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Fire and invertebrates - a review of research methodology and the predictability of post-fire response patterns

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ABSTRACT

Invertebrates are now recognized as critical elements in the maintenance of ecosystems, and many are seen to have potential as bio-indicators of environmental conditions. Information on their responses to environmental disturbance is therefore critical. With regard to the impact of fire on invertebrates, however, many conflicting results have arisen. It was therefore considered timely to carry out a detailed review of the sampling methods employed in most of the studies to date, and of the post-fire invertebrate response patterns recorded.

Considerable variability was found in the sampling methods used, and there were many shortcomings in experimental design and length of study, with few studies adopting an experimental approach incorporating adequate pre- and post-fire sampling. Such deficiencies make it difficult to determine whether the outcomes observed are a true feature of invertebrate responses to fire, or are largely artefacts of the sampling procedure.

Available data indicate that Araneae and also probably Lepidoptera, Isopoda, Blattodea and Thysanura are sensitive to fire and exhibit consistent response patterns across a variety of habitat types, thus qualifying them as potential indicator groups. Trends in invertebrate resilience to fire across broad habitat and climatic gradients suggest there is a need for conservatism in the application of high frequency and large scale fire regimes, particularly in the more mesic forested areas of Australia.

INTRODUCTION

The role of prescribed burning in the management of vegetation throughout temperate Australia is a complex and sometimes contentious issue. Currently, most fire management decisions are based on a reasonably detailed knowledge of weather, fuel and other site parameters and their influence on fire behaviour. This knowledge forms the main rationale for the prescribed burning of forested areas of south-western and south-eastern Australia to reduce fuel loads and wildfire hazard (Shea *et al.* 1981; Cheney 1985; McCaw and Burrows 1989).

In the context of ecosystem management, however, most decisions must be made against a background of little research data on the effects of fire (or a fire regime) on the biota. There is thus a serious dichotomy in our levels of understanding of the principles of fire physics and prescibed burning technology on the one hand, and the impacts of fire and its role in ecosystem management on the other. This points to an urgent need to obtain reliable data on the effects of fires of varying intensities and season of burn on the biota, in conjunction with studies on the behaviour of these fires and the management planning processes involved.

Most studies of fire effects have concentrated on vegetational aspects, perhaps because plants are the organisms perceived as being most directly affected by fire. Until the last decade, relatively little work had been carried out relating to the effects of fire on fauna, and there is still a dearth of knowledge with respect to herpetofauna and invertebrates (see reviews by Suckling and Macfarlane 1984; Christensen and Abbott 1989; Friend 1993).

Invertebrates as Bio-indicators

There is a considerable and growing body of evidence that invertebrates are more important in the maintenance of ecosystems than are vertebrates, yet there remains a paucity of information on them (Key 1978; Majer 1987; Hill and Michaelis 1988). Most of the biological diversity we are dealing with in nature conservation is contributed by invertebrates (Greenslade and Greenslade 1984; New 1984, 1987; CONCOM 1989; Kim 1993), but they are usually ignored in ecological research (Majer 1987). Furthermore, certain guilds of invertebrates are proving excellent bio-indicators of environmental conditions, including pyric status. Groups which have received some attention to date include ants (Majer 1983; Andersen 1987), spiders (Clausen 1986; Main 1987) and beetles (Friend and Williams 1993). Through analysis of insects comprising small vertebrate diets (e.g. of dasyurids, lizards, frogs) and insect/plant interactions (especially herbivory rates), invertebrate studies have the potential to contribute to an understanding of the processes involved in pyric disturbance ecology.

Invertebrates and Fire

As part of a research program examining the impact of experimental fires on invertebrate communities within remnant shrublands in the Stirling Range National Park (Friend and Williams 1993), a significant portion of the literature on fire and invertebrates was reviewed. From this general review it became apparent that most impacts are relatively short-term (e.g. less than 2-3 years), that high intensity wildfires have much greater impacts than lower-intensity prescribed burns, and that spring prescribed burns may have a greater impact than those carried out in autumn. The review, however, also highlighted that a wide variety of post-fire response patterns may occur, and that these are often not consistent within taxonomic group or habitat type between different studies. In many instances invertebrate groups show marked locality, season and year-to-year effects which outweigh any changes attributable to fire.

