FIRE REGIMES AND BIODIVERSITY CONSERVATION: A BRIEF REVIEW OF SCIENTIFIC LITERATURE WITH PARTICULAR EMPHASIS ON SOUTHWEST AUSTRALIAN STUDIES

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ABSTRACT

To assist the EPA in its review of fire management by the Department of Conservation and Land Management, this paper briefly reviews the published scientific literature pertaining to the impact of fire regimes on biodiversity conservation. With some exceptions, literature on this subject is primarily descriptive, short term and correlational, and often lacks sufficient definitional and experimental rigour for conclusive and predictive statements on hypotheses to be drawn. Consequently, alternative interpretations and conclusions are commonplace, and much remains to be investigated.

Understandably, no studies address the role of fire in maintaining and protecting all biodiversity. The literature is selective as to species and communities investigated, with a focus on some vascular plants and some vertebrates. The importance of sampling effects, replication issues and surrogacy have rarely been tested. Taxonomic impediments and cryptic life history stages such as resting or dormant propagules confound attempts to rigorously sample biota. A few descriptive studies where effects of more than a single fire have been documented show changes in the relative abundance of some plants and animals. Rigorous experimental science has been applied to hypotheses relating to life history attributes with obvious fire effects, such as the role of smoke and heat on germination of many vascular plants. Fire exclusion combined with predator control and experimental translocation have led to increased abundance of rare vertebrates such as Noisy Scrub Birds. However, trends in metapopulation dynamics under different fire regimes are known for few organisms, and even less has been documented about interactions between fire effects and those caused by other processes such as disease attack, predation, herbivory, salinity etc.

Much more research is required to approach an adequate understanding of fire regimes and biodiversity conservation. Two broad streams are recommended – (i) long term descriptive and correlational monitoring studies to generate hypotheses on the impact of fire scale, intensity, season and patchiness – monitoring sites need to be replicated frequently across southwest Australian landscapes to adequately sample rapid geographical turnover in less vagile organisms such as most vascular plants, land snails etc.; and (ii) rigorous experimental studies with adequate sampling, replication and controls to test hypotheses and develop predictive theory regarding fire regimes and biodiversity conservation. High priority should be given to test current hypotheses enumerated herein.

INTRODUCTION

To assist the EPA in its review of fire management by the Department of Conservation and Land Management, this paper briefly reviews the published scientific literature pertaining to the impact of fire regimes on biodiversity conservation. We focus on southwest Australian studies as requested in our terms of reference (Appendix A). The review is limited to edited books and peer-reviewed scientific journals. Time available (one month) did not allow for the voluminous grey literature on fire regimes and biodiversity conservation to be consulted and considered. However, we have drawn upon the collective reading of the two junior authors of the scientific literature over the past two decades in addition to the month of intensive review conducted by the senior author.

The review is broadly structured in line with headings and subject areas identified in the terms of reference (Appendix A). However, to enhance clarity, two subjects are first addressed: (i) definitional issues and (ii) descriptive v/s experimental studies.

DEFINITIONAL ISSUES

Biodiversity is the variety of life – the genes, species and communities of all living things. *Biodiversity conservation* is the process of minimising extinction of living things – genes, species and communities.

Fire regime is the frequency, interval, season, intensity, scale and patchiness of fire. *Prescribed burns* are those ignited for the application of planned fire regimes by land managers. *Wildfires* are those ignited by nonhuman causes or by humans in a manner not planned by land managers.

Much confusion and debate has been generated by the use of scientific terminology in nonspecialist literature regarding fire regimes and biodiversity conservation. For example, evolutionary terms relating to “adaptation” require rigorous testing and proof to be accurately invoked, including experimental demonstration of function, heritability, and natural selection, and application of phylogenetic tests (Hopper 2003).

Needless to say, few traits of Australian biota have been subject to such rigorous tests to demonstrate the existence of evolutionary adaptations to fire. Yet many authors, including scientists, use terms such as “fire-adapted” when discussing Australian biota, rather than neutral terms such as “fire tolerant”. These logical leaps lead some readers/listeners to draw the conclusion that a “fire-adapted” biota should therefore be able to deal with any fire regime it is exposed to.

A classic example is the commonly observed fire response of plants resprouting from underground rootstocks. Many authors glibly cite resprouting as an adaptation to fire. Yet it may be an effect of fire, with entirely different evolutionary origins, rather than an adaptation, since multiple other causes could select for resprouting – grazing, flooding, freezing etc.

DESCRIPTIVE V/S EXPERIMENTAL STUDIES

The foregoing highlights a major confusion often evident even in refereed scientific papers - that between a correlation or effect established in a descriptive study v/s a causal link established through rigorous experimentation. Descriptive studies can establish pattern and correlation, and help formulation of causal hypotheses, but they cannot establish causation. The latter requires rigorous experimentation with adequate sampling, replication and controls to test hypotheses. A further logical trap occurs when conclusions are drawn from extrapolations beyond those reasonably inferred from evidence at hand.

To highlight this difference, take a controversial contemporary southwest Australian example – inferences on historical fire regimes made from fire-scar patterns on balgas (grasstrees – Lamont *et al*. 2003). It has been elegantly demonstrated that a correlation exists between a change in the number of fire scars on grasstrees and the approximate dates of a change from Aboriginal to predominant European land management in the southwest (Figure 1). Fire scars appear more frequently (averaging 3-5 years) between 1860 and 1900 than subsequently (averaging 8-10 years since the 1950s). Some authors extrapolate this correlation to the whole landscape in which the balgas sit, arguing that Aboriginals burnt country on average every 3-5 years Lamont *et al*. 2003).

However, the evidence does not allow concluding anything more than that that individual grasstrees were burnt more frequently prior to European land management than afterwards. On the descriptive evidence available, to extrapolate from individual grasstrees to the surrounding landscape is not warranted. There are significant reasons why caution should be applied in this case. Firstly, a number of plants associated with the balgas require longer fire return intervals than 3-5 years to build up an adequate seed supply for replacement (Burrrows and Wardell-Johnson 2003). How could they have persisted in the landscape if the balga fire scar intervals applied to whole landscapes?

Secondly, palynological data and charcoal in fossil deposits similarly suggest longer average intervals (Hassell and Dodson 2003).

