Department of
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Environment

Ecological effects of repeated low-intensity fire on the invertebrates of a mixed eucalypt foothill forest in south-eastern Australia

Research report no. 61

Effects of repeated low-intensity fire on the invertebrates of a mixed eucalypt foothill forest in south-eastern Australia

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Cover photographs 1. After low-intensity burn, DSE/K.Tolhurst 2. Invertebrate sampling, DSE/K.Tolhurst

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Foreword

The vegetation, topography and climate of south-eastern Australia combine to make the region one of the most wildfire-prone areas on Earth. Over tens of thousands of years, naturally occurring fires have been highly significant in shaping the distribution and composition of much of the region's native flora and fauna. The arrival of humans here is also considered to have had a more recent influence on these evolutionary processes. Paradoxically, it has been estimated that, in the last one hundred years, two-thirds of all human deaths related to bushfires in Australia and more than half of all significant related property losses have occurred in Victoria.

The severity of a bushfire depends on topography, weather and fuel conditions. Fuel is the only factor over which a land manager can exert some control. The strategic use of prescribed fire (under specified environmental and fire behaviour prescriptions), generally in spring or autumn, is the only practical method of reducing fuels over significant areas and has been a key component of park and forest management in Victoria since the late 1950s – early 1960s.

The threat posed by fire to life and property and the relationship between fire regimes and biodiversity are arguably the key on-going issues confronting the managers of Victoria's parks and forests.

In 1984, a multidisciplinary study was established in the Wombat State Forest, 80 km north-west of Melbourne (Victoria), to investigate the effects of repeated low-intensity prescribed burning in mixed eucalypt foothill forest. The study—the Wombat Fire Effects Study—is quantitative and statistically based and includes various aspects of fauna, flora, soils, tree growth, fuel management and fire behaviour.

On the same permanent plots, various methodologies are used to investigate the ecological impacts of fire on understorey flora, invertebrates, birds, bats, reptiles, terrestrial mammals, soil chemistry and the growth, bark thickness and defect development in trees. Local climate and weather, fuel dynamics and fire behaviour are also studied, along with their interactions. Numerous published papers and reports have been produced as a result of the work. Fire Management Research Reports comprising the current (2003) series are:

No. Title

57. Ecological effects of repeated low-intensity fire in a mixed eucalypt foothill forest in south-eastern Australia - Summary report (1984–1999) - Department of Sustainability and Environment
58. Effects of repeated low-intensity fire on the understorey of a mixed eucalypt foothill forest in south-eastern Australia - K.G. Tolhurst
59. Effects of repeated low-intensity fire on fuel dynamics in a mixed eucalypt foothill forest in south-eastern Australia - K.G. Tolhurst & N. Kelly
60. Effects of repeated low-intensity fire on carbon, nitrogen and phosphorus in the soils of a mixed eucalypt foothill forest in south-eastern Australia - P. Hopmans
61. Effects of repeated low-intensity fire on the invertebrates of a mixed eucalypt foothill forest in south-eastern Australia - N. Collett & F. Neumann
62. Effects of repeated low-intensity fire on bird abundance in a mixed eucalypt foothill forest in south-eastern Australia - R. Loyn, R. Cunningham & C. Donnelly
63. Effects of repeated low-intensity fire on terrestrial mammal populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, M. Westbrooke & M. Gibson
64. Effects of repeated low-intensity fire on insectivorous bat populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, P. Prevett & M. Westbrooke

65. Effects of repeated low-intensity fire on reptile populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, M. Westbrooke & M. Gibson
66. Effects of repeated low-intensity fire on tree growth and bark in a mixed eucalypt foothill forest in south-eastern Australia - K. Chatto, T. Bell & J. Kellas

The foreword to the summary report (Fire Management *Research Report* No. 57) sets out more fully the background to the research, the impact it has had on fire management in the State and the future of the program.

I would like to acknowledge the very considerable efforts of the scientists and technical officers who have contributed to this specific report and more generally to this most significant project.

Gary Morgan AFSM

CHIEF FIRE OFFICER
Department of Sustainability and Environment

2003

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Summary

The effects of short- and long-rotation burning in spring and autumn on surface-active invertebrates were studied in mixed eucalypt foothill forest in west-central Victoria between 1985 and 1999. The prescribed fires were of low-intensity (<500 kW m^{-1}). The 14-year study was based on many tens of thousands of arthropod specimens, representing 36 ordinal or lower level taxa contained in pitfall trap samples from a range of short- and long-term spring and autumn treatment areas and an unburnt control treatment area within the Blakeville Fire Effects Study Area in west-central Victoria.

There appears to be no effect of prescribed fires on surface-active invertebrates in the short and long term on spring burnt treatment areas, and in the short term on autumn-burnt treatment areas. However, significant increases in total taxa activity late in the study, primarily as a result of increases in activity of the groups: ‘total non-insects’, Acarina (mites) and Formicidae (ants) were observed in the longer term (over 14 years) on autumn-burnt treatment areas. Conversely, a decrease in activity of the Dermaptera (earwigs) was recorded, while the situation for the Collembola (springtails) and Diptera (flies) is less certain as changes in activity occurred on both the autumn burnt and the unburnt (control) treatment areas. However, as no significant change in activity was observed in the short term (i.e. in the period immediately before and after fire) for any of the aforementioned taxa, it cannot be stated for certain that the changes in activity following the second fire were due to fire or other environmental effects.

As this study was conducted to ordinal and sub-ordinal level only for most taxa, it is uncertain whether the results are applicable to a range of species within ordinal groups, or whether there is species-specific variation to the different fire treatments. Initial studies conducted to family and species level for Coleoptera (beetles) indicated some species groups underwent short-term changes in activity before soon returning to pre-fire levels. Further study is required to address this issue more fully for other ordinal/sub-ordinal groups.