Furthermore, many inconsistencies seem to have arisen because of variations or shortcomings in experimental design, taxonomic treatment and length of study. Few studies have any pre-fire data (see review by Majer 1985c for Western Australian studies), or any long-term post-fire data (Abbott 1984; Tap and Whelan 1984; Majer 1980, 1985a, 1985c). In the majority of cases, invertebrates have been identified only to ordinal level, thus potentially masking important changes in species and family composition following fire. In addition, most workers have contemporaneously sampled areas of different fire histories and ascribed faunal differences to the effect of these fires. Given the inherent within-site variability of invertebrate populations (Campbell and Tanton 1981), this assumption of pre-fire homogeneity between control and treatment plots is tenuous. Furthermore, the effects of intensity and season of burning are likely to be profound, but have frequently been ignored.

Given the outcomes which arose from this general overview, it was considered timely to conduct a more detailed examination of invertebrate response patterns following fire in order to: (a) quantitatively assess whether or not various groups (e.g. Orders) have consistent post-fire response patterns; (b) highlight groups or taxa which are sensitive to fire and therefore could serve as indicator species of pyric status; and (c) examine trends in relation to habitat type across a broad climatic gradient. In addition, the opportunity was taken to gather some statistics on experimental design and sampling methodologies employed in studies of invertebrate responses to fire.

STUDIES AND PARAMETERS EXAMINED

Twenty-four studies were reviewed which represented a broad cross-section of research carried out in temperate Australia over the past 40 years. More than half of these studies were conducted during the mid 1980s and a large proportion (62 per cent) were undertaken in Western Australia. However, Victoria, South Australia, New South Wales and the Australian Capital Territory also were represented.

The following parameters were noted for each of the studies reviewed:

- Methods - whether pitfall traps, soil/litter samples combined with heat extraction or hand sort or other method, the preservative used in pits and the number of days the pits were open;
- Duration (months) of pre and post-fire monitoring for experimental studies;
- Duration (months) of post-fire monitoring in studies utilizing a space-for-time approach (Pickett 1989);
- Level of identification - whether order, family or species;
- Habitat type - whether tall open-forest, open-forest, eucalypt woodland, banksia woodland or shrubland;
- Fire type - whether wildfire or prescribed fire;
- Season of fire - whether autumn, spring or summer; and
- Fire intensity - whether high or low;

For each study, the responses of invertebrate groups (mainly orders) were assigned to one of three categories: (a) no marked change in abundance post-fire or highly variable over time (designated zero); (b) a general increase in abundance post-fire (designated plus); and (c) a general decrease in abundance post-fire (designated minus). In this manner response data were accumulated for a total of 20 invertebrate groups (mainly orders) *viz.* Oligochaeta (earthworms), Araneae (spiders), Pseudoscorpionida (pseudoscorpions), Acarina (mites), Isopoda (slaters), Chilopoda (centipedes), Diplopoda (millipedes), Collembola (springtails), Thysanura (bristletails), Blattodea (cockroaches), Isoptera (termites), Dermaptera (earwigs), Orthoptera (grasshoppers), Hemiptera (bugs), Thysanoptera (thrips), Coleoptera (beetles), Diptera (flies), Lepidoptera (moths and butterflies), Hymenoptera (bees and wasps but excluding ants), and Hymenoptera (ants).

RESULTS AND DISCUSSION

Sampling Methods

Seventeen of the 24 studies reviewed (71 per cent) used pitfall traps, but the dimensions varied greatly and were often tailored for specific purposes. For example, small diameter pitfall traps (e.g. 18 mm test tubes) have frequently been used by researchers with a primary interest in ants (e.g. Majer 1980), while more generalized studies have utilized larger traps (e.g. plastic vials or cups up to 90 mm diameter; Abbott 1984; Friend and Williams 1993; Strehlow 1993). One study (Campbell and Tanton 1981) used pitfall traps but provided no details of their dimensions or preservative used, while Bornemissza (1969; abstract only) did not describe any of the methods used in his study.

A mixture of ethanol and glycerol was the most common preservative used in pitfall traps (10 studies), followed by Galt's solution (Friend and Williams 1993; Main and Gaull 1993; Strehlow 1993) and methanol (Neumann and Tolhurst 1991; Neumann 1991). Pitfall traps were left open for between two to 14 days, with the majority (9 of the 13 which provided such detail) being either seven or ten days.

Heat extraction of soil cores and/or leaf litter samples using Tullgren or Berlese funnels was also a common method used (11 studies) while two studies (Springett 1976, 1979) employed hand sorting. Clearly, as pointed out by Campbell and Tanton (1981), this latter method would be biased against small, cryptic animals and could not be recommended for general studies of invertebrate communities.

