FIRE SEVERITY AND ECOSYSTEM RESILIENCE – LESSONS FROM THE WOMBAT FIRE EFFECTS STUDY (1984-2003)

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The Wombat Fire Effects Study was established to address a number of questions in relation to the effects of repeated low-intensity fires in mixed species eucalypt forest in the foothills of Victoria. This study has now been going for 25 years and has included the study of understorey plants, fuels, bats, terrestrial mammals, reptiles, invertebrates, fungi, birds, soils, tree growth, fire behaviour and weather. This forest system has shown a high resilience to fire that is attributed here to the patchiness and variability in the fire characteristics within a fire and the relatively small proportion of the landscape being affected. A means of comparing the level of "injury" caused by low-intensity prescribed fire with high intensity wildfire is proposed so that the debate about leverage benefits (the reduction in wildfire area compared to the area of planned burning) can be more rational. There are some significant implications for assessing the relative environmental impacts of wildfire compared with the planned burning program being implemented in Victoria since the Victorian Bushfires Royal Commission recommendations (Teague et al. 2010).

Keywords: Prescribed Fire, Resilience, Landscape, Mosaic, Leverage

THE WOMBAT Fire Effects Study is a multidisciplinary fire experiment designed to gain a better understanding of the effects of fire season and frequency with repeated low intensity fire on the ecosystem in mixed eucalypt foothill forest. There are five experimental fire treatments and these are replicated in five "Areas" spread across the geographic range of this forest type in the Wombat State Forest, a forest covering some 50,000 ha in west-central Victoria (Fig. 1). Up to four successive fires had been applied to the most frequently burnt treatments before the last comprehensive analysis and reporting in 2003, but there have now been six successive fires applied to the most frequently burnt sites.

The five fire treatments include 'as frequent as possible' (nominally 3 years) in spring and autumn, moderate frequency (nominally 10 years) in spring and autumn, and long-unburnt (last burnt between 1931 and 1974 depending on the 'Area'). Treatments are at least 10 ha in size in all 'Areas', except one where they are about 3 ha.

Measurements have been taken of understorey plants, tree growth and bark thickness, various soil properties to 20 cm depth, surface active invertebrates, birds, reptiles, terrestrial mammals, bats, fine fuel levels, fire characteristics, coarse woody debris, and weather at each of the five 'Areas'.

Summaries of this research program (methods and progressive results) have been published in two reports (Tolhurst et al. 1992a, Department of Sustainability and Environment 2003) and there have been over 65 published scientific papers and reports dealing with particular aspects of this research.

After the first 14 years of treatment, no plant or animal species had been lost from a treatment area even though there had been some significant changes in the relative abundance of species (Department of Sustainability and Environment 2003). This shows a strong ability of the forest system to resist permanent change in the light of the fire treatments being applied. However, all the recovery rates were dependent on some of the long-unburnt habitat, or 'old growth' elements being maintained within the treated area and the extent of the burning being only a small proportion of the landscape.

These results seem to be at odds with the often assumed adverse impact of regular burning on fauna and flora populations (Keith 1996). This has sometimes led to the criticism that these experiments are not representative (McMullan-Fisher et al. 2011), this is because the fire severity and the resilience of the system have not been considered.

RESILIENCE AND FIRE SEVERITY

There is often a desire to maintain stability in ecosystems as this is seen as a conservative and low risk state. However, 'stability' is the property of a system

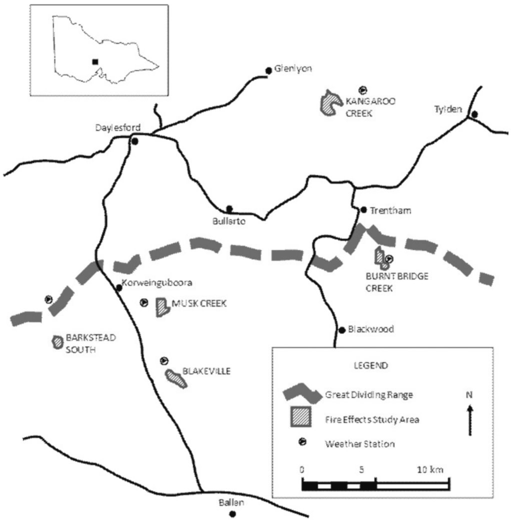

Fig. 1. Location of the five Fire Effects Study Areas (FESAs) and their associated weather stations in the Wombat State Forest.

