Good Fire vs. Bad Fire: Progressing the Debate from Value-Based Judgements to Evidence-Based Management

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Abstract
While a majority of Australians agree that fire is a natural component of our ecosystems, there is ongoing confusion concerning what constitutes 'good' and 'bad' fire, and a lack of consensus on appropriate strategies to mitigate the threat of wildfire. Wildfires clearly threaten human life and property, and many observers assume they are also 'bad' for native ecosystems because large, intense fires cause higher mortality and reduce habitat suitability, at least temporarily. In contrast, ecologists are less concerned with avoiding wildfires than with maintaining regimes of recurring fire that are compatible with the population biology of native species.

These contrasting perspectives imply divergent management strategies, and an ongoing tension exists between those who support the current management paradigm (fire regime thresholds), which treats conservation and protection objectives separately, and those who advocate the use of prescribed ecological burns in order to create fire mosaics which seek to fulfil conservation and wildfire protection objectives simultaneously. I argue that there is a significant degree of uncertainty in predicting conservation outcomes under either management approach, and that measuring the response of species to alternative management actions in an experimental framework is the best way to resolve this uncertainty. This approach is illustrated using a case study from Royal National Park in which populations of the grass tree Xanthorrhoea resinosa were monitored through successive fires since 1988. I consider whether declines in grass tree populations observed during this period warrant a reappraisal of the current fire management approach, and what the implications of these results are under a changing climate.

INTRODUCTION

Session two of the Nature Conservation Council of NSW 9th Biennial Bushfire Conference (Good fire vs. bad fire - Managing fire to meet desirable local outcomes) set out to 'explore the role holistic fire management can play in sustaining healthier landscapes and investigate ways to build cohesive communities which are more connected to their local environment under a changing climate'. Fire management (in general) and ecological burning (in particular) are held to be contentious issues in both the scientific and lay communities. In this context, I interpret holistic fire management to mean actions which meet protection (human life, property and infrastructure) and conservation (plant and animal species, ecosystems) objectives simultaneously. I begin by describing the current framework for fire management as applied to the public conservation estate of NSW, then explore the challenges of attempting to meet protection and conservation objectives simultaneously. Mosaic burning is identified as the primary alternative promoted by critics of the current management paradigm. A focus on assessing the conservation outcomes of alternative management strategies, as opposed to the details of their implementation, is advocated as a means to resolving the debate.

THE CURRENT MANAGEMENT PARADIGM IN NSW

Contemporary fire management under the NSW government effectively operates as a dichotomy between human protection and conservation objectives (Office of Environment and Heritage - OEH, 2013). Fuel reduction burns comprise a primary tool for reducing the risk of wildfire to human lives and infrastructure. These are typically carried out under mild weather conditions at cooler times of the year and are more effective at reducing the intensity of unplanned fires than preventing fire spread (Price and Bradstock, 2011). Current resource and weather constraints limit the application of fuel reduction burns to a small proportion of the landscape; therefore a concentration of effort at the urban interface is most efficient in facilitating the safe evacuation and defence of properties and infrastructure (Price and Bradstock, 2012). Fuel reduction burns may occur more frequently than can be tolerated by many species (OEH, 2013), and be sub-optimal in intensity (too cool) or timing (season) for seed release, germination or seedling survival (Bradstock and Bedward, 1992; Whelan, 1995; Ooi, Auld and Whelan, 2004).

In contrast, ecological burns are designed to promote specific responses in elements of the biota, have specific requirements in relation to season or intensity, and may be applied at a variety of spatial scales and configurations depending on the objectives (Whelan, 1995). In NSW National Parks objectives for ecological burns are designed to minimise the risk of extinction of any species (as opposed to optimising the abundance), by maintaining variable fire regimes within a range tolerable to all species (Bradstock, Keith and Auld, 1995). As currently applied, fire regime thresholds draw heavily on the fire interval hypothesis of plant population dynamics i.e. the interval between fires is held to be the primary determinant of population change because it determines the point at which population phases such as growth, maturation, reproduction and senescence are interrupted (Bond and van Wilgen, 1996). This approach weights fire frequency effects over event-dependent effects such as fire intensity, and assumes that animal taxa persist as a consequence of appropriate management of vegetation communities. Conceptually, however, fire regime thresholds are amenable to modification to accommodate other aspects of the fire regime such as season or intensity, as knowledge of the importance of such factors becomes available. Ecological burns may also fulfil fire protection objectives, although this is incidental to their primary purpose.

