The Role of Indicators in Developing Appropriate Fire Regimes

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Abstract

In regions that experience seasonal or periodic drying, fire is an important environmental factor influencing biodiversity. Although many studies have been conducted in a variety of ecosystems, knowledge of the temporal and spatial effects of fire regimes (frequency, intensity, season and scale) is imperfect. This is due in part to the complexity of ecosystem processes, spatial and temporal variability, and to the poor taxonomic knowledge of numerous organisms, particularly invertebrates and microflora. Too often, land management agencies are paralysed by this complexity and by the largely incorrect notion that natural ecosystems are fragile and delicately balanced when in fact, in response to fire and in the absence of weed invasion, most ecosystems are quite robust and durable. A positive management approach is to fully utilise the available knowledge to implement strategies to achieve desired outcomes. In the absence of comprehensive long-term fire effects data, interim fire regimes that are practical and strive to protect biodiversity as well as human life and property (appropriate fire regimes) can be devised at a regional level by compiling and interpreting key climatic, historic and biotic information. This includes climatic characteristics that affect fire proneness, evidence of historical fire regimes and specific biological attributes of key floral and faunal elements. In the jarrah forests of Western Australia, these pieces of information, or indicators, show consistent patterns of the role of fire in natural ecosystems and are being used as a basis for determining appropriate fire frequencies, fire intensities, fire scales and patchiness.

1. Introduction

Maintaining biodiversity is clearly a major scientific, management and political issue. In many ecosystems, including the sclerophyll forests of south-west Western Australia, it is equally important to provide a level of protection to human life and property values against wildfires. These objectives are often seen as mutually exclusive. The challenge for scientists and managers in this context is to develop and implement practical fire regimes (season, frequency, intensity and scale/patchiness) that satisfy this dual objective. Such fire regimes are referred to in this paper as "appropriate" fire regimes.

The ecological effects of fire are many and complex and it is highly unlikely that they will ever be well understood for all organisms and ecosystems. This reality is sometimes used by management agencies to justify passive management, which often results in undesirable social consequences such as devastating wildfires. We believe that, in the absence of perfect knowledge, certain key information, or indicators (of appropriate fire regimes) can be used to devise fire management strategies to achieve positive ecological and social outcomes. Indicators of appropriate fire regimes include climate, fire history and biological information. These factors are intrinsically linked so fire regime patterns or consistencies can be expected to emerge. This paper discusses how these indicators are being used to devise appropriate fire regimes in jarrah forest region.

2. Some Useful Fire Regime Indicators

2.1 Climatic indicators include:

- Season and amount of precipitation,
- Frequency of drought, temperature and humidity regimes and,
- Frequency of lightning ignitions.

Use: These indicators, together with vegetation (fuel) properties, can be used to describe the "fire-proneness" of the region, to identify fire seasons and to indicate fire frequency ranges.

2.2 Historic indicators include:

- Traditional Aboriginal use of fire.

Use: Depending on level of detail available, this can be used to define "natural" (pre-European) fire regimes that can provide bounds for contemporary regimes.

2.3 Biological indicators (flora) include:

- Post-fire regeneration strategies (seeders and resprouters.
- Post-fire floristic and structural changes.
- Fire sensitive taxa - these have long juvenile periods, thin bark, crowns close to the fuel bed, are dependent on canopy-stored seed for regeneration and have limited dispersal capacity.
- Role of fire in (seedling) recruitment, especially of fire sensitive taxa.
- Post-fire fuel (phytomass) accumulation rates.

Use: Vegetation regeneration strategies provide an indication of historical fire frequencies. Woody plant communities containing a high proportion of species capable of resprouting generally indicates a moderate frequency of fire rather than a high or low frequency (see Table 1 for biological definitions of fire frequencies). Floristic and structural changes following fire can be used to set fire interval ranges to maintain species richness and structural diversity. The juvenile period of fire sensitive taxa can be used to set minimum fire intervals and for providing a biological basis for quantifying fire frequency (see Table 1). Seedling regeneration response can be used to set season and intensity of fire. Post-fire fuel accumulation rates can be used to a) identify the minimum possible fire interval based on fuel available for burning, b) the time after fire when phytomass productivity plateaus c) fire intervals necessary to manage fuel levels to within desirable limits.

2.4 Biological indicators (fauna):

- Fire sensitive taxa - these have specialised habitat requirements (food, shelter and breeding), long juvenile periods, low fecundity, poor dispersal capacity, high site fidelity and poor mobility,
- post-fire response patterns of fire sensitive fauna.
- Fire-proneness of refuge/shelter sites of fire sensitive taxa.