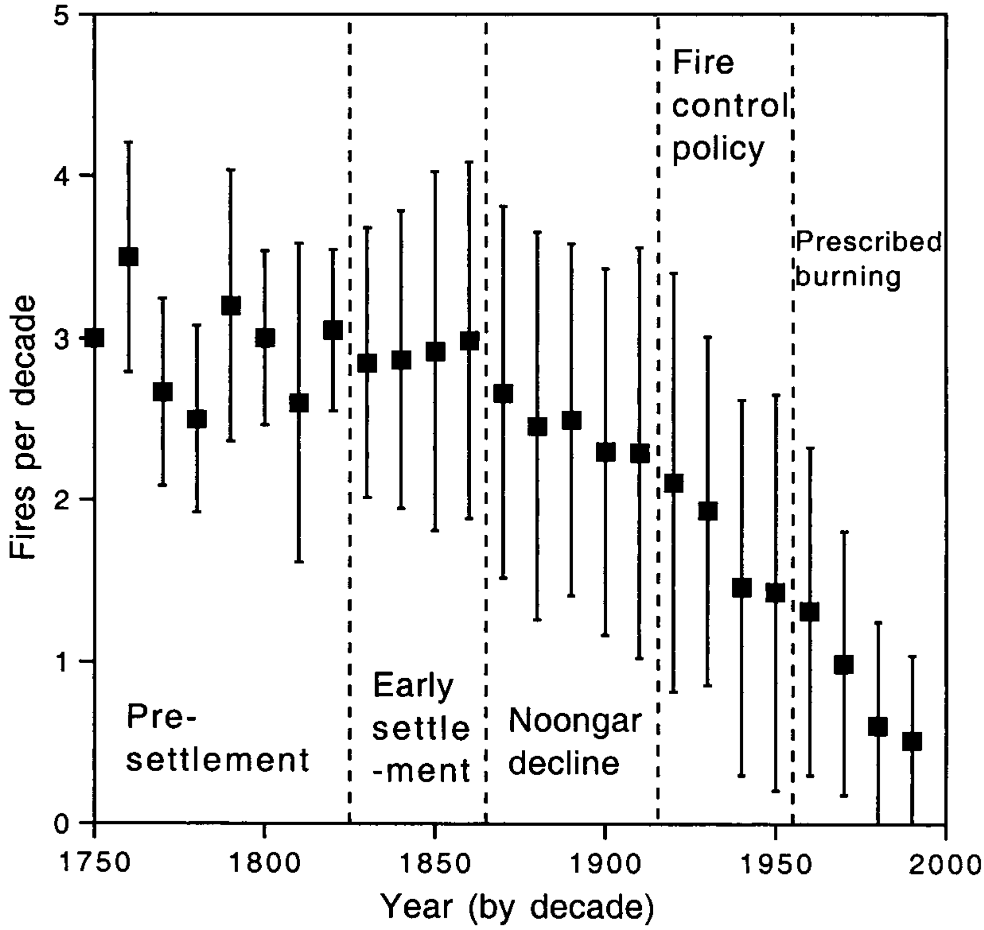

Figure 1: Mean number of fires per decade (± SD) for grasstrees at 50 sites scattered throughout the jarrah forest/woodland (Lamont *et al.* 2003).

Thirdly, it has been known since the journals of Banks and Menzies in the 18th Century that Aboriginal people burnt individual grasstrees for cultural reasons, especially to promote resinous exudates for use as glues, conceal their body odour, hunt for animals nesting within the grasstree, signal other people, etc. Given the sophisticated knowledge of fire use evident among Aboriginal people, perhaps they were able to burn grasstrees regularly for the above cultural purposes without incinerating the surrounding landscape. Evidence is therefore needed to falsify the hypothesis that surrounding landscape did not burn at the same frequency as inferred from fire scars on grasstrees before it could be argued that the fire scar pattern reflects a landscape pattern in fire regime. This is a difficult hypothesis to test in southwest Australia given that traditional Aboriginal land management is no longer practised. In such circumstances, it would be reasonable to simply note an interesting correlation (balga fire scars decrease in frequency over the transition from Aboriginal to European land management) but draw no conclusions regarding historical burning of landscapes from the balga fire scar data.

This is an exemplary case where alternative hypotheses can be invoked to explain a correlational pattern described from nature – balga fire scar frequency directly reflects landscape-level fire regimes v/s targeted cultural burning of balgas occurred independent of landscape-level fire regimes. Critical experiments are needed to test the competing hypotheses and ascertain more probable causal relationships. As will be evident, most of the literature we have reviewed below is descriptive and correlational in relation to fire regimes and biodiversity conservation. We should exercise similar caution in their interpretation, and be especially careful about extrapolation, inferring causation and predicting from correlations untested through rigorous experiment.

Although in the minority, there have been experimental studies that provide a link between attributes of fires and biodiversity. For example, increased germination of native species occurs after a smoke presowing treatment (Dixon *et al.* 1995, Roche *et al.* 1997a,b, Tieu *et al.* 1999). Studies were undertaken following observations that seedlings of some native species established only following fire. These correlational observations prompted the alternative hypotheses that either heat, smoke, ethylene or some other attrribute of fire causes germination. Subsequent experimentation in the laboratory and nursery has determined that both heat and smoke (Roche *et al.* 1997a,b, Tieu *et al.* 1999) can promote germination of seed of many plant taxa. These studies have identified that components of fire can cause a recruitment response from native species and therefore provide a link to fire effecting some components of biodiversity.

SCIENTIFIC EVIDENCE OF THE IMPACTS OF FIRE ON BIODIVERSITY

Scientific Evidence of a Long History of Fire in South-West Western Australia

Fire in southwest Australia predates human occupation (Aboriginal and European) by millions of years (Atahan and Dodson 2004; Hassell and Dodson 2003, Dodson 2001). A number of pre-human fire intervals have been estimated from charcoal records, including:

- Sediment cores from Fitzgerald River National Park of 30-100+ yr intervals operating 4.6-2.7 thousand years before present (Hassell and Dodson 2003);
- Return periods of 5-13 years during the Pliocene in south-west Western Australia (Atahan *et al.* 2004).

Human influence on fire regimes commenced c. 50, 000 years ago with the arrival of Aboriginals (Roberts *et al*., 1990, 1994 in Atahan *et al.* 2004; Turney *et al.* 2001 in Hassell and Dodson 2003). A number of methods have been employed to estimate the impact of human ignition on the fire regime including charcoal records (Atahan and Dodson 2004; Hassell and Dodson 2003, Dodson 2001), fire scars on elements of the flora including grasstrees (Lamont *et al.* 2003) and tree species (Burrows *et al.* 1995), and observations from the written records of early European settlers and explorers (Abbott 2003, Dixon and Barrett 2003). Some of these studies have suggested that fire intervals decreased following Aboriginal occupancy (Abbott 2003, Burrows *et al.* 1995. Ward *et al.* 2001) including the observation that modern-day Aborigines in northern Australia burn some areas annually (Haynes 1985). However, Hassell and Dodson (2003) suggest that this was only the case for areas permanently occupied by Aborigines and intervals remained much longer in areas into which they rarely ventured including the area presently known as Fitzgerald River National Park where intervals of 30-100 years persisted. Wardell-Johnson *et al.* (2004) suggested that while fire frequency increased with the arrival of Aboriginals, intervals between intense fires in the jarrah forest was in the vicinity of 80yrs. Post-European settlement, the fire regime has been altered again both through use of fire (e.g. prescribed burns), displacement of Aboriginals, and fragmentation of the landscape by agricultural and urban infrastructure. Fire intervals evident on kwongan grasstree scars following the 1940's were of the order of c.10 years, wih a range 2-26 (Lamont *et al.* 2003). Life history studies of *Banksia* species indicate a range of 10-16 years in the kwongan (Yates *et al.* 2003) . In the jarrah forest, post-European fire intervals of 5-7 yrs have occurred on balgas since arrival of Europeans with a current mean interval c. 8 yrs (Lamont *et al.* 2003).