Understandably, most researchers use their own method consistently, and while this makes studies by the one person comparable, the large differences in trap sizes, layout, days of sampling and preservative used render quantitative comparisons between studies invalid. Indeed, in examining the many variables affecting sampling with pitfall traps, Adis (1979) called for the quantitative testing of many existing designs and the development of a standard pitfall trap for future universal use. However, trends in the abundance of invertebrate groups following disturbance can be compared for different studies, and this was the approach adopted here.

Duration of Monitoring

Eighteen of the 24 studies examined were based on sampling before and after fire, although two studies (Bornemissza 1969; Hutson and Kirkby 1985; both in summary form) did not specify the length of post-fire sampling. Pre-fire sampling occurred for a mean of 12.2 ± 9.3 months (n = 18; range 1-36; CV = 76 per cent), while post-fire monitoring proceeded for a mean of 18.5 ± 11.2 months (n = 16; range 1-39; CV = 60 per cent). Nine studies (50 per cent) had less than 12 months pre-fire data, but 13 (72 per cent) had more than 12 months post-fire data. Thus many studies had acquired only a minimal amount of pre-fire data, but had adequate post-fire data. Indeed, five studies (Leonard 1972; Abbott 1984; Majer 1984; Andersen 1988; Neumann and Tolhurst 1991) showed great discrepancies in the duration of pre- and post-fire monitoring, with all but Andersen (1988) having less than seven months pre-fire data but one to three or more years of post-fire information. In essence, those studies with the most post-fire data were also among those with the least pre-fire data. Such an unbalanced sampling schedule is of questionable benefit.

Nine studies adopted a space-for-time approach either wholly (i.e. with no pre-fire information; McNamara 1955; Springett 1976, 1979; Whelan *et al.* 1980; Abbott, van Heurck and Wong 1984; Majer 1985b) or as an adjunct to before/after experimental work (e.g. Bamford 1986; Strehlow 1993; Friend and Williams 1993). The latter approach has the advantage in providing both short-term and long-term data on the impact of several fires within a relatively short research time-frame. Space-for-time monitoring proceeded for a mean of 8.4 ± 12.2 months (n = 8, [McNamara (1955) gave no details] range 0.3 - 36 months), but duration was highly variable (CV = 145 per cent).

Level of Identification

The majority of studies (about 75 per cent) examined one or two groups in detail to the family or species level and identified the remainder to order level. The family or species level identifications generally concerned ants and to a lesser extent spiders. Five studies (Curry *et al.* 1985; Hutson and Kirkby 1985; Andersen 1988; Main and Gaull 1993; Strehlow 1993) concentrated only on specific groups (ants, spiders, mites or springtails) and did not examine other order level data. Thus studies have been either very general or highly specific, and to date no fire ecology study has identified a broad range of invertebrates to family or species level. This situation is understandable given the huge diversity of invertebrates and the current (and specialized) taxonomic knowledge of this fauna (the 'taxonomic impediment', New 1984), and makes the search for species or groups which can be used to indicate certain environmental regimes all the more pressing (New 1984). The newly developing field of Rapid Biodiversity Assessment (RBA; Beattie *et al.* 1993) also shows much promise in helping to resolve the taxonomic problems associated with the use of invertebrates in ecological studies.

Research Emphasis to Date

In order to gain some insight into where the emphasis has to date been directed in invertebrate fire ecology research the 24 studies were each categorized according to habitat type, fire type, season and intensity. Classifying studies on this basis immediately indicates where the major research emphasis has been to date, and where more effort is needed.

Only four of the 24 studies reviewed addressed tall open-forest, and only Neumann (1991) examined wildfire impacts, this being for a high intensity summer burn. The remaining three studies addressed prescribed burns, two being high intensity summer/autumn burns (O'Dowd and Gill 1985; Curry *et al.* 1985) in *Eucalyptus delegatensis* and *Eucalyptus diversicolor*, and the other a low intensity spring burn in *E. diversicolor* (Springett 1976).

Eleven of the reviewed studies addressed open-forest, but only that by Hutson and Kirkby (1985) focussed on wildfire, this being a high intensity autumn burn. Of the remaining 10 studies in this habitat type which addressed prescribed fires, four examined autumn burns (Springett 1979; Abbott 1984; Majer 1984; O'Dowd 1985; Neumann and Tolhurst 1991), five examined spring burns (McNamara 1955; Leonard 1972; Springett 1976; Campbell and Tanton 1981; Abbott, van Heurck and Wong 1984), while the comprehensive studies of Neumann and Tolhurst (1991) examined both spring and autumn burns. All except the case studied by Springett (1976) were low intensity prescribed burns.

