Effect of fire retardant on heathland invertebrate communities in Victoria

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Foreword

Fire retardants have been used around the World in forest fire suppression operations for more than thirty-five years, particularly in places such as North America and the southern Mediterranean. In Victoria and other Australian States fire retardants have been used for approximately thirty years.

Retardant is typically used to help control wildfires when access by ground crews is difficult or unsafe, or when there will be lengthy travel times for crews to arrive at the fire. Retardants restrict the spread of fire and enable firefighters to control the extent of the area burnt. In an average year, Victoria experiences more than 600 wildfires in its parks and forests. These wildfires burn about 110 000 hectares. Retardant is used to assist with suppression on about ten percent of these fires.

Many different fire retardants are available commercially, but not all have been subject to rigorous environmental and health studies. Victoria, in common with other land management agencies in Australia, has adopted a position of only using those fire retardants that have been subjected to lengthy testing and approval by the United States Department of Agriculture (USDA).

In 1998, the Department sought advice from Victoria's State Chemistry Laboratory following local community concerns about water quality following the extensive (32 000 ha) Caledonia wildfire in Gippsland in January 1998. The State Chemistry Laboratory advised that the claims of risk to public health were not scientifically well-founded. Subsequent investigations of water quality in the Macalister River by the local water authority found no evidence of contamination by fire retardants. There were, however, significantly increased levels of suspended sediments thought to be due to the extensive surface flows resulting from heavy thunderstorm activity after the fire.

To assist Victorian park and forest managers to better evaluate the wildfire control options available, the Department in 1999 commissioned the CSIRO Division of Forestry and Forest Products to assess the effectiveness and environmental risk associated with the use of retardants. The resultant report - *Assessment of the effectiveness and environment risk of the use of retardants to assist in wildfire control in Victoria* (DSE Fire Research Report No. 50, February 2000) - represented the most detailed examination of the subject in an Australian context.

The CSIRO report stated "We consider that the aerial application of long-term fire retardant which meets or exceeds the USDA Forest Service performance standard is essential for efficient fire fighting in the Victorian environment…"

The CSIRO review did, however, recommend that further research into the impact of the use of retardant on specific Australian ecosystems be conducted.

In response to the CSIRO findings, the Department further strengthened its management of the use of fire retardants. In addition, it set up a specific research program to examine the impact of long-term fire retardant on three elements of eastern Australian heathland communities, namely the vegetation, invertebrates and soils. This report derives from one of those studies.

More generally, Victoria's *Code of Practice for Fire Management on Public Land* sets out principles for environmental care that underpin all fire management activities. The application of chemicals in wildfire suppression does have some environmental impacts, as does the building of control lines (with either bulldozers or hand-tools) and backburning—but so too does uncontrolled wildfire. Managers of park and forest fires have to make regular judgements about these matters; often in highly dynamic situations. The information derived from these studies should further assist land managers in the judgements they are required to make when managing wildfire suppression operations.

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December 2003

Fire Research Reports derived from this investigation are:

No.	Title
68.	Effects of fire retardant on vegetation in eastern Australian heathlands: a preliminary investigation
69.	Effects of fire retardant on heathland invertebrate communities in Victoria
70.	Effects of fire retardant on soils of heathland in Victoria

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Summary

The effects of fire retardant on invertebrates in heathland communities were assessed over a one-year period from March 2001 to March 2002. The study was conducted at two sites, one at Marlo in East Gippsland and the other in the Grampians region of south-west Victoria. A total of 136 190 specimens representing 30 ordinal and sub-ordinal taxa contained in 5400 pitfall trap samples were collected. It was concluded that, despite the application of fire retardant at varying rates, there was no significant effect on invertebrate activity at ground level amongst the ordinal groups Acarina and Dermaptera. These ordinal groups appear to form a stable component of the heathland invertebrate community at both sites. Although significant changes were observed in other major taxonomic groups (total taxa, total insects, total non-insects, Araneae, Collembola, Coleoptera and Diptera) these changes were confined to either increased or decreased activity within a single plot and were judged to be not representative of treatment. While a significant change in activity was recorded for Formicidae at both sites, this was also due to single plot variations in activity across different treatments. Such information indicates that any significant changes observed in invertebrate activity appeared to be due to site-related environmental factors rather than the effects of the retardant itself. When assessed in terms of general diversity, taxon richness and community evenness, ordinal and sub-ordinal taxa were unaffected by the retardant applied at the Marlo site. Significant changes in insect diversity at the Grampians site were again due to site-related factors rather than retardant effects. Further study is required to determine whether this stability is reflected at family, genus and species level, and if there are any seasonal and longer-term effects of retardant application. The combined effect of fire and retardant on invertebrate communities also requires further study.

Introduction

Victoria has some of the most bushfire-prone environments in Australia. Over the last 150 years more than half of the economic damage caused by bushfires in Australia has occurred in Victoria (Luke & McArthur 1978; CSIRO 2000). To minimise such damage, there is a heavy reliance on intensive fire suppression activities including the application of fire retardant chemicals from aircraft. Fire retardants have been used operationally in Victoria's parks and forests since 1967 and, today, are used in approximately 10% of all fires on public lands. Each year the Department of Sustainability and Environment (DSE) and its predecessors has applied an average of 120 000 litres of fire retardant throughout Victoria (CSIRO 2000). Retardants are particularly useful in slowing the spread of fires in remote, inaccessible terrain as well as in controlling spotfires, allowing time for the construction of control lines. The retardant applied is Phos-Chek D75-R (hereafter referred to as Phos-Chek), which contains ammonium sulphates, ammonium phosphates, guar gum, iron oxide and performance additives (CSIRO 2000). While Phos-Chek is approved for use in natural environments by the United States Department of Agriculture, CSIRO (2000) identified that no experiments have been conducted in Australia to examine the effects of Phos-Chek on native flora and fauna. Given the highly endemic nature of Australian ecosystems, it is possible that they may respond quite differently to retardant application than those of the northern hemisphere. Research into this issue is therefore of great importance to assist in the responsible management of fire suppression activities in the Australian landscape.

Only one previous study, by Bradstock et al. (1987), has investigated the effect of ammonium sulphate on Australian plants. That study was conducted in eucalypt forests, with results indicating significant short-term effects, including widespread leaf death in trees, shrubs and ground-cover plants. While it may be argued that the latter effect is comparable to the effects of fire, there is concern that the resulting increase in phosphates and sulphates in the soil may deleteriously affect vegetation species that have evolved under low-nutrient conditions. It is anticipated that these changes may also impact on other aspects of the ecosystem.

Invertebrates are closely associated with vegetation structure and composition, as they represent foliage-feeders, nectar-feeders, seed-gatherers, wood-suckers and wood-bores, while others are predators and parasites of these first-order consumers (Majer & Greenslade 1988). The potential of direct toxicity with regard to invertebrates has only been studied on earthworms (Beyer & Olsen 1996), with the findings of that study showing Phos-Chek was non-toxic to earthworms when applied at 1000 ppm. However, that study did not represent the full diversity in invertebrate physiology and morphology, nor did it represent the range of concentrations at which retardant is applied. Furthermore, there are potential indirect effects involving both the possible increase in nutrient concentration in plants and the subsequent toxicity to invertebrates that feed directly on, or decompose this material (CSIRO 2000).

Fire Management Officers have a responsibility to minimise environmental damage during fire suppression operations. However, without adequate knowledge of the environmental impacts of different suppression techniques, informed decisions cannot be made. This issue is of particular importance in vegetation communities that have evolved under low nutrient conditions and/or are of high conservation value. In light of the aforementioned concerns, Fire Management, of the former Department of Natural Resources and Environment, initiated a multidisciplinary study in 2000 to assess the effects of fire retardant application on vegetation, soil chemistry and surface-active invertebrates in fire-prone heathland communities of Victoria.

The aim of this component of the study is to determine the immediate and longer-term responses of fire retardant application on the composition and relative abundance of litter-invertebrates in heathland communities in Victoria. The results obtained will assist in developing management practises that minimise any potential adverse effects to invertebrates that may result from the application of fire retardant in these ecosystems.

Materials and methods

Study sites

Two study sites were selected in heathland areas in Victoria. One was located at Victoria Valley airstrip in the Grampians (37º 11' 5.09" S, 142º 20' 27.90" E) at an elevation of 220 m on a flat aspect, approximately 25 km west of Halls Gap in western Victoria—Figure 1(a). The other was located at Marlo airstrip (37º 47' 26.58" S, 148º 36' 28.99" E) at an elevation of 20 m on a flat aspect approximately 20 km south-east of Orbost in East Gippsland—Figure 1(b).

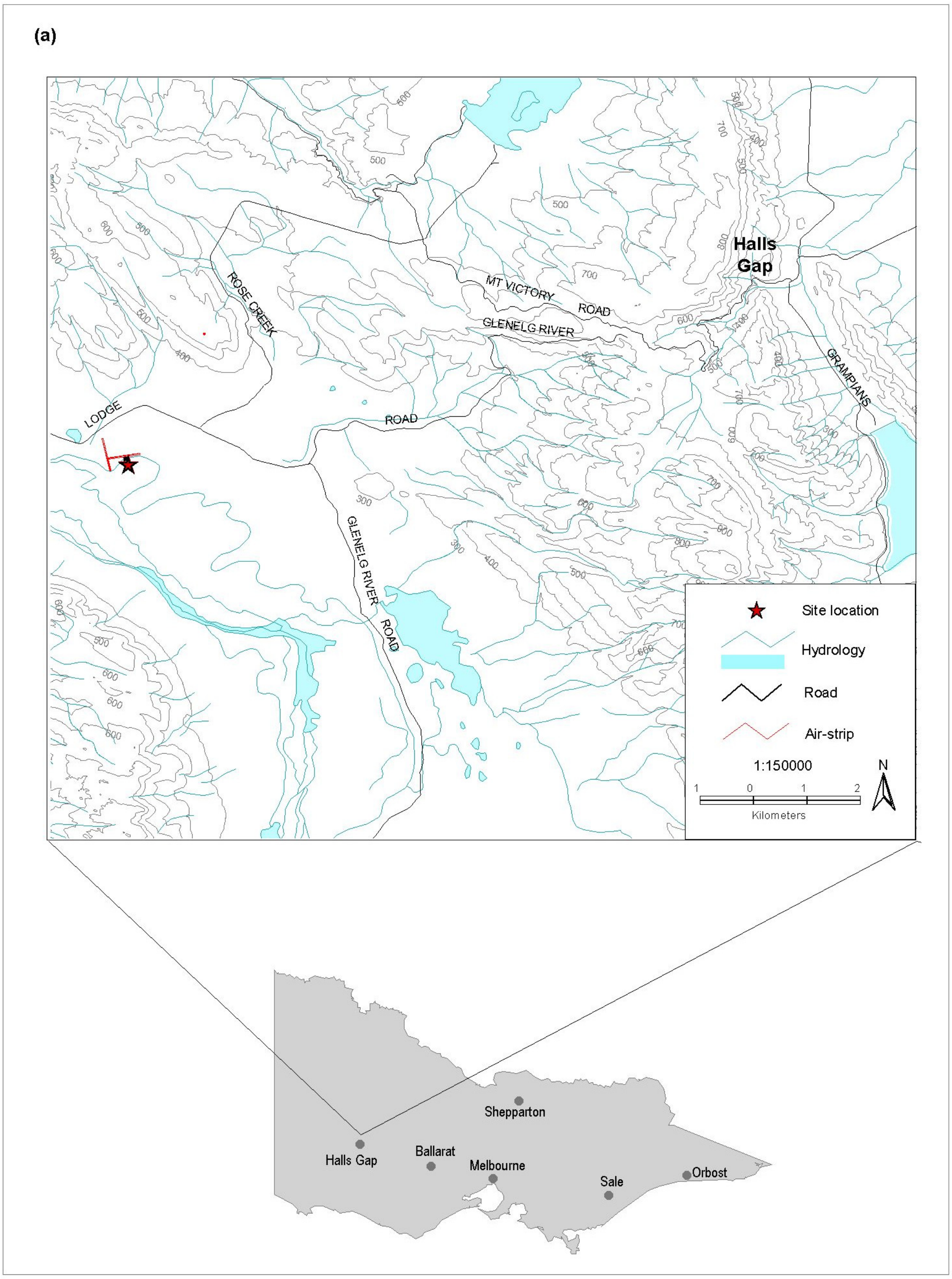


Figure 1(a) Location of the Grampians fire retardant study site in heathland areas of Western Victoria

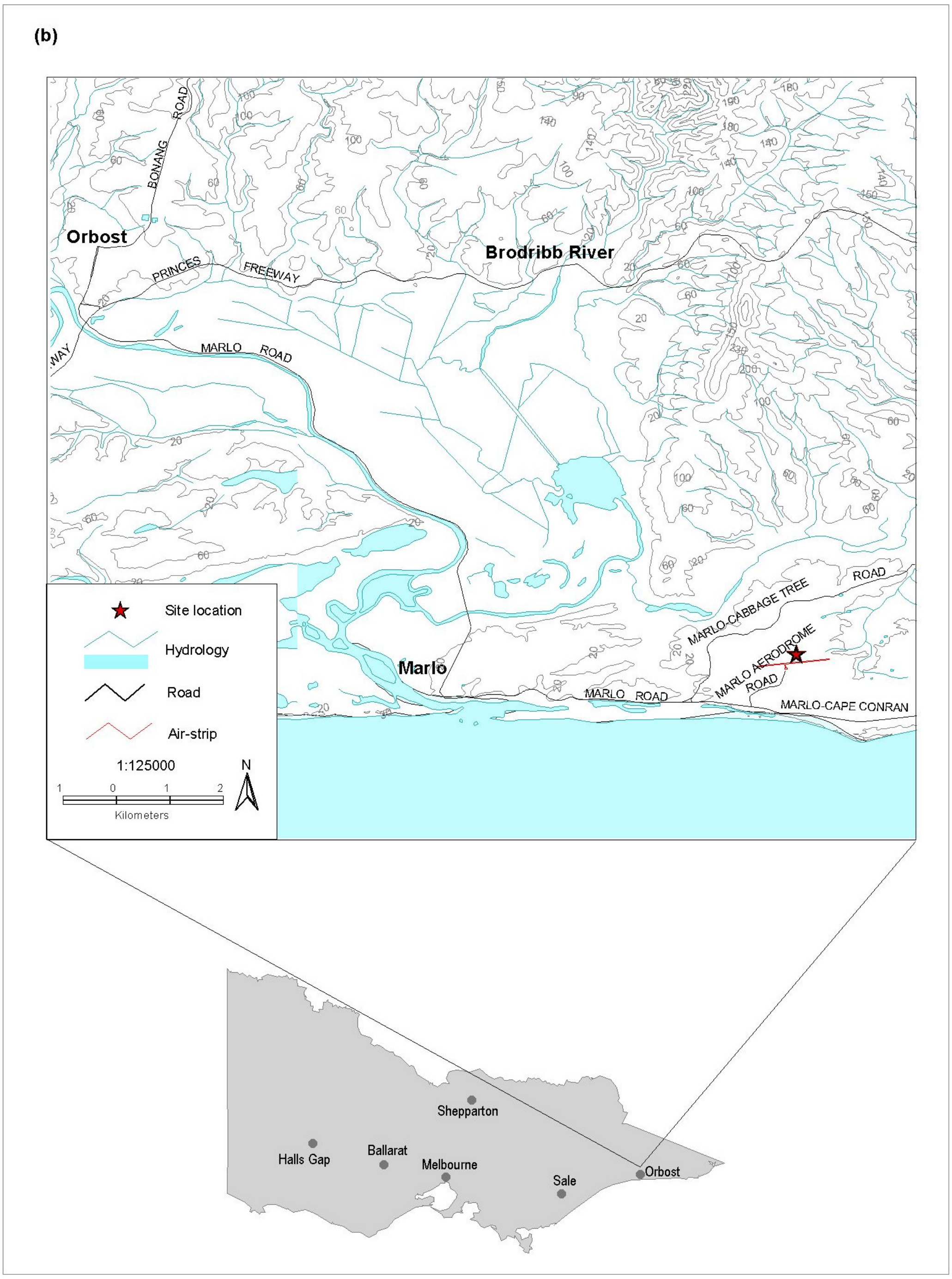


Figure 1(b) Location of the Marlo fire retardant study site in heathland areas of East Gippsland