Use: Habitat requirements (preferred post-fire state), juvenile period, fecundity and site fidelity of fire sensitive taxa can be used to set fire intervals and season. Fecundity, dispersal capacity, site fidelity, mobility, and post-fire population response patterns of fire sensitive taxa can be used to set fire size and patchiness. Nature of refuge/shelter can be used to set fire season and intensity.

3. Applying the Indicators to the Jarrah Forest Region

Jarrah forest is the general description given to forested regions of south-west Western Australia in which the dominant overstorey species is jarrah or a mixture of jarrah and marri (*Corymbia calophylla*). The above indicators are being used to devise appropriate fire regimes in the following way.

3.1 Climatic Indicators:

- Mediterranean-type climate; cool wet winters and warm/hot dry summers.
- Average annual rainfall across the range of the main forest belt varies from about 650 mm to 1300 mm of which about 80% falls over winter.
- The average number of days in the year when forest fuels are dry enough to burn varies from 140 to 160 across the region. The region experiences an annual summer/early autumn "drought".
- 15-30 lightning-caused wildfires each year.

Management applications: Based on climate and the flammable nature of the vegetation (continuous, accumulates to high levels), the region is characterised as highly fire-prone. There is potential to use these factors to develop a quantifiable fire-proneness value for Australian bioregions.

3.2 Historical indicators:

- Aborigines (Nyungars) used fire extensively for thousands of years prior to European settlement (e.g., Hallam 1975; Kelly 1999).
- Pattern of season, frequency and size of fires varied in accordance with patterns of social and ecological activity (e.g., Hallam 1975; Kelly 1999).
- Most of the forest experienced frequent, low intensity ("cool") fires, with occasional "hot" fires to stimulate the growth of certain habitat types (Kelly 1999). This is supported by historical and dendrochronological evidence (Hallam 1975; Burrows *et al.* 1995; Ward and Sneeuwjagt 1999).
- Using balga trees (*Xanthorrhoea* spp) as fire event markers has shown that prior to European settlement, the average fire interval in the jarrah forest region was 3-4 years. This is constant across the range of jarrah forest, exceptions being along moist or sheltered habitats such as riparian zones and rock outcrops, and tree-less areas with low fuel levels, where the fire interval was longer (Ward 1997; Ward and Sneeuwjagt 1999).
- Historical evidence suggests that most fires occurred in summer and early autumn (Hallam 1975; Burrows *et al.* 1995).

Management applications: Traditional Nyungar fire knowledge exists and should be utilised. Prior to European settlement, drier parts of the jarrah forest were burnt by low intensity fires every 3-4 years on average; riparian zones, treeless moist areas and thickets in broad valley floors burnt at longer (unknown) intervals, coastal grasslands burnt at shorter interval (2 years). Most fires occurred in summer and early autumn. High intensity fires occurred occasionally.

3.3 Biological indicators (flora):

- About 70-75% of all understorey species on drier, upland jarrah forest sites re-sprout following fire with the remainder regenerating from seed stored in the soil or in woody fruits in the canopy (Christensen and Kimber 1975; Bell and Koch 1980; Burrows and Friend 1998).
- In moister and sheltered habitats (e.g., riparian zones, rock outcrops) the proportion of obligate seeders is usually higher, varying from 40-60%. Thicket-forming species in broad valley floors are obligate seeders (Christensen and Kimber 1975; Christensen and Maisey 1987; Burrows and Friend 1998).
- A single fire has little long-term effect on floristic composition (Bell and Koch 1980).
- On some sites, species richness is greatest 3-5 years after fire then decreases slightly as relatively short lived obligate seed species and herbs decline (Bell and Koch 1980).
- On other sites floristic composition remains virtually unchanged but there are changes in the abundance of some species following fire (Christensen and Abbott 1989).
- Seedling germination and thicket establishment is most successful following moderate intensity fire under dry soil conditions (Shea *et al.* 1979; Christensen 1982; Burrows and Friend 1998).
- Upland jarrah forest understorey species flower within 3 to 4 years of fire depending on rainfall (Burrows and Friend 1998) (Figure 1).
- Some obligate seed species occurring along creek systems, rock outcrops or moist broad valley floors in parts of the jarrah forest (e.g., *Lambertia rariflora, Melaleuca viminea, Banksia seminuda*) take 6-8 years to flower after fire. *L. rariflora* relies on soil-stored seed while the other species rely on canopy-stored seed to regenerate after fire.
- Litter fuel accumulates rapidly in the first 3-5 years after fire, reaching about 8 t ha^{-1} after 6-10 years and stabilising at 10-16 t ha^{-1} after about 15 years (depending on rainfall) (Burrows 1994).
- The rate of post-fire recovery of understorey vegetation structure (height and cover) is also rapid in the first 3-5 years after fire. Vegetation is considerably denser and taller in riparian zones than on drier sites (Burrows 1994) and when mature, forms important habitat for a suite of mammals (Burrows and Friend 1998).

