Implementing fire mosaics to promote biodiversity and reduce the severity of wildfires in south-west Australian ecosystems

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Abstract:

Natural landscapes are heterogeneous in space and time, comprising a mosaic of biotic assemblages at different scales and varying composition, structure and function. At one scale, heterogeneity determined by factors such as climate, landform and soil, results in habitat patches that are relatively stable through time. Superimposed on this is a finer scale, more dynamic heterogeneity induced by natural disturbances. The spatial and temporal patterning of the mosaic affects the distribution and abundance of organisms and it can also greatly affect the severity and intensity of natural disturbances such as fire. Having evolved with fire over millions of years, south-west Australian forests and associated ecosystems are maintained by specific fire regimes. Organisms and communities display a variety of adaptations to fire and many depend on fire for their persistence. There is ample evidence that at the landscape scale, a diverse fire regime promotes biodiversity. Therefore, where the conservation of biodiversity is a primary objective, fire management is an integral part of land management. Attempting to exclude fire from the landscape for long periods and over large areas will diminish heterogeneity and threaten ecosystem health. It will also ensure heavy and contiguous fuel accumulations, resulting in large and damaging wildfires. Whether planned or unplanned, coarse-scale and repetitive fire regimes may also diminish habitat heterogeneity and biodiversity values over time. On the other hand, we postulate that managing fire to create a fine-grained mosaic of habitat patches at many different post-fire stages will enhance biodiversity at landscape scales and provide better protection against large wildfires by creating a fuel pattern that will reduce the scale and intensity (severity) of wildfires. The frequent and targeted introduction of fire into the landscape should, in time, result in a fine-grained shifting mosaic of patches at different post-fire stages ranging from recently and frequently burnt to long unburnt. Consistent with adaptive management, a landscape-scale trial, the Fire Mosaic Project, is being planned in the south-west of Western Australia to investigate this.

1. INTRODUCTION

Landscapes can be characterised as heterogeneous areas composed of a mosaic of interacting ecosystems, or patches, over a kilometres-wide area (Forman 1995). Landscapes of the forested region of south-western Australia comprise a remarkable heterogeneity of biotic and abiotic structures across a variety of spatial and temporal scales. These scales are now recognised as important components in understanding the composition and functioning of ecological systems and processes. Spatial patterning of biotic elements, such as the distribution of plant and animal assemblages, is primarily determined by abiotic factors (climate, landform and soils) (Mattiske and Havel 1998), which in the absence of major extraneous perturbations such as land clearing and introduced pests and diseases, are relatively stable over time. Within this patterning of biodiversity, episodic disturbances such as fire impinge on almost all ecosystems, providing a dynamic diversity overlay on that established by climate and geomorphology. Fire has played an important role in shaping the structure, composition and functioning of south-west Australian forests and associated ecosystems over the last 2.5 million years (Kershaw *et al.* 2002, Hassell and Dodson 2003) and anthropogenic fire has influenced these ecosystems to varying degrees for tens of thousands of years (Hallam 1975, Abbott 2003). Consequently, the biota of the region displays an array of fire adaptations that enables organisms to persist, and in many cases, depend upon a variety of fire regimes across various scales of space and time (Abbott and Burrows 2003). For many plant species, reproduction and regeneration are cued or enhanced by fire and for many plant communities, particular fire regimes are necessary for the maintenance of floristic and structural diversity (Burrows and Wardell-Johnson 2003). A particular sequence and scale of fires are necessary to provide habitat diversity and opportunity for animals to recover and maintain their populations across the landscape. However, the way in which species and communities respond to fire is variable. Some assemblages are quite resilient to frequent fire and recover to their pre-fire state relatively quickly, while others are more sensitive to fire and can take many decades to recover. Thus, no fire regime or history of fire interval, season, intensity, patchiness and scale is optimal for all species and communities and although fire diversity can promote biodiversity, some fire regimes can also threaten biodiversity.

The damage potential and suppression difficulty of a wildfire is largely determined by the amount of vegetation that burns (the fuel), fuel dryness and topography and weather conditions. The challenge for managers in fire prone and biodiversity-rich regions is to devise practical and affordable fire regimes that conserve biodiversity at agreed spatial scales, and minimize the adverse impact of wildfires on social, economic and environmental values. In south-west Australia this is being achieved by the implementation of essentially four broad fire regimes, the objectives of which can be compatible and overlapping, but which may be mutually exclusive at the extremes;

- Fire regimes based on vital attributes and life histories of focal species, including fire sensitive (fire regime dependent) taxa.
- Fire regimes based on the vital attributes and life histories of threatened and keystone species.
- Fire regimes based on fuel accumulation rates to manage fuel build-up (hence potential fire intensity) in strategic areas.
- Fire regimes to regenerate and protect forests available for timber harvesting (see Armstrong this volume).

