Surviving Suppression: no detectable impacts of Class A foam on soil invertebrates and some Australian native plants

R. Adams[1], D. Simmons[1], K. Hartskeerl[12] and M. Koehler[13]

[1] School of Ecology and Environment, Deakin University, Burwood, Victoria, Australia.
[2] Land Protection Officer -Mornington Peninsula Shire, Victoria, Australia.
[3] Country Fire Authority, Victoria, Australia.

Corresponding Author. Robyn Adams, School of Ecology and Environment, Deakin University, 221 Burwood Highway, Burwood, Victoria, 3125 AUSTRALIA. telephone 03 9251 7606, facsimile03 9251 7626, email radams@deakin.edu.au

Key Issues: ecological impacts, Class A foam, native plant species, soil invertebrates, minimum impact suppression tactics

Abstract

Firefighting foams (Class A foams) are an effective and widespread firefighting tool which are frequently used in environmentally sensitive areas. Firefighting foams are known to be ecologically damaging in aquatic environments, however their impacts at the plant species or ecosystem level are relatively unknown. Reports of shoot damage to plants, suppressed flowering, and changes in plant community composition suggested that the ecological damage caused by their use may be unacceptable. However, applications of foam to seedlings of some Australian plant species from representative and widespread families, showed no detectable impacts on a range of vegetative growth characteristics. Application of 1.0% foam to heathland soils showed no detectable impacts on soil invertebrate Orders sampled over several months. The results are encouraging for the continued use of Class A foam as a fire suppression technique.

Introduction

Protection of natural resources and conservation values, in addition to the protection of life and property, is now a widespread community expectation of fire management agencies (Sutton 1999; Nature Conservation Council NSW 2000). However, many fire management practices may conflict with biodiversity management (Morrison *et al.* 1996), or have the potential to disrupt critical ecological processes such as in nutrient cycling, energy flow, and hydrology (Lefroy and Hobbs 1992).

Minimum impact suppression tactics, a well accepted part of fire suppression in North America (Mohr 1994), is a 'do least damage' philosophy where the objective is to contain the fire while producing the least possible impact on protected resources. These resources include forest products, soils, fences, livestock, remnant native vegetation, rare species, critical limiting resources such as habitat trees, or in many areas, simply bushland character. Changing community values, and increasing emphasis on biodiversity values, require the re-examination of assumptions about the acceptability of traditional fire suppression activities, particularly where there may be adverse ecological impacts. We now need to ask whether the ecological damage and economic cost caused by wildfire suppression activities is potentially greater than the damage done by the wildfire itself. That is, if the environmental resources being “protected” by fire suppression, do not survive the suppression activities used, those activities are inappropriate in that environmental context (CFA 2003). It is therefore necessary to identify the suppression activities commonly used in natural and other protected areas, and to examine the impact of the activity on the maintenance or recovery of those resources.

Common and potentially damaging suppression activities associated with complete extinguishment of the fire include construction of access tracks and mineral earth firebreaks, tree felling, and use of long-term fire retardants, Class A foams and wetting agents. Nutrient enrichment of nutrient-poor soils from the application of long-term fire retardants, is likely to be irreversible (Adams and Simmons 1999) and cause regional plant community change (Gould *et al.* 2000) and possible biodiversity loss (Connor and Wilson 1968; Specht 1963). Total extinguishment may have negative impacts on animal populations and plant communities dependent on fire for regeneration or habitat maintenance (Bradstock *et al*. 2002), or may prevent fire assisting in the formation and enlargement of critical fauna habitat such as tree hollows (Inions *et al.* 1989; Williams and Faunt 1996). Recovery by natural ecological processes, from damage caused by suppression activities, may not occur. For example, removal of weeds may not be possible, or recovery will occur over an unacceptable time-frame such as the re-growth of large, hollow bearing trees over 100-300 years, or the reduction in soil compaction levels which may take 50-100 years (Caling and Adams1999).