This long history of fire has promoted two important hypotheses:

i) components of the biota have evolved with and adapted to fire (Burrows and Wardell-Johnson 2003, Bowman 2003). However, as pointed out earlier in this text, Hopper (2003) contended that the term fire-tolerant, rather than fire-adapted, more appropriately describes present knowledge for most organisms as there are alternative hypotheses to the evolution of the 'fire-adaptative' traits such as resprouting and bradyspory. There are three fire–response traits which require further examination to determine whether they are a true adaptation to fire: smoke induced germination, life cycles of fire ephemerals and fire induced flowering (Hopper 2003).

and, ii) a return to a historical fire regime may benefit biodiversity conservation. A number of authors query both the purpose and capacity for a return to historical fire regimes. Abbott (2003) questioned the value and potential of returning to Aboriginal burning practices pointing out that "Noongars set fires for their own purposes, especially for generating an ongoing food supply, and not for biodiversity conservation." Similarly, Lamont *et al.* (2003) questioned the value of reverting to a past fire regime as there have been no studies to determine if such regimes are optimal for the conservation of species. Hobbs (2003) also questioned reversion to past practices suggesting that "when considering fire regimes in fragmented systems, it is important to do so in the context of the vastly altered landscapes and communities which currently exist". Regardless of these historical patterns, the considerable changes wrought by Europeans on the Australian landscape (e.g. clearing, exploitation, fragmentation, introduction of weeds and feral animals) make attempts to restore historical regimes both problematic and arguably inappropriate (Wardell-Johnson *et al.* 2004). For example, fragmentation of the landscape and current legislation that makes burning during the summer months illegal are obstacles to reinstating Aboriginal burning strategies (Abbott 2003).

In short, it remains difficult to ascertain how frequently areas were burned historically, what effect this has had on the evolution of the biota and whether a return to a historic fire regime would facilitate biodiversity conservation.

Scientific Evidence of Impacts of Fire Regime on Biodiversity Conservation

A few descriptive studies where the effect of more than a single fire has been documented have shown changes in the relative abundance of some plants (Burrows and Wardell-Johnson 2003, Yates *et al.* 2003) and animals (van Heurck and Abbott 2003). For example, the frequency of *Acacia browniana* in jarrah forest in southwest Australia has been shown to differ between areas under different fire regimes including wildfire and prescribed burns (Figure 2). Note that the abundance of this shrub varies complexly even when prescribed burns occur in the same season, such as autumn.

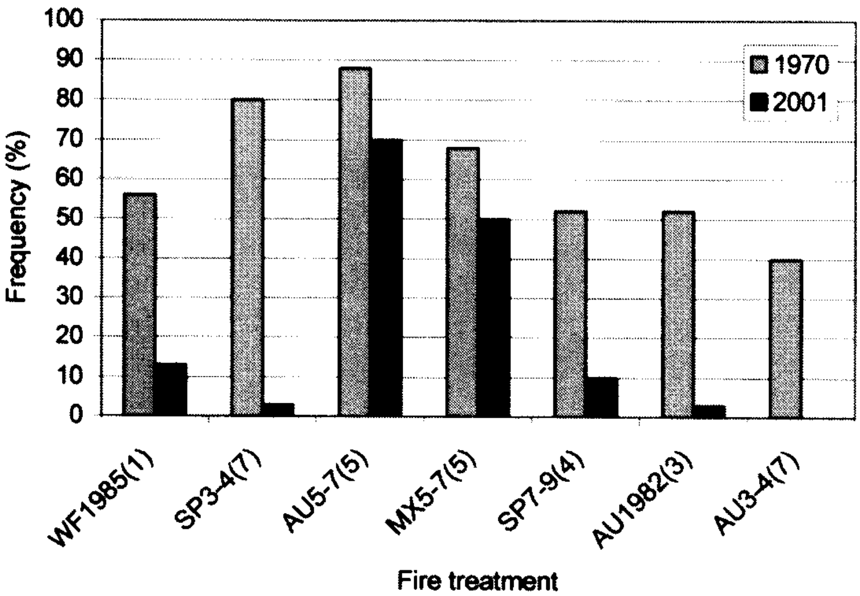

Figure 2: Changes in the frequency of occurrence of *Acacia browniana* (Mimosaceae) in sample plots in response to fire regimes over the period 1970-2001 in the Lindsay jarrah forest block west of Manjimup. Fire treatments over this period; WF1985 = a summer wildfire in 1985, SP3-4 = spring fire at 3-4 year intervals, AU5-7 = autumn fire at 5-7 year intervals, MX5-7 = fire various seasons at 5-7 year intervals, SP7-9 = spring fire at 7-9 year intervals, AU1982 = autumn fire in 1982, AU 3-4 = autumn fire at 3-4 year intervals. The number of fires experienced over the period 1970-2001 is shown in parentheses (Burrows and Wardell-Johnson 2003).

These results indicate that fire has the potential to alter biodiversity as it may result in changes to the abundance of some components of the biota. However, understandably there has been no empirical study which addresses the role of fire in maintaining and protecting all biodiversity as there are insurmountable impediments to this task including:

- Taxonomic restrictions: 5-10% of Australian fungi is named (Robinson and Bougher 2003), and it is probable that the current number of plant species in southwest Australia shall increase from c. 7500 to c. 8000 (Hopper 2003).
- Resource restrictions: there are an estimated 18 000 insect species in jarrah and karri forests (van Heurck and Abbott 2003), and an estimated 250 000 species of fungi in Australia (Robinson and Bougher 2003).

The large number of taxa alone prohibits monitoring for the effect of fire regimes on the entire biota. As such the literature is selective as to species and communities that have been investigated. A number of authors have noted a disparity in the knowledge on different components of the biota. Fire management is currently based on observations of too few taxa. Bamford and Roberts (2003) contended that prescribed burning regimes were designed to maximise containment of wildfires but the variations, eg. spring v/s autumn burns, complete v/s mosaic burns, were largely designed from responses of vegetation, not fauna, to fire. "With very few exceptions we are not in a position to make predictions about fire responses or to select optimal fire regimes to maintain, for example, even a simple value like species richness for the frog or reptile fauna" (Bamford and Roberts 2003). Other authors have similarly identified disparities in the amount of information available on different components of the biota. For example "most studies have examined the impact of fire on small mammals and birds, very few studies have focussed on reptiles and/or amphibians (Friend and Wayne 2003)".

Difficulties in monitoring the biota are also compounded by sampling errors (Thomson *et al*. 2003, 2004), replication issues (Hobbs and Yates 2003)) and the fact that the use of surrogates (indicator species) has yet to be ratified as an effective measure of biodiversity conservation for other groups of organisms. For example, Landsberg and Crowley (2004) promoted flora as the most convenient indicators because plants reflect the physical environment, they are the primary target of many of the pressures acting on the landscape, and plants are relatively amenable to measurement. However, Andersen *et al*. (2004) contended that due to the overwhelming contribution of invertebrates to biodiversity, no monitoring program can be considered credible if invertebrates are not addressed.

Similarly, use of space-for-time approaches are commonplace in the literature (reviews in Abbott and Burrows 2003) but their veracity as surrogates for long term monitoring of the same sites subjected to variable fire regimes has yet to be tested to our knowledge.

At the current time, hypotheses for management of fire to conserve biodiversity are restricted to typically short-term correlational studies of selected components of the biota. No fire regime has been shown to conserve all biodiversity of a region, even at a local scale. Conversely, it is the opinion of many authors that no fire regime is optimal for all components of the biota (e.g. Burrows and Abbott 2003).

In summary, with some exceptions, literature on this subject is primarily descriptive, short term and correlational, and often lacks sufficient definitional and experimental rigour for conclusive and predictive statements on hypotheses to be drawn. Consequently, alternative interpretations and conclusions are commonplace, and much remains to be investigated.

