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ORIGINAL PAPER

Planned fires and invertebrate conservation in south east Australia

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Abstract Unusually intense wildfires in south east Australia in early February 2009 led to the deaths of 173 people in Victoria and massive loss of property, with several towns essentially obliterated. More than 450,000 ha were burned. The severity of those fires has led to calls for massively increased planned burning for fuel reduction, with a Government Enquiry (a Royal Commission) currently considering all aspects of the fires and future policy, to help safeguard life and property. Public concerns are naturally high, and any measures suggested to reduce the likelihood and severity of future fires must be appraised seriously. However, the conservation of Victoria's heritage of biodiversity is also of major concern, and—in particular—the outcomes of the more extensive use of fire for invertebrates have scarcely been heeded even in current prescriptions for planned burning. In this essay, we assemble some information on invertebrate interactions with fire in the region, and use this to suggest guides for improved fire management practices that are based more on scientific principles that focus on invertebrate conservation.

Keywords Burning · Land management · Fire regimes · Monitoring · Refuges · Threatening processes

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Introduction

Periodic wildfires (bushfires) are integral features of some Australian environments, and are naturally started by lightning (Bowman et al. 2009). Debate continues over the influences of burning by indigenous Australians, with opinions ranging from it being a major structuring force on vegetation, such as generation of grasslands in Tasmania (Kirkpatrick 1994) to much smaller scale influences. The inherent variety of natural fire regimes tends to assure a mosaic of different habitats with varying stages of succession intermingled. Some ecologists claim that Australia's biota is adapted closely to natural fire regimes, that much of the flora depends on fires for reproduction or regeneration (Gill et al. 2002), and that the deliberate use of fires in landscape management is beneficial. Other ecologists have queried the generality of this assumption, and the validity of evidence that underpins it, and have emphasised that inappropriate burning may be just as much a threat as 'suitable' burning may be a useful management tool. In general, the field is one in which more scientific

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information and decidedly less emotion and supposition is needed in formulating practice and policy.

Broadly, planned burning is the controlled use of fire on vegetation within selected areas, and has four major purposes: (1) fuel management, mostly the reduction of amounts of flammable leaf litter, bark and coarser debris on or near the ground; (2) habitat manipulation, such as promoting the germination of seeds from the soil seedbank; (3) control of alien vegetation (weeds, although fires also facilitate invasions by alien weeds); and (4) for silvicultural purposes (Fuller 1991). Management burning is viewed by some proponents as an important conservation tool, but it is necessary to distinguish carefully between 'ecological burns' and 'fuel reduction burns', with the former based soundly in ecological understanding of the impacts of fire regimes, and the latter largely in expediency. The main objectives of possibly reducing the intensity of any future wildfires and aiding protection of property and human life by reducing fuel loads have led to increased interests in planned burning, with recent proposals to massively increase the areas to be burned in south eastern Australia, across a wide variety of biotopes or vegetation classes. It is hoped (but not proven) that such planned burns will increase prospects for future safety by (1) reducing the intensity of future wildfires and (2) decreasing their rate of spread, so (3) facilitating chances of control through fuel reduction burning, and (4) reducing the likelihood of fires starting and carrying from lightning strikes or other ignition sources. In general, most planned burns are of low intensity, in contrast to high intensity wild fires, but both have potential to change community composition and distribution to produce a mosaic of different environments. The outcomes of any fire are not predictable, with the combined impacts of variations in fire intensity, season, area burnt, frequency, and intervals between fires (collectively, the 'fire regime'), as well as vegetation type and structure, and weather all playing a part.