Introduction

Detailed studies of the effects of fire on Australian invertebrates over a prolonged period of time remain relatively rare. This impacts significantly on the abilities of land managers to develop sustainable strategies that conserve the invertebrate fauna as well as satisfy other management objectives. This report presents the effects of various prescribed fire regimes (in spring or autumn; single or multiple fires; short or long rotation) on invertebrates sampled in the same forest over the 14-year period: 1985–99.

Arthropods that frequent the soil layer are especially vulnerable to ground fires that destroy their habitats and desiccate upper soil layers. Earthworms (Annelida) require a continuous film of moisture over their permeable outer skin (cuticle) for respiratory exchange (Lee 1983) and are therefore highly fire-sensitive due to their intolerance to ambient temperatures above 25 ºC (Reynolds 1973) and to low moisture levels in the litter/upper soil horizons.

Humus/litter and upper soil horizons provide temporary or permanent habitats for a diverse range of invertebrate macrofauna (> 10 mm in length) and mesofauna (0.1–10 mm). These invertebrates, together with microbes (< 0.1 mm), perform essential ecological functions, such as regulating the decomposition of organic matter, recycling of nutrients, aerating the soil and facilitating biological control among invertebrate populations (Crossley 1977; Greenslade & Greenslade 1983; Spain & Hutson 1983).

Low-intensity prescribed fires are designed to provide barriers of low fuel hazard that reduce the frequency, rate of spread and intensity of wildfires which, in turn, reduce the associated damage to forest ecosystems and their biological diversity (Johnston et al. 1983; Rawson et al. 1983; Department of Conservation, Forests and Lands 1986; Greig 1986; Department of Primary Industries and Energy 1990; McCarthy et al. 1998). Prescribed fires have been used in Victoria since the 1920s, but the extent of the burning increased significantly in the early 1960s. Concerns that such operational practices may induce adverse side-effects on the physical, biotic and aesthetic attributes of forest ecosystems (Springett l976; —1979; Warcup 1981), coupled with the lessons of the devastating aftermath of the 'Ash Wednesday' wildfires in February 1983, led to the initiation in 1984 of a long-term multidisciplinary study by the then Forests Commission Victoria (now Department of Sustainability and Environment) in typical mixed eucalypt foothill forest. The objectives were to: (i) assess short- and long-term impacts of high- and low-frequency prescribed fire regimes on flora, fauna, soil chemistry and fuel loads; and (ii) fine-tune management practices in order to minimise any adverse effects resulting from fuel reduction burning activity.

Methods

Treatment areas

The Blakeville (37°31'S, 144°10'E) Fire Effects Study Area (FESA) is located in a mixed eucalypt foothill forest in the Wombat State Forest, approximately 18 km south of Daylesford in west-central Victoria. Its topography is gently undulating, aspect predominantly south-westerly, elevation 625–700 m above sea level and average annual rainfall 905 mm. It is one of five FESAs established in the forest. Each FESA comprises five adjacent fire treatment areas: an unburnt control (C), short-rotation autumn burn (A3), long-rotation autumn burn (A10), short-rotation spring burn (S3) and a long-rotation spring burn (S10). The short-rotation autumn and short-rotation spring burn treatment sites were burnt approximately every three years, and the long-rotation autumn and long-rotation spring treatment sites were burnt approximately every ten years. The unburnt control treatment remained unburnt throughout the study. The fires were lit using handheld driptorches.

At the beginning of sampling surface-active arthropods in 1985, none of the treatment areas had been burned since 1935, and the mean depth of surface fuel (humus, litter and twigs of < 26 mm in diameter) on the forest floor was around 36 mm (n = 100). The projective foliage cover of the overstorey and understorey were approximately 66% and 35% respectively. The vegetation was similar across all areas, with a total of 110 plant species being recorded (Neumann & Tolhurst 1991). The overstorey trees were about 100 years old, originating from regeneration following timber harvesting during the gold-mining era. Some thinning to remove trees of low commercial value had been carried out during 1961 and 1964. In 1985 the basal area of the overstorey was 25.8 m^2 ha^{-1} and of the regrowth understorey was 7.8 m^2 ha^{-1} (Tolhurst & Flinn 1992). The overstorey, 35 m tall, was dominated by Messmate Stringybark (*Eucalyptus obliqua* L'Herit), Narrow-leaved Peppermint (*E. radiata* Sieber ex DC) and Candlebark (*E. rubida* M. Deane & Maiden). The understorey was generally <2 m tall and composed mainly of Silver Wattle (*Acacia dealbata* Link.), Hop Wattle (*A. stricta* (Andr.) Willd.), Austral Bracken (*Pteridium esculentum* (Forst. F.) Cockayne), Forest Wire-grass (*Tetrarrhena juncea* R. Br.), tussock grass (*Poa sieberiana* Sprengel), wallaby grasses (*Danthonia* spp.), Common Raspwort (*Gonocarpus tetragynus* Labill.) and Ivy-leaf Violet (*Viola hederacea* Labill.). The nomenclature of these species is based on Forbes and Ross (1988).

Arthropod sampling and analysis

Arthropods were sampled contemporaneously between 1985 and 1999 within a one-hectare permanent plot at each of the five burning treatments. Twenty pitfall traps were positioned at 5-m intervals along a fixed 100-m transect through the centre of each plot.

Each trap consisted of a test tube 18 mm in diameter in a PVC sleeve (providing a 2.5 cm^2 receptive surface area), half filled with 75% methanol. The 18 mm diameter proved to be effective in preventing overflow of the traps during rainstorms, yet it did not appear to exclude the larger arthropods such as the Malacostraca (Decapoda)—land crayfish—and some of the larger families of Coleoptera (beetles). Effects of digging-in the traps were minimised by commencing sampling two weeks after positioning them. Arthropod activity was measured as the number of individuals trapped per composite sample of 20 pitfall traps at the litter surface over a seven-day period.