Impact of Prescribed Burning on Biodiversity Conservation and Reduction of the Impact of Wildfire

In the terms of reference for this review (Appendix A) we were asked to identify in the literature scientific evidence of the impact of fire on biodiversity and to determine whether there are differences in impacts from prescribed burns and wildfire. No empirical study comparing the effects on biodiversity conservation of wildfire v/s prescribed burns was found during the review. However, it became evident that the real questions which require attention are not related to differences in wildfire and prescribed burning,. Rather, it is their combined effect on biodiversity and management implications that needs to be addressed.

Abbott and Burrows (1999) provided a map of an area in the south-west Western Australia indicating regions burnt by the Department for Conservation and Land Management (DCLM) in the ongoing prescribed burning program (Figure 3). A map of wildfires ignited as a result of lightning strikes (Figure 4 - Mc Caw and Hanstrum 2003) indicates that prescribed burning does not eliminate fire from non-human ignition sources. The presence of both types of fires within the one landscape also suggests that the fire regime of any area in the southwest is likely to include both prescribed burns and wildfire.

These results are supported by studies of fuel loads (Mc Caw and Hanstrum 2003, Grove and Malajczuk 1985) in areas that are prescribed burnt. Such studies suggest that in some ecosystems fine fuel loads may carry a wildfire unless burnt at intervals of 2-4 years or less. Grove and Malajczuk (1985) observed litter accumulation in 4 year post-fire *Eucalyptus diversicolor* (karri) forest to be equivalent to a stand which had remained unburnt for 36 years. The authors suggest that "periodic fuel reduction burning in *E. diversicolor* forest results in regular regeneration of the understorey and may explain the high rates of understorey biomass accumulation compared with other eucalypt forests in which fire is excluded". This result suggests that prescribed burning, even at short intervals of 4 years may not prevent wildfire. Mc Caw and Hanstrum (2003) observed fire to burn patches in areas of woodlands and shrublands in southwest Australia that had been burnt 3-5 years previously. Similarly Birk and Bridges (1989) identified that fine-fuel levels 2–4 years after fire were capable of carrying a high-intensity fire in areas of *Eucalyptus pilularis* (blackbutt) forest in New South Wales that had been prescription burnt at 2 and 4-year intervals.

These results indicate that in the area studied, prescribed burns may offer some protection from wildfire but only if conducted on a frequent basis. Too frequent fire has been shown to result in a greater decrease in species diversity than too infrequent fire (Watson and Wardell-Johnson 2004) and it has been suggested that frequent fire may be the greatest threat to studied biota (e.g. Yates *et al.* 2003). It would seem, therefore, that if prescribed burning is to be conducted frequently enough to reduce wildfire risk then there is the potential to alter the biodiversity of a region.

Although sample sizes are low despite 60 years of data, records of wildfire and prescribed burns in native bushland in Kings Park suggest that a period of prescribed block burns at an interval of three years, or prescribed buffer strip burns, had little effect on reducing either the frequency or scale of wildfires (Figure 5 – KPBG 1995).

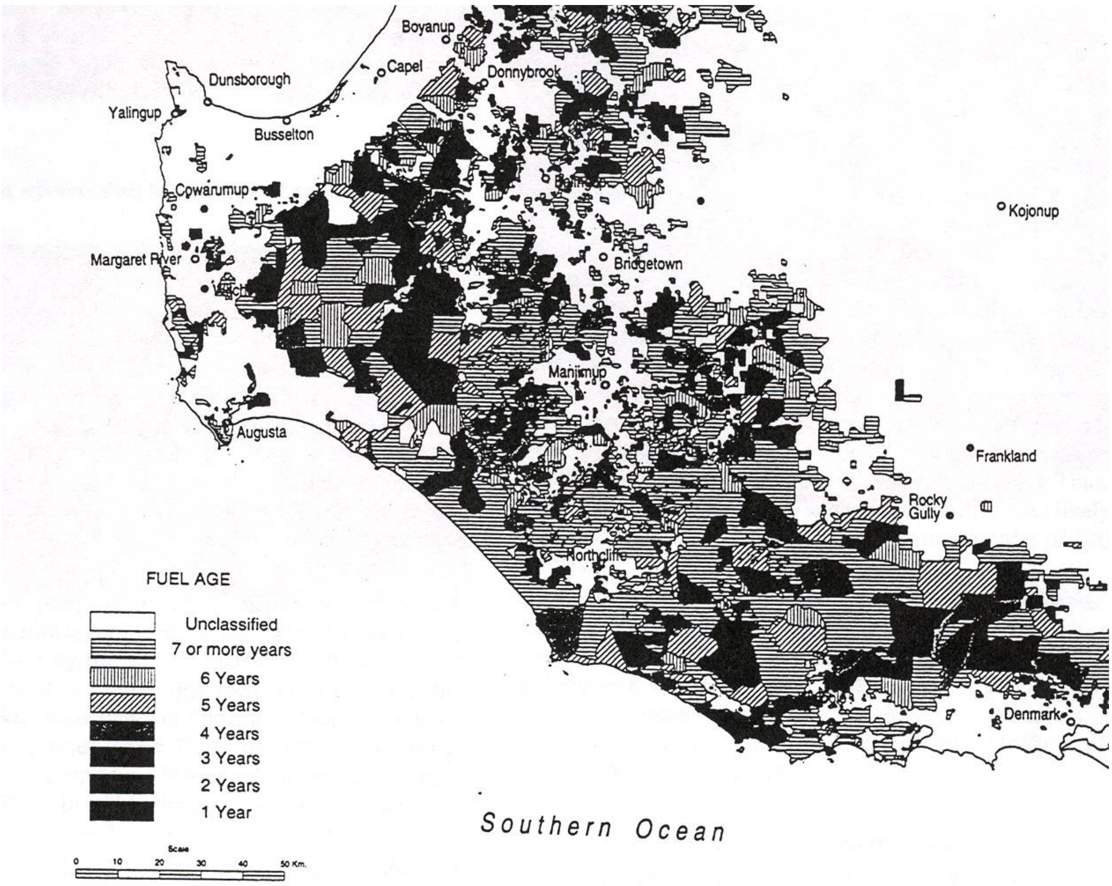

Figure 3: Prescribed burns in the southwest of Western Australia (Abbott and Burrows 1999).

In summary, there is evidence to suggest that prescribed burns may succeed or fail to reduce the incidence and severity of wildfire, depending upon local circumstances and the age of post-fire vegetation. Moreover, wildfire and prescribed burns co-occur. As such, in terms of scientific research, it is the impact of the fire regime (wildfire plus prescribed burns) on biodiversity conservation that requires investigation.

Does Fire Diversity Promote Biodiversity ?

The hypothesis that a mosaic of fire ages promotes biodiversity requires rigorous investigation. This hypothesis is promoted by several authors on the observation that some species become rare in the absence of fire and others rare with too frequent fire (e.g. Burrows and Abbott 2003, Burrows and Wardell-Johnson 2003). However, typically, the absence of species in systems is declared without due consideration to cryptic life stages of the organisms concerned.