In this paper, we introduce an alternative and novel approach to operational fire management to achieve multiple objectives, that being the frequent introduction of fire into the landscape (frequent patch-burning) to promote the development of a fine-grained mosaic of habitat patches at different post-fire stages.

There is accumulating scientific evidence suggesting that at the landscape scale, a heterogenous fine-grained fire-induced habitat mosaic promotes biodiversity and buffers landscapes against the environmentally and socially damaging impacts of large scale intense wildfires (Abbott and Burrows 2003). A key to achieve this is maintaining the long history of anthropogenic fire in the landscape at appropriate temporal and spatial scales. In an adaptive management framework, we aim to test the hypothesis that frequent introduction of fire into the landscape (patch-burning) will a) maintain and promote a fine-scaled habitat mosaic incorporating a range of interlocking seral stages, and b) that this mosaic will promote biodiversity <u>and</u> reduce the severity and impact of wildfires. This ecologically appropriate fire regime contrasts with regimes (planned and unplanned) that result in coarse-scale patches of uniform seral stages, including large and damaging wildfires, which threaten both biodiversity and human life and property. The Fire Mosaic Project (Burrows *et al.* 2003) is a long term project that utilises the fire management expertise within the Western Australian Department of Conservation and Land Management to carry out frequent patch-burning over an area of some 4,000 ha. The project will describe and map spatial patterns of land systems and associated biotic assemblages through space and time. This information, supported by quadrat-based biodiversity information and remotely sensed burnt patch data, will be collated in a GIS environment to map and characterise the dynamic fine-scale fire mosaics in a landscape context. This approach will also facilitate the interpretation of how the mosaic influences the composition, structure and distribution of biodiversity, and how it influences the behaviour and severity of wildfires.

2. HETEROGENEITY OF BIODIVERSITY IN THE SOUTH-WEST AUSTRALIAN FOREST REGION

Landscapes of the south-west Australian forest region occur as a mosaic of native forests, woodlands, wetlands, rock outcrops, riparian systems, plantations, agricultural land and settlements over an area of several million hectares. Considerable heterogeneity in environmental and floristic pattern over relatively small spatial scales has been documented in the natural ecosystems (e.g. Wardell-Johnson & Williams 1996, Mattiske & Havel 1998), despite subdued topographic relief. This subtle variation in landform, soils, climate and therefore vegetation (fuel) may have had a significant influence on the historical variation in disturbance regimes experienced over millennia (Burrows & Wardell-Johnson 2003). This variability, often over short distances, can strongly influence the spread and behaviour of fire, despite subdued topographic relief. These 'pyro-botanical' boundaries will be most clearly expressed in low intensity fires burning under moist and mild weather conditions or sparse fine biomass (fuel). Conversely, these boundaries are least evident in high intensity fires burning under dry and hot weather conditions and/or heavy fuel.

The region includes levels of endemism and biodiversity notable on a world scale (Myers *et a*l. 2000), including both recently derived lineages, and a diverse array of relictual species occurring in refugial habitat (Wardell-Johnson and Coates 1997). Many relictual endemic taxa are confined to more mesic or less flammable sites including riparian systems, some wetlands, wetter forest areas and granite outcrops (Wardell-Johnson and Horwitz 1996, Burrows and Wardell-Johnson 2003). Due to localised moisture regime and the characteristics of the vegetation as fuel, these communities are less subject to frequent fires than the surrounding matrix, and organisms often display life history attributes that render them vulnerable to frequent fire or large, high intensity fires. Generally, plant communities in drier, more flammable parts of the landscape, such as jarrah forest uplands, display a greater resilience to frequent or intense fire than those in less flammable parts (Burrows and Wardell-Johnson 2003). Thus, at the landscape scale, the maintenance of heterogeneity through diversity of fire regimes is fundamental to biodiversity conservation.