Pitfall trapping estimates the relative population levels of surface-active invertebrates and, thereby, measures their relative importance on the forest floor (Greenslade 1964; —1973; Greenslade & Greenslade 1971; Majer 1978). The technique is therefore considered appropriate for this study, which uses sampling over time to assess the effects of low-intensity repeated prescribed fires on epigeal invertebrates. Limitations in sampling technique would apply equally to all burning treatments because sampling was done contemporaneously at adjacent sites of similar age, aspect, elevation, vegetation and wildfire/logging history, thereby minimising the effects of variable weather conditions and site characteristics on arthropod activity.

The trapped arthropod specimens were classified into ordinal, sub-ordinal and some family and species groups for the Coleoptera (Manton 1977; Harvey & Yen 1989; Lawrence & Britton 1994) and counted. As the range and activity of arthropod taxa often varied substantially between the 20 traps within each site, each set of 20 contemporaneous trap collections was pooled into a composite sample.

For the unburnt control area, the mean annual activity between 1985 and 1999 of total arthropods, total non-insect arthropods, total insects and seven other arthropod categories was calculated from the 11–13 available composite samples per year; differences between years were tested by analysis of variance (ANOVA) after $\log_{10}(x + 1)$ transformations of the raw data to account for any zeros in the data base. The differences between the means of seasonal activity among these arthropod categories between 1985 and 1999 at the control were similarly tested.

The effects of the fires on surface-active arthropods were assessed using a BACI design (Stewart-Oaten et al. 1986), which is an appropriate way to treat data of a two-sites (control/impact) and several times' study (Green 1993). Comparisons made in the study were: (i) the set of differences between contemporaneous observations at both the autumn and spring burnt and control areas before and after the first, and after the second consecutive fires; and (ii) the corresponding sets for the periods between the fires and after the second fire.

Various arthropod parameters were tested using the Mann-Whitney non-parametric two-sample U-test (Zar 1999). The use of differences eliminated the effects of site factors and seasonality and strengthened the validity of the assumption in the Mann-Whitney test that consecutive observations are independent. Parameters examined in the comparison were: (i) the Shannon-Wiener diversity index (Poole 1974); the Margalef taxon richness index (Southwood 1978); and Pielou's community evenness index (Pielou 1966) for total arthropod taxa; and (ii) activity at the soil surface of total arthropods, total non-insect arthropods and total insects as well as seven other arthropod categories. Although the three ecological indices tested have certain limitations (Hurlbert 1971), they were considered appropriate here because sampling was relative over time, restricted to adjacent sites in the same forest type and not aimed at a complete census of the epigeal arthropod community. To determine the fire effects on taxon richness among total arthropods, two-dimensional χ^2-analyses were performed on the total number of taxa recorded before and after each fire at the burnt and unburnt (control) areas (2 x 2 contingency tables). Also, three-dimensional χ^2-tests (3 x 2 x 3 contingency tables) were carried out to test for mutual independence between the variables: (i) taxon frequency within selected arthropod categories; (ii) the control and burnt treatments; and (iii) the fire treatments at the burnt areas (Zar 1999).

Results

A total of 36 ordinal or lower-level arthropod taxa were identified among the tens of thousands of specimens collected during the course of the study. These represented the classes Arachnida (arachnids), Malacostraca (crustaceans), Chilopoda (centipedes), Diplopoda (millipedes), Symphyla (symphlans), Collembola (springtails), Protura (proturans), Diplura (diplurans) and Insecta (insects). The feeding types of predators, decomposers, herbivores, sapfeeders, omnivores, parasitoids and seed feeders were all well represented in the litter surface of each burning treatment (Table 1). The most commonly trapped taxa were the Coleoptera (beetles), Diptera (flies), Formicidae (ants), Araneae (spiders), Acarina (mites) and Collembola (springtails) and are referred to as the 'major' taxa to distinguish them from the less-commonly trapped 'minor' taxa.

The specimens were collected in pitfall traps recovered from the four fire-treated areas and one unburnt control treatment within the Blakeville FESA. Because of the size of the task, intensive sampling was confined to a single FESA, and thus replication of the study in adjacent forest of a similar type did not occur (Neumann & Tolhurst 1991; Collett et al. 1993; Collett 1998; —2003). However, control treatments at other FESAs in the Wombat State Forest were sampled early in the study to confirm that invertebrate populations at Blakeville were representative of those present across all study areas. Despite this limitation, the results obtained allowed some specific trends to be observed, and are detailed in the following section.

Table 1 Taxa of litter arthropods trapped in the mixed eucalypt foothill forest

	Taxon	Feeding type
Arachnida	Scorpionida (scorpions)	Predators
	Araneae (spiders)	Predators
	Pseudoscorpionida (pseudoscorpions)	Predators
	Opilionida (harvestmen)	Predators
	Acarina (mites)	Predators/decomposers
Malacostraca	Amphipoda (landhoppers)	Decomposers
	Isopoda (woodlice)	Decomposers
Chilopoda	Geophilida (earth centipedes)	Predators
	Lithobiida (lithobiid centipedes)	Predators
	Scolopendrida (scolopendrid centipedes)	Predators
	Scutigerida (house centipedes)	Predators
Diplopoda	Polydesmida (polydesmid millipedes)	Decomposers
Symphyla	(symphylans)	Decomposers
Collembola	Collembola (springtails)	Decomposers
Protura	(proturans)	Decomposers
Diplura	(diplurans)	Herbivores/predators
Insecta	Thysanura (silverfish, bristletails)	Omnivores
	Blattodea (cockroaches)	Omnivores
	Isoptera (termites)	Decomposers
	Mantodea (mantids)	Predators
	Dermaptera (earwigs)	Predators
	Orthoptera-Tettigoniidae (long-horned grasshoppers)	Herbivores
	Orthoptera – Acrididae (short-horned grasshoppers)	Herbivores
	Pscocoptera (psocids)	Decomposers
	Homoptera (aphids, leafhoppers, scale insects)	Sapfeeders
	Heteroptera (true bugs)	Sapfeeders/predators
	Thysanoptera (thrips)	Herbivores
	Neuroptera (lace wings)	Predators
	Coleoptera (beetles)	Various
	Siphonaptera (fleas)	Parasitoids
	Diptera (flies)	Various
	Trichoptera (caddis flies)	Predators
	Lepidoptera (month, butterflies)	Herbivores
	Lepidoptera-Coleophoridae (case-bearers)	Herbivores
	Hymenoptera-Formicidae (ants)	Sap/seed feeders
	Hymenoptera-Aprocrita (wasps)	Parasitoids/predators