Fire fighting foams (Class A foams) are alkaline surfactants containing foaming and wetting agents, and are used extensively during wildfire suppression in environmentally sensitive areas (Finger 1995; Larsen *et al.* 1999). Foam impacts at the species or ecosystem level are relatively unknown (Norecol 1989; Adams and Simmons 1999; Adams 2000) but they have potential ecological impacts which should be considered before using them near protected resources (Larson and Duncan 1982; Adams and Simmons 2002). In freshwater ecosystems Class A foams are known to adversely affect fish and aquatic invertebrates, and disrupt ecosystem functions (Gaikowski *et al.* 1996; McDonald *et al.* 1997). Studies on Class A foam impacts on terrestrial vertebrate fauna are limited but appear to be less harmful (Vyas and Hill 1994; Vyas *et al.* 1996), and there are almost no data on potential impacts on terrestrial invertebrates (Vyas *et al*. 1996). Reported effects on terrestrial vegetation include exotic species invasion, suppressed flowering, leaf damage, decreased species richness, shoot damage and decreased stem density in some riparian species' populations (Larson and Newton 1996; Adams and Simmons 1999; Larsen *et al.* 1999). Class A foams have the potential to change ecological processes such as nutrient cycling, as surfactants are known to affect soil physical and biological properties including changes to structural stability (Cardinali and Stoppini 1981). Soils may become hydrophobic, altering infiltration rates (Batyuk and Samochvalenko 1981; Sebastiani *et al*. 1981a), and soil microorganism growth may be stimulated (Simonetti *et al*. 1981) and microorganism mobility altered (Overcash 1981).

An assessment of the appropriateness of a suppression activity such as Class A foam application is not possible without data indicating the type and severity of any impacts. During wildfire suppression, Class A foam is applied directly to vegetation, and indirectly to the soil. Results from two studies examining the short-term impacts of Class A form on the growth of several Australian native plant species (Hartskeerl 1999) and on selected soil parameters and soil dwelling invertebrates (Koehler 2001), are reported.

Methods

Site selection and materials

Plant communities in south-eastern and south-western Australia contain a high percentage of sclerophyllous (heathy) species, and habitats are typified by seasonal drought and low soil-nutrient levels (Specht 1994). They are fire prone (Keith *et al.* 2002) and wildfire suppression activities in these communities frequently include the use of Class A foams. Sclerophyllous heathlands are characteristically invertebrate rich (Specht 1994), but populations are known to fluctuate seasonally in response to growth and flowering rhythms (Majer and Greenslade 1988). As invertebrates play a critical role in ecosystem maintenance (Kim 1993), many have the potential to act as biological indicators (Clausen 1986; Disney 1986). Soil macro-invertebrates were sampled from ten heathland sites on French Island, Victoria. Floristic composition of these sites included plant species from the families chosen for the pot trials. Seven plant species representing some Australian plant families typical of sclerophyllous vegetation, were selected for the pot trials. Fabaceae and Mimosaceae are important families involved in nitrogen fixation; Myrtaceae and Poaceae are widespread and dominant families in many Australian plant communities, and Proteaceae are extremely sensitive to changed edaphic conditions, especially changes in nutrient status and symbiotic relationships.

Angus ForExpan S (Angus 1997) Class A foam was used for both studies, and was applied using standard fire service foam proportioning equipment.

Soil properties and macro-invertebrates

Ten 20m x 20m plots, subdivided into twenty-five 4m x 4m quadrats, were randomly assigned to one of five sampling times; T0D (before foam application May 2000), T1D, T7D, T1M and T6M (numbers indicate the time in days (D) or months (M) after foam application). Five quadrats from each plot were sampled at each time. Five plots were left untreated as controls, and Class A foam was applied at maximum field concentration (1%) in May 2000 to the other five. The foam was applied evenly across the sites and readily penetrated the vegetation to form a layer on the soil.

Macro-invertebrates were recovered from a soil sample 30cm x 30cm x 5cm collected from each of the 5 assigned quadrats (50 samples per sampling time). The soil was bagged and sealed until sieved. The large number of samples to be processed in a short time (150 samples in one week) precluded the use of more time-consuming recovery techniques. All individuals collected were counted and identified to Order (Harvey and Yen 1995). Soil water infiltration capacity (ml/sec), soil-water content (%), and soil pH were measured at each sampling interval (Koehler 2001).