Some researchers (Pyne 2003, Wardell-Johnson and Burrows 2003, Bamford and Roberts 2003, van Heurk and Abbott 2003, Robinson and Bougher 2003) hypothesise that species may become rare if fire is too infrequent. However, such hypotheses are often based on observations that frequently fail to address the issue of cryptic life stages. The taxon deemed to have become reduced in abundance may actually be present but not as adult organisms. For example, Burrows and Wardell-Johnson (2003) observed that certain plant species are rare in long unburnt sites but their data do not falsify the hypothesis that viable seed of the species was present in the soil seed bank. Similarly, Robinson and Bougher (2003) noted that a high proportion of fungi observed in burnt areas were not present in unburnt areas. These observations are based on counts of fruiting bodies and as such did not ascertain whether fungal hyphae were present in the soil and simply not fruiting. At the other end of the scale, researchers have observed species to become rare with too frequent fire (e.g. Yates *et al.* 2003). However, again the presence of these species in cryptic life stages is rarely considered.

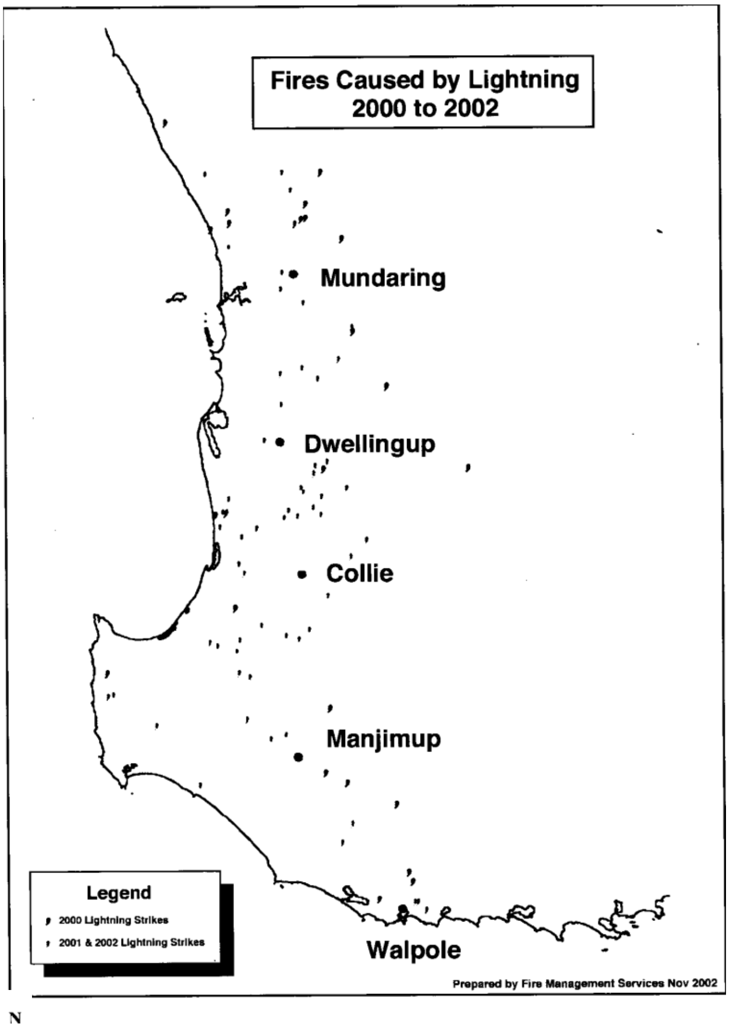

Figure 4: Patten of lightning-caused fires in forest areas of southwest Australia from June 2000-June 2002 (McCaw and Hanstrum 2003).

To determine whether fire is impacting on the presence/abundance of an organism it is necessary to ensure that the taxon is not present in some cryptic life stage. Few studies that discuss the impacts of fire have sufficiently addressed this issue.

Potential Value in the Conservation of Rare Species

Fire use or exclusion has been involved in the management of some rare species. For example, Smith 1985) suggested that fire exclusion combined with predator control have been primary influences in the increase in abundance of the Noisy Scrub Bird in southwest Australia. In contrast, use of prescribed burns as part of an integrated pest management program offers the potential to stimulate the threatened native *Pimelea spicata* populations while controlling bridal creeper (Willis *et al.* 2003).

Some authors consider that fire-sensitive taxa exhibit relictual distribution patterns in being confined to naturally less flammable sites including mesic areas, permanent waterbodies, rocky areas and offshore islands (Burrows and Abbott 2003). These areas may require longer fire intervals than surrounding vegetation and special attention should be given to endemic components of the biota to ensure those species are conserved (Wardell-Johnson and Horwitz 2000). For example, Yates *et al*. (2003) concluded that there is a dearth of experimental studies to understand the complex relationship between fire and rarity in southwest WA. Fire response for the 327 rarest flora in Western Australia is known or inferred for just under two-thirds (209). However, of these, the greatest proportion are nonsprouters and thus may be particularly susceptible to fire regimes. Indeed fire sensitive taxa are known for all major habitats and dryland systems in the southwest.

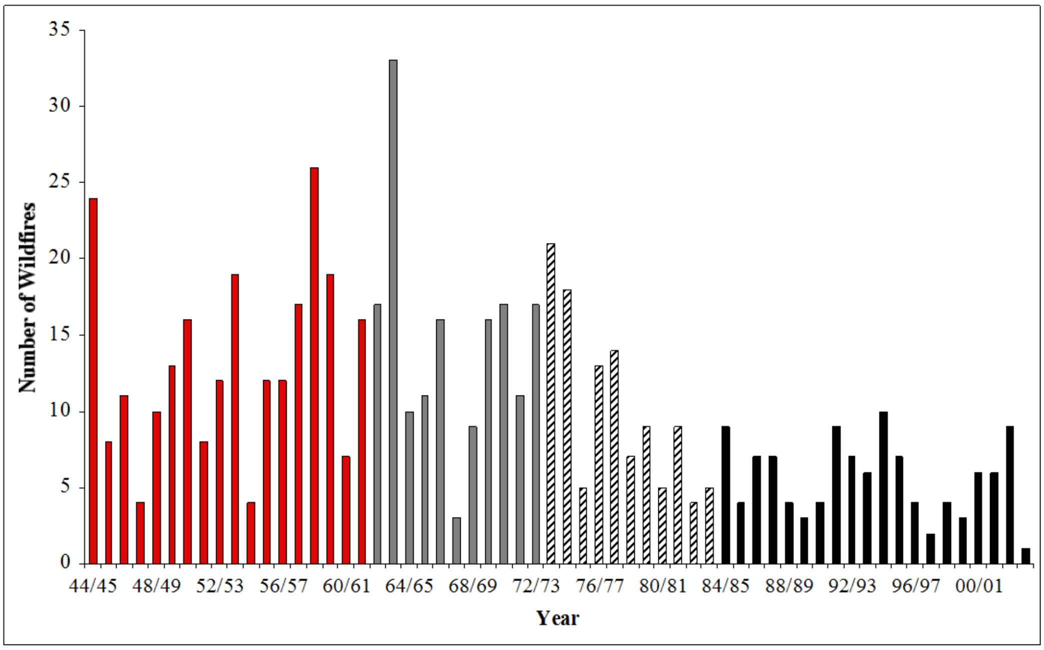

Figure 5: Number of wildfires in Kings Park over 60 years (1944-2004) under differing management regimes – prescribed block burning on a three year rotation (red), no burning (grey), buffer-strip burning (striped) and integrated management with no prescribed burning (black) Data updated from KPBG1995.