Effects of a single spring and autumn burn

Neumann and Tolhurst (1991) found that, after a single spring burn, Collembola, Diptera and earthworm populations temporarily declined, as did Collembola populations after a single autumn fire, although Collembola and Diptera populations recovered within one year and earthworms within three years. It was observed that fine fuel loads accumulated more rapidly in the first year after the spring fire compared with the autumn fire, although, in the subsequent two years after fire, fine fuel loads rose fairly evenly at both treatment areas. These results suggested that the spring burn and, to a lesser extent, the autumn burn induced a short-term decline in the decomposer cycle, especially as the Collembola, larval Diptera and earthworms are important components among decomposers in the forest litter (Greenslade & Greenslade 1983; Spain & Hutson 1983). It was concluded that the effects of a single spring fire coupled with the desiccating conditions of the subsequent summer period impacted more adversely on earthworms than an autumn fire, which is a period of naturally low activity coupled with the cool and wet conditions in the following winter. With respect to Coleoptera alone, detailed studies by Neumann et al. (1995) to family and species level found that a single spring fire caused short bursts of increased activity among the family groups Staphylinidae and Leiodidae, and the fungus-feeding nitidulid species *Thalycrodes pulchrum* immediately following fire, although activity of these groups soon returned to pre-fire levels.

A marked decline in activity of Collembola on both the autumn burnt and unburnt control areas during dry conditions persisting from December 1987 to April 1988, suggesting that this important decomposer taxon is very sensitive to moisture levels within the litter layer. Fuel reduction burning during protracted drought periods is therefore likely to impact adversely on already disrupted populations of Collembola. For similar reasons, it is likely that such conditions would also impact on earthworm and larval Diptera populations.

A moderate boost to Formicidae populations was recorded after a single spring burn. This may reflect either: (i) increased activity of existing populations due to drastic changes in microclimate at the litter surface and to greater food availability; or, (ii) an increase in trapping efficiency as a result of the simplification of the habitat and a widening of the foraging range (Majer 1980; Andersen & Yen 1985; Andersen 1988). The autumn burn did not enhance ant activity, and it is hypothesised that this was due to the cooler conditions following the fire confining many ants to their nests. This hypothesis requires further investigation. The moderate interactions between low-intensity fire and ants in foothill forest are in marked contrast to the massive increase in populations of the seed-feeding ant *Prolasius pallidus* Clark (Formicinae) observed in response to high-intensity wildfire in mature Mountain Ash *(E.regnans* F. Muell.) forest in the Victorian Central Highlands in 1983 (Neumann 1991).

Effects of two short-rotation burns in spring

After each of two short-rotation spring burns, Collett et al. (1993) found activity levels for both Collembola and earthworm populations to be significantly depressed, although population levels did recover within three years. Campbell and Tanton (1981) made similar observations. Declines in activity were accompanied by a marked decline in fine fuel loads immediately after each burn, as observed by Neumann and Tolhurst (1991) after a single spring fire. The prolonged period required by earthworm populations to recover to pre-burn levels after short-rotation spring burns suggests that spring burns, coupled with the dry, warm conditions of the subsequent post-burn summer period, impact adversely on earthworm activity (Neumann & Tolhurst 1991). This situation is likely to be exacerbated during protracted drought periods that impose severe soil moisture stress in these forests. In addition to loss of litter habitat, the large difference in surface soil temperature between the first and second burn (161 ºC compared with 403 ºC respectively) may have caused earthworm levels to be severely depressed over an 18-month period after the second fire compared to only 10 months after the first fire.

Coleoptera activity levels were lower after the second spring burn compared to the first burn, which may indicate that repeated fuel reduction burning at close intervals has a debilitating effect on this order. This finding was examined in more detail by Collett and Neumann (1995), who found two spring fires caused the Coleopteran family Staphylinidae to decline after the second fire. However, as Coleopteran activity in the unburnt control generally declined to low levels during the summer after the second burn, it is likely that the observed decline was due to 'other environmental factors', rather than to the effects of the burn. Diptera activity was also depressed after the first burn, but not after the second, indicating factors other than burning may also have affected their activity levels.

Formicidae activity followed a consistent pattern of peaks during warm periods of the year and troughs during cool periods at both the control and burnt areas. Moderate increases in ant activity occurred after both burns, but populations quickly returned to pre-burn levels. Again, these moderate short-term increases of ant numbers within foothill forest in response to low-intensity prescribed burns in spring are in marked contrast to the very substantial boosts in Formicidae activity following a high-intensity wildfire in 54-year-old Mountain Ash regrowth forest in the Victorian Central Highlands in 1983 (Neumann 1991; —1992).

Effects of two short-rotation burns in autumn

Collett (1998) found that the results of the two- and three-dimensional χ^2 tests performed on the pre- and post-fire collections of the arthropod taxa at the control and burnt areas provided good indications of the effects of fire on taxon richness. As the null hypothesis of a nil effect was accepted in all of these tests, it appears that neither the burns on their own, nor their cumulative effect, had significantly altered the profiles of the arthropod taxa. This conclusion was supported by the non-significant results of the Mann-Whitney U-tests on pre- and post-fire data sets based on the total arthropod taxa for the Margalef taxon richness and Pielou community evenness indices and also for the general Shannon-Wiener diversity index. The results presented by Neumann and Tolhurst (1991), which also indicated no significant differences for total arthropods before and after a single autumn fire for the aforementioned three population indices, are also in line with the above conclusion.

