From fire science to fire management to protect communities and conservation values

Neil Burrows

Department of Environment and Conservation, 17 Dick Perry Ave Kensington Western Australia 6151, neil.burrows@dec.wa.gov.au

Abstract

South-west Australia is a region of remarkable biological diversity, predominantly shaped by diversity of climate and geomorphology. Fire has also played an important role in shaping biodiversity over at least 2.5 million years and anthropogenic fire has been a part of this environment for tens of thousands of years. Forest ecosystems are fire-maintained, having evolved traits that enable them to persist with, and depend upon a variety of fire regimes. No single regime is optimal for all organisms and communities, but diverse regimes, within ecological limits, are essential for maintaining biodiversity. Bushfires can also threaten people, property and industry so fire management, especially prescribed fire, is essential to conserve biodiversity and to mitigate negative impacts of bushfires. There exists a substantial body of fire ecology literature for these ecosystems. If on-ground fire management is to advance commensurate with advances in fire science, then this often complex plethora of information needs to be synthesized, simplified and presented as practical fire management paradigms, policies and prescriptions. This paper attempts to achieve this by describing a range of evidence-based practical fire regimes that can be implemented to conserve biodiversity and to protect human life and property in south-west Australia.

1. Introduction

A Mediterranean-type climate and flammable vegetation have ensured that the jarrah and karri forests of south-western Australia have evolved with fire over thousands of years (Hassell and Dodson 2003). Not only does the rich biodiversity of the forests display a variety of physical and behavioral adaptations to fire, but specific fire regimes are necessary to maintain the healthy functioning of these ecosystems.

The relatively recent arrival of Aboriginal people (probably within the last 50 000 years) would undoubtedly have led to dramatic changes in fire patterns (Abbott 2003). The co-existence of fire, people and of organisms that exhibit a variety of responses to fire regime has resulted in diverse patterns of response at the species, community and ecosystem level. The arrival of Europeans in the early 1800s and the rapid changes brought about by exploitation, settlement, clearing, fragmentation and agriculture, and the introduction and spread of pests and diseases, have resulted in significant changes in fire regime (Mills 1989, Lamont *et al*. 2003). Today, the predominantly state-owned forests are managed for a variety of purposes including conservation, recreation and production (e.g. timber, mining, potable water, wildflower harvesting, etc.). Forest fire management goals are to protect human life and property as well as a range of forest values including biodiversity, timber, water and amenity.

There is a substantial body of scientific literature on fire behaviour and fire ecology of south-west Australian forests (Abbott and Burrows (eds.) 2003) and of other fire-prone regions of the world. However, there is a gap between this knowledge and its on-ground application to deliver fire management outcomes. One of the reasons for this is that the scientific literature is often complex, equivocal and disaggregated across the spectrum of fire ecology so does not readily lend itself to the development of practical on-ground policies, paradigms and prescriptions that advance fire management commensurate with advances in fire science. The purpose of this paper is to present practical, manageable approaches to contemporary fire management in south-west Australian forests that are underpinned by best available knowledge and understanding of fire ecology to achieve fire management goals.

2. Evidence-based fire management

Uncertainty surrounding ecosystem responses to fire is not a valid reason to avoid taking action to protect people, property, biodiversity and other assets from threatening fire regimes. Delaying action may result in undesirable and irreversible social, environmental or economic consequences. Fire is a natural environmental factor that can threaten or benefit people and biodiversity depending on the fire regime and the prevalence of other interacting factors such as fragmentation, pests, disease and biological invaders (Hobbs 2003). Uncertainty with respect to fire regime outcomes for biodiversity, and other values, applies to both unplanned and planned fires, the latter often being a management response intended to divert a threatening process. However, it is not always possible to have clear evidence of a threat to the environment before the damage occurs. The framework for contemporary forest fire management that aims to conserve biodiversity and to protect other assets needs to embrace four fundamental elements; i) fire regimes based on best available ecological knowledge to conserve biodiversity, ii) accommodating other land use requirements without compromising biodiversity, iii) assessing the risk that these regimes present to other community assets and values, and iv) where the risk is unacceptable to the community, or could lead to unacceptable consequences, spatially or temporally adjusting the regime to reduce the risk or threat – and this may include making trade-offs.