Table 1: Using the longest juvenile period (LJP) of the slowest maturing plant species as a basis for quantifying fire frequency in jarrah forest ecosystems. The sustainable fire interval is based on the rule of thumb that twice the juvenile period is required for seed bank replenishment (Gill and Nicholls 1989). The fire frequency ratio (FFR) = actual fire interval:LPJ.

Ecosystem	Longest juvenile period (LPJ) (yrs)	Sustainable fire interval (2xLPJ) (yrs)	**High fire frequency** FFR=2 (yrs)	**Moderate** fire frequency FFR=2-4 (yrs)	**Low fire** frequency FFR = 4-6 (yrs)	**Very low** fire frequency FFR>6 (yrs)
High rainfall upland forest (>900 mm)	3	6	<6	6-12	12-18	>18
Low rainfall upland forest (<900 mm)	4	8	<8	8-16	16-24	>24
High rainfall riparian (>900 mm)	6	12	<12	12-24	24-36	>36
Low rainfall riparian (<900 mm)	8	16	<16	16-32	32-48	>48

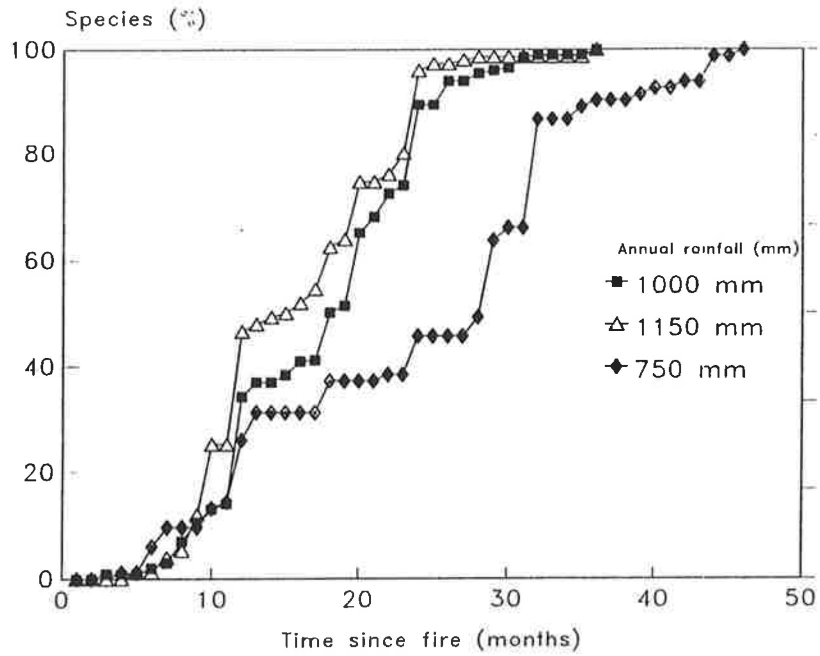

Figure 1: The proportion of upland jarrah forest understorey species to have flowered with time since fre for various rainfall zones.

Management applications: A high proportion of resprouting woody shrubs in drier parts of the forest indicates a history of moderate fire frequency (see Table 1). Conversely, a higher proportion of obligate seeders in riparian zones, broad valley floors and other sheltered sites indicates a lower fire frequency (Table 1). The maximum juvenile period for upland understorey species is 3-4 years, and for moister habitats, 5-8 years. Gill and Nichols (1989) suggest that the minimum interval between fires should be double the juvenile period of the slowest maturing species to allow sufficient replenishment of seed banks (soil and canopy) following fire. Based on this criterion, the minimum, sustainable fire frequency for upland jarrah forests is about 6 and 8 years for high rainfall and low rainfall forests respectively. For low lying areas, creek lines and broad valley floors that contain obligate seeders with longer juvenile periods, the minimum fire interval is 12-16 years. Thus, a minimum fire interval dichotomy exists, based on this criterion, between dry upland sites and moister lowland sites. The historical evidence suggests that the pre-European frequency throughout much of the forest was 3-4 years, which is consistent with the longest juvenile periods, so the seed bank rule of thumb (Gill and Nichols 1989) may be conservative. Occasional fires at shorter intervals are unlikely to be harmful to species richness while a viable *in situ* or *ex situ* seed bank exists. Habitat requirements for jarrah forest mammals varies for each species with some preferring low open vegetation associated with drier upland sites and with early post-fire conditions, and others preferring tall, dense mature vegetation associated with riparian zones, thickets in broad valley floors (Figure 2 and Table 2).