Implementation of ecological burns under fire regime threshold management is typically conservative because the risks associated with exceeding fire regime thresholds are greater at the lower end of the tolerable range compared with the upper end. For example, there is a high short term risk of local extinction of certain groups of species (e.g. serotinous obligate seeders) as a result of intervals shorter than the specified minimum because (near certain) death prior to maturation prevents post-fire recruitment and re-establishment of the population. Conversely, population decline due to senescence and seed bank decay during long inter-fire intervals is more gradual. The decision to implement an ecological burn is based on an assessment of the state of the system (i.e. its previous fire history) and the risk of unplanned fire with respect to the fire regime thresholds. The implementation of any ecological burn increases the risk of a short fire interval as a consequence of subsequent unplanned fire, while a decision not to burn in any one year retains the option to conduct a burn in subsequent years with relatively low risk of species loss.

Conservative application of ecological burns is also a consequence of uncertainty surrounding the level of spatial and temporal heterogeneity required to sustain plant and animal populations. The fire regime threshold approach, as currently applied, makes no prescription for spatial heterogeneity in fire regimes. Rather, it assumes that dynamic spatial mosaics arise as a consequence of fire regimes interacting with factors such as topography, vegetation and weather, and that these permit coexistence of species at the landscape scale, irrespective of the transience of individual populations (Keith, 2012). Declines in a range of plant and animal species have been attributed to a reduction in habitat heterogeneity in terms of recent fire history (Bowman, Murphy, Burrows and Crisp, 2012). However the risk of increased fire frequency associated with implementing ecological burns currently out-weighs the potential benefits of introducing patchy landscape burns because these benefits have yet to be clearly demonstrated (Bradstock, Williams and Gill, 2012).

THE THREAT OF CLIMATE CHANGE – A CHALLENGE FOR CURRENT MANAGEMENT?

Global warming associated with atmospheric CO_2 enrichment poses potential challenges for fire management in Australia. As the 21st century progresses, temperate regions of south-east Australia are predicted to experience increases in both the length of the bushfire season and average Forest Fire Danger Index (FFDI), as well as the frequency of extreme fire danger days (Clarke, Smith and Pitman, 2011). While the effects of climate change on fuel dynamics and ignition patterns are more difficult to predict (Matthews, Sullivan, Watson and Williams, 2012), changes in fire weather may result in increases in fire frequency or severity, as well as shifts in the timing of major fires (Cary, Bradstock, Gill and William*s,* 2012). Such changes represent an increased risk to human life and property during individual wildfire events, and potential changes in fire regimes affecting the dynamics of plant and animal populations.

CAN HOLISTIC MANAGEMENT CONFER RESILIENCE UNDER A CHANGING CLIMATE?

An increase in the extent and/or frequency of fuel reduction burns at the urban interface is a possible strategy to combat the increased risk of wildfire impacts associated with climate change (Price and Bradstock, 2013). However, advancing holistic management as a solution to these threats implies that there are deficiencies in the current management approach that might be resolved by contriving management strategies which simultaneously meet protection and conservation goals. In light of the vociferous calls for more hazard reduction burns which follow every major wildfire event, and the perceived deficiencies of the fire regime threshold approach, this proposition may be interpreted as follows: a higher level of wildfire risk requires more fuel reduction burning, which could be achieved by conducting more burns across the landscape, thus conferring more protection from intense fires for both humans and native ecosystems.

Contrary to the current management paradigm, this proposition suggests coexistence of species should be viewed less as a mechanistic outcome of the interaction of fire regime and population processes - and more as an emergent property of fire prone ecosystems (Goodenough and Deacon, 2006). It foreshadows an inevitable increase in average fire frequency as well as a fundamental shift from a reactive (act when risk of extinction becomes intolerable) to prescriptive management stance.