Three of the reviewed studies encompassed eucalypt woodland, all focussing on low intensity spring burns (Majer 1980, 1985b; Andersen 1988), but with the space-for-time study of Majer (1985b) also examining impacts of a low intensity autumn fire in wandoo woodland. Banksia woodland was also examined by three studies, one investigating a high intensity autumn wildfire (Whelan *et al.* 1980), another comparing moderate to high intensity spring and autumn prescribed burns (Bamford 1986), and the third not specifying fire season or intensity (Bornemisszа 1969).

Shrublands were investigated in four of the reviewed studies, three of these having recently been carried out in the wheatbelt and south coast areas of Western Australia. Two of the studies concerned high intensity summer/autumn wildfires (Tap and Whelan 1984; Main and Gaull 1993), one focussed on a high intensity autumn burn on an isolated wheatbelt nature reserve (Strehlow 1993), while the studies of Friend and Williams (1993) examined the relative impacts of low-moderate intensity spring and autumn burns and a high intensity autumn wildfire.

From the above it is clear that most of the emphasis in invertebrate fire ecology has been on prescribed burning in open forest, an area of considerable controversy Australia-wide. Although such effort is well placed, there has been little concensus reached from the results to date (e.g. Campbell and Tanton 1981; Abbott 1984; Majer 1984; *cf* McNamara 1955; Springett 1976, 1979) and other areas, particularly the drier woodlands and shrublands, have received comparatively little attention. There is a need for comprehensive long-term research to clarify the impacts of fire in forest environments, but there is also clearly a need to gather more data from the drier ecosystems and to commence work in the mulga woodlands and hummock grasslands which have received no attention to date. Such studies are now underway in Western Australia (A. Start, S. van Leeuwen, D. Pearson *personal communications*).

Invertebrate Response Patterns and Indicator Groups

Response patterns of the major invertebrate groups were examined across all 24 studies, and with the studies separated according to major habitat type. For the latter analysis there were insufficient data to examine tall open forest (only four studies) and the data for the drier woodland and shrubland habitats were combined. For each invertebrate group for which post-fire response information was available, the proportion of cases showing no post-fire change in abundance (designated zero), a post-fire increase (plus) or a post-fire decrease (minus) was calculated and tabulated. This provided information on both the strength and the consistency of the post-fire responses which could be compared between different invertebrate groups or between the same groups in different habitat types. Thus, in highlighting potential indicator groups, those which are common across a broad range of habitats, and score only in the minus or the zero and minus categories (and not those which score in both the plus and minus categories) should be considered. Groups which satisfy these criteria are common, sensitive to fire and show a consistent response to it, thus conforming to the desirable criteria for selection of indicator taxa (New 1984). A further restriction is that there must be an adequate number of cases (studies) which have provided the data for the particular group (e.g. >5 cases).

Indicator Groups

Across all studies (Table 1) six invertebrate groups satisfy these criteria: Araneae, Isopoda, Thysanura, Blattodea, Isoptera and Lepidoptera. A seventh group, the Diptera, may also qualify because the two plus response cases both related to high intensity wildfires (Neumann 1991; Friend and Williams 1993), indicating some differential but consistent responses associated with type of fire. All of the remaining (13) groups were either insufficiently studied or were inconsistent in their responses.

In open-forest (Table 2) Araneae, Isopoda, Blattodea, Diptera and Lepidoptera were again quite consistent, and, in addition, Acarina, Collembola and Coleoptera qualified. Although few studies included Thysanura (4), all responses were minus suggesting that this group also may be worthy of consideration in this habitat type. Interestingly, ants, which have been frequently used as indicator species registered inconsistent responses in this habitat type. In the drier woodland and shrubland habitats, however, (Table 3) ants showed very consistent post-fire responses (increases), suggesting that their value as indicators of disturbance or pyric status may vary according to climate and habitat.