Initial examination of the data indicated that the 6 month (T6M) data reflected extreme soil dryness rather than any foam effect. In addition, as Class A foam biodegrades in about 28 days, it was also assumed that foam effects would be most apparent in the four sampling times immediately following foam application. Therefore macro-invertebrate data for the ten common Orders and only the first four sampling times were analysed using two-way ANOVA (SPSS 11.5). Multivariate analysis of all sampling times and all Orders, using the Bray-Curtis similarity measure, and clustering using Ward's method (PATN Belbin 1993), was used to examine overall patterns in the data. Soil parameter data were examined using one way ANOVA (SPSS 11.5).

Native plant species

Fifty individuals of similar size and habit, of each species except *Indigofera australis* (n=24) were selected. All individuals had mature foliage at the time of treatment. Following treatment, plants were grown in the shade-house, watered weekly, and pots rearranged fortnightly. Periodic spraying of all plants using a commercial insecticide was also carried out.

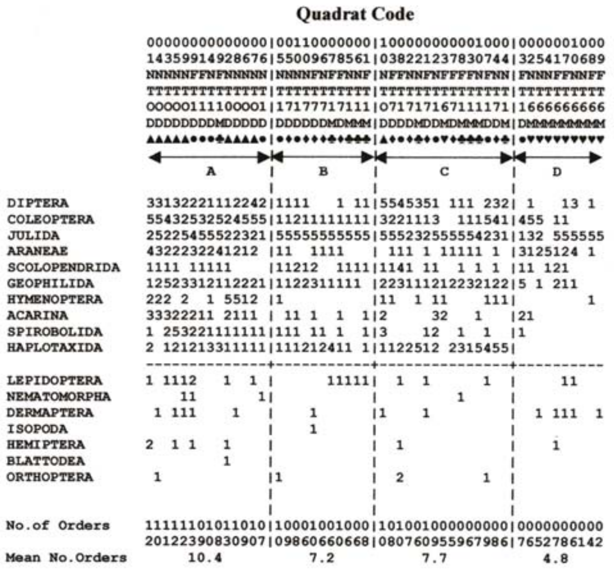

Figure 1 Two-way table of 17 Orders, for all quadrats in the 10 plots over total sampling period (T0D - T6M). Numbers 1 to 5 indicate relative abundance. F = Foam, N = No foam. Sampling intervals T0D▲, T1D●, T7D♦, T1M♣, T6M♥; eg. 09FT1M♣ = plot 09, foam, one month post-application.

Five Class A foam concentrations typical of field concentrations (Colletti 1992) were applied; treatment 1 - 0% (no foam, water only), treatment 2 - 0.1% (foam solution), treatment 3 - 0.3% (wet foam), treatment 4 - 0.6% (fluid foam) and treatment 5 - 1.0% (dry foam) (CFA 1997). Ten individuals of each species were randomly assigned to one of the five treatments. Plants of *Indigofera australis* were divided into three groups of eight individuals, and subjected to treatments 1, 3 and 5 only. Plants assigned to treatment 1 (0% foam) were sprayed with water only, while foam was applied to the other treatment groups. All plants were left undisturbed for 48 hours before being returned to the shade-house and arranged into a randomised block design.

A number of plant growth attributes (eg. stem length SL, number of branches NB, leaf length LL) were measured prior to foam application and plants were grown for a further 14 weeks, when the final set of measurements was taken (Hartskeerl *et al.* in press). Initial and final leaf/phyllode colour was determined using a Munsell Color Chart.

At the termination of the trial, differences among the five treatments and changes over time from pre-treatment to post-treatment were assessed using two-way repeated measures ANOVA for all growth attributes (SYSTAT Software Inc.). Tests for multivariate normality, homogeneity of covariance, and independence were carried out. Mauchly's test of sphericity was used to test that the variances of the differences between values of the attributes being measured was the same for all pairs of treatments. A Power Analysis was also carried out. Newman-Keuls multiple comparisons tests were used to further examine post-treatment differences among the five groups where appropriate.