3. RECENT HISTORY OF FIRE MANAGEMENT IN SOUTH-WESTERN AUSTRALIA

An understanding of historical fire regimes can provide evidence for planning current and future regimes. The arrival of Aboriginal people (probably within the last 40 000 years) would undoubtedly have led to dramatic changes to previous fire patterns and the fire environment (Hallam 1975, Bowman 1998). Presumably, a fire regime of predominantly anthropogenic burning supplemented by lightning-caused fires evolved with the economic, spiritual and ecological needs of people (Bowman 1998, Wardell-Johnson and Horwitz 2000). It is likely that prior to European settlement, regular burning of parts of the landscape by Noongar people maintained a mosaic of vegetation at different pyric stages – from recently to infrequently burnt (Wardell-Johnson *et al.* 2004). It has been suggested that much of the landscape was maintained in an early post-fire state (Lamont *et al.* 2003), although conclusions drawn from the methods employed are controversial (cf Ward *et al.* 2001, Wardell-Johnson *et al.* 2004). Although dominant, relictual overstorey species are capable of resprouting following moderate to high intensity fire events (Wardell-Johnson 2000), the matrix also includes patches of vegetation that burnt infrequently (Wardell-Johnson and Horwitz 1996, Wardell-Johnson *et al.* 2004). This fire mosaic would have helped to contain the spread and intensity of wildfires. Very large and intense wildfires were not in the best interests of Aboriginal people, or the environment generally, and were probably rare events (Burrows *et al.* 1995).

The relatively recent arrival of Europeans and the rapid changes to the landscape as a result of exploitation, land clearing, fragmentation and agriculture, and the introduction and spread of exotic pests and diseases, have brought about changes in fire regimes (Burrows *et al.* 1995, Wardell-Johnson and Horwitz 2000), a process that continues to evolve. Climate change associated with greenhouse effects will lead to future far reaching changes in fire regimes and impacts (Hughes 2003, Abbott and Burrows 2003).

Following settlement by Europeans in 1829, clearing of land for agriculture and logging of timber for domestic consumption and the export trade became important developments (Mills 1989). Logging was largely unregulated up until 1918. Much of the forest overstorey was opened and logging debris accumulated on the forest floor. These actions, coupled with the use of steam-driven equipment and a general carelessness with fire, led to fires of unprecedented intensity and wide geographic spread (Burrows *et al.* 1995, Calver and Wardell-Johnson 2004). Following the Forests Act of 1918, policy was directed towards protection and fire prevention with limited application of prescribed fire in strategic areas around towns and forest regrowth. This culminated in massive and destructive fires in the south-west in the 1960's, among other things, resulting in a very coarse-grained mosaic (tens of thousands of ha) of recently (and severely) burnt 'patches'. This lead into a third management era (Burrows *et al.* 1995, Calver and Wardell-Johnson 2004) in which the policy was characterized by an expansion of broad-scale prescribed burning, mainly in spring, to reduce fuel build-up and wildfire threat. Fire policy sought to achieve regular burning of about 70 % of the most productive jarrah forest at around five to seven year intervals. Gill *et al.* (1997) estimated that the fire cycle decreased from 16 years in 1951/52 to five years in 1968/69. It then increased to about 14 years in 1995/96. The area of prescribed burning has continued to decrease since 1995/96 (Burrows and Wardell-Johnson 2003).

Low intensity prescribed burning has been applied routinely, particularly in spring when moisture differentials exist, over many areas of the forested south-west for several decades. However, in some areas, particularly in areas of complex and structurally diverse vegetation mosaics, there is a risk of later re-ignition, leading to the burning of the entire designated area, and to possible fire escape. These risks become pronounced if the interval between fires is increased. Thus, such a strategy usually results in a relatively coarse-grained mosaic (patches of uniform seral stage up to several thousand hectares) (Figure 1), resulting either from prescribed burning or from wildfires (Wardell-Johnson and Horwitz 1996, Burrows and Wardell-Johnson 2003, Burrows *et al.* 2003).