No significant change in activity was observed among total insects, Araneae, Coleoptera and Diptera throughout the 1986–94 study period. This indicated that, despite the application of two low-intensity burns in autumn within the 7.8-year period, the activity of these taxa remained unchanged. Insects therefore appear to form a fire-stable part of the litter fauna of foothill forests. However, when the pre-burn period was compared to the between-burns period, a significant decrease in activity was detected among total arthropod taxa and total non-insects, primarily as a result of a significant concomitant drop in activity of the Collembola (Figure 1). A similar result was observed when the pre-burn period was compared with the post-second burn period (i.e. the total taxa and non-insects decreased significantly as a result of a decrease in activity among Collembola and, to a lesser extent, Acarina). These results on Collembola confirm findings by Neumann and Tolhurst (1991) who noted that Collembolan activity significantly decreased following a single autumn low-intensity prescribed burn, most probably due to the fire temporarily eliminating leaf litter, reducing high humidity habitats and exposing the Collembola to desiccation.

Comparing the between-burns period with the post-second burn period showed no significant change in activity among total arthropod taxa, non-insects and Collembola. This suggests that a second prescribed fire within five years may not necessarily impact adversely on these broad arthropod categories, unless other significant events, such as a protracted drought, supervene. However, the second autumn burn was less intense than the first, indicating that sufficient litter cover may have remained, allowing the Collembola to remain relatively unaffected.

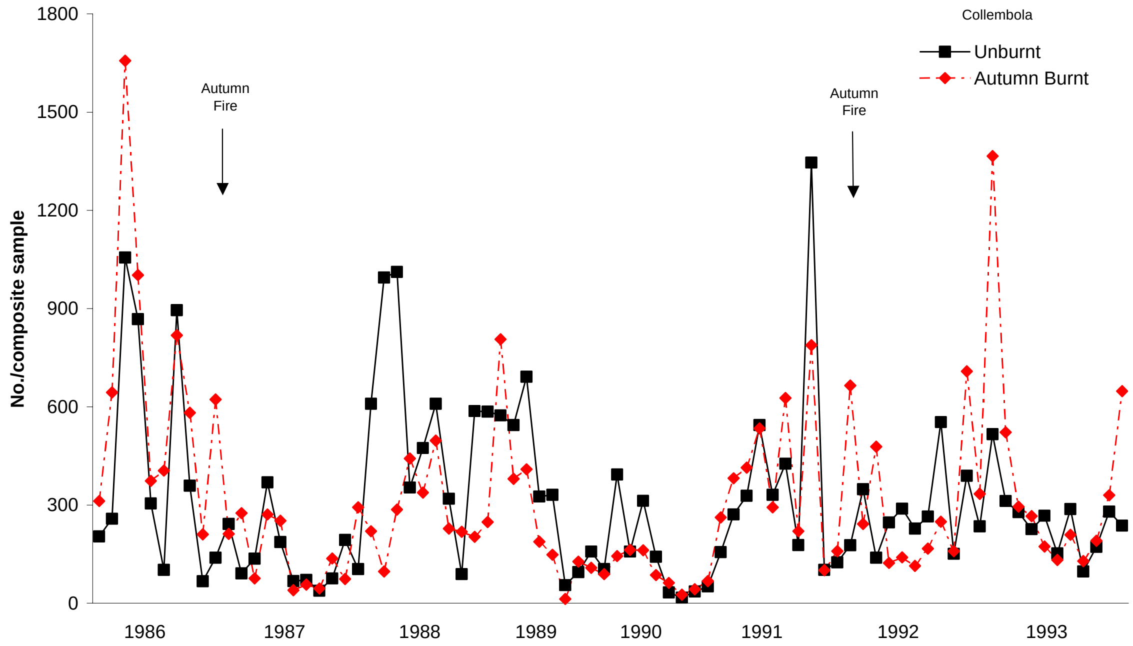

Figure 1 Temporal variations in monthly activity of Collembola from April 1986 to February 1994 at the litter surface of the Control Treatment Area and of that burnt in March 1987 and March 1992 (Collett 1998)

A significant increase in ant activity during the post-second burn period was predominantly due to increased activity in the second summer after the second burn. It is uncertain whether this observed boost in ant activity reflected: (i) increased activity of existing populations due to changes in the microclimate at the litter surface; (ii) greater food availability; or (iii) an increase in trapping efficiency resulting from the simplification of the fire-affected habitat and a widening of the foraging range (Majer 1980; Andersen & Yen 1985; Andersen 1988; Neumann & Tolhurst 1991). However, as no such boost in activity occurred among the Formicidae after the first burn, its seems probable that the rise in activity following the second fire was more likely due to some environmental variable other than fire (Collett et al. 1993). The decrease in activity levels of Dermaptera following the second burn coincided with a decrease in activity on the control area, indicating that the decrease may have occurred as a result of some variable other than fire.

Effects of three short-rotation burns in spring

Strong seasonal trends among the major arthropod groups in the unburnt control were identified (Collett et al. 1993; Collett 1998; —1999). This highlights the need for contemporaneous sampling to achieve valid comparisons in such work. Differences between sampling times associated with pre- and post-burn periods (e.g. post-1985 – pre-1988 and post-1988 – pre-1991 are both three-year periods compared to the one-year pre-burn periods) does not imply that an increase in taxon richness had occurred as a result of the burning. The results of the two- and three-dimensional χ^2tests performed on the pre- and post-burn collections of the arthropod taxa at the burnt and control areas showed that a null hypothesis (or 'nil effect') was accepted throughout. This indicates that none of the burns in isolation, nor their cumulative effects, had significantly changed the profiles of the arthropod taxa. This conclusion is supported by both the non-significant results of the Mann Whitney U-test on the Margalef taxon richness community index and the non-significant results of the Mann-Whitney U-tests on pre- and post-burn data sets for activities of total taxa, total non-insects, Araneae, Acarina, Collembola, total insects and Formicidae. All of these tests indicate that three consecutive spring burns have no effect on either taxon richness or activity of the major arthropod groups.