Vegetation at the Marlo site is generally described as a 'wet coastal heathland assemblage' with the dominant overstorey species including *Leptospermum continentale* Joy Thomps. (Prickly Tea-tree), *Allocasuarina paludosa* Sieber ex Spreng. (Scrub Sheoak) and *Bossiaea prostrata R. Br.* (Creeping Bossiaea), while dominant understorey species include *Panicum simile* Domin. (Hairy Panic) and *Poa clelandii* Vickery (Tussock Grass). Plant heights range from 85 cm (*A. paludosa*) to 70 cm (*L. continentale*) while cover estimates for the dominant overstorey species range from 1% to 50% on the Braun Blanquet scale (Kent & Coker 1992). Soil acidity at Marlo ranges from pH 5.4 to 5.7. The soils contain 15–20 g/kg total carbon, 1 mg/kg extractable phosphorus, 0.4–1.0 g/kg total nitrogen and 10–20 mg/kg mineralisable nitrogen (T.Bell pers. comm. 2002).

Nomenclature of the vegetation is based on Walsh and Entwistle (1994, 1996).

Vegetation at the Grampians study site is generally described as a 'sandy heathland assemblage' with the dominant overstorey species including *Leptospermum continentale*, *L. myrsinoides* Schltdl. (Heath Tea-tree), *Banksia marginata* Cav. (Silver Banksia), *Brachyloma daphnoides* Sm. Benth. (Daphne Heath) and *Allocasuarina paludosa*, while dominant understorey species include *Hypolaena fastigiata* R. Br. (Tassle Rope-rush) and *Lomandra multiflora* R. Br. (Many-flowered Mat-rush). Plant heights range from 115 cm (*A. paludosa*) to 80 cm (*B. marginata*) while cover estimates for the dominant overstorey species range from 1% to 25% (on the Braun Blanquet scale). Soil pH at the Grampians site ranges from 5.3 to 5.4. The soils contain 5–10 g/kg total carbon, 1 mg/kg extractable phosphorus, 0.3–0.5 g/kg total nitrogen and 5–10 mg/kg mineralisable nitrogen (T.Bell pers. comm. 2002).

At the Marlo study site, disturbance has been confined to a single fire in the mid-1960s and some slashing of the heath as a fire-prevention measure which ceased in 1985—86 (G.McCarthy pers. comm. 2002). At the Grampians study site, since records were commenced in 1939, the trial site has been prescribed burnt twice: 1963 and 1985 (M.Wouters pers. comm. 2002).

Trial design and treatment application

At the Marlo study site, a randomised block design with five replicates x five treatments was used, while at the Grampians study site, a Latin square design was used with five replicates x five treatments. The five treatments applied at both sites in the study were:

Treatment One:	'untreated control'
Treatment Two:	water at 1.0 L m^{-2} ('water only')
Treatment Three:	fire retardant at 0.5 L m^{-2} ('low retardant')
Treatment Four:	fire retardant at 1.0 L m^{-2} ('medium retardant')
Treatment Five:	fire retardant at 1.5 L m^{-2} ('high retardant')

The retardant was prepared at the recommended mixing ratio of 0.144 kg of retardant powder per litre of water (CSIRO 2000). Treatments Three (low retardant), Four (medium retardant) and Five (high retardant) represent the range of application rates at which fire retardant is used operationally in fire situations in Victoria, with Treatment Four (medium retardant) the desired rate of application (CSIRO 2000). Treatment Two consisted of water only, given that moisture can potentially act as a stimulatory trigger to epigeal invertebrate activity (Holt 1985; Hutson & Veitch 1983; —1987). Treatment plots at both sites consisted of a 20 m x 20 m plot to which each treatment was applied, with an internal measurement/sampling plot of 10 m x 10 m to minimise the effects of epigeal invertebrates migrating in from adjacent treatments or areas external to the study boundaries. The use of internal sampling plots also eliminated the potential of the immediate edges of treatments being 'contaminated' by the treatment application in the adjacent plot and thus possibly affecting invertebrate activity in the plot. The Marlo site had all five treatments applied within the five-day period 2—6 March 2001, while the Grampians site had all five treatments applied within the six-day period 29 March to 3 April 2001.

Sampling

Prevailing weather conditions in terms of mean monthly rainfall and maximum and minimum monthly temperatures were recorded from January to December 2001 at weather stations located at Marlo and Victoria Valley, close to both sites. Surface-active arthropods were sampled at each site within a 10 m x 10 m area within each plot over 12 weekly periods between 16 March 2001 and 14 February 2002 for the Marlo site, and 12 April 2001 and 15 March 2002 for the Grampians site. Within each 10 m x 10 m internal measurement plot, pitfall traps were positioned on a grid interval of 5 m x 5m giving a total of nine pitfall traps per plot. A total of 5400 pitfall samples (2 study sites x 5 replicates x 5 treatments x 9 pitfall traps x 12 weekly samples) were collected during the entire study.

Each pitfall trap consisted of an 18 mm diameter test tube in a PVC sleeve, half filled with 75% ethanol and providing a 2.5 cm^2 receptive surface area. The 18 mm diameter test tube proved to be generally effective in preventing overflow of the traps during rainstorms and yet did not tend to exclude the larger arthropods. Effects related to the establishment of the pitfall traps were minimised by commencing sampling four weeks after positioning of the traps. Arthropod activity was measured as the number of individuals trapped per composite sample of nine pitfall traps over a seven-day period at the ground surface. Pitfall trapping estimates the relative population levels of epigeal invertebrates, and thereby measures their relative importance on the forest floor (Greenslade 1964; —1973; Greenslade & Greenslade 1971; Majer 1978; Collett 1996). The technique is considered appropriate for this study, which uses sampling over time to assess the effects of fire retardant application on epigeal invertebrates. Limitations in sampling technique would apply equally across both study sites because sampling was done contemporaneously within all plots at each study site of similar age, aspect, elevation, vegetation and fire/general history, thus negating the effects of variable weather conditions and site characteristics on invertebrate activity.

The trapped arthropod specimens were counted and classified to ordinal and, where possible, sub-ordinal level using a low-power microscope, with the nomenclature of families used and their varying feeding types based on that given by CSIRO (1991), Zborowski and Storey (1995), Pechenick (1996) and McGavin (2000).

Analysis

As the range and activity of arthropod taxa often varied between the nine pitfall traps within each plot, each set of nine contemporaneous trap collections was pooled into a composite sample. In the present study, examination of the arthropod data collected at both sites determined it not to be normally distributed. Different treatments at both sites were therefore compared using the Kruskal-Wallis H test that allows for statistical comparisons to be made of non-normally distributed data between the medians of three or more samples by ranking observations within each treatment (Fowler et al. 1998; Zar 1999).

To determine whether or not the different treatments had any effect on the diversity of invertebrates at both sites, the Shannon-Wiener general diversity (Poole 1974), Margalef taxon richness (Southwood 1978) and Pielou community evenness indices (Pielou 1966) were compared using the Kruskal-Wallis H test. Although the three ecological indices have certain limitations (Hurlbert 1971), they were considered appropriate as sampling was relative over time, confined to sites experiencing the same set of environmental conditions and not aimed at a complete census of the invertebrate community (Collett 2000).

In order to determine the effects of fire retardant application on the taxon richness of invertebrates, two-dimensional Chi-square analyses were performed on the taxa totals for all treatments at both sites using 2 x 2 contingency tables (Zar 1999).

To examine whether trapping efficiency of invertebrates was affected by the trial design, where some treatment plots within replications were either bordered or totally surrounded by other plots, the five untreated control plots at both sites were compared using the Kruskal-Wallis H test to compare major taxonomic categories (Fowler et al. 1998).

Results

Weather conditions

At Marlo, the mean daily maximum air temperature per month ranged from the highest recorded maximum of 25ºC in February to the lowest maximum of 15ºC in July (Figure 2a), while the corresponding means for the Grampians site were 28ºC (January) and 12ºC in July (Figure 2b). The mean daily minimum air temperature at Marlo ranged from the highest recorded minimum of 15ºC in February to the lowest minimum of 3ºC in July (Figure 2a), while the corresponding means for the Grampians were 13ºC (February) and 3ºC in July (Figure 2b). Mean annual rainfall was 920 mm for Marlo and 700 mm for the Grampians. Mean monthly rainfall varied substantially between both study sites, especially with respect to minimum rainfall, with Marlo recording a maximum of 93 mm in May and a minimum of 67 mm in February while the respective figures for the Grampians were 84 mm in July and 27 mm in January (Figure 2ab).

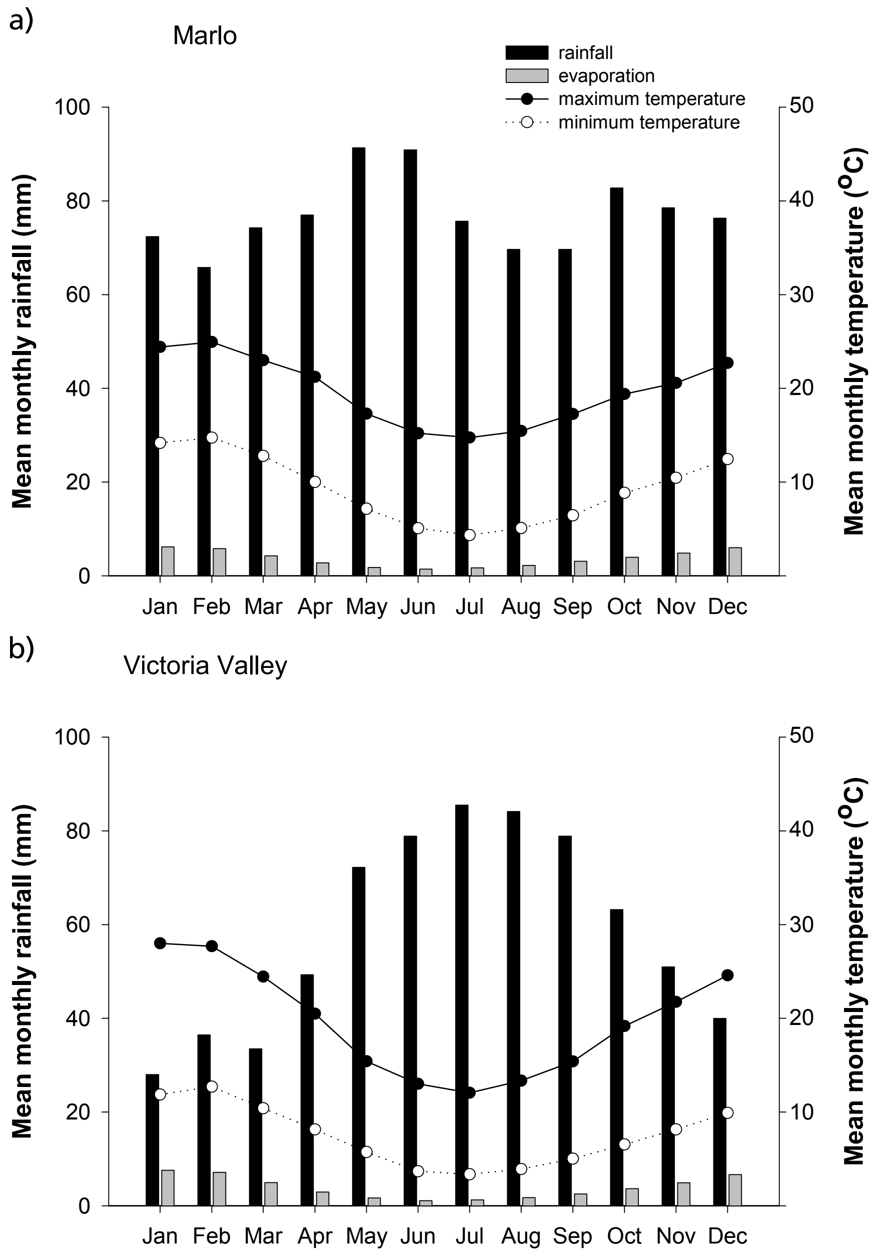


Figure 2 Mean monthly rainfall and mean monthly maximum and minimum temperature for a) Marlo and b) Grampians study sites January to December 2001 (T.Bell pers. comm. 2002)

Overview of arthropod fauna trapped at the Marlo and Grampians study sites

A total of 30 ordinal/sub-ordinal groups were identified among the total of 136 190 arthropod specimens trapped at both sites across all treatments, with 26 groups totalling 79 853 specimens trapped at Marlo between March 2001 and February 2002, and 28 groups totalling 56 337 specimens trapped at the Grampians between April 2001 and March 2002 (Table 1). The total number of specimens collected among the Acarina, Araneae, Collembola, Dermaptera, Coleoptera, Diptera and Formicidae at both sites ranged between 1161 and 112 419, representing 98.9% and 92.5% of the total arthropod fauna trapped at the Marlo and Grampians sites respectively. These were referred to as the 'major' taxa, to distinguish them from the 23 less-commonly trapped 'minor' taxa, which represented 76.6% of the ordinal/sub-ordinal groups trapped across both sites while only representing 3.8% of the total individuals trapped. While 3891 individuals of the taxa Copepoda were trapped at both sites, only 96 individuals were trapped at Marlo. Unlike the other 'major' taxa, where approximately similar numbers were trapped at both sites, the Copepoda were predominantly confined to the Grampians and were therefore excluded from the 'major' taxa group for the purposes of the study. Twenty-four (80%) of the ordinal/sub-ordinal groups were trapped at both sites. Two groups (Decapoda and Neuroptera) were trapped at Marlo only, while four groups (Protura, Mantodea, Psocoptera and Phasmatodea) were exclusively trapped at the Grampians site (Table 1). Up to 84 specimens of each of these six taxa were trapped at both sites over the period of the study indicating that either they are a 'rare' component of the arthropod ground fauna or that pitfall trapping was not the preferred technique for trapping these taxa.