Much has been written on these influences (a review on insects by Swengel 2001, includes examples from many parts of the world), but the emphasis on plant ecology leading to detection and categorisation of fire-adapted forms in Australia has not been paralleled for fauna. Even for conspicuous vertebrates, little information on fire effects beyond immediate impacts was available until the 1980s (Friend 1993, Attiwill and Wilson 2003). Despite a number of important earlier studies (as examples, by Andersen 1988, Campbell and Tanton 1981, Majer 1985, Neumann and Tolhurst 1991, O'Dowd and Gill 1985) showing different effects of fire on invertebrates, the various studies are difficult to integrate, with the variety of sampling methods, contexts and length of studies hampering detailed comparison. Inconsistency of taxonomic penetration has also been a problem. Many reported studies identified invertebrates only to order level, so that more informative changes of family and species compositions could not be detected. York (2002) found only 52 refereed papers on Australian invertebrates and fire from 1969 onward, most of them confined to ground-dwelling arthropods. Further, a high proportion of surveys have been opportunistic, concentrating on areas after a fire and presuming valid comparison with invertebrates on nearby unburnt areas in similar vegetation. Spatial heterogeneity in epigaeic arthropods, the groups most usually sampled, can render any such comparisons misleading. Invertebrate responses, other than in manipulative trials involving single species, can be detected most reliably by pre-fire and post-fire sampling on the same sites, preferably several replicated sites, and also including similar data for adjacent unburned sites to monitor changes in assemblages that eventuate. Nevertheless, some early 'clues' to responses noted by Friend (1995) were that (1) most impacts may be relatively short term, of 2–3 years; (2) high intensity fires have much greater impacts than low intensity fires; and (3) spring burns may be more harmful than those in autumn. Without species level analyses, the first of these can not be confirmed, and many ecologically specialised species may suffer much longer impacts or disappear completely. In addition, observed short-term responses on some invertebrates may be misleading—increased richness of ants in the Victorian mallee following fire reflected enhanced activity in the more open ground environment and consequent increase in pitfall trap catches (Andersen 1983, Andersen and Yen 1985).

Clarke (2008) emphasised that issues of fauna conservation under imposed fires need much further clarification. They should be focused on four main themes widely cited as presumptions used to justify this form of management, but none of which is universally sound (Table 1). In Clarke's words '… all (studies) suffer from such profound knowledge gaps that they provide little concrete direction for land managers' involved with conservation. As noted above, much of their encapsulated 'conventional wisdom' comes from botanical studies, and generalisations on fire effects on animals are difficult even in relation to large vertebrates. In any conservation management programme in which planned fire is a constituent, the management 'target' is often ill-defined, because the comparative model to be aimed for has itself not been defined.

In this essay, we discuss some of the ways in which planned burning may threaten terrestrial invertebrates, what modifications may foster their conservation, and how those changes might be achieved, starting from the point noted by Gill (2008) that 'Fire (and fuel) management is a difficult and contentious practice', and one in which invertebrate conservation issues have rarely been considered in Australia. As Greenslade (1996) emphasised

Table 1 The four major premises that appear to underpin current fire management practices in Australia (after Clarke 2008)

1.	Pyrodiversity begets biodiversity: landscapes exposed to a greater diversity of fire regimes equate to landscapes with greater biodiversity
2.	Organisms are more likely to be able to cope with disturbance regimes with which they are evolutionarily familiar
3.	Current knowledge of the needs of plants in regard to fire is a sufficient basis upon which to determine over-represented and under-represented seral stages of a vegetation type in a landscape
4.	Burning one over-represented age class of a vegetation type reliably produces the desired under-represented age class of the same vegetation type

'… reliable scientific evidence is accumulating that we still, through ignorance, are unnecessarily eliminating a major part of Australia's biodiversity'.