Furthermore, it evokes the ongoing antagonism between advocates of a proactive approach to promoting fire landscape heterogeneity (mosaic burning) and the fire regime threshold approach (Bradstock et al., 2012).

FIRE-STICK FARMING – AN EXAMPLE OF HOLISTIC MANAGEMENT?

The genesis of mosaic burning as a management paradigm may be traced at least as far back as 1969. Rhys Jones first articulated a growing realisation among anthropologists and ecologists that Australian ecosystems at the time of European settlement were not, as had been popularly believed, natural in the sense of being devoid of human influence. Rather, he suggested they were the product of thousands of years of Aboriginal hunting, gathering and burning (Jones, 1969). Jones argued that not only were whole ecosystems a product of the systematic use of fire by Aboriginal people but also, as a result, there existed a co-dependence among humans, plants and animals on this regime of fire-stick farming. Furthermore, when Europeans evicted Aboriginal Australians, the cessation of fire-stick farming led to an expansion of vegetation dominated by fire sensitive species at the expense of productive, palatable species. This, in turn, led to a build-up of fuel and uncontrolled wildfire, all of which resulted in the decline of various animal species.

Although there is general acceptance of parts of this thesis, the precise consequences of the cessation of Aboriginal burning and the degree to which apparent changes in the landscape can be attributed to other factors is disputed. Nonetheless, it forms the basis of a fire management hypothesis, which is that the mimicking of Aboriginal burning will result in habitat heterogeneity by which plant and animal species with diverse and contrary resource requirements will coexist as they did up to the time of European settlement (Bowman et al., 2012). Mosaic burning by humans encapsulates the essence of holistic management i.e. species are maintained in equilibrium at the landscape scale by patch burning at the sub-landscape scale, thus sustaining resources important to humans and providing protection from fire. The mosaic hypothesis also tends intuitively to holism in the scientific sense; Aboriginal burning maintained biodiversity in a way that cannot be simply explained by a set of underlying processes.

FIRE REGIME THRESHOLDS – REDUCTIONIST SCIENCE

Coincidentally, the seeds of the fire regime thresholds approach were also sown at the time Jones published the fire-stick farming hypothesis. In 1967 John Harper, a passionate reductionist became the founding head of the highly influential School of Plant Biology at the University College of North Wales (Turkington, 2010). Harper argued that the abundance and distribution of species could only be understood through the processes which control the lives, deaths and reproduction of individual plants (Harper, 1982). His work revolutionised ecology and was the catalyst for a plethora of studies examining the dynamics of plant populations in relation to fire. Persuasive accounts of the effects of short fire intervals on non-resprouters in the Sydney Basin first appeared in the 1970s (e.g. Siddiqui, Carolin and Myerscough, 1976). Combined with functional attribute classifications (e.g. Noble and Slatyer, 1980), population studies contributed a framework for predicting the effects of fire regimes in diverse plant communities and devising appropriate fire management guidelines.

The current ascendancy of the fire regime thresholds model in management can be attributed to four factors:

- Accidental: with the rise of the conservation movement in the 1970s and 80s, the expansion of the fledgling National Parks and Wildlife Scientific Services Division included a disproportionate number of plant demographers of the Harperian school. They set about constructing a process based model for fire management of the protected areas network (Bradstock et al., 1995).

- Theoretical: contemporary ecological theory emphasises the dynamic nature of ecosystems and the formulation of conservation management goals in terms of minimising extinction risk (Burgman, 1993). A management approach that is reactive to the threat of exceeding critical thresholds is more aligned with this theory than the mosaic approach which employs a prescriptive approach focused on stable populations.

- Geographical: much of the pioneering work in plant demography was carried out in the Sydney Basin in the 1980s and 90s, where the failure of even very recent fuel reduction burns to halt wildfire was observed on several occasions. Such observations emphasised the potential for ecological burns to increase the average fire frequency, at least in those ecosystems.