Of the 26 ordinal and sub-ordinal groups trapped at Marlo, 17 (65.4%) were found on all five treatment sites and represented over 99.9% of the total individuals trapped. At the Grampians site, 12 (42.8%) of the 28 ordinal and sub-ordinal groups were found on all five treatments and also represented over 99.9% of the total individuals trapped (Table 1). Of the nine groups not found on all five treatments at Marlo, four (Isopoda, Blattodea, Thysanoptera, Oligochaeta) were found on four treatments, one (Lithobiida) was trapped on three treatments, three (Opilionida, Orthoptera—Gryllidae, Hymenoptera—Symphyta) on two treatments and one (Neuroptera) on one treatment (Table 1). Of the 16 groups not found on all five treatments at the Grampians, one (Oligochaeta) was found on four treatments, nine (Opilionida, Lithobiida, Polydesmida, Blattodea, Mantodea, Orthoptera—Acrididae, Psocoptera, Thysanoptera, Lepidoptera) were trapped on three treatments, three (Amphipoda, Hymenoptera (Symphyta), Phasmatodea) on two treatments and two (Protura, Orthoptera—Gryllidae) on one treatment (Table 1). The feeding types—sap and seed feeders, herbivores, algal feeding and omnivores—were represented at both sites but the majority of the arthropod fauna trapped were predators and decomposers (Table 1).

Table 1 Taxa and numbers of individual epigeal arthropods trapped at the study sites

Taxon	Feeding type	Retardant treatments/study sites									
		Control		Water only		Low		Medium		High	
		M	G	M	G	M	G	M	G	M	G
1.1 Arachnida											
Araneae (spiders)	Predators	79	165	88	136	107	133	75	142	85	151
Opilionida (harvestmen)	Predators	0	3	0	2	2	2	4	0	0	0
Acarina (mites)	Predators decomposers	252	195	224	227	304	226	414	320	325	239
1.2 Malacostraca											
Amphipoda (landhoppers)	Decomposers	23	0	25	0	34	0	25	2	13	1
Decapoda (land crayfish)	Decomposers/ scavengers	16	0	17	0	16	0	16	0	19	0
Isopoda (woodlice)	Decomposers	0	1	12	0	4	0	2	0	3	0
Chilopoda											
Lithobiida (lithobiid centipedes)	Predators	0	1	0	0	2	2	2	0	1	2
Diplopoda											
Polydesmida (polydesmid millipedes)	Decomposers	4	1	16	0	7	0	10	2	8	1
Protura (proturans)	Fungus feeders	0	1	0	0	0	0	0	0	0	0
Collembola (springtails)	Decomposers	13 839	5 909	6 968	6 757	10 348	11 042	14 864	9 824	25 711	7 157
1.3 Insecta											
Blattodea (cockroaches)	Omnivores	4	2	4	1	3	0	0	0	3	1
Mantodea (mantids)	Predators	0	0	0	2	0	1	0	2	0	0
Dermaptera (earwigs)	Predators	360	386	418	317	428	250	388	236	372	243
Orthoptera -Tettigoniidae (grasshopper)	Herbivores	30	24	36	9	12	5	7	20	21	13
" -Acrididae (locusts)	Herbivores	4	2	9	0	7	0	9	2	8	2
" -Gryllidae (crickets)	Herbivores	1	0	1	0	0	0	0	1	0	0
Psocoptera (psocids)	Decomposers	0	1	0	0	0	1	0	0	0	1
Homoptera (aphids, leafhoppers)	Sapfeeders	37	19	18	21	22	25	17	35	23	29
Heteroptera (true bugs)	Sapfeeders, predators	10	10	12	6	37	27	29	20	53	24
Thysanoptera (thrips)	Herbivores	1	4	0	3	2	0	2	1	2	0
Neuroptera (lace wings)	Predators	1	0	0	0	0	0	0	0	0	0
Coleoptera (beetles)	Various	104	373	129	422	167	466	132	421	222	392
Diptera (flies)	Various	59	226	59	230	75	287	122	311	164	344
Lepidoptera (moths, butterflies)	Herbivores	2	0	5	2	1	1	2	0	1	1
Hymenoptera-Formicidae (ants)	Sap/seed feeders	448	1 460	388	791	440	667	259	913	581	739
" -Apocrita (wasps)	Parasitoids, predators	4	8	4	8	4	29	10	26	14	22
" Symphyta (wasps)	Parasitoids, predators	0	0	1	1	1	0	0	0	0	1
Phasmatodea (leaf/stick insects)	Herbivores	0	3	0	1	0	0	0	0	0	0
Copepoda (copepods)	Algal feeding	49	377	11	663	20	583	12	1 047	4	1 125
Oligochaeta (Lumbricina)	Decomposer	1	0	1	1	1	1	1	1	0	4
Total arthropods		15 328	9 171	8 446	9 600	12 044	13 748	16 402	13 326	27 633	10 492
Total taxa		**22**	**22**	**22**	**20**	**24**	**18**	**22**	**19**	**21**	**21**

Notes:

Trappings undertaken at Marlo (M) study site from March 2001 to February 2002

Trappings undertaken at Grampians (G) study site from April 2001 to March 2002

Effects of fire retardant at Marlo

The effects of the application in terms of the Shannon-Wiener, Margalef and Pielou indices (Table 2), expressed for the ordinal and sub-ordinal taxonomic groups show that, despite the application of retardant at low, medium and high rates, and the water only treatment, all three indices were not significantly different relative to the untreated control. H statistic for the Shannon-Wiener, Margalef and Pielou indices were 2.34 ($n = 298$; $P>0.05$), 1.98 ($n = 298$; $P>0.05$) and 2.78 ($n = 298$; $P>0.05$) respectively for the five treatments (Table 2). Thus, diversity at the ordinal/sub-ordinal level in terms of general diversity, taxon richness and community evenness had not changed following application.

These results are consistent with the trend observed across all five treatments that activity was similar (i.e. no significant differences were observed) for the three major arthropod categories: total non-insects, Acarina, Collembola and Dermaptera (Table 3a). However, with reference to the other arthropod categories, a short-term burst in activity from May to July 2001 was observed in the category ‘total taxa’, predominantly as a result of Collembola activity which increased substantially over the same period, on the high retardant plots (Table 3a; Figures 3(a) and 3(f)). However, as Collembola activity, unlike total taxa activity, was not significantly different across all five treatments (Table 3a), it is most likely this is due to the activity of Collembola in conjunction with ‘other’ arthropod groups which are responsible for the significant increase in activity observed in the category ‘total taxa’ (Table 3a). A burst of activity in the categories ‘total taxa’ and ‘total non-insects’ was observed during September 2001 in the untreated control plots due to increased Collembola activity in the same period, although, apart from this burst of activity, levels of activity for these three arthropod categories across all treatments from August 2001 onwards had stabilised to display similar trends (Figures 3(a), 3(c) and 3(f)).

Table 2 Significance of differences between four different fire retardant treatment data sets expressed by their mean rankings, for three ecological indices representing community aspects for total arthropods, compared to an untreated control site

Study sites and treatments	Shannon-Wiener (Diversity)	Ecological Index Margalef (Taxon richness)	Pielou (Evenness)
Marlo[1]			
Untreated control (n=60)[3]	161.32	139.52	158.57
Water only (n=59)	144.21	148.03	141.78
Low retardant (n=60)	141.00	160.47	143.42
Medium retardant (n=59)	145.45	146.29	142.91
High retardant (n=60)	155.37	153.10	160.59
H-statistic and significance	2.34NS[4]	1.98NS	2.78NS
Grampians[2]			
Untreated control (n=60)[3]	128.76	128.76	118.53
Water only (n=60)	135.31	151.82	131.47
Low retardant (n=60)	174.24	147.66	178.22
Medium retardant (n=60)	160.43	164.07	168.01
High retardant (n=60)	153.76	160.18	156.27
H-statistic and significance	10.97*	6.06NS	19.87***

Notes

1. Trappings undertaken at the Marlo site from March 2001 to February 2002
2. Trappings undertaken at the Grampians site from April 2001 to March 2002
3. Number of observations in terms of differences between corresponding index values for the different treatments.
4. NS: no significant differences between specified data sets, *: $P<0.05$, ***: $P<0.001$ (Kruskal-Wallis H-test).

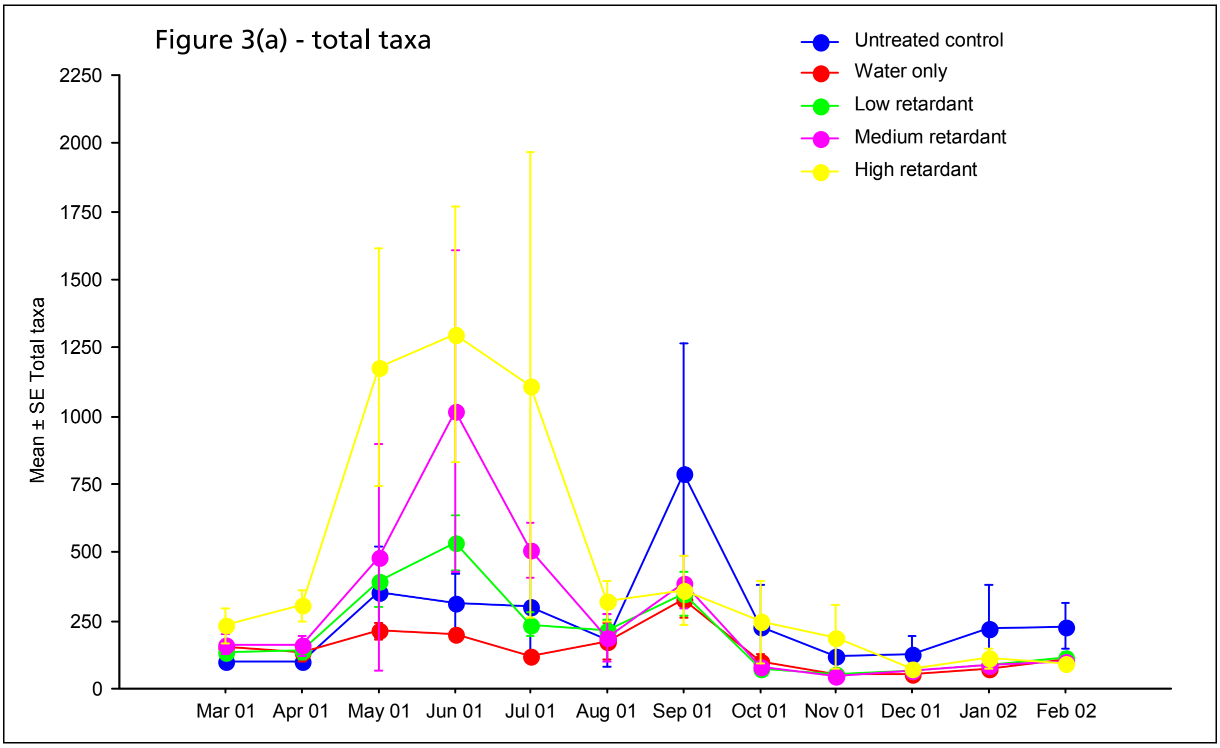
Table 3 Significance of differences between four different fire retardant treatment data sets expressed by their mean rankings, for 10 major arthropod groups, compared to an untreated control site