In the woodland/shrubland habitats (Table 3) there are a paucity of data, but one group stands out as a potential indicator: Araneae. This is not surprising considering that spiders are at the apex of the invertebrate food pyramid, and some representatives (especially the mygalomorphs or trapdoor spiders) are relictual in their distribution, are long-lived and relatively sedentary with poor dispersal powers, and

TABLE 1

Overall post-fire response patterns for major invertebrate groups

GROUP	TOTAL # STUDIES	PROPORTION IN CATEGORIES 0	 +	 –
Acarina	14	0.50	0.10	0.40
Araneae	21	0.60		0.40
Blattodea	11	0.40		0.60
Chilopoda	8	0.50	0.25	0.25
Coleoptera	18	0.50	0.10	0.40
Collembola	13	0.50	0.10	0.40
Dermaptera	4	0.75		0.25
Diplopoda	10	0.30	0.30	0.40
Diptera	12	0.40	0.20	0.40
Hemiptera	13	0.20	0.50	0.30
Hymenoptera (ants)	15	0.20	0.60	0.20
Hymenoptera (excl. ants)	8	0.25	0.25	0.50
Isopoda	8	0.40		0.60
Isoptera	7	0.40		0.60
Lepidoptera	7	0.30		0.70
Oligochaeta	2	0.50		0.50
Orthoptera	10	0.60	0.10	0.30
Pseudoscorpionida	3	0.30		0.70
Thysanoptera	3			1.00
Thysanura	6	0.30		0.70
Total Number of Groups in Categories		19	10	20

0 = no change; + = increase; – = decrease

TABLE 2

Post-fire response patterns for major invertebrate groups
in open forest.

GROUP	TOTAL # STUDIES	PROPORTION IN CATEGORIES 0	 +	 –
Acarina	6	0.50		0.50
Araneae	6	0.70		0.30
Blattodea	5	0.20		0.80
Chilopoda	3	0.70		0.30
Coleoptera	8	0.50		0.50
Collembola	5	0.40		0.60
Dermaptera	2	1.00		
Diplopoda	5	0.60	0.20	0.20
Diptera	6	0.70		0.30
Hemiptera	4	0.50		0.50
Hymenoptera (ants)	6	0.50	0.20	0.30
Hymenoptera (excl. ants)	3	0.30		0.70
Isopoda	5	0.40		0.60
Isoptera	4	0.75		0.25
Lepidoptera	5	0.40		0.60
Oligochaeta	2	0.50		0.50
Orthoptera	4	0.25	0.25	0.50
Pseudoscorpionida	2	0.50		0.50
Thysanoptera	2			1.00
Thysanura	4			1.00
Total Number of Groups in Categories		18	3	19

0 = no change; + = increase; – = decrease

TABLE 3

Post-fire response patterns for major invertebrate groups in woodland/shrubland.

GROUP	TOTAL # STUDIES	PROPORTION IN CATEGORIES		
		0	+	–
Acarina	5	0.60	0.20	0.20
Araneae	11	0.60		0.40
Blattodea	4	0.75		0.25
Chilopoda	3	0.30	0.70	
Coleoptera	7	0.70	0.15	0.15
Collembola	6	0.30	0.30	0.30
Dermaptera	1	1.00		
Diplopoda	2		1.00	
Diptera	4		0.50	0.50
Hemiptera	7	0.15	0.70	0.15
Hymenoptera (ants)	6		1.00	
Hymenoptera (excl. ants)	4	0.25	0.25	0.50
Isopoda	0			
Isoptera	2			1.00
Lepidoptera	1			1.00
Oligochaeta	0			
Orthoptera	5	0.80		0.20
Pseudoscorpionida	0			
Thysanoptera	0			
Thysanura	2			1.00
Total Number of Groups in Categories		10	9	12

0 = no change; + = increase; – = decrease

have very specific microhabitat preferences (Main 1987). Araneae would thus appear the most promising invertebrate indicator group to use in fire ecology studies across a broad range of habitats. Isopoda, Blattodea, Lepidoptera and perhaps Thysanura also appear to have potential as indicator groups, but more data are needed to confirm this. Many of the larger groups for which data are adequate (e.g. Acarina, Collembola, Isoptera, Coleoptera, Diptera and Hymenoptera (ants)) show consistent patterns only in certain habitat types and cannot therefore be considered good indicator groups in fire ecology studies. This is not to say, however, that certain *species* or *taxa* within these groups may not be good indicators, satisfying the criteria defined by New (1984). At this stage, however, there are insufficient fire ecology data available at the species level (perhaps with the exception of ants) to categorize invertebrate species as indicators.