Results

Soil properties and macro-invertebrates

Water infiltration varied over time with a marked increase six months after application (T6M). However, there was no detectable effect due to Class A foam. Soil moisture (%) was not significantly different between the first four sampling times, but decreased significantly six months (T6M) after application. However, this decrease was associated with a substantial decrease in rainfall during November (Koehler 2001) and there was no detectable effect of Class A foam. Class A Foam is an alkaline surfactant but appears to have no detectable effect on raising soil pH. Initial soil pH was pH5.5 (n=50) and ranged between pH5.1 and pH5.7 after the application of foam.

Seventeen Orders were recorded (Figure 1), of which ten Orders (Diptera to Haplotaxida) were recorded relatively consistently over the sampling period, while individuals from the other seven (Lepidoptera to Orthoptera) were found in very low numbers. The mean number of Orders per plot decreased over time with the lowest number of Orders per plot recorded six months after Class A Foam application. This decrease reflects the decrease in soil moisture content and an increase in temperature at the six month sampling time (T6M) (Koehler 2001).

There were no significant interactions between time and Class A foam for any Orders (Table 1), indicating that there was no detectable effect of foam application. Six of the ten Orders examined showed significant changes in population numbers over the 30 day period.

Multivariate analysis indicated four distinct groups of sampled plots (Figure 2) and two distinct groups of Orders (Figure 1). Julida was widespread and abundant across all plots, while Diptera, Coleoptera, Araneae, Scolopendrida and Geophilida were widespread, but less abundant.

Table 1. Results of two-way ANOVA's for numbers of individuals in ten most common Orders and for four sampling times (T0D – T1M). Orders for which a significant *F*-test occurred for a given term in the model are shown in the appropriate row in the Table for that term. *** $P < 0.001$ etc

Source	*df*	*Diptera Julida Scolependrida Geophilida*	*Coleoptera Acarina Spirobolida*	*Araneae*	*Hymenoptera Haplotaxida*
Between Plots	39				
Amongst Foam levels	1	N.S.	N.S.	N.S.	N.S.
Within Plots	40				
Time	3	N.S.	***	**	*
Foam x Time	3	N.S..	N.S. .	N.S.	N.S.

Clustering of plots indicates a seasonal time sequence rather than any pattern associated with a Class A foam effect. Group A containing mostly samples taken before foam application (T0D▲). Groups B and C contain a mixture of plots and suggest macro-invertebrate presence and abundance over winter-spring. Group D mostly contains samples taken six months after foam application (T6M♥), and indicates Orders with members more abundant in drier soils of late spring–early summer.

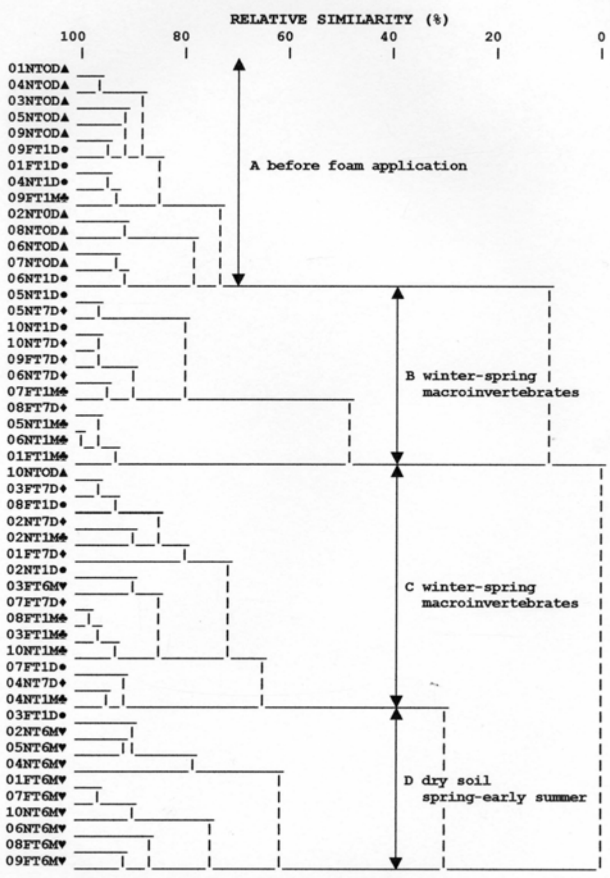

Figure 2 Clustering of all Orders for all quadrats in the 10 plots over total sampling period (T0D - T6M). F = Foam, N = No foam. Sampling intervals T0D▲, T1D●, T7D♦, T1M♣, T6M♥; eg. 09FT1M♣ = plot 09, foam, one month post-application.