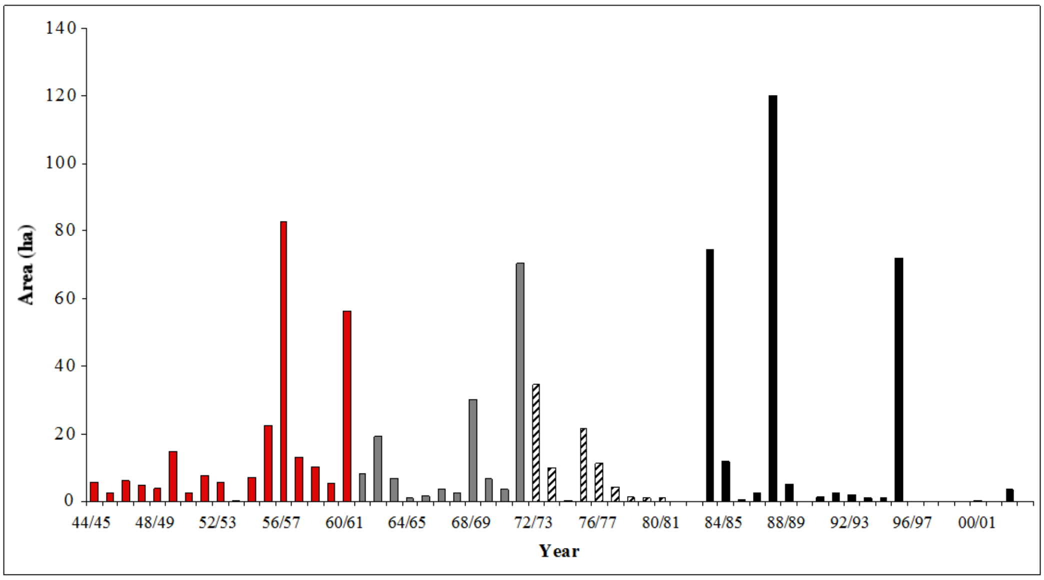

Figure 6: Total area burnt annually (hectares) by wildfire in Kings Park over 60 years (1944-2004) under differing management regimes – prescribed block burning on a three year rotation (red), no burning (grey), buffer strip burning (striped) and integrated management with no prescribed burning (black) Data updated from KPBG1995.

CURRENT LEVEL OF UNDERSTANDING AND OF FIRE MANAGEMENT AND AREAS FOR FUTURE RESEARCH.

"It is important at the outset to recognise that most of us are still settlers in a globally unique and changing environment in south-west WA. We have much to learn before sustainable land management, including the use of fire, is achieved" (Hopper 2003)." Perhaps the most poignant points that can be taken from the substantial amount of scientific research undertaken in recent decades, is "that patterns of post-fire succession can be diverse and complex" (Burrows and Abbott 2003), "we should expect different responses and biodiversity outcomes over short distances from the same fire regime" (Hopper 2003) and no one fire regime appears optimal for the persistence of all components of the biota (Bamford and Roberts 2003, Burbidge 2003, Robinson and Bougher 2003, van Heurck and Abbott 2003). Although some authors have provided guidelines for establishing fire regimes (Lamont *et al*. 2003, Burrows and Friend 1998 in Burrows and Wardell –Johnson 2003) all suggestions are restricted to monitoring a small component of the biota and therefore cannot be shown to be optimal for overall biodiversity conservation.

Research conducted to date on fire is insufficient to allow prescriptions to be made for fire regimes to maximise biodiversity conservation. Further studies are required before an adequate understanding of fire regimes and biodiversity conservation is attained. Two broad themes are recommended:

(i) long term descriptive and correlational monitoring studies to generate hypotheses on the impact of fire scale, intensity, season and patchiness – monitoring sites need to be replicated frequently across southwest Australian landscapes to adequately sample rapid geographical turnover in less vagile organisms such as most vascular plants, land snails etc. (Hopper 2003);

(ii) rigorous experimental studies with adequate sampling, replication and controls to test hypotheses and develop predictive theory regarding fire regimes and biodiversity conservation (e.g. Whelan and Main 1979; Hobbs 2003).

Fire and the Changing Ecosystem

Fire is too often considered in isolation, without references to other important factors that affect the ecosystem and also influence fuel distributions and hence fire characteristics. Consideration needs to be given to the complex ways other disturbances affect the incidence of fire, its impacts, and the ecosystem response to it (Hobbs 2003). Researchers need to consider interactions between disturbance regimes at local and global scales (Wardell-Johnson *et al.* 2004). For example, Western Australia's 1998 State of the Environment Report lists the salinisation of land and inland waters as the highest priority issue for the southwest (Wallace *et al.* 2004). As such future management of fire in the southwest may need to consider the added effects of salinity on biodiversity.

Invasive plant species are one of the most significant threats to natural areas particularly in agricultural and urban environments. The interaction between burning and weed invasion and subsequent influence on biodiversity requires consideration (e.g. KPBG 1995). The incidence of fire can enhance weed invasion, weeds may displace native perennials and weeds can increase fine fuel loads leading to more frequent and more intense fires (Hobbs 2003). Grazing pressures by herbivorous insects have a direct effect on recruitment of some plants depending on the scale of fire in Banksia woodland on the Swan Coastal Plain (Whelan and Main 1979). Consideration is also needed as to what effects perceived global warming will have on the fire regime and its effect on biodiversity and that this needs to be considered in determining appropriate regimes (Wardell-Johnson *et al.* 2004).

Species Specific Studies and Modelling of Biological Patterns

"Overall site-based studies highlighting biogeographic patterns, and critical factors of population decline in key indicator species are the most serious deficits in current understanding in Western Australia (Wardell-Johnson *et al.* 2004)". Understanding trends in populations of key species including such aspects as mortality and fecundity can provide predictors of the overall system health and are critical to risk assessment. However, Wallace *et al.* (2004) contend that "assessment of biodiversity status by direct observation of biota involves the understanding of processes at a range of scales for which data are generally unavailable". The authors suggest that a major challenge for monitoring is to demonstrate links between biodiversity and surrogates that can be monitored at the required scales. For example, remotely-sensed data could form the basis of the monitoring system where vegetation cover monitoring data will inform questions of biodiversity. An ongoing collaborative effort is required to develop understanding between cover responses and landscape health, function and biodiversity (Wallace *et al.* 2004)". There are numerous monitoring programs being run throughout Western Australia for different purposes eg. vegetation change and salinity in the southwest (Wallace *et al.* 2004, pp 102-103). Ensuring these programs are integrated with data shared among researchers may assist in broadening the scope of current studies.

Understanding the effects of fire on biodiversity will require many more years of intensive monitoring. Lindenmeyer (1999) suggested that major changes are required to monitoring programs if this is to be achieved including:

- "identifying innovative ways to secure long-term funding that may be guaranteed beyond typical government and institutional timeframes";
- "education of funding bodies to ensure that they recognise that useful results may take a prolonged period to obtain and that monitoring is not a second-rate science."

Monitoring sites need to be replicated frequently across southwest Australian landscapes to adequately sample rapid geographical turnover in less vagile organisms such as most vascular plants, land snails etc. (Burrows and Wardell-Johnson 2003, Hopper 2003).