Response Patterns and Habitat Type

Examination of the total numbers of groups in the three response categories for the data in Tables 1-3 indicates there are few cases of post-fire increases in the open-forest. These trends were further investigated by summing the total numbers in the zero (no change), plus (increase) and minus (decrease) categories (irrespective of invertebrate group) for tall open-forest, open-forest and woodland/shrubland. These data revealed very clear and significant differences ($X^2 = 32.2$ (DF=4); $p < 0.001$) in the response patterns for the three different habitat types (Table 4). In tall open-forest there were more cases than expected in the decrease category, in open forest more cases than expected occurred in the no change and decrease categories, while in woodlands and shrublands the response pattern was similar to that expected by chance.

This outcome, based on the data available to date, strongly suggests that there is a gradient in invertebrate responses to fire related to habitat type, and ultimately, climate. Invertebrates appear to be less resilient (*sensu* Westman 1986) to fire in the more mesic environments (particularly tall open forest) than in the drier woodland and shrubland ecosystems. Such resilience in the drier habitats is probably a reflection of the invertebrate fauna's adaptations to survive seasonal aridity. This does not imply, however, that faunal composition and abundance would not change greatly under a high frequency fire regime in such areas (i.e. exhibit low malleability, *sensu* Westman 1986). Thus in the wetter forested areas, where the invertebrate fauna appears to be even less resilient, significant changes in species

TABLE 4

Total reponses in categories vs habitat type.

	NO CHANGE	INCREASE	DECREASE
Tall Open-forest	7	6	21
	(11.3)	(11.3)	(11.3)
Open-forest	43	3	43
	(29.7)	(29.7)	(29.7)
Woodland/ Shrubland	30	22	18
	(23.3)	(23.3)	(23.3)

Expected values shown in parentheses

abundance and composition may be expected to occur under a high frequency/large scale fire regime.

Clearly, however, we have much to learn before such trends can be verified so that we can confidently devise optimal fire regimes for various habitat types. In particular, we need much more critical and objective data from both the arid areas (e.g. mulga and hummock grasslands) and the forests, and we need to know the relative proportions of fire-sensitive species in the various habitat types. To achieve this, a much more rigorous approach to sampling and experimental design needs to be adopted.

CONCLUSIONS

This detailed review of invertebrate fire ecology studies indicates that a wide variety of sampling methods are employed and that invertebrate response patterns also vary greatly. Given the inherent variability of invertebrate populations it is crucial that studies obtain pre- and post-fire data over several years, and that they are standardized with respect to experimental design and taxonomic treatment. It is only by minimizing/ eliminating such experimental variability that we can determine whether the outcomes observed are a true feature of invertebrate responses to fire, or are largely human-induced. This has important ramifications for the use of invertebrates in studies examining community stability and resilience.

REFERENCES

Abbott, I. (1984). Changes in the abundance and activity of certain soil and litter fauna in the jarrah forest of Western Australia after a moderate intensity fire. *Australian Journal of Soil Research* **22**, 463-469.

Abbott, I., van Heurck, P. and Wong, L. (1984). Responses to long-term fire exclusion: physical, chemical and faunal features of litter and soil in a Western Australian forest. *Australian Forestry* **47**, 237-242.

Adis, J. (1979). Problems of interpreting arthropod sampling with pitfall traps. *Zoologischer Anzeiger Jena* **202**, 177-184.

Andersen, A.N. (1987). Ant community organization and environmental assessment. In: Majer, J.D. (Ed.) *The Role of Invertebrates in Conservation and Biological Survey.* Western Australian Department of Conservation and Land Management Report. pp 43-52.

Andersen, A.N. (1988). Immediate and longer-term effects of fire on seed predation by ants in sclerophyllous vegetation in south-eastern Australia. *Australian Journal of Ecology* **13**, 285-293.

Bamford, M.J. (1986). The dynamics of small vertebrates in relation to fire in banksia woodland near Perth, Western Australia. Ph.D. Thesis. Murdoch University, WA.

Beattie, A.J., Majer, J.D. and Oliver, I. (1993). Rapid biodiversity assessment: a review. In: Beattie, A.J. (Ed.) *Rapid Biodiversity Assessment - Proceedings of the Biodiversity Assessment Workshop.* Macquarie University, Sydney. pp 4-14.

Bornemissza, G. F. (1969). The reinvasion of burnt woodland areas by insects and mites. *Proceedings of the Ecological Society of Australia* **4**, 138.

Campbell, A.J., and Tanton, M.T. (1981). Effects of fire on the invertebrate fauna of soil and litter of a eucalypt forest. In: Gill, A.M., Groves, R.H. and Noble, I.R. (Eds.) *Fire and the Australian Biota.* Australian Academy of Science, Canberra. pp. 215-241.