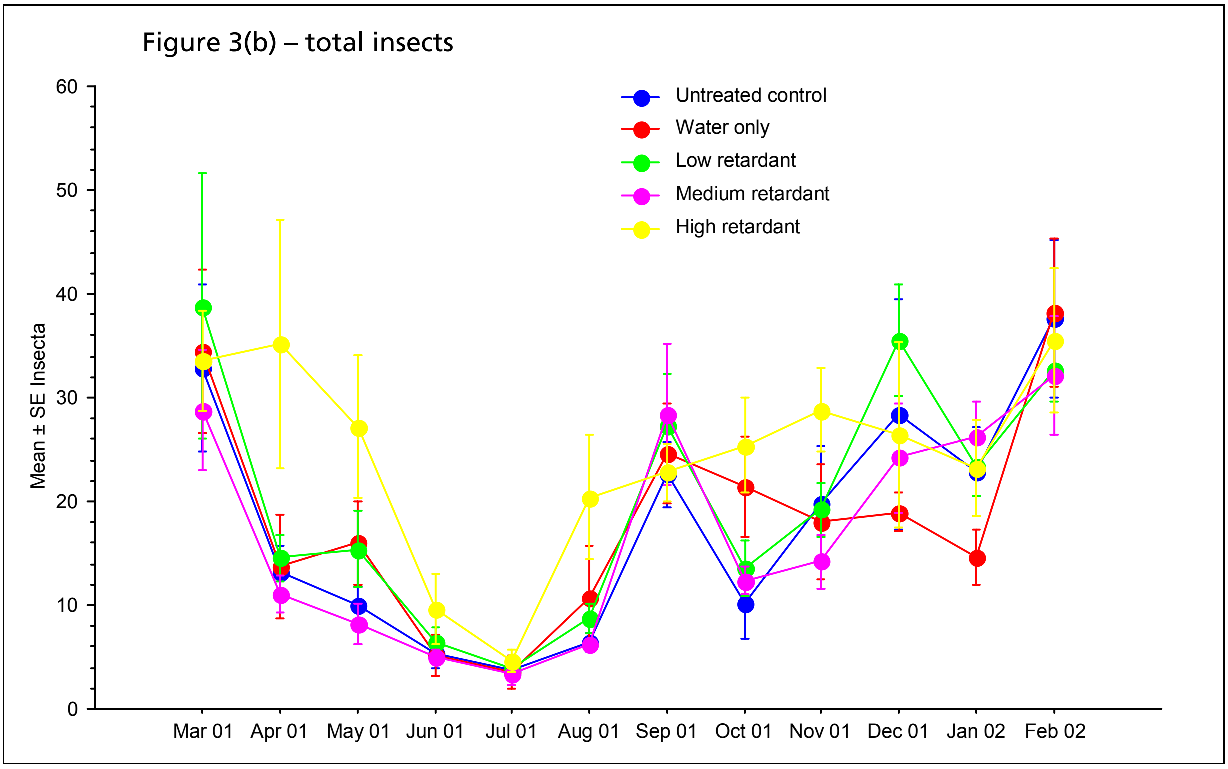
Site and arthropod category	Treatment/Mean rank (n=59, 60)[3]					H-statistic and significance[2]
	Untreated control	Water only	Low retardant	Medium retardant	High retardant	
Table 3a-Marlo[1]						
Total taxa	143.17	133.28	150.99	140.65	178.99	10.08*
Total insects	135.32	143.71	154.47	132.52	181.08	12.45*
Total non-insects	147.31	134.22	147.55	143.78	174.29	7.50NS
Araneae	142.84	161.63	172.26	142.52	128.50	10.30*
Acarina	136.51	126.85	158.33	165.57	160.68	9.28NS
Collembola	148.23	134.14	146.19	143.71	172.78	6.58NS
Dermaptera	140.77	154.29	150.58	147.03	154.85	1.09NS
Coleoptera	127.20	138.60	162.25	144.02	172.30	11.04*
Diptera	126.02	122.63	140.93	168.95	191.76	30.39***
Formicidae	150.76	149.10	155.98	117.34	173.77	13.42**
Table 3b-Grampians[2]						
Total taxa	131.82	132.52	164.35	165.94	157.86	9.22NS
Total insects	178.52	141.87	136.48	152.06	143.57	8.82NS
Total non-insects	121.72	135.29	169.57	165.36	160.55	13.91**
Araneae	142.90	140.81	143.72	173.72	151.34	6.11NS
Acarina	139.51	147.39	139.39	166.27	155.17	4.24NS
Collembola	120.17	136.70	172.79	166.81	156.18	15.27**
Dermaptera	163.90	161.20	151.96	132.89	142.53	5.41NS
Coleoptera	138.03	152.13	163.76	153.44	145.13	2.98NS
Diptera	146.51	140.21	139.88	151.02	164.60	3.42NS
Formicidae	186.41	143.41	130.95	152.48	139.24	14.79**

Notes

1. Trappings undertaken at the Marlo site (Table 3a) from March 2001 to February 2002
2. Trappings undertaken at the Grampians site (Table 3b) from April 2001 to March 2002
3. Denotes number of observations with 59 and 60 observations per treatment at the Marlo and Grampians sites respectively.
4. Levels of significant differences are: *P<0.05, **P<0.01 ***P<0.001 and NS, not significant (Kruskal-Wallis H-test).

Figure 3 Monthly activity of (a) total taxa, (b) total insects, (c) total non-insects, (d) Araneae, (e) Acarina, (f) Collembola, (g) Dermaptera, (h) Coleoptera, (i) Diptera and (j) Formicidae from March 2001 to February 2002 at the ground surface of the Marlo study site treated with various rates of fire retardant and water compared to an untreated control





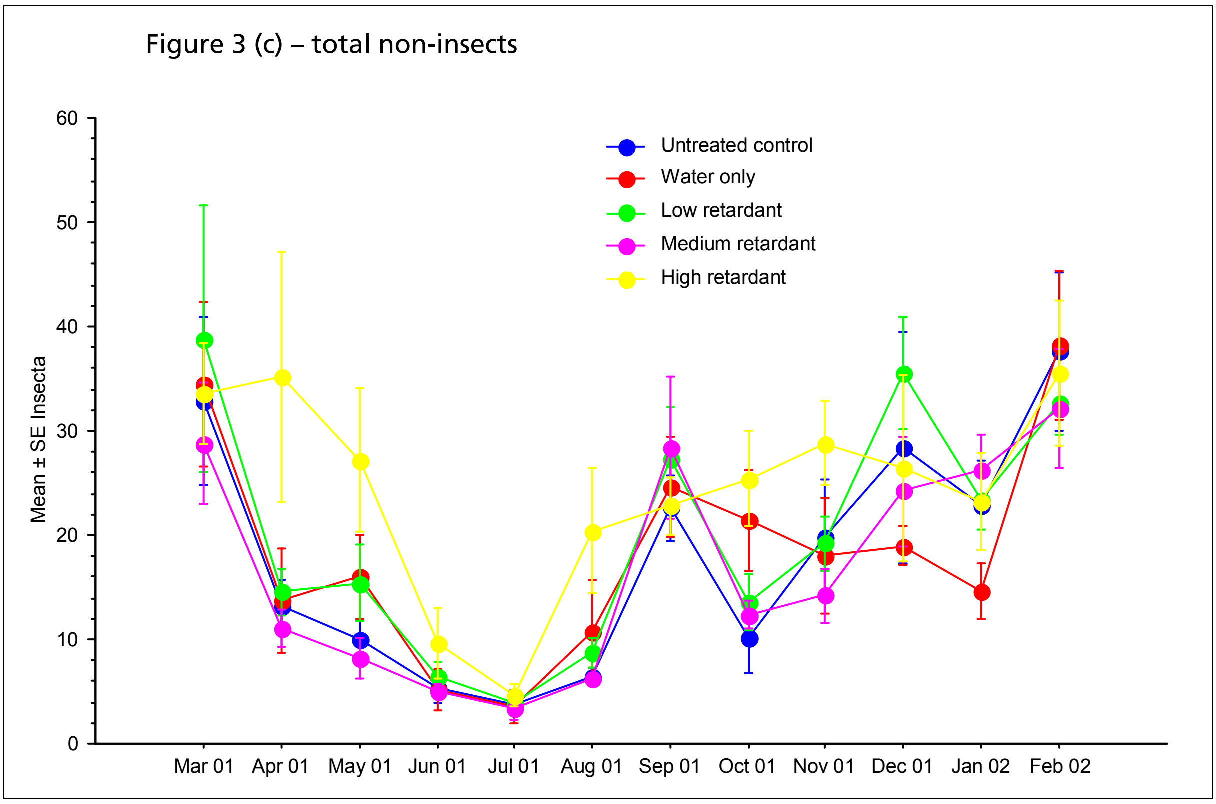


Figure 3 (c) – total non-insects
Mean ± SE Insecta
0
10
20
30
40
50
60
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02

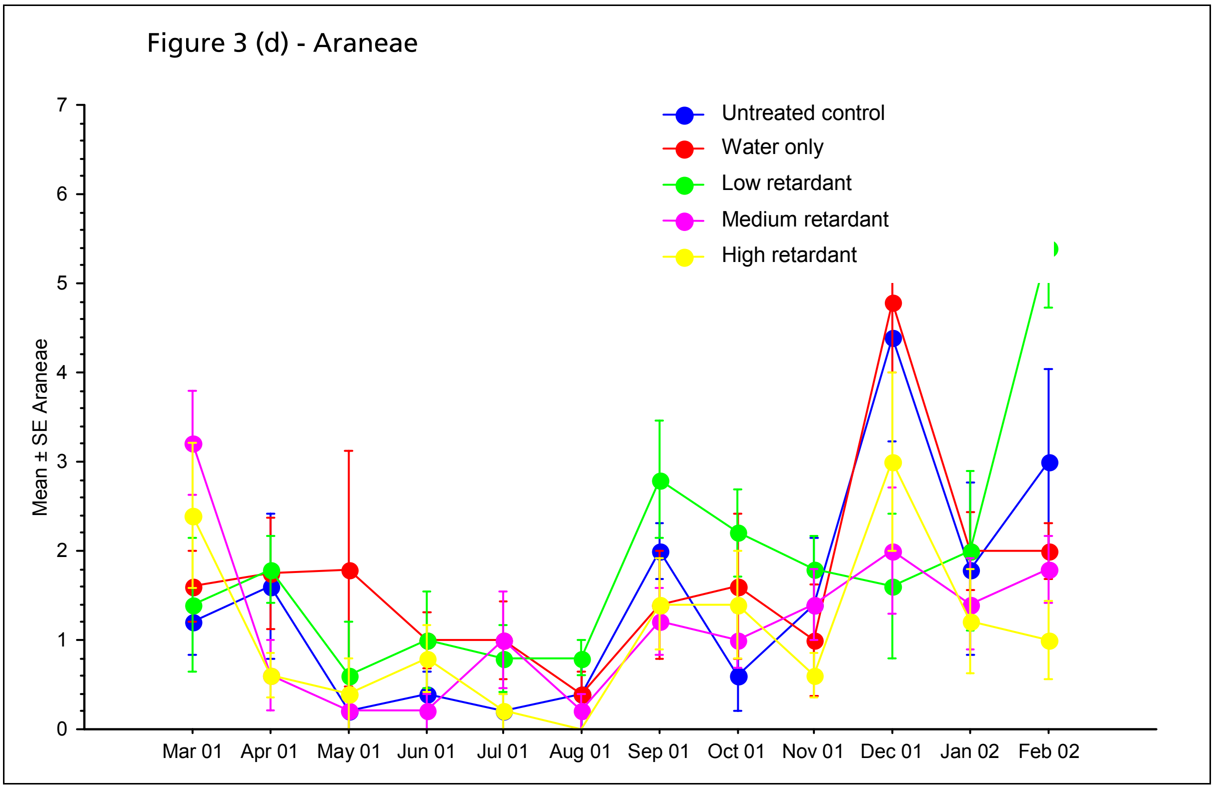


Figure 3 (d) - Araneae
Mean ± SE Araneae
0
1
2
3
4
5
6
7
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02

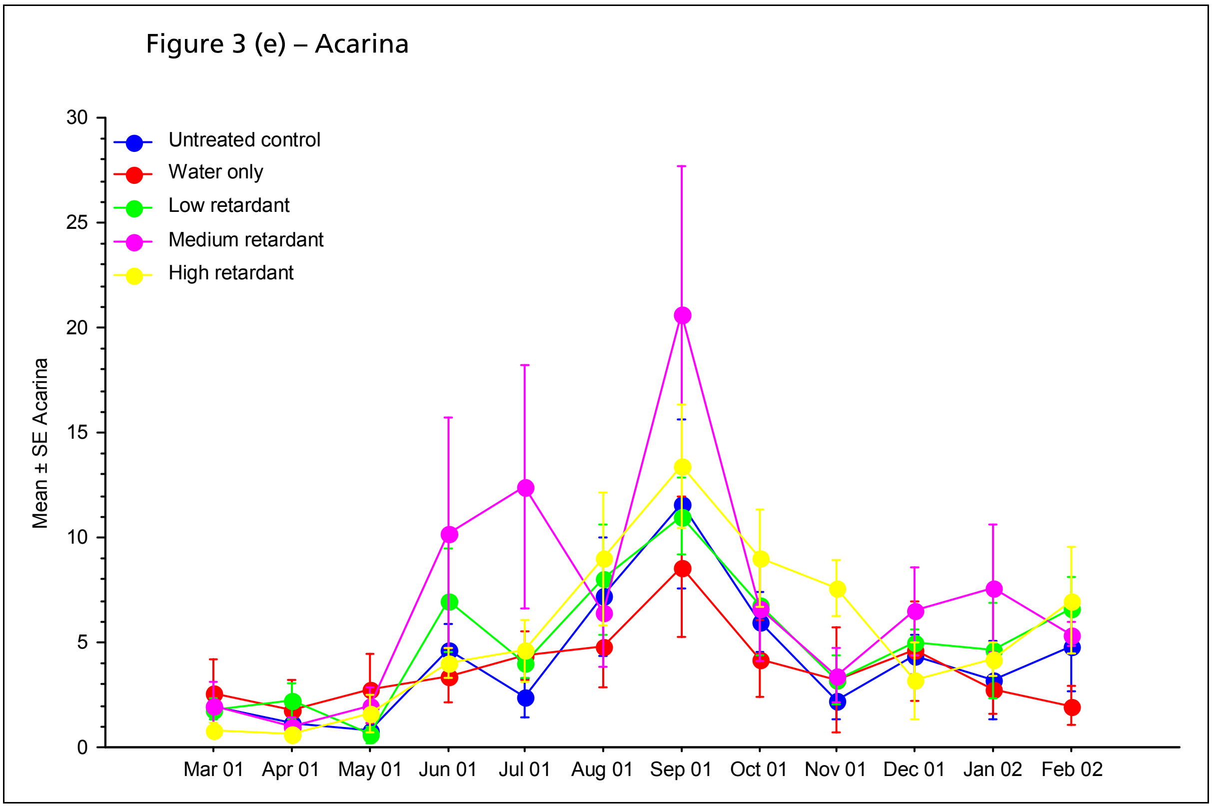


Figure 3 (e) – Acarina
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Acarina
0
5
10
15
20
25
30
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02