For wildfire control, it is desirable to maintain fuel levels in strategic areas below about 8 t ha^{-1}. This equates to prescribed burning every 6-10 years (depending on rainfall). As well as being important in its own right, vegetation provides habitat, with some animals preferring different post-fire stages of maturity (see below).

3.4 Biological indicators (fauna):

- The severity and duration of impact of fire on bird populations is directly correlated with the size and intensity of fire. Small, patchy, low intensity fires have little long-term impact but birds take longer to recover following large, intense fires (Christensen *et al.* 1985).
- Almost without exception, the impact of fire on jarrah forest mammals depends on habitat requirements, life history of the animal and on the intensity, scale and patchiness of the fire, or the extent of habitat fire damage (Whelan 1995; Burrows and Friend 1998).
- There is a group of mammals which prefer the dense cover of mature (older than 5-7 years) vegetation and thickets associated with seasonally moist sites such as is found along creeks, swamps and in broad valleys.
- Infrequent (20-30 years) moderate intensity fire is necessary to regenerate thickets, which provide habitat for a number of important mammals (Christensen 1977, 1982).
- The large and more mobile macropods are most abundant in the first few years after fire (Christensen and Kimber 1975). Burnt areas should exceed 500 ha to minimise adverse post-fire grazing impacts (Per Christensen pers. comm.).
- Like many species, the Honey Possum (*Tarsipes rostratus*) is adversely affected by large and intense fires which result in complete or near complete landscape burn-out (Richardson and Wooller 1991; Burrows and Friend 1998). However, if fires are patchy and relatively small, then they can recolonise relatively quickly from unburnt patches. This animal is "fire sensitive", being highly vulnerable to the acute impacts of fire and having a specialised diet of pollen and nectar. It is most abundant in mature (10-15 years post-fire) vegetation (Burrows and Friend 1998).
- Reptiles are more resilient to fire than mammals because of their physiological adaptations to arid conditions (Friend 1993). Most reptiles are burrowers with generalised invertebrate diets and strongly seasonal activity and breeding patterns. Survival may be relatively high during a fire, but predation and starvation may be significant in the early post-fire period (Newsome *et al.* 1975, Friend 1993). Species which inhabit jarrah forest leaf litter and feed on leaf litter invertebrates (e.g., *Morethia obscura*) were affected for up to two years by a high intensity summer/autumn (dry conditions). This species is less likely to be affected by patchy, low intensity fires (Burrows and Friend 1998).
- Invertebrates typically decline immediately after fire, but most species/groups return to pre-fire abundances and species diversity levels within 2-3 years (Abbott 1984; Majer 1984; Strehlow 1993; Friend and Williams 1996).

- At the regional level, a mosaic of different post-fire periods, including long unburnt patches, and fires burnt in different seasons will optimise invertebrate diversity (Van Heurck *et al.* 1998).
- Unburnt periods in excess of 4 years are important for relictual species (Van Heurck *et al.* 1998).

Table 2: Broad grouping of some jarrah forest mammals based on landform/vegetation types and flammability of habitat.