Cheney, N.P. (1985). Forest fire management in Australia. In: *Proceedings of the Intermountain Fire Council 1983 Fire Management Workshop.* Report NOR-X-271. Canadian Forest Service. pp 75-83.

Christensen P.E.S. and Abbott, I. (1989). Impact of fire in the forest ecosysytem of southern Western Australia: a critical review. *Australian Forestry* **52**, 103-121.

CONCOM (1989). Council of Nature Conservation Ministers - Australian statement on invertebrates. *Myrmecia* **25**, 123-125.

Clausen, I.H.S. (1986). The use of spiders (Araneae) as ecological indicators. *Bulletin of the British Arachnology Society* 7, 83-86.

Curry, S.J., Humphreys, W.F., Koch, L.E. and Main, B.Y. (1985). Changes in arachnid communities resulting from forestry practices in karri forest, south-west Western Australia. *Australian Forest Research* **15,** 469-480.

Friend, G.R. (1993). Impact of fire on small vertebrates in mallee woodlands and shrublands of temperate Australia - a review. *Biological Conservation* **65,** 99-114.

Friend, G.R. and Williams, M.R. (1993). Fire and invertebrate conservation in mallee-heath remnants. Final Report, Project P144, World Wide Fund for Nature Australia. 99pp.

Greenslade, P.J.M. and Greenslade, P. (1984). Invertebrates and environmental assessment. *Environment and Planning* **3,** 13-15.

Hill, L. and Michaelis, F.B. (1988). *Conservation of Insects and Related Wildlife,* Occasional Paper No. 13. Australian National Parks and Wildlife Service, Canberra.

Hutson, B.R. and Kirkby, C.A. (1985). Populations of collembola and acarina in litter and soil of South Australian forests and the effect of a wildfire. In: Greenslade, P. and Majer, J.D. (Eds.) *Soil and Litter Invertebrates of Australian Mediterranean-Type Ecosysytems.* WAIT School of Biology Bulletin No. 12. pp34-36.

Key, K.H.L. (1978). *The Conservation Status of Australia's Insect Fauna.* Occasional Paper No. 1. Australian National Parks and Wildlife Service, Canberra.

Kim, K.C. (1993). Biodiversity, conservation and inventory: why insects matter. *Biodiversity and Conservation* **2,** 191-214.

Leonard, B.V. (1972). The effect of fire upon selected small mammals and leaf litter fauna in sclerophyll forest in southern Australia. M.Sc. Thesis, Monash University, Melbourne.

Main, B.Y. (1987). Persistence of invertebrates in small areas : case studies of trapdoor spiders in Western Australia. In: Saunders, D.A., Arnold, G.W., Burbidge, A.A. and Hopkins, A.J.M. (Eds.) *Nature Conservation: The Role of Remnants of Native Vegetation.* Surrey Beatty and Sons, Sydney. pp 29-39.

Main, B.Y. and Gaull, K. (1993). Response of trapdoor spiders to fire in the Stirling Range. Unpublished Report to Department of Conservation and Land Management, Perth.

Majer, J.D. (1980). Report on a study of invertebrates in relation to the Kojonup Fire Management Plan. WAIT Department of Biology Bulletin No. 2. 22pp.

Majer, J.D. (1983). Ants: bio-indicators of minesite rehabilitation, land-use, and land conservation. *Environmental Management* **7,** 375-383.

Majer, J.D. (1984). Short-term response of soil and litter invertebrates to a cool autumn in Jarrah (*Eucalyptus marginata*) forest in Western Australia. *Pedobiologia* **26,** 229-247.

Majer, J.D. (1985a). Fire effects on invertebrate fauna of forest and woodland. In: *Fire Ecology and Management in Western Australian Ecosystems.* (Ed. J. Ford) pp. 103-106. WAIT Environmental Studies Group Report No. 14. Western Australian Institute of Technology, Perth.

Majer, J.D, (1985b). Invertebrate studies in disturbed and pristine habitats of Dryandra State Forest. Research Paper 80, Forests Department of Western Australia. 11pp.

Majer, J.D. (1985c). A review of pyric succession of soil and litter invertebrates in south-western Australia. In: Greenslade, P. and Majer, J.D. (Eds.) *Soil and Litter Invertebrates of Australian Mediterranean-Type Ecosysytems.* WAIT School of Biology Bulletin No. 12. pp. 28-30.