Native plant species

At the conclusion of the trial all species except *Indigofera australis* showed significant changes in at least some attributes as a result of plant growth over time (Table 2). There were no significant interactions between time and Class A foam treatment for any growth attribute for any of the seven species examined (Table 2), indicating that there was no significant effect of foam application. Power levels were generally about 0.7 indicating an adequate sample size for detecting differences between treatments. Pre-application and final foliage colour indicated no yellowing or browning of foliage.

Table 2. Results of Repeated Measures ANOVA's of plant attributes for 7 species. Attributes (atts.) for which a significant *F*-test occurred for a given term in the model are shown in the appropriate row in the Table for that term. *** $P < 0.001$ etc. [A]*Indigofera* has $df_{2,20}$. See Hartskeerl *et al.* (in press) for details of all plant growth attributes measured.

Source	*df*	*A. melanoxylon*	*E. polyanthemo*	*Grevillea sp.*	*B .integrifolio*	*H. violacea*	*I. australis*[A]	*P. labillardiere*
Between Plants	**49**							
Amongst Foam levels	**4**	**N.S. all atts.**	**N.S. all atts.**	**N.S. all atts.**	**N.S. all atts.**	**LL***	**N.S. all atts.**	**TTH*****
Within Plants	**50**							
Time	**1**	**SL***, NB*****	**SL***, NB*****	**SL***, NL* LL**, LW** L:W***	**all atts.* exce NSt**	**all atts.* exc IL and L:W**	**N.S. all atts.**	**TTH*****
Foam x Time	**4**	**N.S. all atts.**	**N.S. all atts.**	**N.S. all atts.**	**N.S. all atts.**	**N.S. all atts.**	**N.S. all atts.**	**N.S. all atts.**

Discussion

Field observations of suppressed flowering, and leaf damage in sclerophyllous Australian species (Adams and Simmons 1999), and experimental data indicating weed invasion, reduced species richness in mixed-grass prairie in North America (Larson and Newton 1996), and reduced number of stems/m^2 in some riparian plant communities (Larson *et al.* 1999), suggested that Class A foam was having an impact on some species and on plant community structure. However, this study detected no growth response attributable to Class A foam treatment for any of the seven plant species. Significant changes were recorded for most characteristics over time, but these can be explained by normal phenological changes. Even the two species from the Proteaceae, a family frequently sensitive to environmental and particularly to edaphic changes, showed no detectable effect from Class A foam application.

Invertebrate populations are extremely variable, are largely driven by environmental factors, and responses to disturbance such as Class A foam may be difficult to detect where a broad level of taxonomic resolution such as Order has been used (Friend 1994). However, many of the Orders recovered during this study are predators and have potential as bio-indicators of disturbance, particularly Araneae, Diptera, Acarina and Coleoptera (Friend 1994; Neumann *et al.* 1995). Sampling was designed to maximize the detection of population abundance changes due to Class A foam, however no foam impacts were detected at the Order level. No detectable changes in these indicator groups suggests that the soil processes mediated by other less easily sampled microbiota, continue to function after foam application. The changes in number and abundance of Orders over time is likely to be the result of seasonal changes in soil moisture and soil temperature (Friend 1994), rather than foam.