Common Name	Scientific Name	Preferred habitat type and flammability
Quokka Mardo Quenda Honey Possum Pygmy Possum Bush Rat	*Setonix brachyurus* *Antechinus flavipes* *Isoodon obesulus* *Tarsipes rostratus* *Cercatetus concinnus* *Rattus fuscipes*	Tall, dense, mature understorey vegetation in creeks, swamps and valleys. Low flammability in winter and spring, but extremely flammable in summer and autumn.
Numbat Ring-tail Possum Echidna Chuditch Brush-tailed Possum Brush Wallaby Western Grey Kangaroo Woylie	*Myrmecobius fasciatus* *Pseudocheirus peregrinus* *Tachyglossus aculeatus* *Dasyurus geoffroii* *Trichosurus vulpecula* *Macropus irma* *Macropus fuliginosus* *Bettongia penicilata*	Low open understorey vegetation, ridges, midslopes and broad valleys. Low flammability in winter, moderate in spring and highly flammable in summer and autumn.
Tammar	*Macropus eugenii*	Tall, dense thickets with grassy ground cover along broad valley floors. Very low flammability in winter and spring, highly flammable in summer and autumn.
Brush-tailed Phascogale Red-tailed Phascogale Fat-tailed Dunnart Dunnart	*Phascogale tapoatafa* *Phascogale calura* *Sminthopsis crassicaudata* *Sminthopsis murina*	Recorded in a wide range of habitat types including ridges, midslopes, creek lines and swamps

Management applications: Minimise the occurrence and severity of large wildfires. Enhance burn patchiness either by limiting the size of fires and/or by burning under weather and seasonal conditions, which result in drier patches of the landscape burning. No single fire regime will suit all faunas. Generally, fauna which inhabit less flammable parts of the landscape (riparian zones, broad valley floors) prefer mature, long unburnt vegetation so these habitats should be burnt less frequently but more intensely to ensure regeneration. Some species prefer recently burnt vegetation. An interlocking mosaic of burns at different ages and seasons, including recently burnt and long unburnt, is most likely to enhance biodiversity at the regional level.

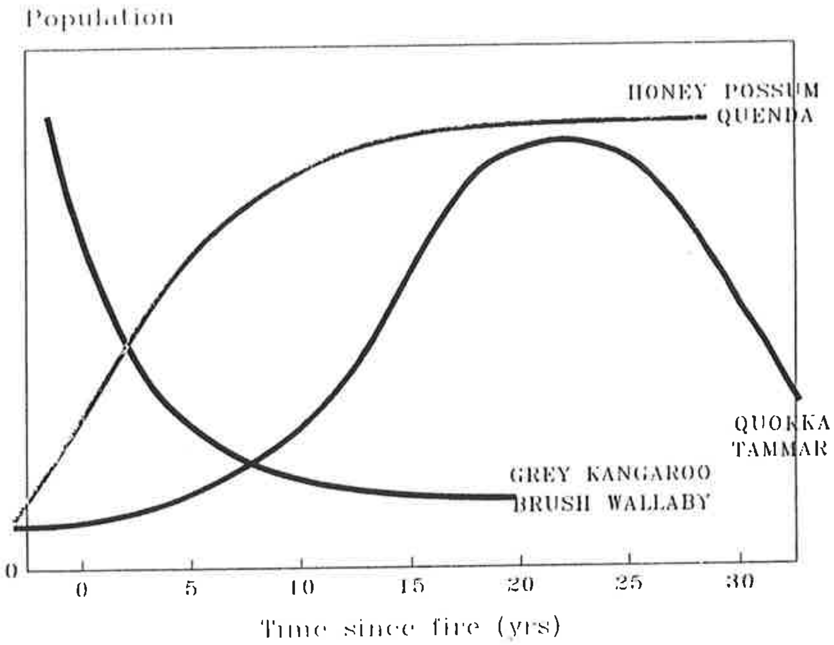

Figure 2: Idealised post-fire response patterns for a range of mammals which occur in jarrah forests. Information used to devise these response curves is from the following sources: Grey Kangaroo and Brush Wallaby, Christensen and Kimber (1975), Honey Possum, Burrows and Friend (1998), Brushtail and Western Ring-tail (Burrows *et al* 1996). Response patterns for other species are based on reported life histories and unpublished field observations and are indicative only. These responses are for complete burning out of habitat; recolonisation is likely to be more rapid where the habitat is only partially burnt. Predation by introduced predators such as foxes and cats will affect post-fire recovery.

4. A Recommended Fire Regime for Jarrah Forests

4.1 Setting fire frequencies:

- Minimum sustainable fire frequency 6-8 years on drier midslope and ridge sites.
- Frequency of 6-10 years preferred for managing fuel levels
- Minimum sustainable fire frequency 12-16 years in riparian zones and broad valley floors.
- At the local scale (thousands of ha) within a broad forest type, there is a requirement for differential fire frequencies based on the habitat type and position in the landscape (Table 2). A frequency of 6-8 years is adequate for uplands, but the lowlands require at least double this for the preservation of biodiversity. Moisture differentials, which exist at certain times of year, can be exploited to achieve different fire frequencies in different parts of the landscape (see below).