to return to an equilibrium state after a disturbance, with the more rapidly the system returns to this equilibrium and the less it fluctuates, the more stable it would be considered (Holling 1973). However, ecosystems subjected to periodic fire are inherently ‘unstable’ and do not have any true equilibrium or climax state. In older ecological texts, communities which were maintained by recurring disturbances, such as fire, were termed ‘disclimax communities’ (Daubenmire 1968) and it was in the range of these disclimax communities across the landscape that the full expression of structural and floristic diversity was expressed. Perhaps a better way to conceptualize this dynamic and heterogeneous condition across the landscape is to refer to the ‘resilience’ of the community. Holling (1973) defined resilience as ‘… a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables.’. Episodic disturbance events such as fires, droughts, storms, and disease epidemics are a normal component of many sustainable ecosystems. It is in the evolution of these systems, that disturbance events have not made the systems ‘unstable’, but rather highly resilient systems capable of recovering after disturbances and persisting over time.

If we can then change our focus from expecting different ecosystems having some optimal state, some developmental climax or some ultimate stable state, then we can fully engage in defining landscape management objectives that result in resilient and sustainable ecosystems. Holling (1973) concludes that once we have identified resilience as a key objective for ecosystems subjected to widely varying climatic, biological or other environmental factors such as fire, then we need to concentrate on defining the ‘… boundaries to the domain of attraction rather than on equilibrium states.’, where these domains of attraction are the environmental and biological forces that maintain a system in a particular state, e.g. as a heathy woodland or a grassland. However, it is important to appreciate that the acceptance of this concept of resilience requires the de facto acceptance that an ecosystem will exist in a landscape as ‘… a mosaic of spatial elements with distinct biological, physical and chemical characteristics that are linked by mechanisms of biological and physical transport.’ (Holling 1973). Walker (1995) espouses a similar view, but emphasizes the importance of ecological redundancy in keeping areas within a landscape mosaic functioning in the short-term. The implication of this is that it is the links between the different components of the system which are more important than the makeup of the components themselves – a fundamental understanding in complexity theory (Bossomaier and Green 1998). So it is to be expected that if a species becomes locally extinct in one component of the system, there will be adequate links in space and time for that species to reoccupy that area at some time in the future from a connected area.

Severity then is a measure of the degree of impact that pushes a system towards the ‘outer edge’ of the “domain of attraction” and closer to the possibility of a system being changed from one functional state to another. Much has been written about the inadequacy of using the ‘time since fire’ as a measure of recovery (Parr and Andersen 2006), but there has not been a satisfactory replacement for this. Quantifying the nature of the resilience of a community and defining the ‘domain of attraction’ could provide a more ecologically meaningful way of assessing the state of a system. Using a life history of fauna and flora can help define the domain of attraction (Noble and Slatyer 1980; Tolhurst and Friend 2001), but it has to be applied at a landscape scale not a local one as is often the case (Cheal 2010).

Fire severity has commonly been classified according to the degree of foliage loss on the shrub and tree strata of forests and woodlands (Keeley 2009; Bradstock and Price 2010b). This is largely

Table 1. Fire severity scale where severity is a measure of relative time to recover to unburnt condition. Level 7 is when irreversible change occurs.