The lack of significant change in activity observed among total taxa, total non- insects, Araneae, Acarina, Collembola, total insects and Formicidae indicated that, despite the application of three prescribed low-intensity spring burns within the 8.6-year period (1985–93), their activity remained unchanged and therefore appear to form a fire-stable part of the litter fauna in foothill forests. Similar stability in arthropod populations was reported after a single and two consecutive spring burns (Neumann & Tolhurst 1991; Collett et al. 1993). However, despite the indications of an apparent 'nil effect' of the three consecutive fires on the litter fauna, the data indicates a significant increase in the Shannon-Wiener general diversity index as a result of significant increases in the Pielou community evenness index. Screening of the data suggested that these trends were due primarily to a marked decline in Coleopteran activity between the pre-burn periods and the post-1988 – pre-1991 and post-1991 burn periods, as well as between the post-1985 – pre-1988 burn period and the post-1988 – pre-1991 and post-1991 burn periods. Collett and Neumann (1995) noted a similar decline in Coleopteran activity following a second spring fire and identified the Staphylinidae, the largest group of all the Coleopteran families found at the study area, to be the cause. It was also observed that the reduction in Coleoptera— or, more specifically, in Staphylinid— activity, in response to spring fires, occurred evenly over the species' range. It is therefore likely that a similar trend may have applied after the three spring burns, although this has yet to be fully investigated.

However, as Coleopteran activity also declined at the control area during the periods following the second and third burns, it is uncertain whether the observed drop in activity was due to the burns rather than other environmental factors. For example, Coleopteran activity prior to the 1985 fire was similar to the post-1985 – pre-1988 fire period, and activity for the post-1988 – pre-1991 fire period was also comparable to the post-1991 fire period. Similarly, the significant increases in Dipteran activity in the periods after the second and third fires were also probably not fire-related due to a concomitant reduction at the control area. Such non-fire related factors may have included changes in the microclimate at the litter layer, greater availability in food or breeding habitat or simplification of the habitat due to the removal of surface fuel by burning which allowed for greater trapping efficiency (Majer 1980; Andersen 1988; Andersen & Yen 1985; Neumann & Tolhurst 1991; Collett 1998).

Effects of long-term rotation burning over ten years in spring and autumn

Of the taxa that recovered during the study on the long-term rotation treatment areas, only the Formicidae (ants) appeared to be sensitive to low-intensity burning, as shown by the increase in activity at the autumn-burnt area and, to a lesser extent, at the spring-burnt area, in the post-second fire period, without corresponding increases at the control. As the ants were not identified to species level, it is still uncertain whether the observed increase in activity was due to a single species or a range of species (Collett 2003).

The first prescribed burns in both spring and autumn produced different responses among the Formicidae than second spring and autumn burns, probably due to a much smaller reduction in fine fuel loads in the latter round of fires (Figure 2). Lower fine fuel loads at the treatment areas following the second post-spring–autumn fires may have created a more favourable microclimate for ant activity on the forest floor and possibly widened the foraging range and consequently increased food availability. The detected different responses may also be due in part to an increase in trapping efficiency resulting from the simplification of the fire-affected habitat (Majer 1980; Andersen 1988; Andersen & Yen 1985; Neumann & Tolhurst 1991; Collett 1998).

Pitfall trapping

The broad taxonomic approach generally adopted throughout the study assumed that the findings for individual arthropod taxa gave a cumulative estimate of the responses of the species within each of the larger taxa groups (Neumann & Tolhurst 1991). Sampling of arthropods was largely restricted to the litter surface and to pitfall trapping. While pitfall trapping is an excellent method for sampling certain taxa such as Coleoptera and Formicidae, it may not be appropriate for sampling taxa such as Pseudoscorpionida, Isopoda, Chilopoda, Diplura, Thysanura, Neuroptera, Isoptera, Lepidoptera and Mantodea (Neumann & Tolhurst 1991; Collett 1998; —1999; —2003) that may either occupy ecological niches other than forest litter, or may not be suited for sampling using the pitfall trap method (Collett et al. 1993; Collett 1999; —2003).

Strong seasonal trends were identified among the major arthropod taxa collected, thereby strengthening the assertion by Stewart-Oaten et al. (1986), Collett and Neumann (1995), Neumann et al. (1995) and Collett (1998) that sampling for fire effects on taxon richness should ideally be done contemporaneously to achieve valid comparisons between burnt and control areas (Neumann et al. 1995). Ideally, similar lengths of time for collection should also be applied. For example, in this study, situations arose when the between-burns period may have corresponded to approximately five years of sampling compared to a single year of pre-burn sampling and two years of sampling after the second burn period. Thus, the higher taxon totals recorded for the between-burns period did not necessarily imply that a substantial increase in taxon richness had occurred as a result of the first fire (Collett 1998).