- Practical: even a rudimentary understanding of fire limited population processes can be expressed in a quantitative form and management thresholds are amenable to iterative adjustment as knowledge of population processes develop. Given a limited knowledge of the system, this approach evokes the medical maxim 'do no evil'. In contrast, an alternative, mosaic based approach could not be based on any empirical evidence.

While the creation of fire mosaics has an intuitive appeal, the fire regime thresholds approach highlights the problem that the introduction of more fire into the system can have quantifiable, deleterious effects. Thus, these alternative world views have been thrown into conflict following every significant wildfire event. Proponents of the mosaic burning contend that more fire is required to mimic fire regimes of the fire stick farmers, thus preventing extensive, high intensity fires from occurring, while advocates of fire interval thresholds are obliged to adopt the opposite approach as a defence against the potential threat posed by too frequent fire. Furthermore, there is empirical evidence to suggest that many plant and animal species are not adversely affected by intense fire (Bradstock et al., 2012) and, conversely, evidence that the season of burn may have a significant impact on seedling recruitment (Bradstock and Bedward, 1992; Ooi et al. 2004; Ooi, 2010).

The argument may be irreconcilable. As Timothy Neale noted in a review of Bill Gammage's book 'The Biggest Estate on Earth': those for which mosaic burning has an intuitive or cultural appeal may

> *'bristle at the sight of this rationalist razor of environmental science...[which] not only covers over its own dependence on uncertain causes or conceits, but also, present practices, oral traditions and abundant settler accounts are always outweighed by some higher and ever evasive empiricism supposedly uncorrupted by contemporary politics.' (Neale, 2013).*

Nevertheless, proponents of mosaic burning are not bound to reject an empirical approach to assessing the success or otherwise of this management approach.

PROGRESSING THE DEBATE: OUTCOMES INSTEAD OF APPROACHES

Do we need more ecological burns? How can we decide? The key to answering these questions lies not in resolving a philosophical or epistemological debate, but in measuring the outcomes of alternative management approaches against explicit conservation goals. The desired outcome of fire management is neither to maintain ecosystems within set thresholds, nor to create a specified level of patch heterogeneity, but to ensure the ongoing viability of plant and animal populations and the ecological processes they sustain.

Flannery (2012) suggested that a general lack of accountability is evident with respect to biodiversity conservation management carried out by Australian government agencies. He argued that proper accountability requires the articulation of clear goals, a means to monitor changes in the environment, reporting back to the community on progress and submitting to penalties in the event of failure.

However, there is considerable uncertainty surrounding the implementation of either the fire regime threshold or the mosaic burning management paradigms. For example, there is a lack of guidance concerning the size, shape and spatial configuration of the mosaic burns, which in turn reflects a lack of evidence showing exactly how mosaics support the diversity of plant and animal species (Bradstock et al., 2012).

Conversely, the fire interval threshold approach is only explicitly directed at plant populations and reflects only one of several competing hypotheses concerning the relationships between fire and plant species distribution (Bond and van Wilgen, 1996). Thresholds do not explicitly address the issue of spatial heterogeneity and they are currently applied only to broad formations of vegetation, thus they potentially do not account for differences in fire regime tolerance among plant communities.

Management must accommodate this uncertainty by adopting an experimental framework. This will facilitate an objective comparison of the outcomes of alternative management strategies and helps to resolve which of the available management options are more effective. Critical components include:

i) clear hypotheses concerning the cause and direction of change;

ii) an experimental framework for interpreting responses to alternative management strategies or scenarios;

iii) measurement of appropriate response variables;

iv) interpretation of differences in species response to different management strategies; and

v) iterative improvement of management outcomes.

In the following section, this approach is illustrated in the context of fire management within the Royal National Park (RNP), south of Sydney. Large areas of heathlands within the park are currently within the fire regime thresholds defined by management and therefore are not in need of ecological burning. This case study examines whether population changes observed in a prominent grass tree (*Xanthorrhoea resinosa*) warrant a reappraisal of these guidelines.