SEVERITY	**Low Level 1**	**Moderate Level 2**	**High Level 3**	**Very High Level 4**	**Extreme Level 5**	**Catastrophic Level 6**
Within Burnt Area						
Plants (species population)	Unburnt	Moisture stressed	Low Scorch	Partial canopy scorch	Shoots killed	Buds / seeds killed
Animals (species population)	Untouched	Temporary shift to avoid fire	Partial loss of habitat	Individuals killed	Population killed; Structural habitat change	Regionally extinct
Nutrients (% catchment)	Unburnt	N-volatilization (>20% total)	Soil-C loss (>20% total)	Total P loss (>20% total)	Surface erosion (>20% total)	Mass erosion (any amount)
Within Ecological Landscape Unit						
Communities (landscape) or Plant and Animal populations	Unburnt	<10% occurrence in landscape	Patchy burn 10 - 30%	30 - 70% occurrence in landscape	70 - 85% occurrence in landscape	>85% occurrence in landscape
Recovery Time (Nominal)						
Within Burnt Area	nil	1 year	2 - 4 years	4 - 8 years	20 years	30+ years
Within Landscape	nil	5 years	10 - 15 years	20 - 30 years	30 - 40 years	40+ years

due to the ease of assessing this with remote sensing such as satellite imagery or aerial photogrammetry. However, as Keeley (2009) correctly points out, this type of severity mapping is often very useful for resource managers, but not very useful for quantifying ecosystem impact. I would therefore propose a fire severity scale that is assessed at a local burn scale as well as at a landscape scale and in each scale there are specific attributes assessed. These are summarized in Table 1.

I would propose a seven level severity scale. In risk assessment terms, these would be called: low, moderate, high, very high, extreme, catastrophic and irreversible. As shown in Table 1, for animals, this would translate into: untouched, temporary shift to avoid fire, partial loss of habitat, individuals killed, population killed (locally extinct), regionally extinct, extinct. A similar scale is shown for plants and nutrients. An additional factor is included in Table 1, which is the extent of an ecological landscape unit burnt in a single fire event. The assumptions here is that if only a small proportion of the total landscape is burnt in a single event, the rate of recovery will be quicker and conversely, if the majority of the landscape is burnt, then the recovery time will be longer. Within a single fire, and based on the results of the Wombat Fire Effects Study, I have nominally set the recovery time for the 'Moderate' level to be one year, the 'High' level 2-4 years, the 'Very High' level to be 4–8 years, the 'Extreme' level to be 20 years and the 'Catastrophic' level to be more than 30 years. An addition severity level would be 'irreversible change' where the resilience of the system has been exceeded and the system changes into a different state or domain.

RESILIENCE IN THE WOMBAT FIRE EFFECTS STUDY AREAS

This concept of resilience and severity can now be used to evaluate the effects of repeated low-intensity prescribed burning in the Wombat State Forest.

Surface litter loads returned to long-unburnt levels within 10 years of burning in any season (Tolhurst et al. 1992b, Tolhurst and Kelly 2003). This is consistent with a Level 4 severity (Very High) because 50–90% of all the litter was removed in the fires.

Surface active invertebrates returned to long-unburnt levels within three years (two breeding seasons) (Neumann 1992, Collett and Neumann 2003) with annelids (earthworms), Collembola (springtails) and Diptera (flies) being the most affected groups (Neumann and Tolhurst 1991). This is consistent with Level 3 severity (High). Unburnt patches within the fire area provided refuges for many invertebrates and no habitats or microhabitats were created or completely destroyed by the low intensity fires (Tolhurst et al. 1992b; Loyn et al. 1992; Irvin et al. 2003a).

There was no detectible difference in either the species diversity or abundance in soil borne fungi or sporophytes three years after burning in any season and the long-unburnt areas (Osborn 2007; McMullan-Fisher et al. 2011). This is consistent with level 3 severity (High).

Small terrestrial mammals were initially reduced after burning, but recovered to levels equivalent to long-unburnt sites within two breeding seasons (Humphries and Tolhurst 1992). However, this was conditional on there being at least 40% of the gully vegetation, where more complex habitat occurred, and 10% of the mid-slope vegetation, was left unburnt. It is not known how long it took for the gully dwelling mammals to return because the surveying did not extend beyond three years. It was also found that the abundance of small mammals was statistically correlated with the extent of unburnt patches (Humphries and Tolhurst 1992; Irvin et al. 2003c). Therefore, in most cases, the fire severity could be classified as Level 3 (High), except where more than 40% of the more complex gully habitat was also burnt and then it would be more likely to be Level 4 (Very High) or Level 5 (Extreme).