3. Fire management for biodiversity conservation

Biodiversity is usually considered at three levels - genetic, species and ecosystem diversity (species assemblages, habitat and structural differences and ecological processes). Numerous studies in a range of fire-prone ecosystems and at a variety of taxonomic levels report on the changing species assemblages and species diversity in response to time since last fire, fire season, or fire interval. The literature also reports on how fire, particularly fire intensity and time since fire, alters live and dead vegetation composition and structure, hence habitat characteristics, and on the ways in which fire influences ecosystem processes such as nutrient cycling (e.g. Whelan 1995, Bond and van Wilgen 1996, Abbott and Burrows (eds.) 2003). It follows then that a diverse fire regime increases functional biodiversity in a landscape because of its influence not only on species assemblages and composition, but on vegetation structures, habitat characteristics and processes such as nutrient cycling.

While there is general acceptance of the need for prescribed burning to avert a socio-environmental fire threat, there is often debate about the most ecologically appropriate fire regimes to achieve this. Because of the scientific complexity of fire behaviour and ecology, there will continue to be uncertainty and risks surrounding the outcomes of various fire regimes. Approaches to prescribed burning that are consistent with the precautionary principle and with evidenced-based management include;

- maintaining diverse fire regimes based on vital attributes and life histories of threatened, keystone or focal (umbrella) species,
- maintaining a diverse but fine-grain mosaic by regularly introducing fire into the landscape,
- in strategic areas, implementing fire regimes at intervals based on fuel accumulation rates, and
- implementing fire regimes based on historical evidence and knowledge of traditional Aboriginal use of fire.

Fire regimes based on vital attributes and life histories

Plant vital attributes have been used to simulate and predict the response of vegetation associations and of individual species to various disturbances, including fire, and to guide the development and implementation of ecologically appropriate fire regimes (e.g. Noble and Slatyer 1980, van Wilgen and

Forsyth 1992, Tolhurst 1998). As well as providing fuel for fire and habitat for many other organisms, plants, being primary producers, form the first trophic level of terrestrial ecosystems, so basing an ecological understanding of fire on plant vital attributes is biologically meaningful. Knowledge of these attributes, including regeneration requirements, post-fire regeneration syndromes, the juvenile period and the longevity of longer-lived woody species that mostly reproduce after fire are useful criteria for determining the minimum and maximum intervals between *lethal* fires for a particular ecosystem (Gill and McCarthy 1998). If the interval between fires *that are lethal* to the parent plants is shorter than the time to first flowering (juvenile period) and seed set, then it is reasonable to assume that obligate seed species could be at risk of decline under such a regime. In this context, it is important to make the distinction between fire interval *per se* and the interval between fires that are lethal to particular plant guilds of interest, such as obligate seeders. Plant mortality and damage levels are directly related to fire intensity which in turn, is a function of the amount of fuel that burns and the rate of combustion. Many so-called 'fire sensitive' species may survive or escape very low intensity fires, or patchy fires. Ironically, while such species are often referred to as 'fire sensitive', many depend on fire at some stage of their life cycle for their persistence (Burrows and Wardell-Johnson 2003). While juvenile period is useful for establishing minimum intervals between lethal fires, plant species could also decline if the interval between fires is longer than the longevity of the seed bank of those species that are dependent on fire to stimulate regeneration and growth (van Wilgen and Forsyth 1992, Bradstock *et al.* 1996, Gill and McCarthy 1998, Burrows and Wardell-Johnson 2003).