CASE STUDY: COASTAL HEATHLANDS ROYAL NATIONAL PARK

Fire management for biodiversity conservation within RNP addresses the goal of avoiding the extinction of local populations of all species. This goal reflects the need to conserve genetic variation among populations and the fact that the role individual species play within ecosystems varies from place to place (Keith et al., 2002). The problem of monitoring the vast diversity of species within any management area is rendered tractable by basing performance measures around a subset of species which are considered vulnerable to decline under some fire regimes.

COASTAL HEATHLANDS IN ROYAL NATIONAL PARK:

The heathlands of RNP belong to the Sydney Coastal Heaths in Keith (2004) which dominate the exposed plateaus along the coastline between Gosford and Jervis Bay. They occur on shallow, infertile soils derived from medium-coarse grained Triassic and Permian quartz sandstone and are characterised by diverse ground cover of sedges, forbs and low shrubs with a variable cover of taller shrubs up to four metres tall (Tozer et al., 2010). Heathlands are structurally and compositionally dynamic, and form complex mosaics of open heath, thicket, sedgelands and woodlands in response to environmental factors such as soils and drainage (Keith and Myerscough, 1993), interspecific competition (Keith and Bradstock, 1994; Tozer and Bradstock, 2003) and fire regimes (Tozer and Keith, 2012).

The distribution of plant growth forms and fire response types among growth forms is not even. For example, heathlands contain relatively few tall shrubs species and these are dominated by serotinous obligate seeders (e.g. *Banksia*, *Hakea* spp). Conversely, there is a greater diversity of subordinate shrubs and herbs, comprising a mix of resprouters and seeders, species with either serotinous or soil seed banks or species solely reliant on fire stimulated (pyrogenic) flowering for reproduction (Tozer et al., 2010). As a consequence, fire regimes have the potential to drive major changes in structure and composition of heathlands.

Fire interval effects form the primary criteria for defining fire regime thresholds. The RNP fire management plan (DECC, 2009) specifies the avoidance of consecutive fire intervals of less than seven years in reflection of the typical maturation times of fire sensitive shrubs species. It is well established that intervals shorter than seven years lead to sudden declines in those species (e.g. Bradstock and O'Connell, 1988). Conversely, the maximum specified interval of 30 years reflects the life span of the dominant species (which are susceptible to seed bank loss following senescence) and competitive exclusion of subordinate species (tall species drive out low species unless competition is periodically interrupted by fire). Fire intervals at either extreme are predicted to favour one group over another. Maintaining variability in fire intervals is thus a key component of management, allowing the heathland to fluctuate between alternative states and avoiding either the elimination of overstorey shrubs by frequent fires or the decline of understorey species through to elimination following prolonged suppression (Keith, Williams and Woinarski, 2002). However, in comparison to the effects of short fire intervals, patterns of decline under long fire intervals are less certain.

CURRENT STATUS: WHAT DO WE PREDICT IS HAPPENING?

Heathlands in RNP are almost exclusively within the specified management thresholds. Some 66% of heathland was burnt in intense wildfires occurring in October 1988 and January 1994, thus a short interval (5.25 years) was followed by a long interval (19+ years). While recruitment of serotinous obligate seeder shrubs was noticeably depressed following the short interval, densities were nevertheless sufficient to restore a continuous cover of shrubs over significant areas. Populations of understorey species are therefore expected to have been in decline since shrub cover re-established (approx. 14 years ago). A further 29% of heathland was also burnt in a wildfire in December 2001. These areas have experienced consecutive fire intervals at the shorter end of the spectrum (5.25 years, 8 years, and 11+ years). Relative to areas not burnt in 2001, less decline in populations of understorey species is predicted.

MONITORING TO DETECT CHANGE: WHAT IS ACTUALLY HAPPENING?