Skinks showed a range of responses following fires. Southern Water Skink (*Eulamprus tympanum*) used coarse woody debris as its main micro-habitat and it was little affected by the fire treatments (Irvin et al. 2003b). However, McCoy's Skink (*Nannoscincus maccoyi*) is a cryptic species greatly dependent on leaf litter for its micro-habitat and it was affected by the fire treatments for at least three years (Irvin et al. 2003b). The general level of severity for skinks would thus be about Level 4 (Very High) indicating that it would take about 4–8 years to fully recover from a fire.

The greatest impact of the low-intensity fires was probably to soil chemical properties. There was a small but significant decrease in soil-carbon and soil-nitrogen in the frequently burnt sites (Hopmans 2003). It is unclear from these early results if this is part of an ongoing decline, whether a new but lower sustainable state will be reached or if the recovery time is greater than 10 years. Until this position is known, it is impossible to decide whether the impact of the soil nutrient status would be classified as Level 5 (Extreme), or some lesser severity level. Hatch's (1959) early work in Western Australia, would suggest that a new sustainable level might be reached if the burning frequency is maintained. O'Connell and Grove (1991) found that the nutrients of greatest concern were nitrogen and phosphorus and these would recover in the wetter Karri (*Eucalyptus diversicolor* F.Muell.) forest in 9–18 years depending on the fire severity and in a shorter time in the drier Jarrah (*Eucalyptus marginata* Donn. ex Sm.) forest.

There was a change in the relative abundance of different bird species, but not species were lost or gained as a result of any of the fire treatments (Loyn et al. 1992; Loyn et al. 2003). No new habitats were created and none were lost. This represents a Level 3 severity (Table 1) requiring a nominal 2–4 year recovery period.

Similarly, there was a change in the relative abundance of understorey plants, but no species were gained or lost as a result of the fire treatments (Tolhurst and Oswin 1992; Tolhurst 2003). Clearly, the populations of some species became dominated by juvenile forms of the plants rather than being dominated by older structures. Structurally, the severity of the fires were Level 4 (Very High) with a nominal recovery time of 4–8 years, but in isolated instances there were Level 5 (Extreme) impacts with a longer recovery time.

Bat activity was found to be similar in all fire treatments (Irvin et al. 2003a). This suggested that the value of habitat for bats was relatively equal for all burning treatments. However, this conclusion was based on areas of only 10–20 hectares in size and bats were found to travel at least 1–5 km, so having access to nearby habitat with a different fire history was probably important. The severity rating for bats was therefore about Level 3 (High) with a nominal recovery period of 2–4 years.

Coarse woody debris (fallen timber) in the experimental areas did not show any net effect of three repeated burns (Tolhurst et al. 1992b). Coarse woody debris consumed in the fires was replaced by new tree falls resulting in no net change. The severity rating for coarse woody debris was therefore about Level 3 (High) with a nominal recovery period

Table 2. Nominal recovery time of the Kilmore and Murrindindi fire areas burnt on Black Saturday, 7 February 2009, based on rankings in Table 1. Time in brackets are the nominal times used to calculate averages.

Severity (DSE Classification)	**% Total Area**	**Severity Level as per Table 1**	**Nominal Recovery Time (yrs)**
Crown Fire	12.6	6 Catastrophic	30+ (50)
Complete Scorch	37.9	5 Extreme	20
Moderate Scorch	19.5	4 Very High	4 to 8 (6)
Understorey Fire	18.7	3 High	2 to 4 (3)
Unburnt/Patchy	11.3	2 Moderate	1
Overall (weighted average)	100		15.7 years

of 2–4 years.