4. NEW DIRECTIONS IN FIRE MANAGEMENT

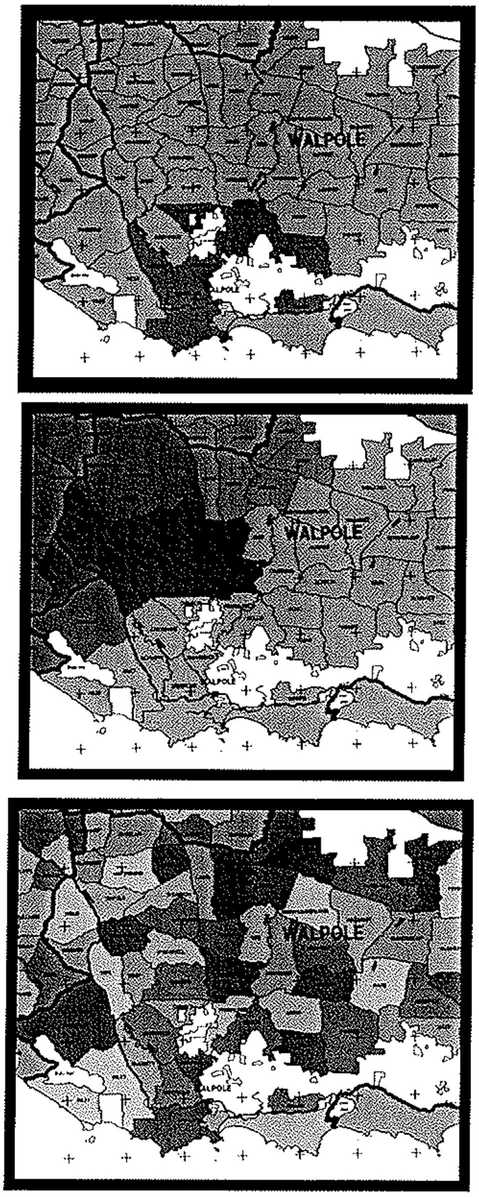
There is growing recognition that fire and ecosystems interact to produce mosaic landscape patterns and that these patterns are present in even the most subdued topographic regions (Wardell-Johnson & Horwitz 1996). There is also an increasing recognition that mosaic burning patterns provide a greater conservation focus on fire management on public lands (Burrows and Wardell-Johnson 2003). In fire-prone landscapes, the potential exists for numerous types of fire mosaics to develop in space and time. The scale, number and distribution of patches at different seral stages can vary, as illustrated by the hypothetical examples in Figure 1. The characteristics of the mosaic will be influenced by biotic and abiotic factors, as discussed above, and by the frequency and distribution of ignitions in the landscape. If the frequency and distribution of ignitions is relatively low, then a stable but coarse grain fire mosaic of a few large patches representing few seral stages is likely to persist. This will be characterised by cycles of infrequent but large and intense fires (top of Figure 1). On the other hand, where frequency and intensity of ignition is relatively high, then a shifting mosaic of numerous small patches representing many seral stages is likely to persist, *ceteris paribus* (bottom of Figure 1). Although incomplete, scientific knowledge suggests that the latter mosaic characteristics are more likely to enhance the conservation of biodiversity and reduce the adverse impacts of wildfires (Abbott and Burrows 2003).

There are many possible approaches to maintaining diverse fire regimes. For example, the fire regime applied to a fire management unit within a landscape can be varied. This includes varying the season, frequency and interval of fire based on vital attributes and life histories of key taxa (fire regime specific taxa) (Burrows and Friend 1995). It is also possible to prescribe a majority of fires that burn patchily, with occasional burns of greater extent (that is, create patchiness within patches - an intra-patch mosaic). Fine-grained mosaics can be achieved in several ways. These include physically breaking up the management unit with a network of mineral earth or natural physical fire barriers and treating each cell differently; introducing fire into the landscape when moisture differentials exist; using wind-driven strips; using predetermined lighting/ignition patterns and time of ignition; and introducing fire into the landscape frequently when fuel flammability (quantity and cover) differentials exist (Burrows and Wardell-Johnson 2003, Burrows *et al.* 2003).

In the ancient landscapes of south-western Australia, the baring of soil by mineral earth breaks is generally unacceptable and undesirable (Hopper 2003). Reliance on moisture differentials comes with the risk of re-ignition and complete burnout as the season and vegetation dries with the onset of summer (McCaw and Hanstrum 2003). Wind driven fires have a place particularly in heath or mallee heath vegetation but are more limited in forest areas (McCaw 1997). The regular introduction of fire into the landscape has some similarities to what is thought were likely Noongar Aboriginal burning regimes (Wardell-Johnson and Calver 2004).