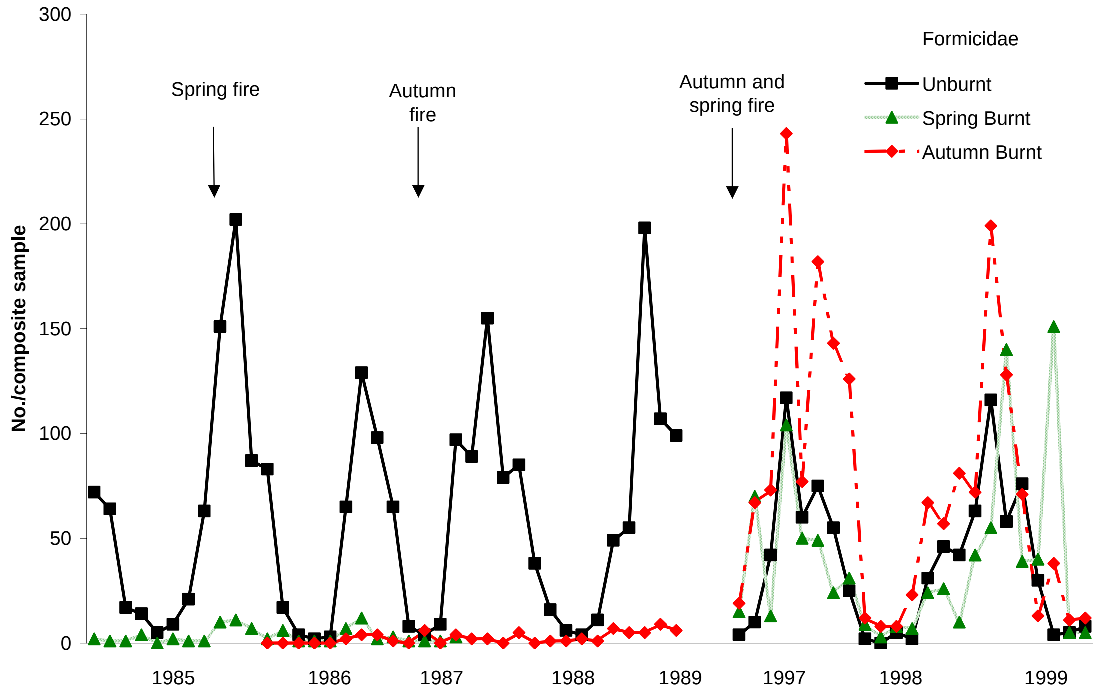

Figure 2 Temporal variations in monthly activity of Formicidae from March 1985 to February 1999 at the Control Treatment Area, from March 1985 to November 1987 at the spring burnt Treatment Area, from April 1986 to February 1989 at the autumn burnt Treatment Area, and at all three Treatment Areas from August 1997 to July 1999 (Collett 2003).

Conclusions

Neumann and Tolhurst (1991) determined that no changes in activity or abundance among invertebrates occurred following a single low-intensity prescribed burn in spring or autumn, with Collembola and Diptera populations recovering to pre-burn levels within one year and earthworms within three years.

Collett et al. (1993) found that two low-intensity prescribed spring burns within three years of each other affected Collembola and earthworm populations, although Collembola activity levels also declined at the control area; indicating there may have been other environmental factors apart from burning responsible for the decline. This compares to studies examining the effects of two short-rotation prescribed fires in autumn which found that two consecutive fires in autumn appear to have minimal effect on the activity of major arthropod groups in the forest litter layer (Collett 1998). It was recommended that any scheduled fuel reduction or low-intensity burning be done outside protracted drought periods and at intervals exceeding three years for spring burns and five years in the case of autumn burns. The intervals at which the burns were conducted during both studies formed the basis for the period of time recommended in each season. Further studies in autumn with burning conducted at shorter intervals will assist determining whether this five-year period between autumn burning could be reduced further.

It appears that three low-intensity prescribed spring burns within eight years has minimal impact on litter arthropods in mixed eucalypt foothill forest, although the effect of short-term rotational burns on the abundance of Coleoptera and Diptera is less clear due to the significant change in activity levels also observed in the control areas (Collett 1999). Burning in autumn is not considered to be any more beneficial than burning in spring as activity of both Coleoptera and Diptera was found to be similar after both autumn and spring burning periods. Notwithstanding the above, it is recommended that any fuel reduction burning in spring should be conducted at intervals of no less than three years to enable minimal impact on litter arthropods. When a period of drought has intervened, the following fuel reduction fire should be further delayed until the drought period has ended.

The effects of fire in the longer term (i.e. at intervals of ten years or greater in spring and autumn) require further study, especially in relation to the Formicidae in spring, which recorded increases in activity following the second round of fires. However, as these increases were not observed after the first fire, other factors, such as site factors and fuel loads, may be responsible; this requires follow-up examination (Collett 2003).

Neumann and Tolhurst (1991) found that the litter/upper soil fauna populations sampled in foothill forest appear to be 'fire-stable' when subjected to occasional low-intensity ground fire. This attribute would appear essential for forest types in which the risk of fire is high between summer and mid-autumn. However, the responses of individual species, as distinct from the broader ordinal and sub-ordinal taxa examined, to the effects of high-frequency burning requires further study. Such studies have already been conducted for Coleoptera to species level by Collett and Neumann (1995) and Neumann et al. (1995), who observed that some species enjoyed short bursts of increased activity following fire before subsequently returning to pre-fire activity levels. Future studies should examine major groups such as the Collembola that play a major role in the nutrient cycling of forest ecosystems.

References

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.

Andersen, A.N. and Yen, A.L. (1985) Immediate effects of fire on ants in the mallee of north-western Victoria. *Australian Journal of Ecology*. **10**: 25–30.

Campbell, A.J. and Tanton, M.T. (1981) Effects of fire on the invertebrate fauna of soil and litter of a eucalypt forest. **In**: A.M. Gill, R.H. Groves and I.R. Noble (Eds). *Fire and the Australian Biota*. Australian Academy of Science. Canberra. pp.216–241.

Collett, N.G. (1998) Effects of two short rotation prescribed fires in autumn on surface-active arthropods in dry sclerophyll eucalypt forest of west-central Victoria. *Forest Ecology and Management*. **107**: 253–273.

Collett, N.G. (1999) Effects of three short rotation prescribed fires in spring on surface-active arthropods in dry sclerophyll eucalypt forest of west-central Victoria. *Australian Forestry*. **62** (4): 295–306.

Collett, N.G. (2003) Short and long-term effects of prescribed fires in autumn and spring on surface-active arthropods in dry sclerophyll eucalypt forests of Victoria. *Forest Ecology and Management* (in press).

Collett, N.G. and Neumann, F.G. (1995) Effects of two spring prescribed fires on epigeal Coleoptera in dry sclerophyll forest in Victoria, Australia. *Forest Ecology and Management*. **76**: 69–85.