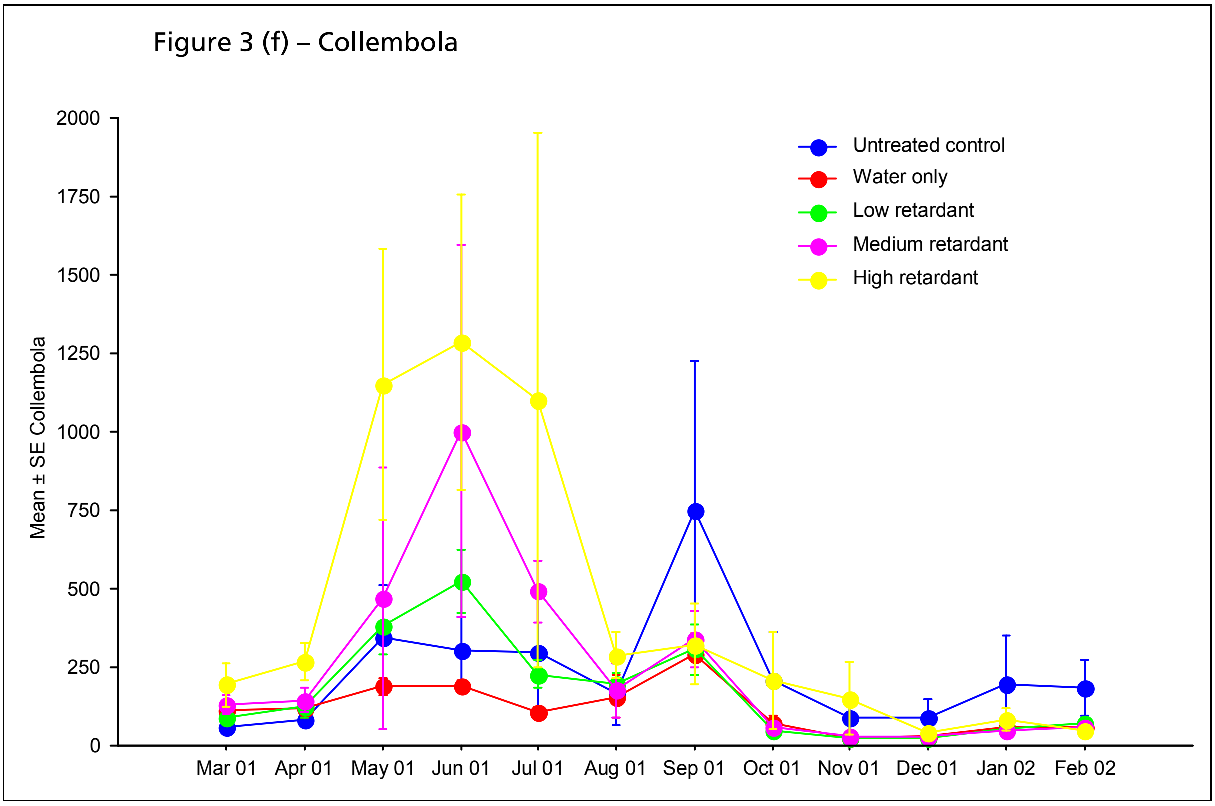


Figure 3 (f) – Collembola
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Collembola
0
250
500
750
1000
1250
1500
1750
2000
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02

Figure 3 (g) – Dermaptera

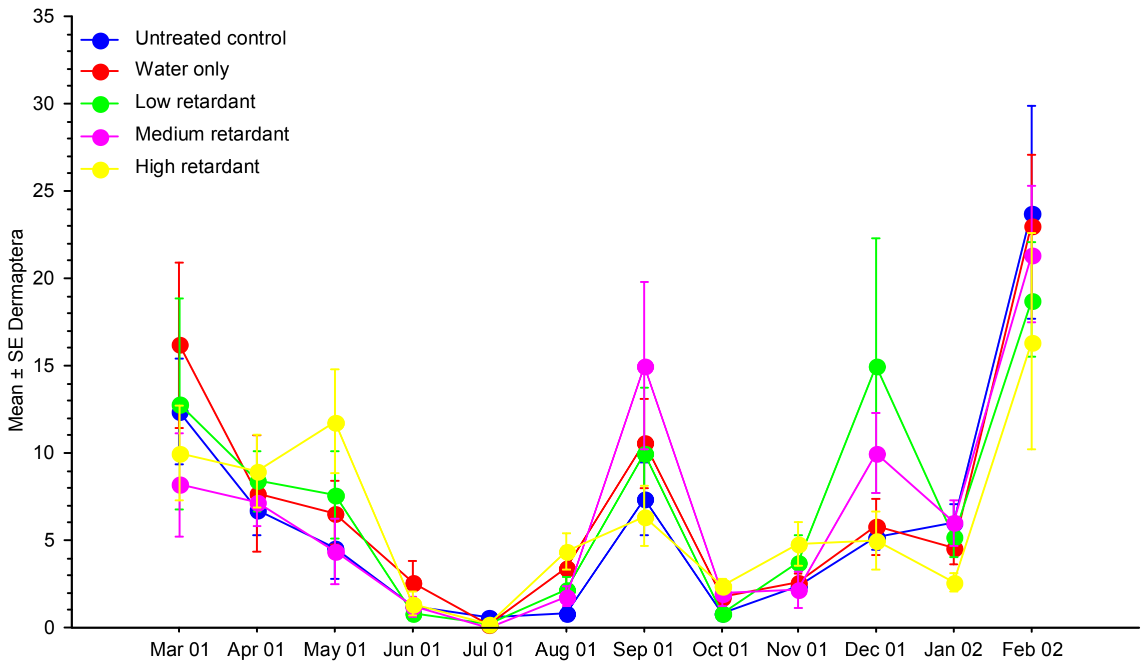
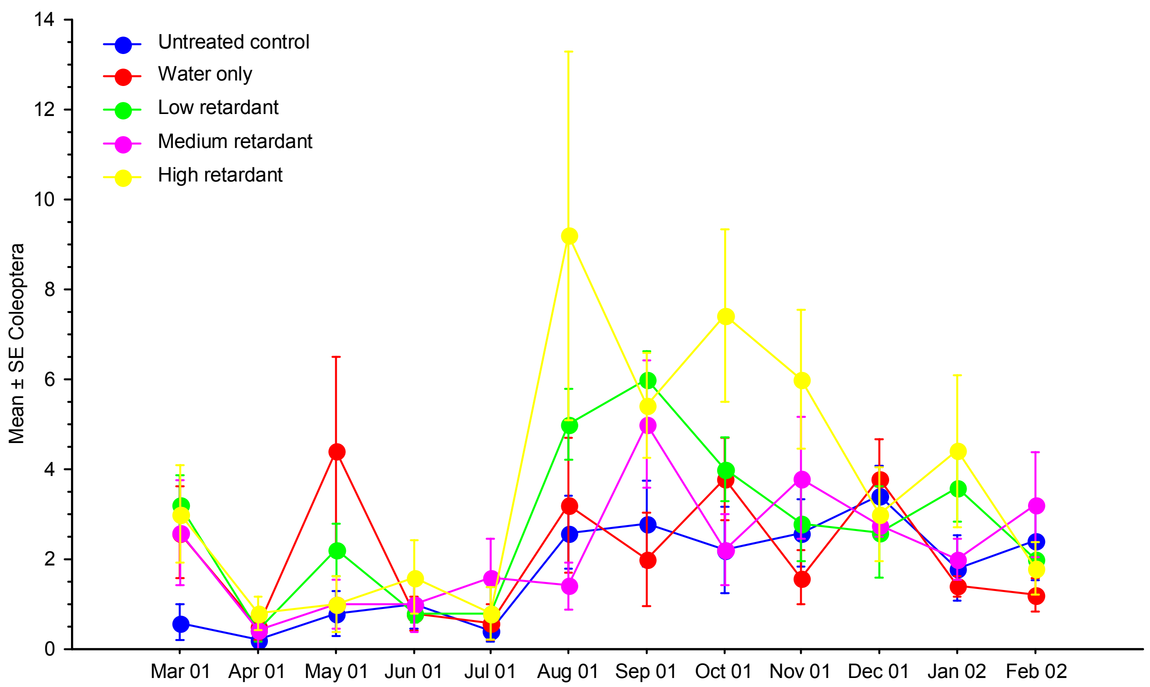


Figure 3 (h) – Coleoptera



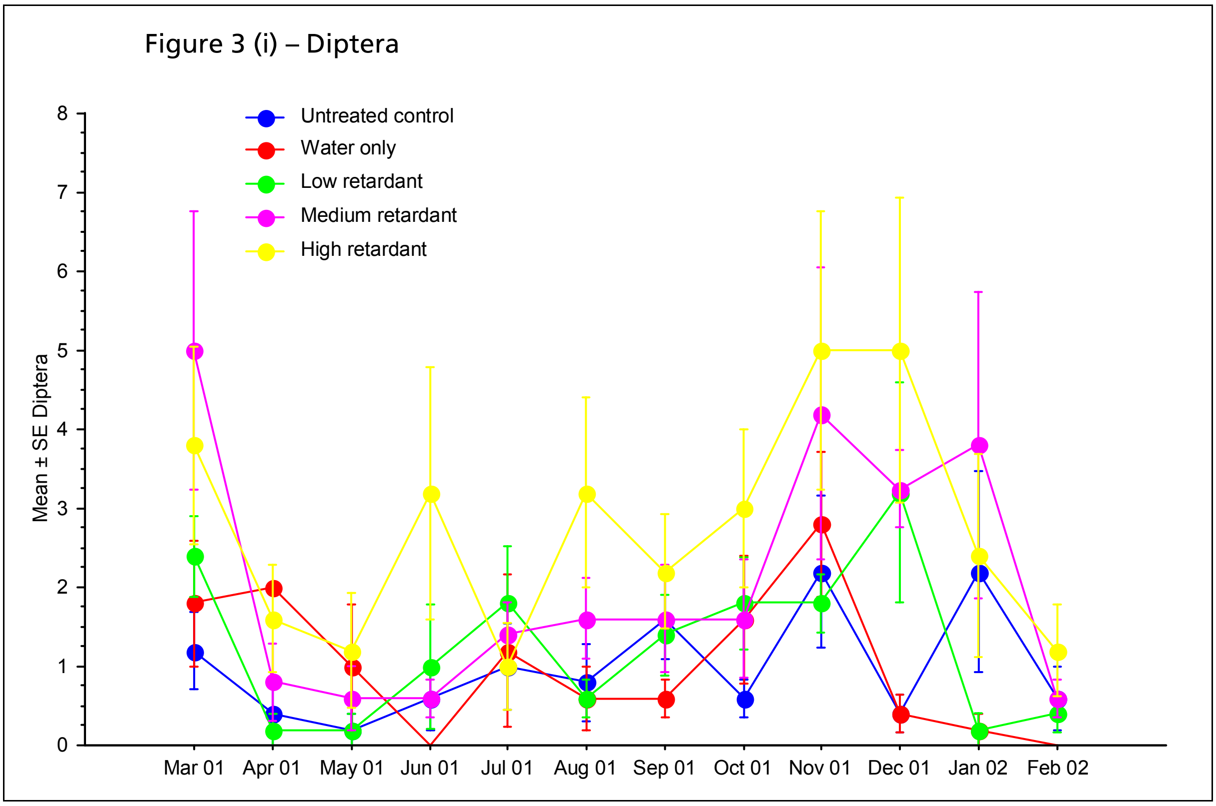


Figure 3 (i) – Diptera
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Diptera
0
1
2
3
4
5
6
7
8
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02

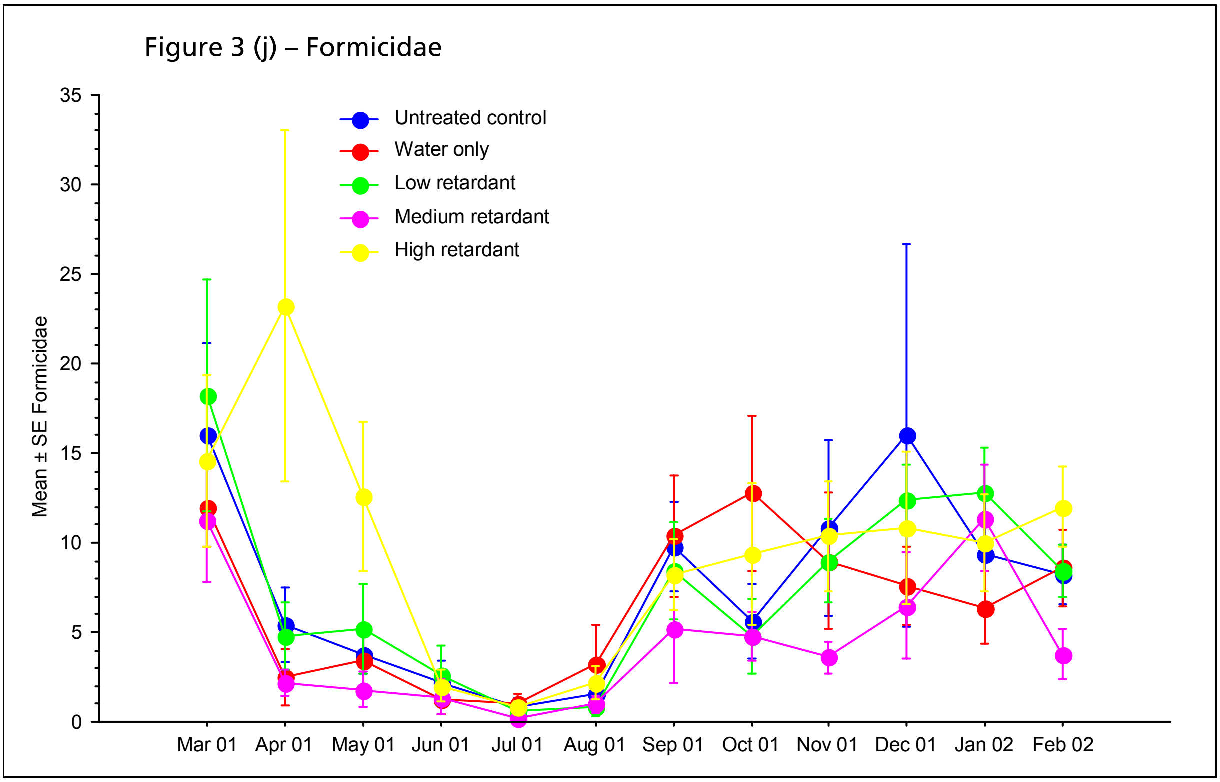


Figure 3 (j) – Formicidae
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Formicidae
0
5
10
15
20
25
30
35
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02

Significantly increased levels of activity were also observed on the high retardant plots in the category 'total insects' during April and May 2001, due predominantly to the Formicidae which also displayed increased activity in the same treatment over the same period (Table 3a; Figures 3(b) and 3(,j)). However, by June 2001, activity across all five treatments for both the 'total insects' and Formicidae had stabilised to once again display similar trends in activity. The significant increase in 'total insect' activity on the high retardant plots compared to the other treatments is also due, apart from the activity of the Formicidae, to the combined activity of the categories Diptera and Coleoptera which were also significantly higher on the high retardant plots than for the other treatments (Table 3a). For Diptera, peaks in activity on the high retardant plots were observed during June and August 2001 (Figure 3i) while, for Coleoptera, peaks in activity for the same treatment were observed in August, October and November 2001 (Figure 3j). The Araneae recorded significantly increased levels of activity for the low retardant plots compared with the other four treatments (Table 3a), with peaks in activity observed during September 2001 and February 2002 (Figure 3d).

The results of the two-dimensional Chi-square test for mutual independence between the two variables—different treatments within the site and the frequency of taxa in the three groupings: total taxa, total insects and total non-insects—were not significant ($x^2 = 0.949$, df = 4, P>0.05), indicating that taxon richness in the three specified groups had not changed as a result of the different treatments.