The resultant mosaic and effects on biodiversity at the landscape scale over time are as yet unknown. In addition, it should be noted that because of differences in the present environment to that prior to European settlement, such a program would not imply the mimicking of fire regimes in place before European settlement. Rather, proposed regimes must recognize the contemporary environment and land use aspirations

Nevertheless, the regular introduction of fire into particular landscapes is worthy of further investigation and should be trialed and monitored. It should be noted that it does not equate to the "frequent burning" of the landscape, or of the ecosystems therein (cf Ward *et al.* 2001, Wardell-Johnson *et al.* 2004). Under such a regime many elements will escape fire or will be protected from fire by adjacent natural low fuel areas or recently burnt patches. Indeed, such a regime in particular environments would be designed to conserve biological assets, analogous to fuel modification to protect human cultural assets.



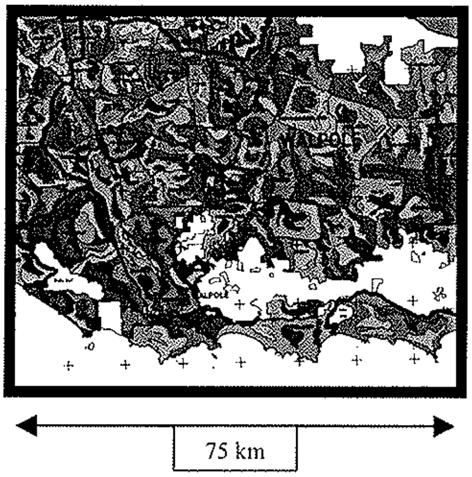


Figure 1. Hypothetical examples of fire mosaics possible in south-west Australian landscapes from coarse-grain (top left) to fine-grain (bottom right), with colours representing different (post-fire) seral stages (or fuel ages).

5. CREATING FIRE-INDUCED (FIRE-GENIC) MOSAICS IN THE LANDSCAPE

In an attempt to trial the more frequent introduction of fire into the landscape, the Department of Conservation and Land Management (CALM) has recently initiated the Fire Mosaic Project (Burrows *et al.* 2003) in an area encompassed by the proposed Walpole Wilderness Area. The proposed location lies within London forest, an area about 30 km north-east of Walpole that is isolated from private property and surrounded by other forest blocks of the same tenure and purpose (Figure 1). This general area has been the subject of intense biological survey including a floristic survey of the Tingle Mosaic (Wardell-Johnson & Williams 1996) and a biological survey of the Walpole Nornalup National Park, carried out during the 1980's (Wardell-Johnson *et al.* 1989). This area has a diverse array of vegetation types ranging from sedgelands to tall open-forest. A large area (28 000 ha) north of London forest was recently (2003) burnt by a severe lightning-caused wildfire. The fire history of the area is known for the most recent 40 years (McCaw *et al.* this volume).

Live and dead vegetation, which becomes the fuel of a bushfire, is insufficiently mature to carry a fire under mild conditions until about three years after fire. Prior to this, fire spread, even under conditions of high fire danger, tends to be patchy and restricted to relatively small areas with a dense overstorey canopy cover, or to grassy understoreys. However, beyond about 3-4 years after fire, a greater proportion of the landscape is flammable, and by about 5-8 years the vegetation/fuel complexes are sufficiently well-developed so that virtually the entire landscape will support an intense bushfire under dry, windy conditions.

Fires burning in light and patchy fuels will not only be very patchy, but will also be of very low intensity. Patchy fires burning at very low intensity that only burn in the more flammable parts of the landscape provide opportunities for species that are specific to particular fire regimes, and communities that mostly occur in less flammable parts to either not burn or to survive very low intensity fire.

We postulate that over time, the frequent introduction of fire into the landscape (every 2-3 years) will result in a fine-grained mosaic of patches of a range of post-fire ages (Figure 1). However, the nature, scale, patterning and dynamics of this mosaic are unknown, as are the effects on the biota. It is likely that the resultant mosaic will afford protection to fire regime specific species and communities and will significantly fragment the size, intensity and uniformity of an impinging wildfire. Because of the patchy nature of the vegetation and fuels, the frequent introduction of fire does not equate to frequent burning of the landscape. In fact, we anticipate that a relatively small proportion of the landscape will carry fire and hence burn regularly.

