Adelaide.

STATE OF VICTORIA, 2009. Submissions of the State of Victoria. In *Victorian Bushfires Royal Commission*. Melbourne, p. 46.

STUWE, J., 1994. The role of fire in ground flora ecology. *Victorian Naturalist* 111: 93-95.

THOMAS, P.B., Morris, E.C. & Auld, T.D., 2003. Interactive effects of heat shock and smoke on germination of nine species forming soil seed banks within the Sydney region. *Austral Ecology* 28: 674-683.

TOLHURST, K.G. & FRIEND, G.R., 2001. An objective basis for ecological fire management – a Victorian case study. In *Bushfire 2001*. FRFANZ Christchurch.

TOLSMA, A.D., 2002. The effects of fire and grazing on the energy reserves of resprouting plants in Victoria's alpine grasslands. PhD thesis, University of Melbourne.

TRAN, C. & WILD, C., 2000. *A review of current knowledge and literature to assist in determining ecologically sustainable fire regimes for the southeast Queensland region*. Griffith University, Brisbane.

van WILGEN, B.W. & VIVIERS, M., 1985. The effect of season of fire on serotinous Proteaceae in the Western Cape and the implications for fynbos management. *South African Forestry Journal* 133: 49-53.

VAUGHTON, G., 1998. Soil seed bank dynamics in the rare obligate seeding shrub, *Grevillea barklyana* (Proteaceae). *Australian Journal of Ecology* 23: 375-384.

WALLIS, A.M., JAMIESON, D. & WALLIS, R.L., 2007. Use by birds and mammals of habitatsof different complexity in remnant and revegetated sites in the Wannon Catchment, Western Victoria. *Victorian Naturalist* 124: 149-156.

WATSON, P., 2001. The role and use of fire for biodiversity conservation in Southeast Queensland: Fire management guidelines derived from ecological research. In pp. 49.

WHELAN, R., KANOWSKI, P, GILL, M. & ANDERSEN, A. , 2006. Living in a land of fire. In. pp. 22.

WHELAN, R.J., 1995. *The Ecology of Fire*. Cambridge University Press, Melbourne.

WHELAN, R.J., 2002. Managing fire regimes for conservation and property protection: an Australian response. *Biological Conservation* 16: 1659-1661.

WHELAN, R.J. & YORK, J., 1998. Post-fire germination of *Hakea sericea* and *Petrophile sessilis* after Spring burning. *Australian Journal of Botany* 46: 367-376.

WILLIAMS, J.E., WHELAN, R.J. & GILL, A.M., 1994. Fire and environmental heterogeneity in southern temperate forest ecosystems: implications for Management. *Australian Journal of Botany* 42: 125-137.

WILLIAMS, M.C. & WARDLE, G.M., 2007. *Pinus radi-*

ata invasion in Australia: Identifying key knowledge gaps and research directions. *Austral Ecology* 32: 721-739.

WILLIAMS, N.S.G., 2006. 'The ecology of fragmented native grasslands in urban and rural landscapes'. PhD thesis, University of Melbourne.

WILTSHIRE, G.G. & LORD, B.L., 1997. Impacts of mosaic burning: the importance of patchiness and herbivory in the post-fire environment. In *Bushfire '97*. B.J. McKaige, R.J. Williams & W.M. Waggitt, eds, CSIRO Tropical Ecosystems Research Centre, Darwin, pp. 101-106.

WITKOWSKI, E.T.F., LAMONT, B.B. & CONNELL S.J., 1991. Seed bank dynamics of three co-occurring Banksias in south coastal Western Australia: the role of plant age, cockatoos, senescence and interfire establishment. *Australian Journal of Botany* 39: 385-397.

WOUTERS, M., 2002. *Analysis of disturbance by fire on public land in Victoria*. Department of Natural Resources and Environment, Melbourne.

WRIGHT, B.R. & CLARKE, P.J., 2007. Fire regime (recency, interval and season) changes the composition of spinifex (*Triodia* spp.)-dominated desert dunes. *Australian Journal of Botany* 55: 709-724.

WUERTHNER, G., 2006. *Wild fire: A Century of failed Forest Policy*. Island Press: Chicago.