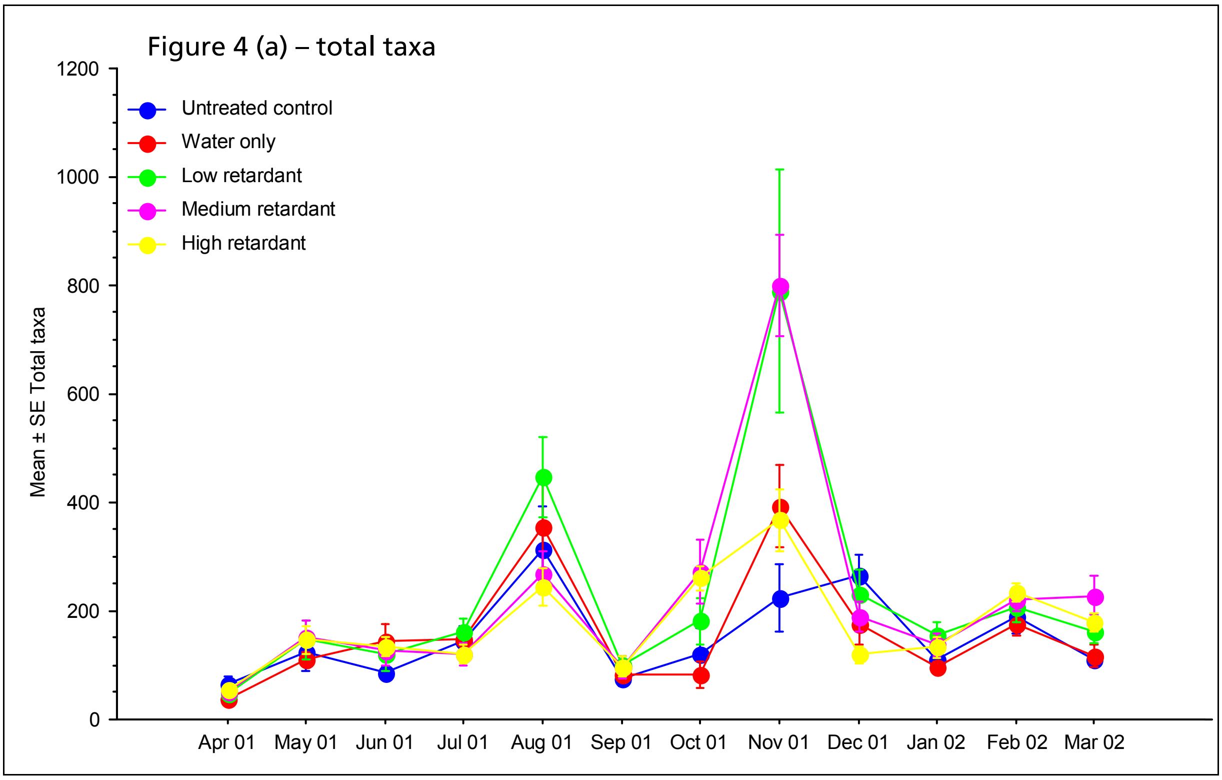
Effects of fire retardant at the Grampians

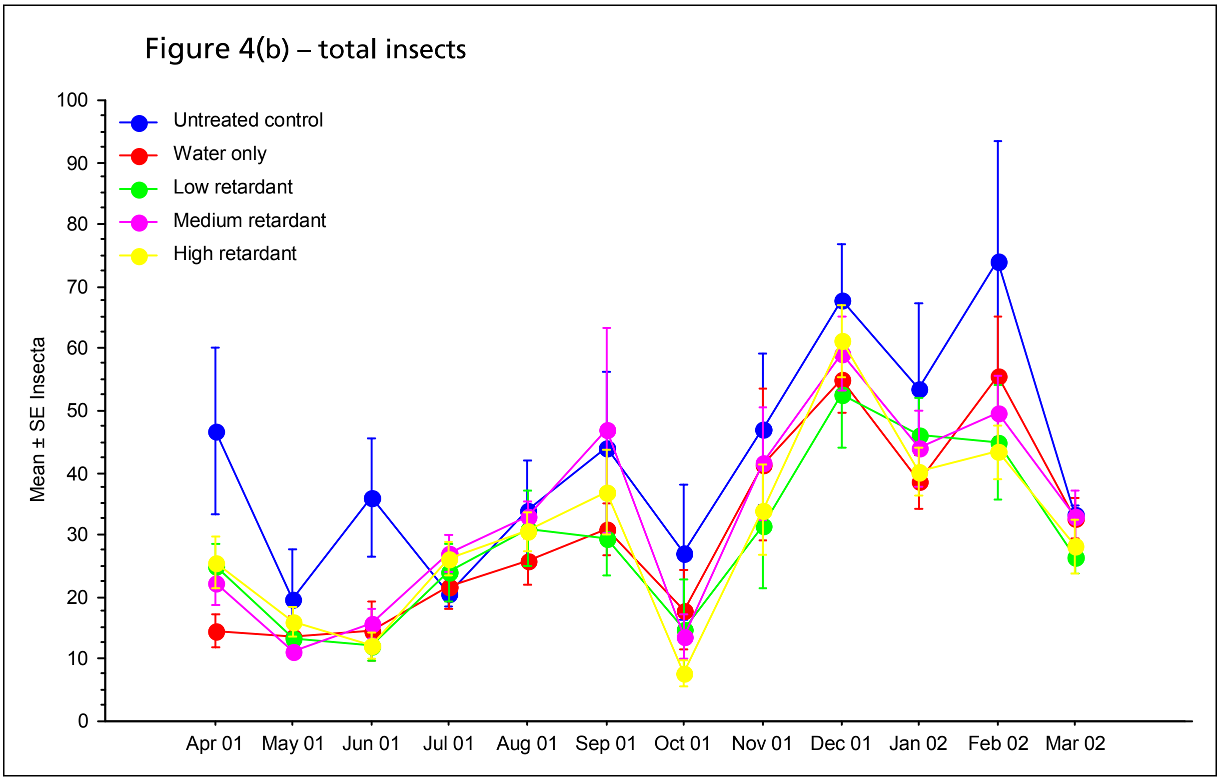
The effects of the retardant application in terms of the Shannon-Wiener, Margalef and Pielou indices, expressed for the ordinal and sub-ordinal taxonomic groups, show that, despite the application of retardant at low, medium and high rates, and the water only treatment, the Margalef (taxon richness) index value was not significantly different relative to the untreated control site (H = 6.06; n = 300, P>0.05) (Table 2). Thus, diversity at the ordinal/sub-ordinal level in terms of taxon richness had not changed following application. However, the Shannon-Wiener (general diversity) and Pielou (community evenness) indices were significantly different (H statistic for the Shannon-Wiener and Pielou indices were 10.97 (n = 300; P<0.05) and 19.87 (n = 300; P<0.001) respectively (Table 2) indicating that diversity had changed as a result of a significant change in community evenness. Examination of the data indicates that this difference is due predominantly to the activity of the Collembola, which represented the most numerous taxa trapped at the study site. Collembola activity was significantly higher on the low and medium retardant treatments compared to the other treatments, which displayed similar levels of activity throughout the entire study period (Figure 4f; Table 3b).

No significant changes in activity were observed in the major arthropod categories: total taxa, total insects, Araneae, Acarina, Dermaptera, Coleoptera and Diptera, indicating that, over the course of the study, activity of these groups remained stable across the five treatments (Figures 4a, 4b, 4d, 4e and 4g–i; Table 3b). However, for the other arthropod category—total non-insects—a significant increase in activity was observed, predominantly as a result of Collembola activity on the low and medium retardant treatments (Table 3b) where peaks in activity occurred during November 2001 over that observed in other treatments (Figures 4c and 4f). From December 2001 to the completion of the study in March 2002, activity of the non-insects and Collembola had stablised to display similar trends in activity. For the Formicidae, significantly increased activity in the untreated control was observed throughout most of the study, with peaks in activity over those observed in other treatments occurring in April and June 2001 and again in February 2002 (Figure 4j; Table 3b).

The results of the two-dimensional Chi-square test for mutual independence between the two variables—different treatments within the site and the frequency of taxa in the three groupings: total taxa, total insects and total non-insects—were not significant ($x^2 = 0.603$, df = 4, P>0.05), indicating that taxon richness in the three specified groups had not changed as a result of the different fire retardant treatments.

Figure 4 Monthly activity of (a) total taxa, (b) total insects, (c) total non-insects, (d) Araneae, (e) Acarina, (f) Collembola, (g) Dermaptera, (h) Coleoptera, (i) Diptera and (j) Formicidae from April 2001 to March 2002 at the ground surface of the Grampians study site treated with various rates of fire retardant and water compared to an untreated control





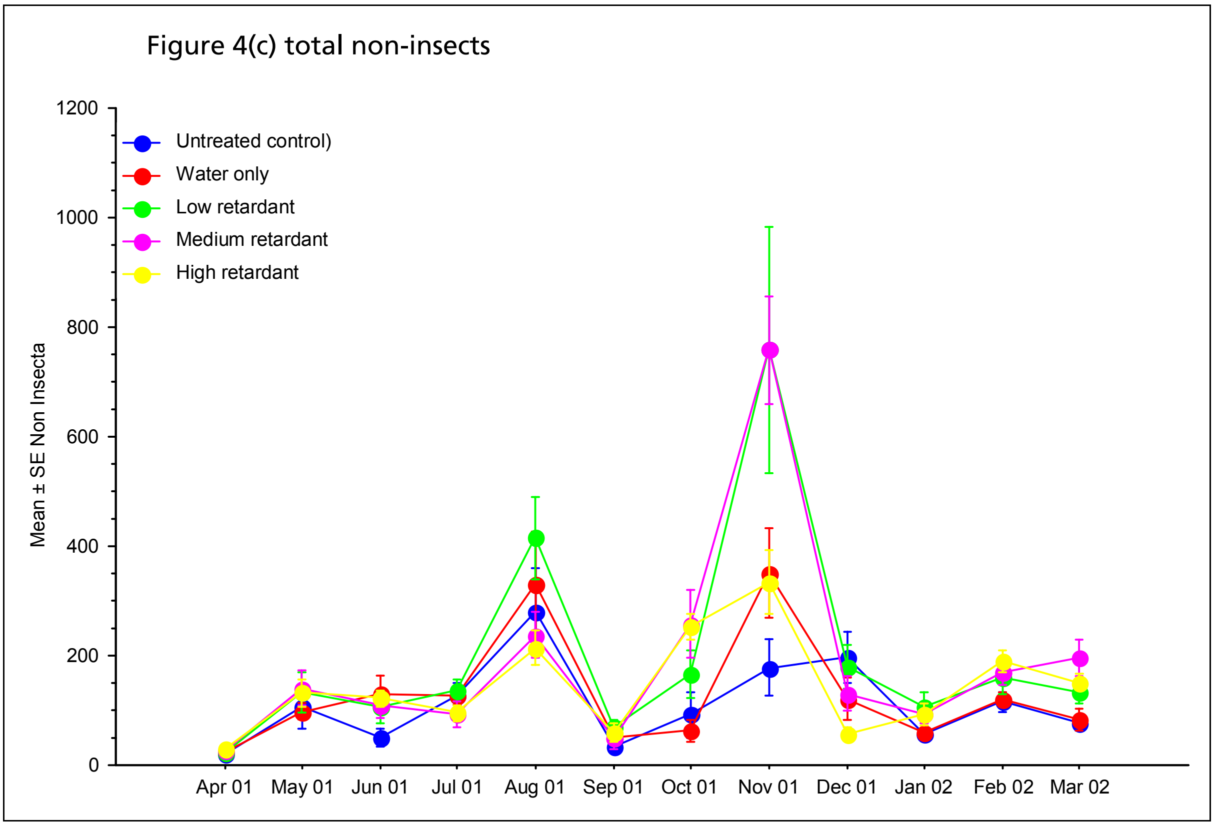


Figure 4(c) total non-insects
Untreated control)
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Non Insecta
0
200
400
600
800
1000
1200
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02

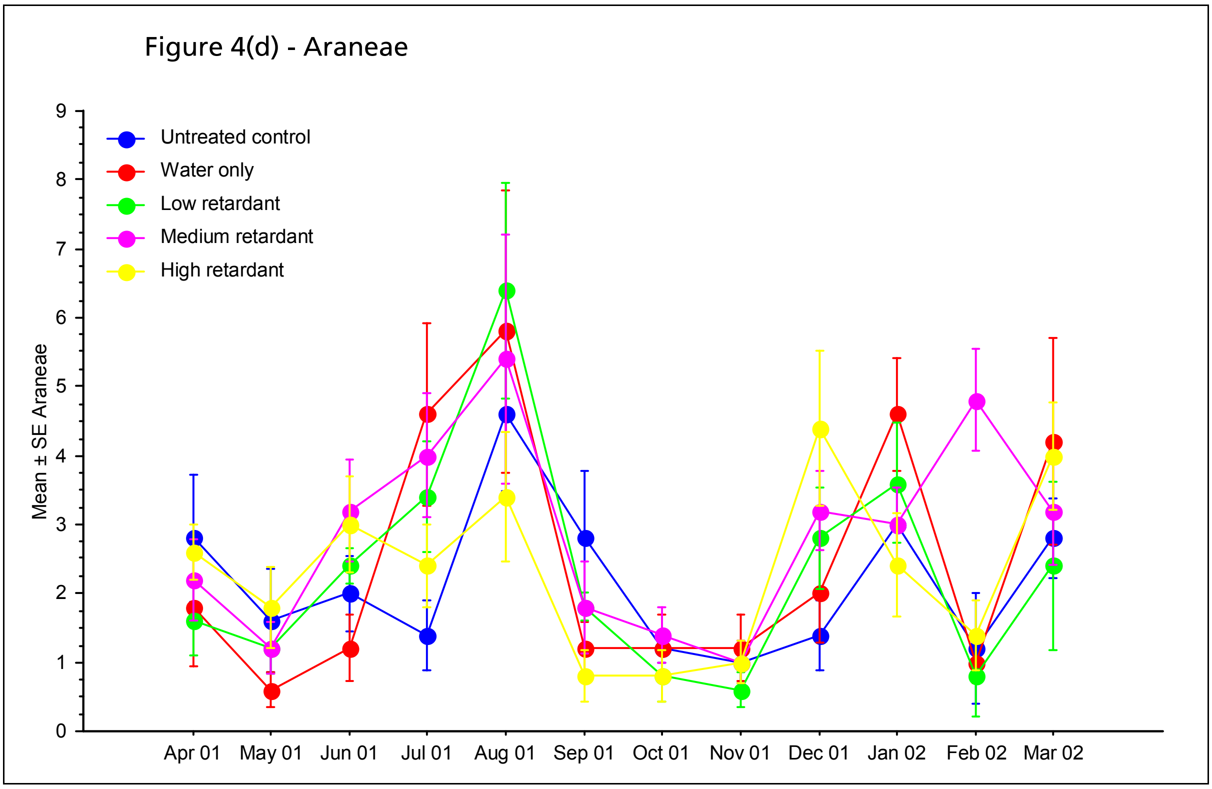


Figure 4(d) - Araneae
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Araneae
0
1
2
3
4
5
6
7
8
9
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02