Collett, N.G., Neumann, F.G. and Tolhurst, K.G. (1993) Effects of two short rotation prescribed fires in spring on surface-active arthropods and earthworms in dry sclerophyll eucalypt forest of west-central Victoria. *Australian Forestry*. **56**: 49–60.

Crossley, D.A. (1977) The role of terrestrial saprophagous arthropods in forest solis: current status of concepts**. In**: *The Role of Arthropods in Forest Ecosystems* (ed. W.J. Mattson) pp. 49–56. Springer-Verlag, New York.

Department of Conservation, Forests and Lands, Victoria (1986) Policy on Fuel Reduction Burning, 8pp.

Department of Primary Industries and Energy (1990) Public Land Fire Management. Statement prepared by the Standing Committee of the Australian Forestry Council. Aust. Govt. Publishing Service, Canberra. 13 pp.

Forbes, S.J. and Ross, J.H. (1988) A census of the vascular plants of Victoria, 2nd edition. Department of Conservation, Forests and Lands, Victoria.

Green, R.H. (1993) Application of repeated measure designs in environmental impact and monitoring studies. *Aust. J. Ecol.* **18**, 81–98.

Greenslade, P. and Greenslade, P.G.M. (1971) The use of baits and preservatives in pitfall traps. *J. Aust. Entomol. Soc.* **10**, 253–260.

Greenslade, P.G.M. (1964) Pitfall trapping as a method for studying populations of Carabidae. *J. Anim. Ecol.* **33**, 301–310.

Greenslade, P.G.M. (1973) Sampling ants with pitfall traps: digging-in effects. *Insects Soc.* **20**, 343–353.

Greenslade, P.J.M. and Greenslade, P. (1983) Ecology of soil invertebrates. **In**: *Soils: An Australian Viewpoint*. Division of Soils. CSIRO. Melbourne/Academic Press. Melbourne. pp. 645–69.

Greig, P.J. (1986) Forest policy developments in Victoria. *Aust. For.* **49**, 197–202.

Harvey, M.S., and Yen, A.L. (1989) *Worms to Wasps: An Illustrated Guide to Australia's Terrestrial Invertebrates.* Oxford University Press, Melbourne, 201 pp.

Hurlbert, S.H. (1971) The non-concept of species diversity. A critique and alternative parameters. *Ecology* **52**, 577–586.

Johnston, J.B., McKittrick, D.J., Flinn, D.W. and Brown, H.G. (1983) Fire protection and fuel-reduction burning in Victoria. Report to the Minister of Forests by a task force of officers of the Forests Commission Victoria. 56 pp. + appendices.

Lawrence, J.F. and Britton, E.B. (1994). *Australian Beetles.* Melbourne University Press, Melbourne.

Lee, K.E. (1983) Soil animals and pedological processes. *In: Soils: An Australian Viewpoint,* pp. 629–44. Division of Soils, CSIRO, Melbourne/Academic Press, London.

Majer, J.D. (1978) An improved pitfall trap for sampling ants and other epigaeic invertebrates. *J. Aust. Entomol. Soc.* **17**, 261–262.

Majer, J.D. (1980) *Report on a study of invertebrates in relation to the Kojanup Nature Reserve Fire Management Plan.* Bulletin No. 2. Department of Biology. Western Australian Institute of Technology.

Manton, S.M. (1977) *The Arthropoda.* Oxford University Press, Oxford.

McCarthy, G.J., Tolhurst, K.G, and Chatto, K. (1998) Overall Fuel Hazard Guide. Department of Natural Resources and Environment, Melbourne.

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

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

Neumann, F.G. (1992) Responses of foraging ant populations to high-intensity wildfire, salvage logging and natural regeneration processes in *Eucalyptus regnans* regrowth forest of the Victorian Central Highlands. *Australian Forestry.* **55**: 29–38.

Neumann, F.G., Collett, N.G. and Tolhurst, K.G. (1995) Coleoptera in litter of dry sclerophyll eucalypt forest and the effects of low-intensity prescribed fire on their activity and composition in west-central Victoria. *Australian Forestry.* **58**: 83–98.

Pielou, E.C. (1966) The measurement of diversity in different types of biological collections. *J. Theor. Biol.,* **13**, 131–144.

Poole, R.W. (1974) *An Introduction to Quantitative Ecology.* McGraw-Hill, New York.

Rawson, R.P., Billing, P.R. and Duncan, S.F. (1983) The 1982–1983 forest fires in Victoria. *Aust. For.* **46**, 163–172.

Reynolds, J.W. (1973) Earthworm (Annelida: Oligochaeta) ecology and systematics. *Proceedings of the 1st Soil Microcommunities Conference,* Syracuse NY 1971 (ed. D.Dindal) pp. 95–120. USAEC, Office of Information Services

Southwood, T.R.E. (1978) *Ecological Methods, with Particular Reference to the Study of Insect Populations.* Methuen, London.

Spain, A.V. & Hutson, B.R. (1983) Dynamics and fauna of the litter layers. **In**: *Soils: An Australian Viewpoint.* Division of Soils. CSIRO. Melbourne/Academic Press. Melbourne. pp. 611–28.

Springett, J.A. (1976) The effects of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. *Aust. J. Ecol.* **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. *Aust. J. Ecol.* **4**, 279–291.

Stewart-Oaten, A., Murdoch, W.W. and Parker, K.R. (1986) Environmental impact assessment: 'pseduoreplication' in time? *Ecology*. **67**: 929–940.

Warcup, J.H. (1981) Effect of fire on the soil microflora and other non-vascular plants. **In**: A.M. Gill, R.H. Groves and I.R. Noble (Eds.), *Fire and the Australian Biota.* Australian Academy of Science, Canberra, pp. 203–214.

Zar, J.H. (1999) *Biostatistical Analysis.* Prentice Hall, London.