Tozer and Keith (2012) describe patterns of survival and reproduction in populations of *X. resinosa* between 1988 and 2011 under each of the fire regimes described above. *X. resinosa* is a common grass tree with leaves in a typical spreading tuft and with or without a woody stem up to 0.6m high (Harden, 1993). It is a common species in heath and low sclerophyll woodland in seasonally wet sandy soils in the Blue Mountains and coastal sites south from Sydney. It resprouts rapidly and reliably after fire, although there is anecdotal evidence of localised high mortality in arborescent individuals as a result of stem combustion during very intense fires (Auld and Tozer unpubl.). *Xanthorrhoea* species belong to a group of species which have in common an ability to resprout, pyrogenic flowering and seeds which are released in a non-dormant state and thus do not form a persistent seed bank. Resprouting species typically exhibit high rates of survival and low rates of growth and reproduction (Keith, Tozer, Regan and Regan, 2007). Populations are thus buffered against recruitment failure but not against episodic high mortality.

Populations of *X. resinosa* in RNP exhibited very slow growth and unexpectedly high mortality between 1988 and 2011 irrespective of fire regime (Fig. 1; Tozer and Keith, 2012). Most deaths were not directly related to fire. Over the course of up to three fires only 27 healthy individuals (2.7%) failed to resprout, and although fire related mortality of up to 10% was recorded at one site after a single fire, most individuals in that case died after first resprouting. Competition from overstorey shrubs and infection by the introduced fungal pathogen *Phytophthora cinnamomi* are likely to be responsible for some proportion of deaths (Tozer and Keith, 2012). Competition for light reduces photosynthetic output in *Xanthorrhoeas* thus interrupting the cyclical storage of starch in the caudex which serves to maintain leaf growth through winter and allow resprouting and flowering following fire (Lamont, Wittkuhn and Korczynskyj, 2004). This may result in a reduced probability of survival following fire, which could be further exacerbated by infection by *Phytophthora cinnamomi.* Very dense shrub cover can result in the complete eradication of a population of *X. resinosa,* as observed by Tozer and Keith (2012) between 1994 and 2011.

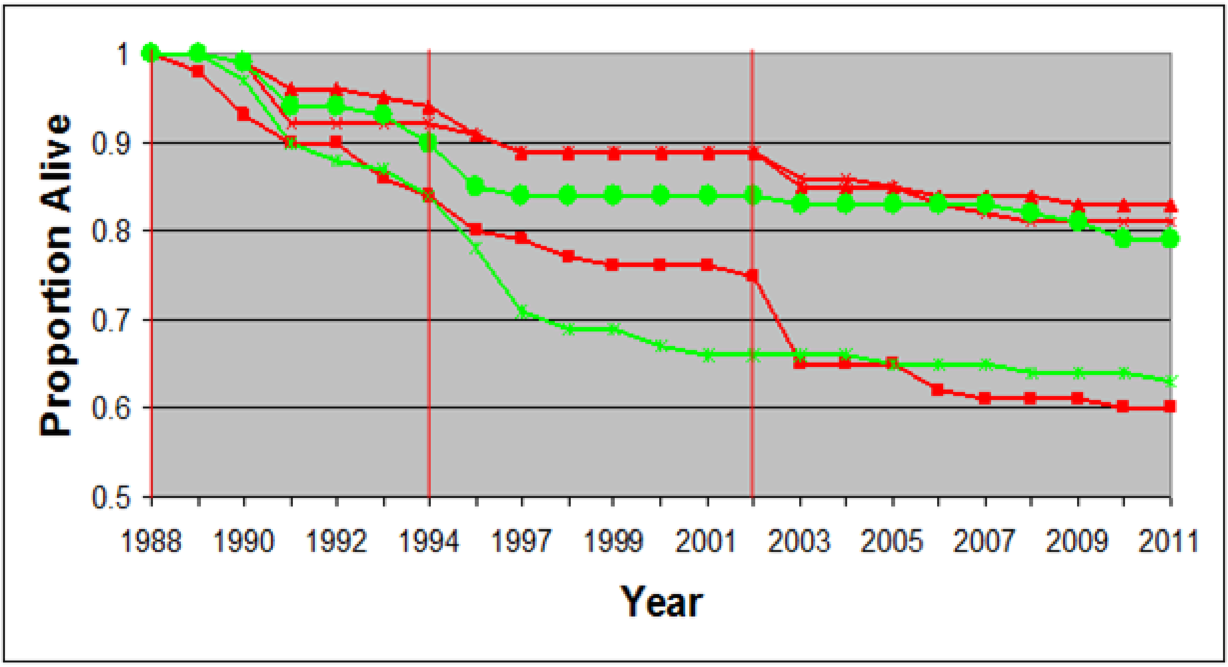

Fig. 1: Survival populations of approximately 200 individuals at each of five sites located in RNP. Vertical red lines indicate wildfires. Populations graphed in red were burnt in all three fires while those in green were burnt in the first two only (reproduced from Tozer and Keith, 2012).