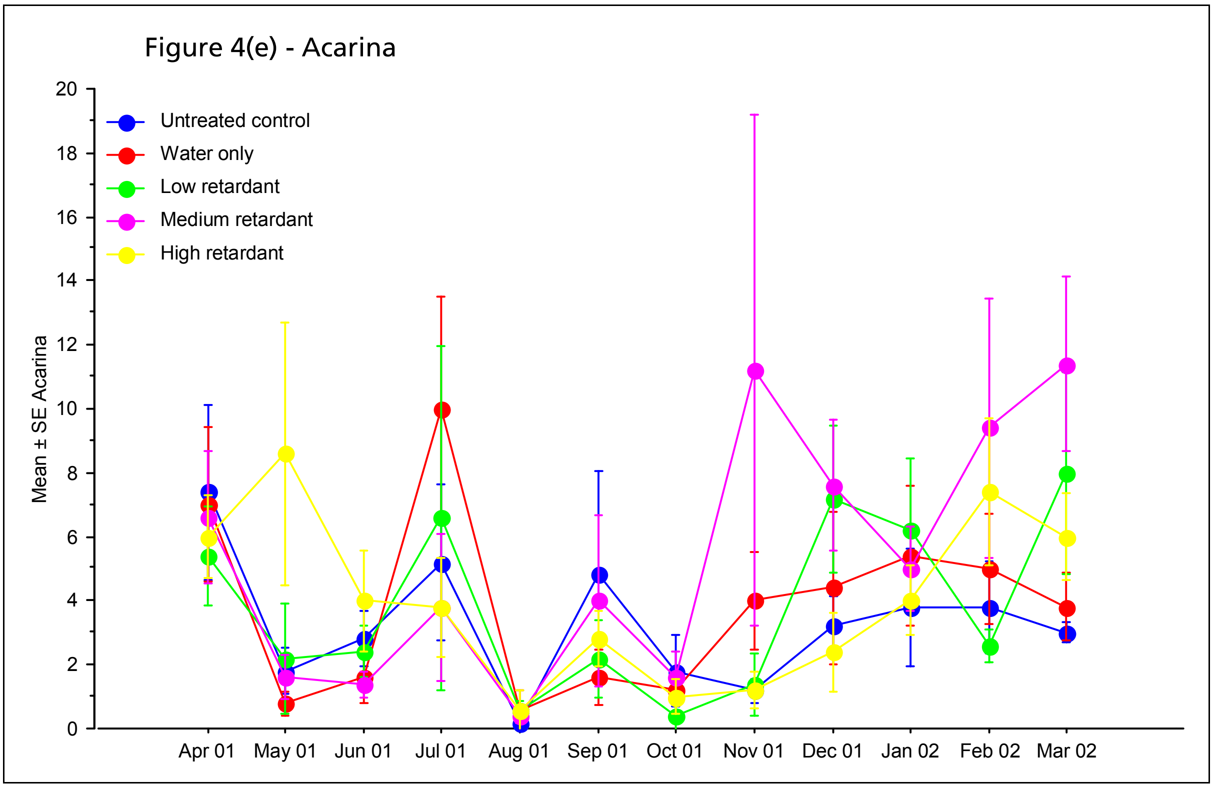


Figure 4(e) - Acarina
Mean ± SE Acarina
20
18
16
14
12
10
8
6
4
2
0
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02

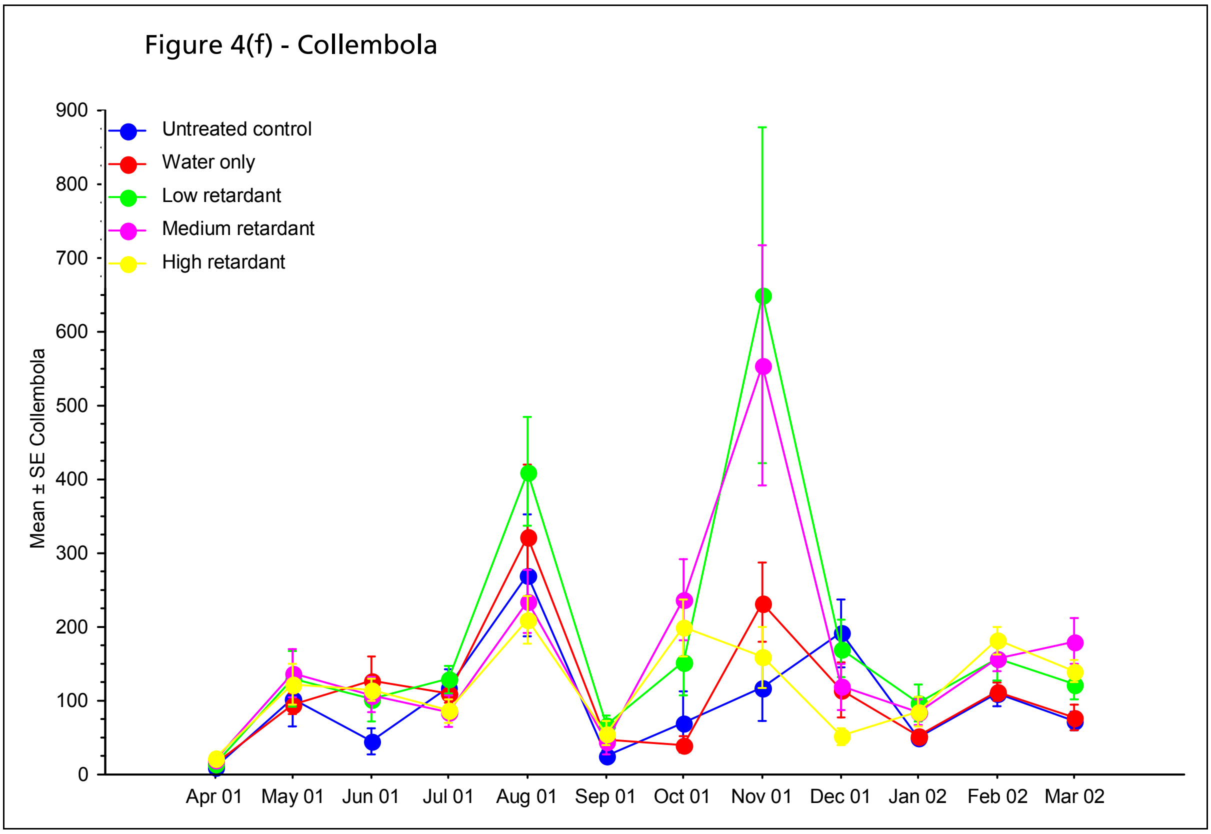


Figure 4(f) - Collembola
Mean ± SE Collembola
900
800
700
600
500
400
300
200
100
0
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02

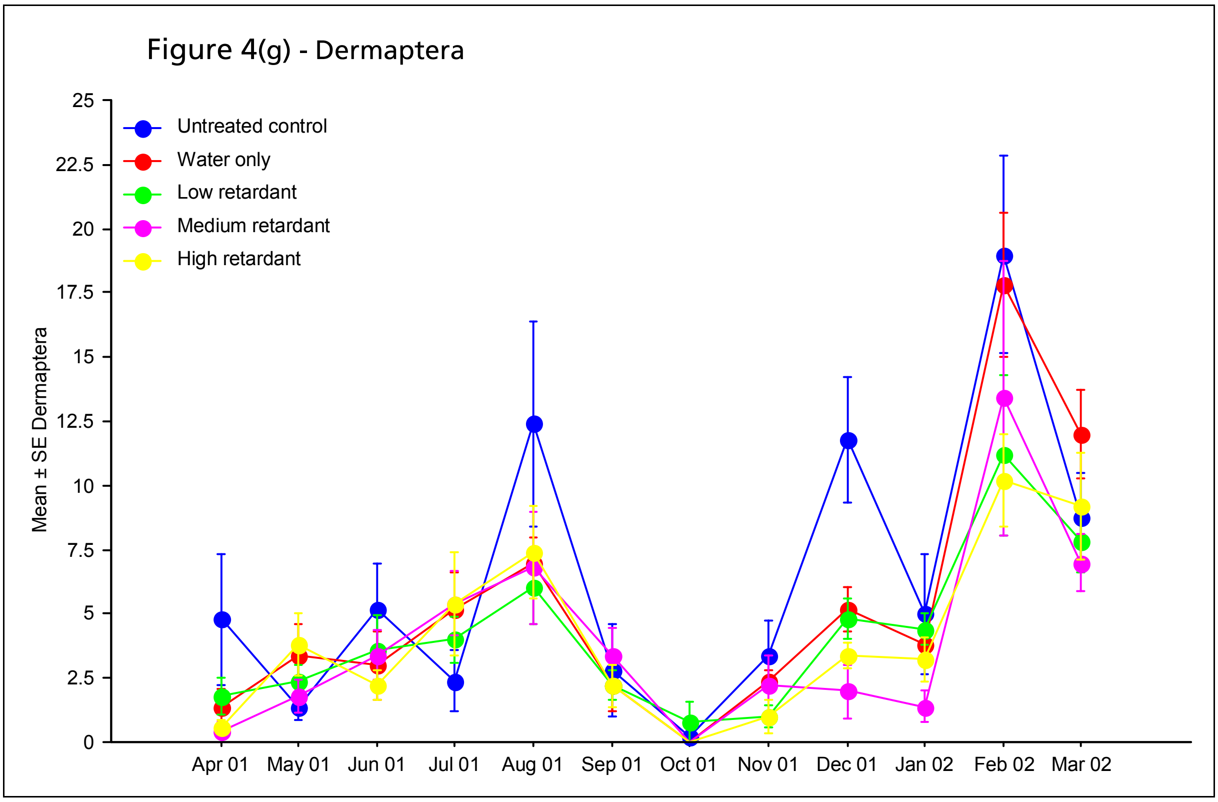


Figure 4(g) - Dermaptera
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Dermaptera
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02

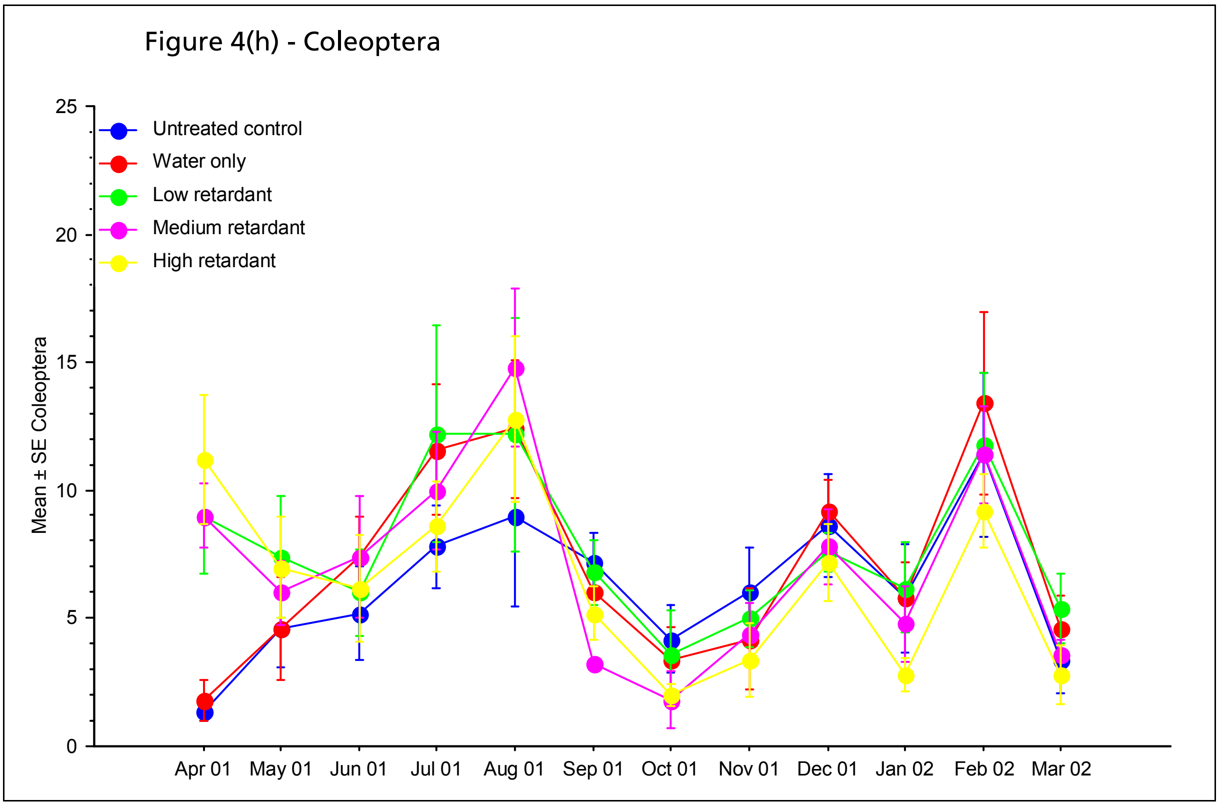


Figure 4(h) - Coleoptera
Untreated control
Water only
Low retardant
Medium retardant
High retardant
Mean ± SE Coleoptera
25
20
15
10
5
0
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 02
Feb 02
Mar 02