Key hypotheses for future research

Burrows and Abbott (2003, pp. 445-446) provided some 12 principles (hypotheses) for fire management in southwest Australia. Hopper (2003) proposed three others. Indeed, the literature is replete with hypotheses in need of future research, as a perusal of the review chapters in Abbott and Burrows (2003) reveals.

Which are most deserving and urgent? In terms of the subject of this review, we suggest that those studies of fire regimes that experimentally establish how to minimise the extinction of genes, species and ecosystems are the most critical.

A consideration of the foregoing in this light therefore enables identification of a number of hypotheses deserving of future research pertaining to fire regimes and biodiversity conservation, with special reference to southwest Australia. These hypotheses, in no particular order, include:

- Adaptations to fire are difficult to distinguish from those for coping with other disturbances;
- Impacts of fire regimes on biodiversity are complex and difficult to predict;
- The relative abundance of organisms may change with fire regime;
- Extinction of genes, species and communities due to fire regime is rare, especially compared with that following habitat destruction, weed and feral animal invasion, dieback disease and salinity;
- The interaction of fire regimes with other disturbances may pose a significant risk to biodiversity conservation;
- Some aspects of fire management have longer term impacts on biodiversity conservation than fire itself eg. bulldozing roads and fire breaks, burning spoil heaps;
- Genes, species and communities most threatened by fire regimes are those that are rare and highly localised in the landscape, especially in cool moist habitats or natural fire refuges eg.:
    1. wetlands (especially peat based)
    2. granite outcrops
    3. Stirling Range montane heath
    4. tingle forest
    5. Callitris forest on islands
    6. Kimberley vine thickets etc.;
- Fire regime diversity promotes biodiversity conservation.

Exploration of these and other hypotheses will assist managers in their quest to achieve biodiversity conservation through appropriate fire regimes. However, choices and priorities have to be made, as funding for science in fire and biodiversity research is limited. Ultimately the community should be involved in helping decide which components of biodiversity are most important to conduct research on first, and then how much effort should scientists place on research on fire regime effects in the context of all major impacts on biodiversity conservation. We see merit in such ongoing community involvement. Given present funding levels, an increased allocation for strategic scientific research on fire regimes and biodiversity conservation in southwest Australia seems warranted.

GENERAL CONCLUSIONS

- The fire regime may impact on biodiversity conservation as changes to the abundance of species have been demonstrated. However, documented extinction of genes, populations and communities are few and taxa predicted to be at threat from fire are typically rare species that are highly localised in refugial habitats in the landscape;
- In terms of scientific research, the combined impacts of prescribed burns and wildfire (the fire regime) on biodiversity conservation warrant attention, as it is difficult to disentangle the two kinds of fire at specific sites;
- Impacts of fire regimes on biodiversity are complex and difficult to predict. Two broad areas of research are required - correlational monitoring studies and rigorous experimental studies with adequate sampling, replication and controls to test hypotheses and develop predictive theory regarding fire regimes and biodiversity conservation, and aimed at testing hypotheses listed above;
- Given present funding levels, an increased allocation for strategic scientific research on fire regimes and biodiversity conservation in southwest Australia seems warranted.

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REFERENCES

Abbott, I. (2003) Aboriginal fire regimes in the south-west Western Australia: evidence from historical documents. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 119-146. Backhuys Publishers, Leiden, Netherlands.

Abbott, I. and Burrows, N. (1999) Biodiversity conservation in the forests and associated vegetation types of southwest Western Australia. Australian Forestry **62**(1), pp. 27-32.

Abbott, I. And Burrrows, N., eds (2003) *Fire in ecosystems of south-west Western Australia: impacts and management.* Backhuys Publishers, Leiden, Netherlands.

Andersen, A. N., Fisher, A., Hoffmann, B. D., Read, J. L. and Richards, R. (2004) Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. *Austral Ecology* **29**, pp 87-92.

Atahan, P., Dodson, J. R. and Itzstein-Davey, F. (2004) A fine-resolution pollen and charcoal record from Yallalie, south-western Australia. *Journal of Biogeography* **31** pp. 199-205.

Bamford, M. J. and Roberts, J. D. (2003). The impact of fire on frogs and reptiles in south-west Western Australia. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 349-361. Backhuys Publishers, Leiden, Netherlands.

Birk E. M. and Bridges R. G. (1989) Recurrent fires and fuel accumulation in even-aged blackbutt (*Eucalyptus pilularis*) forests. *Forest Ecology and Management* **29** pp 59-79.

Bowman, D. M. J. S. (2003) Australia landscape burning: a continental and evolutionary perspective. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 107-118. Backhuys Publishers, Leiden, Netherlands.

Burbidge, A. H. (2003). Birds and fire in the Mediterranean climate of south-west Western Australia. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 321-347. Backhuys Publishers, Leiden, Netherlands.

Burrows, N. D., Ward, B. and Robinson, A. D. (1995) Jarrah forest fire history from stem analysis and anthropological evidence. *Australian Forestry* **58** pp 7-16.

Burrows, N. and Abbott, I. (2003). Fire in south-west Western Australia: a synthesis of current knowledge, management implications and new research directions. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 437-452. Backhuys Publishers, Leiden, Netherlands.

Burrows, N. D. and Friend, G. (1998) Biological indicators of appropriate fire regimes in southwest Australian ecosystems. In: Prudent, T. and Brennan, L. (eds.), Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription, Tall Timbers Fire Ecology Conference Proceedings pp 413-421,Tall Timbers Research Station, Tallahassee.

Burrows, N. and Wardell-Johnson, G. (2003). Fire and plant interactions in forested ecosystems of south-west Western Australia. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 225-268. Backhuys Publishers, Leiden, Netherlands.

Dixon, K. W., Roche, S. and Pate, J. S. (1995) The promotive effect of smoke derived from burnt native vegetation on seed germination of Western Australian plants. *Oecologia* **101(2)** pp 185-192.

Dixon, K. and Barrett, R. (2003) Defining the role of fire in the south-west Western Australian plants. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 205-223. Backhuys Publishers, Leiden, Netherlands.

Dodson, J. R. (2001) Holocene vegetation change in the Mediterranean-type climate regions of Australia. *The Holocene* **11 (6)** pp. 673-680.

Friend, G. and Wayne, A. (2003). Relationships between mammals and fire on south-west Western Australian ecosystems: what we know and what we need to know. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 363-380. Backhuys Publishers, Leiden, Netherlands.

Grove, T. S. and Malajczuk, N. (1985) Biomass production by trees and understorey shrubs in an age-series of *Eucalyptus diversicolor* F. Muell. stands. *Forest Ecology and Management* **11** pp 59-74.

Hassell, C. W. (2000) Fire ecology studies in the Fitzgerald River National Park, Western Australia. PhD Thesis. University of Western Australia, Perth.

Hassell, C. W. and Dodson, J. R. (2003) The fire history of south-west Western Australia prior to European settlement in 1826-1829. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 71-85. Backhuys Publishers, Leiden, Netherlands.

Haynes, C. C. (1985) The pattern and ecology of munwag: traditional aboriginal fire regimes in north-central Arnhemland. *Proceedings of the Ecological society of Australia* **13** pp 203-214.

Hobbs, R. (2003). How fire regimes interact with other forms of ecosystem disturbance and modification. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 421-436. Backhuys Publishers, Leiden, Netherlands.