4.2 Setting fire season, intensity and patchiness (scale):

- Setting prescribed fires under mild weather conditions early in spring when fuel moisture content (therefore flammability) is variable across the landscape will usually result in a low intensity and patchy fires. Most of the drier ridge and midslope areas will burn, but important riparian habitat, swamps and low surface fuel areas (broad valley floors with dense thickets) will not burn because fuels are too moist at this time of year. Likewise, large hollow logs and old trees with hollows, both of which are important faunal refugia, are unlikely to ignite or burn away under these conditions.
- Occasional moderate intensity fires that burn the entire landscape are necessary to regenerate habitat and many plant species.
- Creeks and wetland systems should only be partially burnt in any one prescribed autumn fire event to allow for the potential of recolonisation by fauna from adjacent mature or senescing habitats.

- Individual low intensity spring burns which are patchy (60-70% burn) and do not burn creeks and lowlands, should not exceed about 3 000 -5 000 ha in area.
- Autumn/summer prescribed burns which result in complete landscape burnout should be restricted to about 1 000-2 500 ha. If prescribed burns are interspersed to form an interlocking patchwork of forest blocks (each 1 000 - 5 000 ha) at different stages of post-fire development, this will ensure a mosaic at both local and regional scales of habitat diversity.

5. Conclusions

Fire regimes that strive to achieve protection and biodiversity objectives can be devised at the local and regional scales based on a combination of climatic, historical and biotic evidence. Case studies in the jarrah forests of Western Australia show that patterns emerge which enables the derivation of appropriate fire regimes. Important fire regime components and indicators for setting these are:

- *Minimum interval between fires to sustain biodiversity*: Estimated from the juvenile period of the slowest maturing vascular plants (especially obligate seeders) and from the post-fire response patterns of fire sensitive taxa of fauna and flora.
- *Minimum interval between fires for wildfire control*: Estimated from fuel accumulation and fire behaviour models, and a wildfire threat analysis.
- *Maximum interval between fires to sustain biodiversity*: Estimated from plant species richness with time since fire, seed bank quantity and durability (shelf life), vegetation/habitat biomass increment and structural changes with time, post-fire response patterns and habitat requirements of key fauna.
- *Season of fire*: Estimated from requirements to regenerate habitat, requirements for patchiness of fire and extent of acceptable damage to habitat.
- *Fire intensity*: This will determine the level of acute physical impact of fire on vegetation, on habitat and on individual organisms. Generally, the magnitude of fire impact on organisms and habitat is directly correlated with intensity and scale of fire.
- *Scale and patchiness of fire*: Estimated from habitat requirements, life histories and post-fire response patterns of key fauna.

These elements are contained in the interim fire regime illustrated in Figure 3. Based on current knowledge of these indicators, this fire regime for jarrah forests demonstrates the compatibility of managing fire to satisfy wildfire protection requirements and to maintain biodiversity. Clearly, any managed fire regime will be constrained by factors including resource availability, weather conditions, and other land uses such as timber harvesting, mining, recreation and water production.

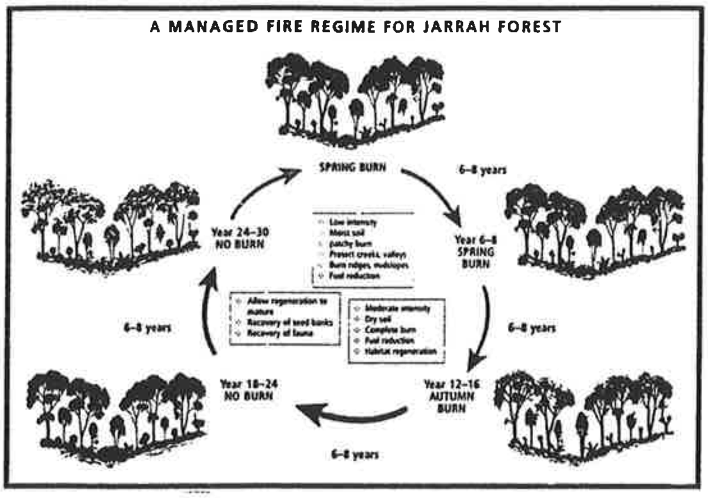

Figure 3: A managed fire regime for jarrah forests developed from climatic, historic and biotic indicators for the dual purpose of ameliorating the threat posed by wildfire and for maintaining biodiversity.

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