Invertebrate importance

Any effective influence on fire management practices must initially communicate the importance of conserving invertebrates, and demonstrate the importance of threats from current practices, in addition to suggesting how conservation may be improved by modifying those practices. The amazingly high abundance and richness of insects and other invertebrates in Australia (Yeates et al. 2003) includes numerous taxa associated with ground litter and vegetation, being the substrates usually burned. Many of these species are undescribed, poorly understood, locally endemic and globally important lineages, members of which constitute complex temporal and spatial mosaics in forests and other biotopes. Simply inventorying the fauna of any given habitat or site is difficult, and most studies relevant to fire management have emphasised the epigaeic fauna. Studies on particular functionally important or taxonomically tractable groups predominate, so that most published accounts focus on one or more of Collembola, Coleoptera, Formicidae, or Araneae, all of which have substantial richness and ecological variety in susceptible substrates. They range from relative generalists to taxa that may depend on very specific resources: within forests, for example, around 10–20% of species of some groups are estimated to be restricted to 'old growth' components (such as deep humus or well-rotted logs) that take decades to centuries to accumulate. Some fire-susceptible invertebrates such as velvetworms (Onychophora) depend on fallen trees as primary habitat. In Tasmania, local extirpations of endemic velvetworms have been associated with frequent or too hot burns (Mesibov and Ruhberg 1991).

A more practical way to communicate the importance of invertebrates to land managers is to give examples of their roles in key ecological processes and sustainability, together with the lack of detailed information to quantify these roles. The richness and complexity of insect assemblages in the region can be demonstrated easily. The moth family Oecophoridae (mallee moths) contains more than 5,000 species in Australia (Zborowski and Edwards 2007)—an impressive number to politicians as it approximates to the richness of the entire terrestrial vertebrate fauna, but it is still less than a quarter of the native Lepidoptera. Oecophorid caterpillars can occur at densities of several hundred/m^2 in woodland and forest litter, where many feed on dead foliage, as do larvae of several hundred species of cryptocephaline Chrysomelidae. These animals are major contributors to decomposition and recycling of organic materials. In a second context, much of Australia's endemic flora is pollinated by native insect vectors, commonly unknown but many associations are presumed to be at least reasonably specific, and many plants rely on seed dispersal by ants (Berg 1975). Other mutualisms abound: many lycaenid butterflies, for example, are myrmecophilous (Eastwood and Fraser 1999).

Fire effects

The exact consequences of any planned fire on invertebrates are undocumented and difficult to study. Fires affect insects both directly and by removing critical resources and by changing microclimatic regimes. Populations or local species may be extirpated, richness may be reduced—particularly by removal of ecologically specialised taxa—and the remaining assemblages may be changed considerably from their pre-fire composition and be forced onto different successional trajectories. They may only rarely recover to resemble the pre-fire condition, and may become increasingly prone to invasion by alien species either rapidly or in the longer term.

'Fire variables' are sufficiently complex to render empirical generalisations difficult, and include fire intensity, season of burning, area burned, frequency (time since fire) and fire interval (time between fires), in addition to weather, the vegetation and structural features of the sites involved. The importance and subtleties of these variables has been illustrated by attempts to use fire as a conservation management tool for single insect taxa, which have confirmed the importance of understanding the ecology of the target species in some detail, particularly in relation to patterns of seasonal development and availability of possible refuges during fire. Changes in management that

result in benefits or severe threats may be subtle, as the following two examples from Victorian butterflies demonstrate.

1. The Eltham copper, *Paralucia pyrodiscus lucida* Crosby (Lycaenidae). Planned fire was used to 'rejuvenate' two small isolated urban sites for this butterfly, by weed removal, ground fuel reduction, and successional maintenance by opening the canopy, as measures needed to sustain habitat quality and allay local fears from risk of wildfire (New et al. 2000). Parameters defined to reduce the risk of butterfly extirpation and to achieve these purposes were needs for a hot fire, spatially controlled with parts (defined within a few metres) of the small sites protected from burning (so with weather conditions suitable for fine control), late in the summer (caterpillars well-grown before food plants destroyed; no adults or exposed eggs present), and during the day (caterpillars are nocturnal and by day are sheltered underground in ant nests as anticipated refuges, ants are also protected).
2. The Altona skipper, *Hesperilla flavescens flavescens* Waterhouse (Hesperiidae). Caterpillars feed, and form characteristic leaf shelters, on tussocks of the sedge *Gahnia filum* on isolated areas of near-coastal wetlands. Senescing tussocks become unsuitable, but fresh growth stimulated by burning encourages oviposition and feeding (Savage 2002, Relf and New 2009). In this example, burning at a small patch mosaic scale (even of single tussocks) can be achieved with adequate care, and late winter burning of uninhabited tussocks (detectable by absence of larval shelters) leads them to regenerate rapidly and produce fresh palatable growth by the butterfly's oviposition period in late October, following colonisation from unburnt refuges.