Figure 4(i)- Diptera

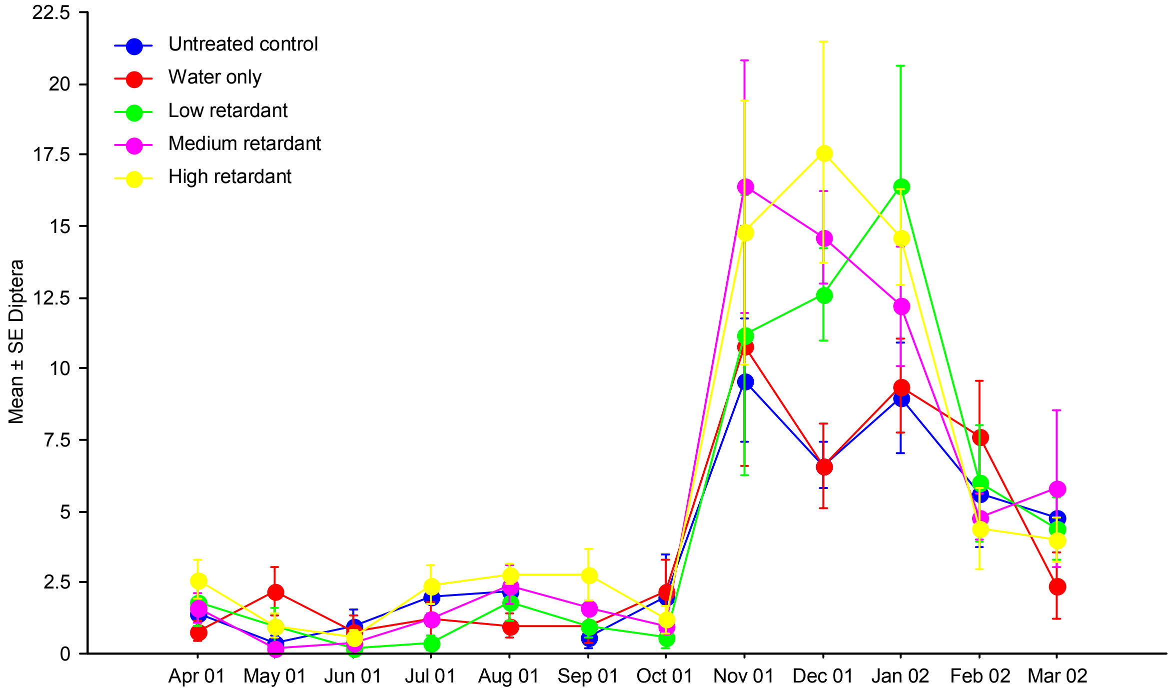
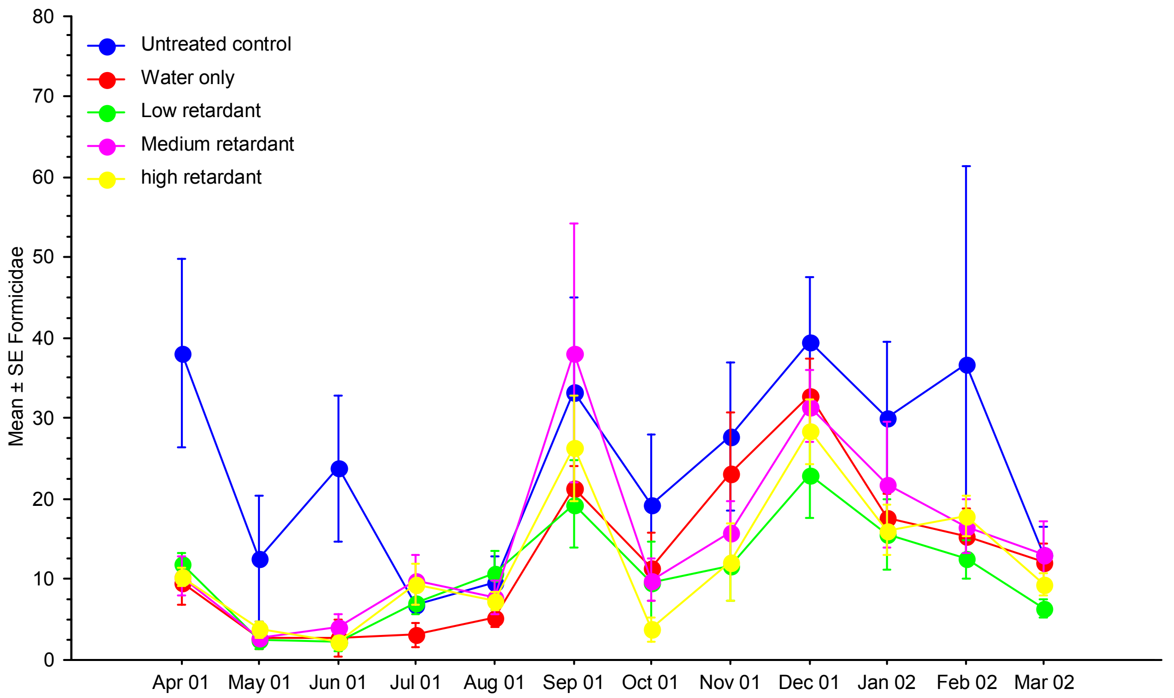


Figure 4(j) - Formicidae



Effects of trial design on trapping efficiency of invertebrates

An examination of the untreated control plots at both study sites found no significant difference in abundance between plots for the major arthropod categories Acarina, Araneae, Diptera, Coleoptera and Dermaptera, indicating trial design had not impacted on trapping efficiency for these ordinal groups. While the Collembola recorded a significant increase in activity in one plot at Marlo ($H = 22.15$, $n = 12$, $P<0.001$), this was not reflected at the Grampians where no significant difference was observed in activity between plots. Conversely, at the Grampians site, a significant increase in Formicidae activity was observed on two plots ($H = 19.42$, $n = 12$, $P<0.001$), while no significant difference in activity was observed at Marlo. Examination of the data indicated that, while there was an increase in Collembola activity at one plot at Marlo, this was not reflected at the other four plots of the randomised block design which all recorded approximately equal levels of activity. At the Grampians site, the increase in Formicidae activity was both in an 'edge' and 'internal' plot of the Latin square design, with the other three plots recording approximately equal activity levels.

Discussion

While the effects of fire on litter invertebrate behaviour and activity to ordinal and sub-ordinal level, in both wildfire and prescribed burning situations, has been examined in detail both within Australia and overseas, this is the first study to examine the effects of fire retardant application on the composition and relative abundance of terrestrial-invertebrates. Previous Australian studies have concentrated on the effects of fire on invertebrates both immediately after and in the years following burning rather than on the effects of suppression activities, with studies by Campbell and Tanton (1981), Abbott (1984), Abbott et al. (1984), Neumann (1991), Neumann and Tolhurst (1991), Collett et al. (1993), Collett and Neumann (1995), Neumann et al. (1995) and Collett (1996, 1998, 1999, 2000) finding that, in general, invertebrate populations recover within two to three years to pre-fire levels. These compare to studies by Springett (1976), Majer (1984) and York (1999; 2000) who found fire altered invertebrate population composition. In terms of the effects of fire retardant application, a review of the available literature shows that, apart from an Australian study examining the effects of retardant application on plants (Bradstock et al. 1987), American studies looking at the effects of fire retardant on earthworms (Beyer & Olsen 1996) and benthic invertebrates (Poulton 1996) and some studies investigating the toxicity of retardant to mammals and birds (Dodge 1970; Boivin & Bailor 1996, Vyas & Hill 1996), very little information exists as to the effects of retardant application on terrestrial plants and wildlife in general and invertebrates in particular (Adams & Simmons 1999; CSIRO 2000). The single study conducted on earthworms found that, of the five different types of retardant applied at 1000 ppm (including Phos-Chek, used in the current study), none was lethal to earthworms and unlikely to reduce populations if applied under field fire-suppression conditions (Beyer & Olson 1996) while the study on benthic invertebrates found higher foam retardant concentrations caused increased mortality over time (Poulton 1996).

In terms of trial design and its effects on invertebrate trapping efficiency, results indicate that no major taxonomic group was affected by the trial layout at both study sites. While a significant difference in Collembola and Formicidae activity was observed at Marlo and Grampians respectively, these changes were either confined to elevated activity within a single plot (Collembola at Marlo) or two plots (Formicidae at Grampians) with all other plots recording approximately equal levels of activity. With reference to the Grampians site, where the Latin square design means some treatment plots are totally surrounded by other plots, no discernible pattern was observed as to the location of the two plots with elevated Formicidae activity in relation to the three remaining plots. Consequently, it appears that site-related rather than trial-design factors were responsible for the differences observed within individual plots and that results from both sites were not influenced by the layout of trial design and pitfall trapping.

With reference to the current study, an examination of both study sites indicated that at least 30 ordinal and sub-ordinal taxonomic groups inhabit the soil surface of heathland ecosystems. Of these groups, 24 (80%)—including the seven 'major' taxa—representing 99.9% of individuals trapped, were common to both study sites; indicating that pitfall trapping gave good comparable results for both sites across the five treatments (Table 1). The only significant variation to this trend was observed within the Copepoda where greater numbers were trapped at the Grampians relative to the Marlo site. However, as the proportions of Copepoda trapped between treatments within both sites remained relatively stable, this appears more indicative of site rather than treatment factors responsible for the variation.

The results of the two-dimensional Chi-square tests conducted on the variables—different treatments within site and the frequency of taxa in the categories: total taxa, total insects and total non-insects—satisfied the null hypothesis in that there was a nil fire-retardant effect, regardless of rate of application, on the frequency of taxa within different treatments. It therefore appears that the application of fire retardant at both study sites had not changed the proportion of ordinal and sub-ordinal taxa totals on the treated plots relative to the untreated control plots. This conclusion is supported by the non-significant results of the Kruskal-Wallis H-tests on the fire retardant treatments for the Shannon-Wiener, Margalef and Pielou ecological indices at the Marlo site, and the non-significant result for the Margalef taxon richness index at the Grampians site (Table 2). While the Shannon-Wiener general diversity index was significantly different at the Grampians due to a significant change in the Pielou index (community evenness), this change in community evenness was due more to short-term bursts of increased activity of the total taxa—predominantly due to the activity of the Collembola within the low and medium retardant treatments during August and November—compared to the untreated control plots (Figures 4a and 4f). As these bursts in activity were confined to single plots within a treatment, it therefore appears that site factors rather than the retardant treatments were responsible for this change in community evenness at the Grampians site.

At both study sites, the non-significant variations between the Acarina and Dermaptera indicate that, despite the application of retardant at low, medium and high rates, these ordinal groups appear to form a stable component of the heathland invertebrate community. This complements the findings of studies concerning Acarina and Dermaptera by Collett (1996; 1998; 1999), Neumann (1991) and Neumann and Tolhurst (1991), in wet and dry sclerophyll eucalypt forests in Victoria, which also found populations remained relatively stable despite the application of fire or being subjected to other site disturbance/alteration factors. This compares however, to studies by York (1999) in coastal blackbutt forests of New South Wales, which found frequent low-intensity fire significantly reduced Acarina population levels.

However, whereas the categories total taxa, total insects, Araneae, Coleoptera and Diptera recorded significant changes in activity at Marlo, these changes were not duplicated within the same categories at the Grampians site where, contrasting the Marlo findings, significant changes in activity were recorded within the total non-insects and Collembola (Table 3). Given changes within these categories were confined to one site only, it appears that unidentified site factors rather than the retardant treatments are responsible for the significant changes observed. This finding is confirmed by the high variability recorded within the same treatment plots between replications, indicating short-term bursts in activity on one or two plots within a treatment were responsible for the significant changes observed within an arthropod category rather than a uniform increase/decrease in activity across all plots within the same treatment across all replications (Figures 3a–j, 4a–j). Furthermore, changes observed were not confined to one particular retardant treatment. Rather, they were spread across all retardant treatments, water only and untreated control plots, further evidence of site- rather than treatment-related factors were responsible for the observed changes. The only arthropod category recording a significant change in activity at both sites was the Formicidae (Table 3). However, these changes were due to a significant reduction in activity on the medium retardant treatment at Marlo and a significant increase on the untreated control at the Grampians within individual rather than across all treatment plots. This indicates that, as with the other changes observed, site- rather than treatment-related factors were responsible.

The findings of this study should be interpreted in a general sense, as the number of ordinal and sub-ordinal groups identified during the study (30 across both sites) were based on cumulative totals of the activity of individual species within those groups. Further research examining the effects of retardant application to family, genus and species level should address the question of whether individual groups at these classification levels are sensitive to fire retardant application. Also, pitfall trapping, while an effective technique for collecting certain taxa (e.g. Formicidae), may not be suitable for collecting other groups (e.g. Neuroptera) that occupy other ecological niches. Consequently, future studies should employ sampling techniques that also target these groups (Collett 2000).

As the study was confined to a single year of sampling in a relatively small area, effects of season and any potential longer-term residual effects of retardant, either directly on invertebrate activity or indirectly through potential alteration of vegetation cover, were not able to be examined. Based on the findings to date, however, it could be inferred that, if no retardant application-related changes occur in the short-term (within one year), these are not likely to translate into longer-term changes. This trend is supported by other studies examining site disturbance, whether by fire or other activities such as logging, which found that, even where the activity of a taxonomic group declined after the disturbance event, recovery to pre-disturbance levels usually occurred within two to three years (Collett 2000; Neumann 1992). Studies conducted by van de Westeringh (1972) and Cooke et al. (1992), examining the effects of the application copper fungicide and aldicarb (an acaricide and nematicide—Crop Protection Publications 1995) in orchards and on soil under wet conditions, found that such applications led to reduced earthworm populations and their predators. These studies, however, concerned potentially hazardous pesticide applications rather than fertiliser-based fire retardants. In forest fire situations, the application of retardant is generally followed by the 'treated' area being subjected to fire; an event not duplicated and examined during the current study. However, given that fire retardant is generally applied to low-intensity rather than high-intensity fires to either extinguish flames or to provide barriers to prevent further spread, the possibility exists of either large areas or small patches carrying unburnt fire retardant material remaining (CSIRO 2000). While little work has been conducted examining the residues after retardant is subjected to fire, the information available suggests that, unless the retardant is subjected to very high temperatures, only partial, incomplete breakdown may occur (CSIRO 2000). Therefore, while further study is required to address the issue of the combined effects of retardant and fire on litter invertebrates, the current study is certainly representative of many operational conditions where retardant is not consumed by fire after application.

Notwithstanding the above issues, it appears that, despite the application of fire retardant at varying rates, there is no significant effect on invertebrate activity at ground level, with any significant change observed due to site-related factors rather than the effects of the retardant itself. While the Formicidae recorded significant changes at both the Marlo and Grampians sites, these changes reflected increased or decreased activity on individual plots rather than representative of the effects of a particular treatment. Future research is required to determine whether retardant causes changes in activity at genus and species levels, as well as over a longer timeframe to examine the effects of season and the residual effects of retardant on invertebrates in heathland ecosystems. The combined effects of retardant followed by fire on invertebrates should also be considered for further study.

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