Hobbs, R. J. and Yates, C. J. (2003) Turner Review No. 7 Impacts of ecological fragmentation on plant populations: generalising the idiosyncratic. *Australian Journal of Botany* **51** pp 471-488.

Hopper, S. D. (2003) An evolutionary perspective on south-west Western Australian landscapes, biodiversity and fire: a review and management implications. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 9-35. Backhuys Publishers, Leiden, Netherlands.

KPBG (1995) Kings Park Bushland Management Plan pp 63. Kings Park and Botanic Garden, Perth, Western Australia.

Lamont, B. B., Ward, D. J., Eldridge, J., Korczynskyi, D., Colangelo, W. I., Fordham, C., Clements, E. and Whittkuhn, R. (2003) Believing the Balga: a new method for gauging the fire history of vegetation using grasstrees.. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 147-169. Backhuys Publishers, Leiden, Netherlands.

Landsberg, J. and Crowley, G. (2004) Monitoring rangeland diversity: Plants as indicators. *Austral Ecology* **29**, pp 59-77.

Lindenmeyer, D. B. (1999) Future directions for biodiversity conservation in managed forests: indicator species, impact studies and monitoring programs. *Forest Ecology and Management* **115** pp 277-287.

McCaw, L. and Hanstrum, B. (2003) Fire environment of Mediterranean south-west Western Australia. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 87-106. Backhuys Publishers, Leiden, Netherlands.

Pyne, S. J. (2003) Fire's lucky country. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 1-8. Backhuys Publishers, Leiden, Netherlands.

Roberts, R. G., Jones, R. and Smith, M. A. (1990) Thermoluminescence dating of a 50, 00-year-old human occupation site in northern Australia. *Nature*, **345** pp 153-156.

Roberts, R. G., Jones, R., Spooner, N. A., Head, M. J., Murray, A. S. Smith, M. A. (1994) The human colonizaton of Australia: optical dates of 53, 000 and 60, 000 years bracket human arrival at Deaf Adder Gorge, Northern territory. *Quaternary Science Reviews* **13** pp 575-583.

Robinson, R. M. and Bougher, N. L. (2003).The response of fungi to fire in jarrah (*Eucalyptus marginata*) and karri (*Eucalyptus diversicolor*) forests of south-west Western Australia. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 269-289. Backhuys Publishers, Leiden, Netherlands.

Roche, S., Dixon, K. W. and Pate, J. S. (1997a) Seed ageing and smoke: partner cues in the amelioration of seed dormancy in selected Australian native species. *Australian Journal of Botany* **45** pp 783-815.

Roche, S., Koch, J. M. and Dixon, K. W. (1997b) Smoke enhanced germination for mine rehabilitation in the southwest of Western Australia. *Restoration Ecology* **5(3)** pp 191-203.

Thompson, G. G., Withers, P. C., Pianka, E. R. and Thompson, S. A. (2003) Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. *Austral Ecology* **28** pp 361-383.

Thompson, S. A. and Thompson, G. G. (2004) Adequacy of rehabilitation monitoring practices in the Western Australian mining industry. *Ecological Management and Restoration* **5(1)** pp .

Tieu, A., Dixon, K. W., Sivasithamparam, K., Plummer, J. A. and Sieler, I. M. (1999) Germination of four native Western Australian plants using plant-derived smoke. *Australian Journal of Botany* **47** pp 207-219.

Turney, C. S. M., Bird, M. I., Fifield, L. K., Roberts, R. G., Smith, M., Dortch, C. E., Grun, R., Lawson, E., Ayliffe, L. K., Miller, G. H., Dortch, J. and Cresswell, R. G. (2001) Early human occupation at Devils Lair, southwestern Australia, 50, 000 years ago. *Quaternary Research* **55** pp 3-13.

van Heurck, P. and Abbott, I. (2003).Fire and terrestrial invertebrates in south-west Western Australia. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 291-319. Backhuys Publishers, Leiden, Netherlands.

Wallace, J. F., Caccetta, P. A. and Kiiveri, H. T. (2004) Recent developments in analysis of spatial and temporal data for landscape qualities and monitoring. *Austral Ecology* **29**, pp 100-107.

Ward, D. J., Lamont, B. B. and Burrows, C. L. (2001) Grasstrees reveal contrasting fire regimes in eucalypt forest before and after European settlement of southwestern Australia. *Forest Ecology and Management* **150** pp 323-329.

Wardell-Johnson and Horwitz (2000) The recognition of heterogeneity and restricted endemism in the management of forested ecosystems in south-western Australia. *Australian Forestry* **63**(3), pp. 218-225.

Wardell-Johnson, G., Calver, M. Saunders, D., Conroy, S. and Jones, B. (2004) Why the integration of demographic and site-based studies of disturbance is essential for the conservation of jarrah forest fauna. ***journal???

Watson, P. and Wardell-Johnson, G. (2004) Fire frequency and time-since-fire effects on the open-forest and woodland flora of Girraween National Park, south-east Queensland, Australia. *Austral Ecology* **29** 225-236.

Whelan, R.J. and Main, A.R. (1979) Insect grazing and post-fire plant succession in south-west Australian woodland. *Australian Journal of Ecology* **4** pp. 387-398.

Willis, A., McKay, R., Vranjic, J. A., Kilby, M. J. and Groves, R. H. (2003) Comparative seed ecology of the endangered shrub, *Pimelea spicata* and a threatening weed, Bridal Creeper: Smoke, heat and other fire-related germination cues. *Ecological Management and Restoration* **4(1)** pp. 55-65.

Yates, C. J., Abbott, I., Hopper, S., D. and Coates, D. J. (2003). Fire a s a determinant of rarity in the south-west Western Australian global biodiversity hotspot. *In: Fire in ecosystems of south-west Western Australia: impacts and management.* (eds I. Abbott and N. Burrows) pp 395-420. Backhuys Publishers, Leiden, Netherlands.

Yates, C. J., Hopper, S. D., Brown, A. and van Leeuwin S. (2003) Impact of two wildfires on endemic granite outcrop vegetation in Western Australia. *Journal of Vegetation Science* **14** pp. 185-194.

APPENDIX A

Review Scope

- Identify the role of fire in maintaining and protecting biodiversity. This will include:
    - beneficial effects from prescribed burns, and the extent to which these are influenced by factors such as scale, frequency, seasonality and intensity.
    - adverse impacts from prescribed burns, and the extent to which these are influenced by factors such as scale, frequency, seasonality and intensity.
    - the effects of wildfire on biodiversity, and
    - whether the effects of wildfire are significantly different from those from prescribed burns
- Provide advice on the current understanding of fire management practices which promotes biodiversity protection, including the value of prescribed burns in reducing the impacts of wildfires.
- Comment on the level of understanding and identify gaps in information that need to be filled to improve our knowledge of fire effects on biodiversity through research, monitoring and data gathering.

Review Focus

- The review is to be limited to books and peer reviewed scientific journals including material accepted for publication awaiting printing.
- There is to be no personal interview component in the review, however, leading publicists on the subject may be approached to provide references they believe relevant.
- Publications included in the report shall be selected through a process of ranking according to scientific rigour utilising a system currently employed by the University of Western Australia and upon the advice of leading biodiversity and fire researchers.
- Studies conducted in the South West portion of Western Australia are to be given priority, however, other relevant Australian and international research material may be included.