Majer, J.D. (1987). The conservation and study of invertebrates in remnants of native vegetation. In: Saunders, D.A., Arnold, G.W., Burbidge, A.A. and Hopkins, A.J.M. (Eds.) *Nature Conservation: The Role of Remnants of Native Vegetation.* Surrey Beatty and Sons, Sydney. pp 333-335.

McCaw, W.L. and Burrows, N.D. (1989). Fire management. In:: Dell, B., Havel, J.J. and Malajczuk, N. (Eds.) *The Jarrah Forest: A Complex Mediterranean Ecosysytem.* Kluwer Academic Publishers, Dordrecht. pp. 317-334.

McNamara, P.J. (1955). A preliminary investigation of the fauna of humus layers in the jarrah forest of Western Australia. Forestry and Timber Bureau Leaflet No. 71.

Neumann, F.G. (1991). Responses of litter arthropods to major natural or artificial ecological disturbances in mountain ash forest. *Australian Journal of Ecology* **16,** 19-32.

Neumann F.G. and Tolhurst, K. (1991). Effects of fuel reduction burning on epigeal arthropods and earthworms in dry sclerophyll eucalypt forest of west-central Victoria. *Australian Journal of Ecology* **16,** 315-330.

New, T.R. (1984). *Insect Conservation : An Australian Perspective.* Dr W. Junk Publishers, Netherlands.

New, T.R. (1987). Insect conservation in Australia: towards rational ecological priorities. In: Majer, J.D. (Ed.) *The Role of Invertebrates in Conservation and Biological Survey.* Department of Conservation and Land Management, Perth. pp.5-20.

O'Dowd, D. (1985). Effect of low-intensity fire on the activity of ants and other invertebrates at Belair Recreation Park, South Australia. In: Greenslade, P. and Majer, J.D. (Eds.) *Soil and Litter Invertebrates of Australian Mediterranean-Type Ecosysytems.* WAIT School of Biology Bulletin No. 12. pp. 73-76.

O'Dowd, D. and Gill, A.M. (1985). Effect of a high-intensity fire on ants and other invertebrates in the Brindabella Range. In: Greenslade, P. and Majer, J.D. (Eds.) *Soil and Litter Invertebrates of Australian Mediterranean-Type Ecosysytems.* WAIT School of Biology Bulletin No. 12. pp. 87-90.

Pickett, S.T.A. (1989). Space-for-time substitution as an alternative to long-term studies. In Likens, G.E. (Ed.) *Long-term Studies In Ecology: Approaches and Alternatives.* Springer-Verlag, New York. pp. 110 - 135.

Shea, S.R., Peet, G.B. and Cheney, N.P. (1981). The role of fire in forest management. In: Gill, A.M., Groves, R.H. and Noble, I.R. (Eds.) *Fire and the Australian Biota.* Australian Academy of Science, Canberra. pp. 443-470.

Springett, J.A. (1976). The effect of prescribed burning on the soil fauna and on litter decomposition in Western Australia. *Australian Journal of Ecology* **1**, 77-82.

Springett, J.A. (1979). The effects of a single hot summer fire on soil fauna and on litter decomposition in jarrah (*Eucalyptus marginata*) forest in Western Australia. *Australian Journal of Ecology* **4**, 279-291.

Strehlow, K.H. (1993). Impact of fires on spider communities inhabiting semi-arid shrublands in Western Australia's wheatbelt. B.Sc. Honours Thesis, Murdoch University.

Suckling, G.C. and Macfarlane, M.A. (1984). The effects of fire on fauna: a review. In: Ealey, E.H.M. (Ed.) *Fighting Fire With Fire.* Graduate School of Environmental Science, Monash University, Melbourne. pp.107-128.

Tap, P. and Whelan, R.J. (1984). The effect of fire on populations of heathland invertebrates. In: Dell, B. (Ed.) *Medecos IV.* Proceedings of the Fourth International Conference on Mediterranean Ecosystems. University of Western Australia. pp. 147-148.

Westman, W.E. (1986). Resilience: concepts and measures. In: Dell, B., Hopkins, A.J.M. and Lamont, B.B. (Eds.) *Resilience in Mediterranean-Type Ecosystems.* Dr W. Junk Publishers, Dordrecht. pp. 5-19.

Whelan, R.J., Langdyk, W. and Pashby, A.S. (1980). The effects of wildfire on arthropod populations in jarrah-*Banksia* woodland. *Western Australian Naturalist* **14**, 214-220.