These examples emphasise the limited conditions and times for burning that may not constitute threats, and emphasise the importance of small scale ('micro-mosaic': see Sands and Hosking 2005) burns across sites inhabited by known threatened species. In both, planned ecological burns have been successful management tactics, but equivalent protocols have not been designed or tested for most individual species, and such detail for wider assemblages is impracticable. They indicate also the substantial risk of extirpation if fire is used without understanding the ecology of any species targeted for management. For another sedge-feeding skipper, *Antipodia chaostola* (Meyrick) in Victoria, fire intervals of 9–12 years have been suggested to maintain the habitat, with the additional proviso of creating a temporal mosaic by burning across different years (Wainer and Yen 2009). Two more general management considerations emerge from individual species studies:

1. The importance of refuges. Most insects and other small animals may not be able to move far, or sufficiently fast, to avoid fires and survival may depend on refuges: for the above butterflies, these are being underground (*Paralucia*) or deep in tussocks (*Hesperilla*) for much of the time. Simplistically, refuges may mean safety, whilst living exposed on foliage exposes insects more obviously to flame and radiant heat. On the ground, coarse woody debris (such as fallen trees) may provide shelter (as Andrew et al. 2000, noted for ants); fine debris almost certainly will not do so. For many insects, availability of any refuge is opportunistic. Only about 20 of the more than 400 Australian butterfly species, for example, have phenological refuges equivalent to that of the Eltham copper, and they also have vulnerable seasons with adult flight and eggs in exposed sites. However, season of fire may be critical in relation to occurrence of vulnerable active stages, whereas diapausing or otherwise dormant stages may themselves be refuges for many species.
2. The importance of the scale of spatial mosaics. Patchy distributions and uneven abundance of insects across landscapes ensure that spatial heterogeneity of assemblages occurs at rather small scales. One consequence is that any large area burn may affect numerous assemblages, and eradicate the variety of substrates and resources that has fostered that variety. Burns of even only a few hectares may destroy localised insect populations, unless they are sufficiently varied in intensity or other factors to leave micro-mosaic conditions that include unburnt patches as refuges to counter this (York 2000). Many invertebrates depend on plants at a given growth stage or age as a critical resource, so that providing that variety underpins management need.

The twin problems of very incomplete knowledge of 'what is there' and 'how the species may respond to fire' endorse the need to rely largely on generalities in planning fires. All fire is certain to kill numerous insects, change assemblages, and influence subsequent ecological processes and successions. Our concerns devolve on minimising invertebrate losses due to inappropriate fire regimes, and preventing adverse long-term changes. Any changes in practice must be accompanied by (and founded in) science-based evidence and documentation to increasingly undertake planned fires that are compatible with invertebrate conservation. Disturbances associated with planned burning activity may occasionally constitute threats on sensitive sites; clearing for fire breaks or access tracks and the use of fire retardant chemicals (Seymour and Collett 2008) may need to be considered carefully.