To assist with planning appropriate fire regimes in south-west Australian forest ecosystems using plant vital attributes, Burrows *et al*. (2008) compiled a database of the post-fire regeneration syndromes, the juvenile period and in some cases, longevity of some 700 species, representing about a third of the known flora of the region. From this database, about 97% of understorey species reach flowering age (secondary flowering in the case of resprouters) within 3 years of fire and all species reach flowering age within 5-6 years of fire. The 3% of species classified as 'fire sensitive' mostly occur in lower rainfall zones where fuel accumulation rates are slower, hence fire return intervals are longer, or in habitats that are less prone to fire because they remain moist for a longer period, or because surface fuels are inherently sparse and discontinuous (Burrows *et al*. 2008). Knowledge of the distribution and habitat preferences of these species can be used to develop and implement fire regimes based on their vital attributes. An example of a managed forest fire regime where fire intervals are based on plant juvenile period and which aims to conserve biodiversity while reducing the severity of wildfires is shown in Figure 1.

In Western Australia, some species of native plants and animals are protected by law because they are under identifiable threat of extinction. Because of their threatened status, especially for species that are listed as 'Critically Endangered', it may be appropriate to devise fire regimes based on the known vital attributes of these taxa, especially if their vital attributes indicate that they are sensitive to fire, or are fire regime specific (depend on a particular combination of fire interval, season and intensity). In this circumstance, the threatened species may also be an 'umbrella', or focal species such that a fire regime that suits the threatened species will also accommodate other species. However, there are potential drawbacks in developing fire management based on single species ecology so this approach needs to be closely evaluated and monitored for possible adverse impacts on other species and communities.

Yates *et al.* (2003) observed that in south-west ecosystems many rare plants persist only in habitats where fire is infrequent, such as riparian zones and rock outcrops. Burrows *et al.* (2008) showed a strong association between the occurrence of fire sensitive plants with long juvenile periods, and habitat flammability, as estimated by seasonal moisture regime and fuel structure. As with rarity, fire sensitive plants tend to occur in the least fire-prone parts of the landscape, such as rock outcrops and riparian zones. The relationship between fire and the distribution of threatened fauna in the region is less clear-cut primarily because of the mobility of fauna and other factors affecting fauna distribution such as the presence of introduced predators.

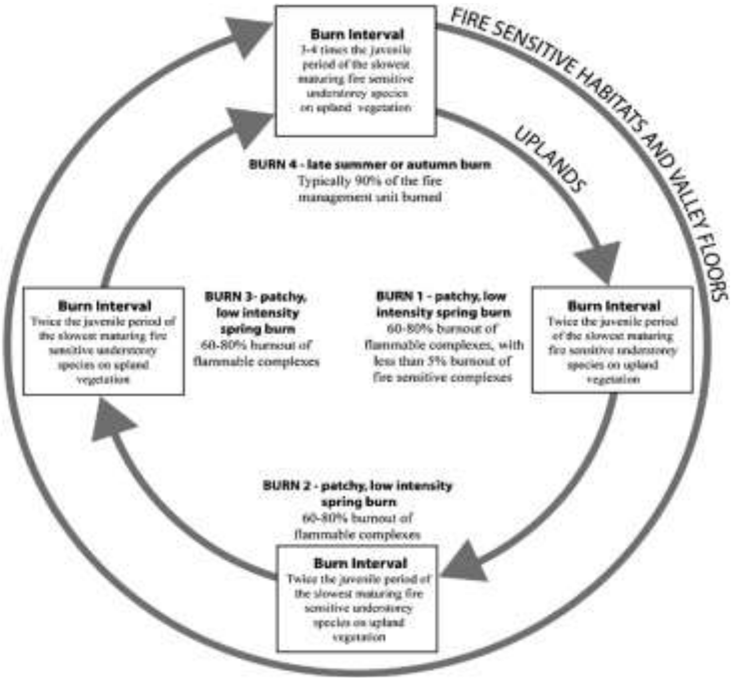

Figure1- A fire regime for a jarrah forest that will a) protect biodiversity values and b) reduce the risk of damaging wildfires

Knowledge of the life histories of select threatened fauna, especially fauna that are recognized as fire sensitive or fire regime specific (as defined above), or are keystone species or focal (umbrella) species within an ecosystem, can be used to understand species responses to fire and to plan appropriate fire regimes for their conservation (Friend and Wayne 2003). In south-west Australia, mammals and birds have attracted most attention in terms of the determination of species conservation status and fire ecology research, including life history studies. However, there has been increasing research activity on the fire ecology of forest invertebrate fauna in recent decades and there is growing evidence that this group are more sensitive to fire intensity and time since last fire than other groups (Van Heurck and Abbott 2003).