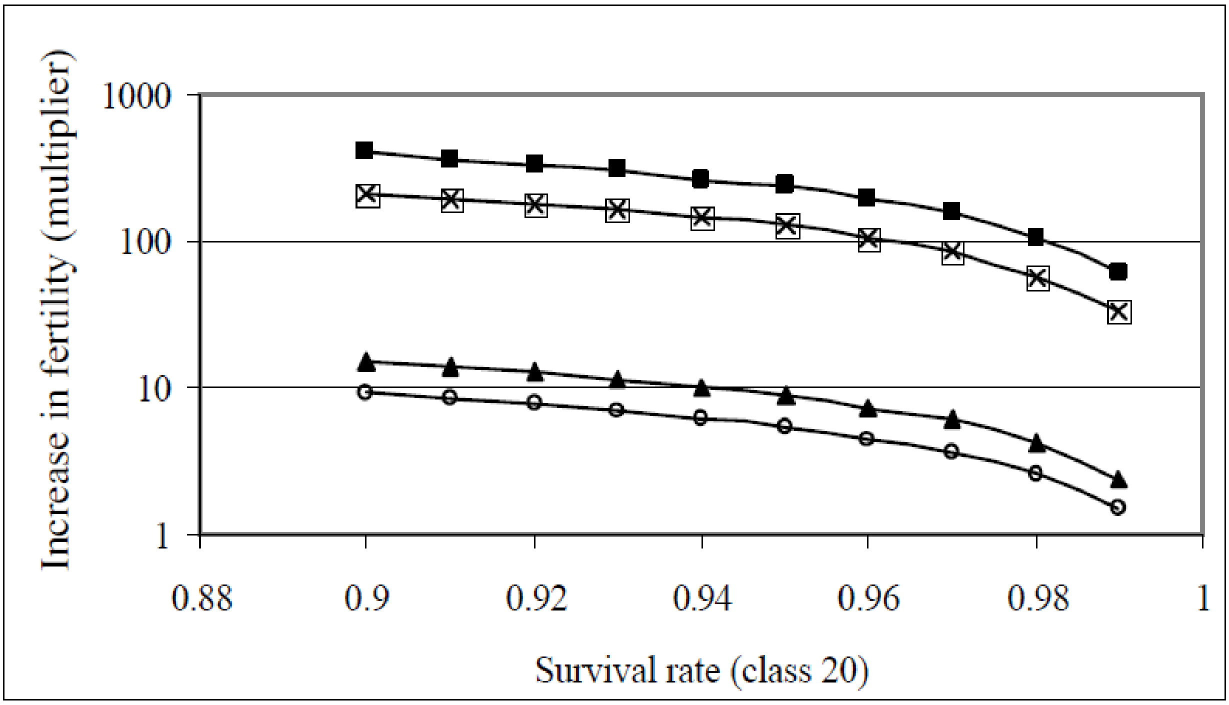

Fig. 2: Increase in fertility required to prevent population decline as a function of mortality of the largest in individuals in the population under four fecundity schedules. Triangles and open squares represent, respectively, the highest lowest seed output observed during the study with bounds (open circles and filled squares) for sampling error (reproduced from Tozer and Keith, 2012).

High mortality was not offset by recruitment in sites experiencing a short followed by a long fire interval because survival of seedlings and juveniles was low and growth was too slow for juveniles to replace reproductive adults. Based on observed growth rates, seedlings may require at least 50 years to reach reproductive age and up to 430 years to reach full size and maximum reproductive output. In contrast, population projections based on sites burnt in 1988, 1994 and 2001 suggested that reproduction presently offsets mortality in these populations. However, projections are apparently very sensitive to increases in mortality. For example increasing mortality in the largest individuals by even 1% may require fertility to increase by several orders of magnitude to maintain population stability (Fig. 2).