Discussion

Study limitations

A high proportion of studies on invertebrates and fire in south eastern Australia (1) have focused on or been restricted to ground-active taxa, using pitfall traps as the sole or predominant sampling tool; (2) lasted no more than about 3 years, commonly less; (3) have been opportunistic data-gathering exercises rather than testing critical hypotheses, commonly following a fire on a site; so (4) have lacked prefire and postfire data on the same sites over the same period as continuous data on 'control' non-burned sites; (5) been analysed to levels above species or morphospecies (studies analysing invertebrates to named species level wherever possible (such as by Driessen and Greenslade 2002) are highly informative, but remain exceptional and for many groups this formal level cannot be achieved); (6) with incomplete background information on soils, vegetation, topography (etc.) of the sites as determinants of microclimate and resources; (7) lacked standardisation for fire intensity, areas burned or season of burning, amongst other variables; (8) been superimposed on areas with incompletely documented fire history, commonly even without knowledge of when last burned; and (9) lacked knowledge of the extent and causes of small scale spatial and phenotypic variations in assemblage structures and susceptibility to fire. Sporadic exceptions to all the above limitations occur, but most published studies include at least some the above concerns, not least because many studies have been opportunistic, as noted by Neville (2000). In addition, most such studies have occurred in forest/woodland environments, with fewer critical studies in grasslands or heathlands. Collectively, as Friend (1996) wrote 'There is a clear need to assess current knowledge of invertebrate fire ecology, and in particular to critically examine whether the information to hand is sufficiently robust to enable sound management plans to be made'.

Invertebrates likely to decline rapidly, and perhaps taking considerable time to recover from fires, include those that depend on ground litter, with attendant moist conditions (York 1999, with similar trends noted by Barratt et al. 2009, for New Zealand tussock grassland fauna). York (1999) noted that many of these species in forests are often uncommon and ecologically specialised forms and that repeated burning might result in up to half the richness of terrestrial invertebrates being lost at the local scale. Conversely, limiting the spatial extent of repeated burning might reduce these losses. As York implied, losses of these important components of the decomposer community might have serious effects on ecological processes. Recovery from a single fire may take at least 3–5 years, but the period may depend substantially on proximity of refuges and of assemblages and populations from which to colonise. Much longer recovery periods, exceeding 20 years, have been noted for the Tasmanian buttongrass moorland fauna (Driessen and Greenslade 2002). It is not uncommon for particular groups of invertebrates (such as amphipods) not to be rediscovered during the life of a survey.

Implicitly, large burned areas may take longer to be reached by organisms with low dispersal capability. Whereas some periodic low intensity fires may not have major lasting effects, any such generalisations must be only tentative, because of the numerous other variables that may be influential. An underlying principle should, perhaps, be to aim to conserve the native invertebrate agents that 'control' or have major influences on ecological processes.

Ecosystem responses

Ecosystems differ markedly in their responses to fires, and those differences reflect individual conditions as well as broader parameters such as vegetation type. Although generalisations are difficult, at contrasting extremes it is highly likely that different fire intervals will be optimal for conservation in a grassland and a eucalypt forest, reflecting vegetation structure and turnover rates. As elsewhere in the world, many Australian forest insects are saproxylic, but the critical values of conserving dead wood, including standing or fallen dead trees (which are well appreciated in North America and Europe), run counter to demands for fuel removal in Australia. We note that 'Removal of dead wood and dead trees', with 'removal' specifically including 'burning on site', is listed as a key threatening process under the New South Wales Threatened Species Conservation Act 1995.

The scenario before us is one of concern for the impacts of fire on vast numbers of invertebrate taxa, combined with massive ignorance over the nature and consequences of those impacts and how to study and document them. There is, for example, no standardised management protocol that transcends use of fire for invertebrate conservation in different assemblages, vegetation types, and climatic regimes or that addresses how impacts may be measured and evaluated. Even following 'what happens in nature', as sometimes suggested in the belief that wildfires have helped to shape the evolutionary responses of the Australian biota (particularly flora) to burning, is difficult, not least because many of the susceptible ecosystems are no longer pristine and now differ in flammability and constitution from their former states. Repeated burns can increase flammability of vegetation (Bowman et al. 2009) and (in northern Australia: Murphy et al. 2010) can severely reduce growth rates of trees. At one extreme, some vegetation types and all creek lines should never be burned