Fire management to conserve the threatened quokka (*Setonix brachyurus*) is an example of using known life history attributes of a species that, because of its specialised habitat requirements, can act as a focal or umbrella species. The quokka is a small kangaroo-like threatened marsupial endemic to the south-west of Western Australia. Fire plays an important role in protecting and maintaining quokka habitat, but inappropriate fire regimes, including intense wildfires, can threaten quokka populations because of their scattered and often isolated distribution throughout the south-west forests. Current knowledge suggests that a managed fire regime based on the requirements of fire regime specific taxa such as the quokka, is likely to benefit other organisms – a useful working hypothesis to test in an adaptive management framework. Christensen and Kimber (1975) found that quokkas require mature but not senescent (swamp and riparian) vegetation for diurnal refuge. They reported that quokkas abandoned older, senescing vegetation that did not provide good cover, some 15-20 years after fire. They also reported that quokkas utilized (browsed) recently burnt vegetation and that infrequent summer or autumn fire was necessary to regenerate senescing habitat. Similarly, Hayward *et al*. (2003), also working in the northern jarrah forest, concluded that quokkas prefer a mosaic of long unburnt and relatively recently burnt (<10 years) vegetation in swamp/riparian systems. A mosaic of mature vegetation (for diurnal cover and refuge) and recently burnt vegetation (for food) appears to provide optimal habitat.

Burning to create diverse seral stages and habitats

The biophysical environment, especially the floristic composition and structure of the vegetation, changes with time since last fire, providing habitat opportunities for a changing and diverse suite of fungi, vascular plants, invertebrates, birds, mammals and reptiles (Abbott and Burrows (eds.) 2003). The management implications of this are that maintaining a diversity of post-fire ages, seral stages or functional habitats, is fundamentally important for ecosystem health, and by definition, benefits biodiversity, which embraces species diversity, genetic diversity and habitat diversity.

How much of each seral stage is enough? In fire-prone environments with relatively regular and random ignitions, and where each part of the landscape, regardless of the time since last fire, has the same chance of ignition, then the most stable models are based on the Weibull probability distribution in the form of a negative exponential (Johnson and Van Wagner 1985, Weir *et al.* 2000, Tolhurst and Friend 2001). In most fire-prone ecosystems in more-or-less contiguous natural landscapes, the most common and stable pattern of vegetation ages, or time-since-last-fire distributions, is one of small patches of older, long-unburnt vegetation in a matrix of predominantly larger patches of younger vegetation (Weir *et al.* 2000). The reverse pattern, that of small patches of younger vegetation embedded in a matrix of older vegetation, is very rare because in order to obtain this pattern, a region would need to experience very long periods with no large fires and only small fires. In a fire-prone environment, this may be possible for a time in remnant fragments or patches of vegetation, or with a supreme fire suppression effort, or during an epoch that was not conducive to the start and spread of fires. Otherwise, such a pattern is unstable and unsustainable.

The negative exponential function can be paramatised by various plant life history attributes, in particular, juvenile period and longevity of fire sensitive taxa within the ecological unit which are used to set maximum and minimum fire intervals (Tolhurst 1998). An alternative, perhaps more biologically meaningful way of describing the distribution of vegetation age classes, or post-fire seral stages, is to characterize them according to their functional habitat traits. For a given ecological unit, habitat characteristics as defined by floristic composition, live and dead vegetation structure (vertical and horizontal) and surface litter coverage and biomass, are a function of time since last fire. Studies of post-fire vegetation dynamics in a variety of fire-prone ecosystems consistently report that; a) plant species richness is greatest in the first few years after fire, then either stabilizes or declines; b) understorey vegetation cover and height increases rapidly after fire, then usually stabilizes for a period before decreasing with increasing plant mortality; c) total biomass and proportion of live and dead vegetation changes with time since fire such that total biomass increases rapidly soon after fire, stabilizes for a period before declining to a quasi steady level; d) the proportion of dead vegetation usually increases with time since fire, then stabilises.