WHAT DO THESE OBSERVATIONS SUGGEST ABOUT THE FIRE REGIME THRESHOLDS APPROACH?

While the trends in *X. resinosa* populations under contrasting fire regimes are generally in accord with management predictions (declining during long intervals between fire, stable under repeated short intervals), there must be considerable concern that declines in the long term are inevitable under a variable fire regime within the current prescribed thresholds. The problem is that individuals grow too slowly, and are not sufficiently fertile for declines sustained under long fire intervals to be offset by reproduction. Compounding the problem is the unexpected catastrophic mortality that can occur under dense canopy. The results suggest a modification to the fire regime thresholds to take account of the structural state of the heathland (and thus the likely competitive interactions). For example, intervals of up to 30 years between fires may be acceptable in open heaths that are relatively free of shrubs but shorter intervals are required when a shrub thicket is present.

WHAT ARE THE IMPLICATIONS UNDER A CHANGING CLIMATE?

Despite anecdotal evidence of the effects of high intensity fire on grass tree survival, few deaths that we recorded could be attributed to the effects of high fire intensity alone. As such, there is no strong case for introducing more ecological burns in cooler seasons to mitigate the effects of higher intensity fires should these eventuate under climate change. Conversely, there is experimental evidence to suggest that flowering in *X. resinosa* may be lower in winter compared with summer burns (Keith and Tozer, unpubl.), thus instituting a regime of cooler season burns may exacerbate population decline.

Growth of overstorey shrubs may be enhanced by high concentrations of atmospheric CO_2 under climate change (Bond and Midgely, 2012), thus promoting higher rates of mortality in *X. resinosa* and other understorey species through competition for light. If this is the case then more ecological burns may be required to promote a lower density of shrub species and discontinuous shrub cover. Conversely, infection by *Phytophthora cinnamomi* may warrant the opposite approach: Regan et al. (2011) predicted that populations are likely to decline more slowly under lower fire frequencies because mortality caused by fire and disease is not likely to be offset by higher fertility under higher fire frequencies. The conclusion to be drawn from this study is that ecological burns may be an appropriate response to management challenges including (possibly) climate change; however the circumstances in which burns are applied will be context specific rather than generic.

WHAT DO THESE OBSERVATIONS SUGGEST ABOUT A HOLISTIC APPROACH TO MANAGEMENT?

Whilst the observations described above are not an explicit test of the relative merits of mosaic burning and fire regime thresholds management *per se*, this case study highlights the danger of imposing any management approach without a functional basis for predicting how species are likely to respond against which the actual outcomes can be compared. It is likely that at any time species may be observed to be in decline or increasing, either in the short term or long term due to a range of factors, some of which may be deleterious and human related.

Neither a generic, mosaic burning strategy nor a holistic philosophical stance provides an adequate context for differentiating declines which warrant management intervention from those that reflect dynamics inherent in ecosystems. The introduction of more ecological burns may be necessary to increase habitat heterogeneity in fire prone ecosystems, however this must be based on functional understanding of the requirements of the target species (patch configuration, spatial scale, location of refuges, foraging requirements) and implemented in a way which permits an objective assessment of the results and suggests possible improvements.

Finally, this case study illustrates the limitations of a reductionist approach in quantifying and predicting the dynamics of fire prone ecosystems. While contrary to the intentions of Bradstock et al. (1995), there is a danger that fire regime thresholds may be interpreted narrowly as prescriptive guidelines for fire intervals, for which only the parameters require tweaking to facilitate deterministic outcomes. While interval-dependent effects are undoubtedly important in structuring fire prone communities, the interactive effects of fire season and intensity, density dependent processes and interspecific interactions are well documented, if poorly understood (Bond and van Wilgen, 1995). While the outcome of these complex interactions may defy reduction to simple fire management guidelines, their importance must nevertheless be acknowledged.

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