deliberately: the centuries needed to re-establish mature eucalypt forests suggest that large scale uncritical burning may cause largely irreparable changes, and some herb and wetland associations are also sensitive. However, in addition to the broad acre burns designated for fuel reduction, many natural areas with conservation values as refuge or reservoir habitats are also susceptible and may be (1) small, and consequently dismissed as insignificant by many biologists and planners who may be unaware of the critical importance of these to invertebrates; (2) urban remnants, where fuel build-up causing public safety concerns can increase pressures for planned fires; or (3) other isolated fragments or remnants within agricultural or forestry landscapes. Other areas may be important for insects as (4) type localities or sites supporting the only known populations in the area or of locally endemic species, and (5) sites with species listed formally under Commonwealth or State legislation as protected or having conservation significance. Yet other sites may transcend the above broad categories as having significance for insect sustainability or evolution. Some hilltops, for example, are included in the former Register of the National Estate as either or both of natural enclaves supporting significant species or richness, and as assembly sites for insects from surrounding landscapes.

Ways forward

All of the above categories of sites will need protection, and their formal recognition imposes a duty-of-care in management. In short, sites in any of the above categories should never be burned without seeking specialist advice and carefully assessing that advice. Establishing a mandatory formal assessment process of sites for invertebrate 'values' is indicated, together with provision for monitoring of outcomes for invertebrates of any burns undertaken. As urged by York (2002), invertebrates should be included routinely in surveys and experiments related to design and impacts of fires, with foci including the effects of mosaic burns and the roles of habitat refuges. Surveys could usefully focus on carefully selected target groups, based on feeding guilds or other defined ecological roles, so that trends (at least in part) can be explained rather than simply detected or inferred.

Site-level considerations extend also to protection of 'hotspots' of richness or local endemism, and to nearby aquatic habitats for which adequate buffers of unburned vegetation may be critical in preventing bank erosion and sediment run-off. Burning of riparian vegetation may cause direct harm to species depending on it or which do not move far from aquatic larval habitats (Crowther et al. 2008). In addition, landscape issues are important for insects, so that connectivity and patchiness of suitable habitats may be vital, in addition to their extent. Maintenance of spatial heterogeneity is advocated increasingly as linked strongly with both higher biodiversity and more comprehensive ecosystem functions (grasslands: Zavaleta et al. 2010). Any means to promote heterogeneity whilst also maintaining connectivity merit serious consideration in land management. Some large scale fires may promote uniformity through leading to large stands of uniform-aged vegetation, countering the heterogeneity in litter and vegetation so important for invertebrate diversity. Small scale fires, conversely, may help promote variety.

The paramount modification needed in planned burn regimes in the region is to institute micro-mosaic burning as the normal practice to replace burns of much larger areas, ideally with burned areas to be of no more than a few hectares each and, within any larger site, staggered in time (years) to conserve the widest possible array of diverse patches within a reasonable distance. This procedure would help assure continuity of refuges and chances of re-colonisation of burned areas from resident populations nearby, and facilitate access by largely non-vagile small animals. In addition, parts (as a rule-of-thumb, at least 20% of an area) of any site should be permanently protected from deliberate burns, and sites less than about 5 ha should be burned only under exceptional circumstances. Any such burn should be undertaken in combination with survey and monitoring to investigate the risks associated with this approach. Because data are insufficient to define detail, the above figures are given simply to indicate the 'spirit' of our recommendations, and are open to validation for any particular context that arises. They are a minimum set of considerations, but their adoption is likely to cause logistic problems in relation to practicality and levels of control and monitoring needed. However, without such controls, current data indicates that planning for increasing burns over large areas based largely on perceived influences on vegetation alone may well be detrimental to many locally endemic insects and other invertebrates in south eastern Australia. The balance between the fire regimes that will either continue to foster diversity or lead to extensive simplification within invertebrate assemblages is indeed difficult to define. Effective adaptive management of landscapes by fire, recognising the lack of detailed knowledge of most invertebrate components of Australia's biodiversity, depends in large part on incorporating them constructively and, at the least, not overlooking their substantial ecological importance.

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