The transition from one functional habitat type to the next is somewhat arbitrary, but could be estimated using an integrating biological measure, such as the juvenile period of the slowest maturing fire sensitive plant species within the major vegetation type (key fire response species – Tolhurst and Friend 2001). In south-west Australian ecosystems, there is a strong relationship between rainfall, site productivity and juvenile period (Burrows *et al.* 2008), so juvenile period is probably a useful indicator of the post-fire rate of change of floristic composition and structure for a given ecological unit.

Fundamental to determining the vital attributes of key fire response species in an ecosystem and to attributing a particular pattern of post-fire vegetation recovery to an ecosystem, is the ability to define and map 'ecosystems'. Stratification of a landscape into map units based on a combination of biophysical characteristics including climate, geomorphology and vegetation, is essential for planning and implementing fire regimes based on plant or animal vital attributes / life histories and post-fire seral stages. South-west forest ecosystems have been defined and mapped at various scales, depending on the mapping application. The finest scale of mapping is vegetation complexes (Mattiske and Havel 1998), which are too fine scale and do not adequately categorise fuel complexes to be useful for fire management. For fire management, ecological units must not only be ecologically meaningful, but be mappable at an appropriate scale and must take account of flammability variability, which determines the way in which fire behaves, or 'reads' the landscape. Vegetation is the fuel for fire, so whether fires start and spread, and how they spread, will depend on the moisture content and the structure of the vegetation, *ceteris paribus*. Ecosystem flammability differentials, caused either by seasonal moisture regimes or variations in fuel properties, can be utilized by fire managers to afford a level of control over which ecological units are likely to burn and which are unlikely to burn (see Fig. 1). The Fauna Habitat Type (Christensen *et al*. 2005) is an ecosystem stratification and mapping system derived from amalgamations of the Mattiske and Havel (1998) vegetation complexes based on similarity of climate, landform (topographical position) and vegetation. Christensen *et al*. reduced more than 300 vegetation complexes to about 50 Fauna Habitat Types. Originally derived as a tool for predicting the presence or absence of vertebrate fauna, the Fauna Habitat Type ecosystem stratification system has the attributes described above, so lends itself to fire management planning.

It is feasible and biologically meaningful to develop fire regimes and time-since-fire distributions, or seral stages, based on plant and animal vital attributes and life histories for Fauna Habitat Types. For example, the post-fire habitat recovery pattern for the Jarrah Forest Uplands East (Fauna Habitat Type) is illustrated in Figure 2 and based on the vital attributes of key fire response plant species for this ecosystem, the idealised time-since-fire distribution for this ecosystem is shown in Figure 3. Using the relationship between juvenile period and functional habitats as represented by the three seral stages described above and in Figure 3, then an idealised proportioning of this ecosystem type is about 30% in the early seral stage (~0-4 years since fire), about 30% in the intermediate seral stage (~5-12 years since fire) and about 40% in the late seral stage (~13-34 years since fire).

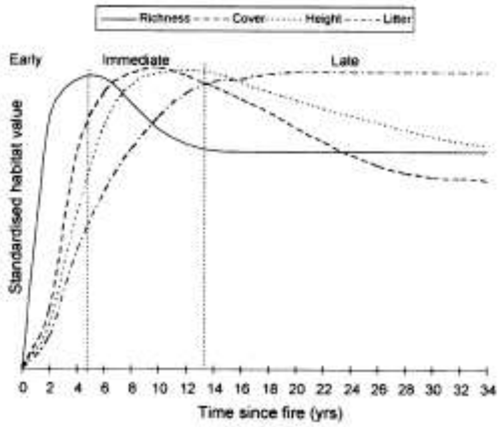

Figure 2- Changing condition of vegetation after fire, with each seral stage offering different habitat opportunities..