RESILIENCE AND LEVERAGE

'Leverage' has become a popular way of quantifying the value of prescribed burning in reducing the extent of wildfires (Loehle 2004; Boer et al. 2009). However, this simple metric does not adequately compare a hectare burnt by wildfire with a hectare burnt by prescribed burning because the severity of the fires and the resilience of the areas burnt are not considered.

Loehle (2004) found that strategically located hazard reduced areas could result in protection of a much larger area of the landscape. He suggested that by treating about 30% of the landscape, a wildfire would be unable to spread beyond a small area and hence the area was 'firesafe'. This effect was well described by percolation models where fire spread is considered as a contagion. However, in eucalypt forest, spotting is a major spread mechanism and fires are capable of breaching low-flammability areas several kilometres across (Luke and McArthur 1978, p.102) so the percolation model is not appropriate. A landscape-scale study of the impact of prescribed burning on reducing the extent of wildfires in Australia has shown that the 'leverage' factor is only about 0.25, i.e. much less than one (Boer et al., 2009). It is easy to then say that prescribed burning is ineffective at reducing the extent of wildfires (e.g. Bradstock and Price 2010a), but this only accounts for the area of fire, not the impact of fire in the landscape.

The relative severity of the Black Saturday fires of 2009 starting at Kilmore East and Murrindindi in Victoria were mapped on the basis of canopy loss by the Department of Sustainability and Environment. This is not a good measure of the full impact of a

Table 3. Nominal recovery times for areas burnt with low-intensity prescribed fires in the Wombat Fire Effects Study, based on rankings in Table 1. Time in brackets are the nominal times used to calculate averages.

System Component	**Severity Level as per Table 1**	**Nominal Recovery Time (yrs)**
Litter	4 Very High	4 to 8 (6)
Surface-active invertebrates	3 High	2 to 4 (3)
Soil-borne fungi	3 High	2 to 4 (3)
Small terrestrial mammals	4 Very High	4 to 8 (6)
Skinks	4 Very High	4 to 8 (6)
Soil nutrients	5 Extreme	20 (10)
Birds	3 High	2 to 4 (3)
Understorey plants	4 Very High	4 to 8 (6)
Bats	3 High	2 to 4 (3)
Coarse Woody Debris	3 High	2 to 4 (3)
Overall		6 years
< 10% Wombat State Forest	2 Moderate	5 years

fire since it does not consider the impacts on soils, coarse woody debris and other potential changes to vegetation structure and composition. However, it is relatively easy to do using various forms of remote sensing. Table 2 shows a summary of the proportion of the total burnt area in each burn severity class and the nominal recovery time using the criteria suggested in Table 1. On the basis of the impact within the burnt area, the weighted average recovery time is about 16 years, but because more than 30% of the Central Highlands landscape area was burnt, then the recovery time is more likely to be about 30 years. By comparison, the impact of the low-intensity prescribed fires in the Wombat Fire Effects Study would indicate the need for about a nominal 6 year recovery time - a factor of 3–5 times less (Table 3). Hence any leverage factor should be weighted by the appropriate likely recovery time to account for the resilience of the system and the severity of the fires.

CONCLUSIONS

The multi-disciplinary nature and long-term nature of the Wombat Fire Effects Study has provided a good basis for understanding how fire severity can be classified and combined with a measure of system resilience to guide sustainable fire management.

Conceptually, fire-prone ecosystems need to be thought of as being inherently unstable, with no equilibrium state, but being resilient. Resilience has to be measured in a landscape context because the connections at a range of scales, ranging from sub-metre to kilometres, need to be considered and it is only at a landscape level that biodiversity and sustainability can be meaningfully assessed. Many existing conceptual models of fire-prone ecosystems assume some stable state and this is wrong.

Whilst the classification of severity and recovery times have been nominal in this example, the approach warrants more development. “Time since fire” and “area burnt” are relatively uninformative as a measure of recovery if the severity and patchiness of the fire have not been assessed. As a proof of concept, this work has shown that one hectare of a large wildfire has the impact of between 3 and 5 times that of a small low-intensity fire. This must be factored into any ‘leverage’ calculations as a weighting factor.

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