The location of the proposed trial is London forest of some 4,000 ha within the Walpole Wilderness Area (Figure 1). This area is relatively isolated from human (built) cultural assets, has all-weather access to all boundaries, has a very diverse array of vegetation types (from sedgelands, swamps, woodlands to tall eucalypt forests), and about 75% of the area was prescribed burnt by low intensity fire in spring 2002. There are uncertainties and risks associated with this trial. For example, it may not be possible to establish a fine-grained mosaic by frequent patch burning, or areas of higher fuel loads may re-ignite subsequent to the initial fire, leading to escapes. It is also potentially more difficult to contain the fires within boundaries within a large study area (~4,000 ha) featuring a range of vegetation types. The introduced soil-borne plant pathogen *Phytophthora cinnamomi* is scattered throughout the region, including the study site. This could confound or compound any effects of fire. Wildfire or adverse weather conditions will both impact on an ability to create and maintain fine-scaled mosaics. This trial will also require on-going resources to continue to meet project objectives and will rely on community and organizational support.

It is anticipated that fire will be introduced into the landscape under moderate conditions in spring, summer or autumn every 2-3 years. It would be appropriate to begin the trial with a relatively wide spacing between ignition points (say 300 m x 150 m) during summer or early autumn on a falling fire hazard. This will need to be carefully monitored to see how many and which of the ignition points develop or extinguish, along with the subsequent fire behaviour. Subsequent lightings would seek to avoid areas burnt previously, the aim being to create a mosaic of burnt patches at different seral stages.

6. MONITORING BIODIVERSITY

Other intrinsic and unique elements of this project, fundamental to its objectives, are that it is landscape-scale (~4,000 ha) and monitoring will be medium to long term. The design will be based around the BACI (Before, After, Impact, Control) experimental design with replications through space and time. Sampling will be stratified according to three landscape scale "fire treatments";

a) fine-grained fire mosaic (London forest),
b) routine fire management as guided by the area management plan (part of Surface forest) and,
c) no planned fire (part of Surface forest).

Burrows and Wardell-Johnson (2003) provided a scaled, hierarchical set of fire management conservation objectives (and some broad strategies) for forest ecosystems. The Fire Mosaic Project seeks to incorporate the spatial and temporal scales important for maintaining biotic diversity in forest ecosystems. Pre-existing quadrat-based data gathered from over 400 sites within the study region have been data-based and quadrats permanently marked in the field. These data include detailed floristic, soil, site, and structure and habitat information.

The establishment of new monitoring grids will focus on threatened and known fire sensitive (regime specific) taxa. A network of permanent stratified sampling grids will also be established in each fire treatment to more comprehensively monitor biodiversity, including vascular plants, cryptogams, fungi, invertebrates, herpetofauna, mammals and birds (see Burrows *et al.* 2003). Landform soils maps, vegetation complexes and contour data are held by CALM for the study region. The recent acquisition of several GIS layers and data suitable for constructing a digital elevation model by CALM allows the effective use of these data for predictive modeling at various landscape scales, allowing effective monitoring and evaluation. The monitoring challenge then is to develop the cost effective tools for monitoring and evaluating landscape-scale fire management regimes and to determine if and how ecological processes at one level of resolution are constrained by those at higher levels and affected by those at lower levels.

7. MAPPING AND DESCRIBING THE FIRE MOSAIC

Recently developed satellite imagery technology (CALM Fire Management Services) will be used to map the fire mosaic. Imagery will be analysed and maps prepared after each introduction of fire into the study area. Areas that did not burn, areas that burnt and fire intensity classes will be mapped. A chronological sequence of such maps will result in a map of the scale and nature of the mosaic (the matrix and the fire history, seral stages, size, shape, composition, number and pattern of patches that make up the mosaic). The expected results will be the modeling of the biota at various landscape scales and the derivation of knowledge based systems using decision tables. This will greatly enhance the effectiveness of the Fire Mosaic Project.

Terrain data will be generated from digital elevation models (DEM), and from digitized stream, ridge, and vegetation layers, which will be inputted into a GIS. Vegetation will be generalized into layers based on floristic composition and classified imagery derived from satellite imagery. Effective monitoring would involve incorporating these data into layers to enable analysis of change following the implementation of the Fire Mosaic Project.

The Fire Mosaic Project is a collaborative landscape-scale operational trial involving staff from the Department's Science Division, Frankland District, South Coast Region, Warren Region and Fire Management Services to determine whether a fine-grained fire-induced mosaic can be created by the frequent and targeted introduction of fire into the landscape. The resulting shifting mosaic will be mapped through time and the response by elements of the biota, especially selected threatened and fire regime specific taxa, will be monitored. Monitoring will also be carried out both at sites from which fire is excluded and from sites experiencing fire regimes. The goal is to ensure that the Fire Mosaic Project becomes an exemplar of science-based adaptive management to improve fire management and biodiversity outcomes in south-west Australian ecosystems.

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