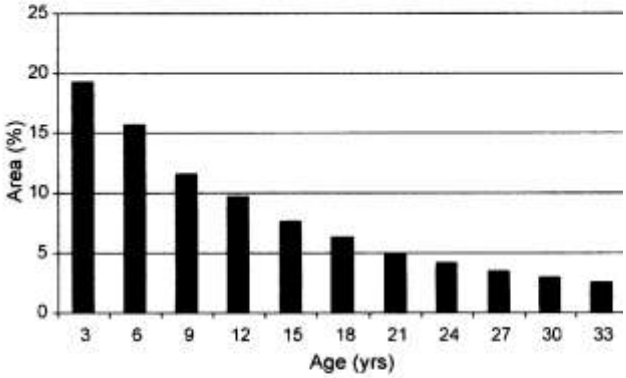

Figure 3- Idealised distribution of fuel / post-fire age for a jarrah forest landscape

Burning to create a fine-grain habitat mosaic

A novel approach to operational fire management is currently being explored in the forests of south-west Australia. In an adaptive management framework the Fire Mosaic Project (Burrows and Wardell-Johnson 2004) aims to test the hypothesis that frequent (2-3 year intervals) introduction of fire into the landscape (patch-burning) will a) create, maintain and promote fine-scaled habitat mosaics incorporating a range of interlocking post-fire seral stages, and b) that this mosaic will promote biodiversity and reduce the severity and impact of wildfires. The frequent introduction of fire into the landscape does not equate to frequent landscape burnt-out. The frequency of introduction of fire over time is expected to create a fine-grain mosaic of different seral stages because of the natural barriers to fire spread created by recently burnt patches. This fire regime contrasts with an alternative regime of attempting to exclude fire from the landscape, which results in coarse-scale patches of uniform seral stages, including large and damaging wildfires, which threaten biodiversity and the built environment. This is a large scale, long term project that utilises spatial patterns of land systems and associated biotic assemblages, quadrat-based biodiversity information and remote sensing data in a geographic information and decision support system to monitor, measure and interpret causes and effects of fine-scale fire-induced habitat mosaics on biodiversity and wildfire severity.

Burning to manage fuel accumulation

It is axiomatic that unless wildfires can be controlled, or at least their impacts managed, then forest fire and land management by objectives is virtually unachievable. Intense summer wildfires threaten human life, destroy property and damage or degrade forest values such as timber, water supplies and amenity. Large, intense wildfires can also be environmentally damaging, posing a threat to conservation values including remnant old growth forests, fire regime sensitive communities and species, and extant populations of rare flora and fauna (Whelan 1995, Abbott and Burrows 2003, Friend and Wayne 2003). Provided the intensity, scale and frequency of wildfires is not excessive, and these limits have yet to be well-defined for various forest types, they can produce some longer term benefits to ecosystems, such as reducing flammable fuel levels, promoting habitat regeneration (Catling *et al.* 2001), increasing the quantity of dead wood (logs and dead standing trees) and promoting hollow formation (Inions *et al.* 1989). However, with adequate resources and knowledge, it is possible for land managers to achieve these benefits by the planned and controlled use of fire under specific fuel and weather conditions without the risk and uncertainty associated with uncontrolled wildfire.

Fire intensity, or the rate of heat energy release, is a measure of the severity of a fire; its damage and mortality potential and suppression difficulty (Cheney 1990). Wildfires derive their energy from the quantity and arrangement of live and dead vegetation (fuel) that burns. Fire intensity is further influenced by fuel dryness, weather conditions and topography. Of the factors that determine potential fire intensity, fuel quantity and arrangement are most important and are the only factors that can be practically managed. Fuel reduction burning is a fire management technique that aims to reduce the severity (scale and intensity) of wildfires by reducing their potential intensity, thus reducing damage and increasing opportunities for safe suppression. It rarely prevents wildfires but where a significant proportion of the landscape is managed this way, wildfire severity and impact can be considerably reduced (Underwood *et al*. 1984, Finney *et al*. 2005).

While planned burning in some areas may have fuel reduction as its primary objective, any fires, including wildfires and burning for biodiversity, will also reduce fuel levels and contribute to the protection of the landscape from large, damaging wildfires. Therefore planned burning can have multiple benefits. Planned burning for fuel reduction can be strategic, where fuel reduced zones are identified and maintained in a state of low fuel level by regular burning or mechanical fuel reduction. This is sometimes employed around settlements and while it can be effective, it overlooks the fact that while many fires impact on the rural-urban interface, they often start deep in rural/forest areas. If opportunities present, such as low fuel areas from planned burning, the fires could be controlled well before they reach the urban interface. Alternatively, a system of rotational fuel reduced buffers can be employed by burning different patches of forest each year, resulting in a mosaic of fuel ages and post-fire seral stages. In fire prone environments such as the south-west Australian forests, the effectiveness of planned burning to reduce the severity and impact of wildfires is a function of the proportion of the landscape that is regularly prescribed burnt, the resultant distribution of fuel ages across the landscape and the scale, or patch-size of the burnt areas.

Fire regimes based on historical evidence

Prior to European settlement, regular and deliberate burning of parts of the landscape by Noongar Aboriginal people probably maintained a mosaic of vegetation at different stages of post-fire development (seral stages) – from recently burnt patches to long unburnt patches. There is some evidence based on historical records (e.g. Abbott 2003) and dendrochronological analysis of grass trees (*Xanthorrhoera preissii*) (Lamont *et al.* 2003) that drier parts of the south-west forests and woodlands were burnt 2-3 times per decade prior to European settlement, although these findings have recently been questioned (Enright *et al.* 2005). Regular and widespread patch-burning by Noongar people, whatever the interval, supplemented by lightning-caused fires, would have provided habitat diversity and reduced the likelihood of very large, damaging wildfires because of the discontinuity of flammable fuel. Such fires were neither in the best interests of Aboriginal people, nor the environment, and were probably unusual events. While it may not be appropriate to implement what was, or thought to be, the pre-European fire regime, knowledge of these regimes provides valuable insight to the regime under which plants and animals persisted for thousands of years and can help define limits for contemporary regimes. Because of post-European settlement changes to the environment, including fragmentation, introduced plants and animals and the prevalence of extractive industries, modern settlements and other infrastructure, it may not be appropriate to mimic traditional Aboriginal burning regimes today, whatever they may have been. However, there may be circumstances where it is safe or desirable to do so, such as in wilderness areas or areas of special significance to Aboriginal people, or as part of the diversity of fire management.

4. Conclusion

In fire-prone environments that support fire-maintained ecosystems, such as the south-west forests of Western Australia, managers are required to manage fire to meet multiple objectives, including the protection of human life and property, and the protection and conservation of biodiversity. An ability to manage wildfires is an essential prerequisite to managing fire for other outcomes. In addition to a detection and suppression capability, prescribed burning is fundamental to achieving fire and other land management objectives. However, managers are often uncertain or confused about the most appropriate fire regimes to apply. While fire behaviour and fire ecology knowledge is incomplete, there is a significant body of knowledge accumulated over many decades. Translating often complex science into relatively simple and practical fire management operations is often overlooked by scientists and managers, resulting in a lag between the state of knowledge and contemporary management policies and practices. Although often complex, fire ecology, as with most science, must be presented as simplified management paradigms if on-ground fire management is to advance commensurate with advances in knowledge. There is no single optimum fire regime that will meet all management objectives, but there are a number of fire regimes, which, based on best available evidence, can be applied to various ecosystems under various circumstances. These include fire regimes based on vital attributes, regimes that provide for fire diversity (diversity of frequency, season and intensity), regimes that provide habitat diversity, regimes that create fine-grain habitat mosaics and regimes that aim specifically to manage fuel accumulation. Implemented in an adaptive management framework, these regimes provide opportunities for continuous learning and better fire management outcomes.

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