These results, in conjunction with other field studies (Larson and Newton 1996; Larson *et al.* 1999) are encouraging for the continued use of Class A foams for fire suppression. Typical exposures of invertebrates and plant species to foam do not appear to have detectable impacts, although further examination of soil invertebrates at finer taxonomic level may reveal population changes. Only a few plant species were tested over a limited time, and there are other plant characteristics such as flowering which should be assessed. However it appears that any impacts of Class A foams are relatively small, or dependent on habitat type and environmental conditions at the time of application. Riparian zones (Larsen *et al.* 1999) and aquatic habitats (McDonald *et al.* 1997) are known to be more vulnerable to the negative effects of foams, but where stream protection plans are in place, applications of Class A foams outside these habitats are likely to have minimal long-term effects on surrounding vegetation (Norris and Webb 1989). This study suggests that many plant species, and many soil invertebrates, are capable of surviving Class A foam application during wildfire suppression.

Biodiversity, and ecological processes which show resilience to disturbance such as wildfire, must also be able to survive the fire suppression effort. Where fire suppression activities cause long-term or irreparable ecological damage to natural resources it is incumbent on good managers to examine those activities and incorporate only sustainable environmental suppression practices into their operations (DNRE 1998; Barnes 2000). Firefighting foam appears to be less ecologically damaging than traditional fire suppression techniques, and offers an effective suppression tool for firefighters.

Acknowledgements

We wish to thank the Country Fire Authority, Victoria, Australia for funding the two projects, and Dr. John Aberton (Deakin University) for statistical advice.

References

Adams,R. (2000) *Ecological effects of Class A foams and their impacts on Australian ecosystems.* Report to Country Fire Authority, Victoria, Australia. School of Ecology and Environment, Deakin University, Victoria, Australia.

Adams,R. and Simmons,D. (1999) Ecological effects of fire fighting foams and retardants: a summary. *Australian Forestry* **62**, 307-14.

Adams,R. (2000) Ecological Effects of Class A Foams and Their Potential Ecological Impacts on Australian Ecosystems. Report to Country Fire Authority, Victoria, Australia. School of Ecology and Environment, Deakin University, Victoria, Australia.

Adams,R. Simmons,D. (2002) Potential Environmental Impacts of Wildfire Prevention and Suppression Activities. Report to Country Fire Authority, Victoria, Australia. School of Ecology and Environment, Deakin University, Victoria, Australia.

Angus Fire Armour (1997) Chemwatch Material Safety Data Sheet Angus ForExpan S Class A Foam Concentrate. Angus Fire Armour.

Barnes,H. (2000) Incorporating ecologically sustainable development into the NSW Fire Brigades. *Red Trucks: Green Futures. Ecologically Sustainable Bushfire Management.* Nature Conservation Council of NSW, Sydney. Pp 85-91.

Belbin,L. (1993) PATN – Pattern Analysis Package. CSIRO Division of Wildlife and Ecology: Canberra.

Bradstock,R.A., Williams,J.E. and Gill,M.A. (2002) *Flammable Australia: the fire regimes and biodiversity of a continent*. Cambridge University Press.

Caling, T. M. and Adams, R. (1999) Ecological impacts of fire suppression operations in a small vegetation remnant. Bushfire 99 Proceedings pp. 69-75. Albury, July 1999.

CFA (1997) Classification System for Foam Types. Country Fire Authority, Victoria, Australia.

CFA (2003) Environment Strategy. Country Fire Authority, Victoria. Melbourne.

Clausen,I.H.S. (1986) The use of spiders (Araneae) as ecological indicators. *Bulletin of the British Arachnology Society* **7**, 83-6.

Colletti D.J. (1992) Class A Foam for Structure Firefighting. *Fire Engineering* **145**, 47-57.

Connor,D.J. and G.L. Wilson (1968) Response of a coastal Queensland Heath community to fertilizer application. *Australian Journal of Botany* **16**, 117-123.
Disney,R.H.L. (1986) Assessments using invertebrates: posing the problem. In 'Wildlife Conservation Evaluation'. (Ed. M. B. Usher.) pp. 271-93. Chapman and Hall: London.
DNRE (1998) *Code of Practice for Fire Management on Public Land*. Department of Natural Resources and Environment, Victoria.
Finger, S. (1995) Environmental implications of firefighting chemicals. *Foam Applications for Wildland & Urban Fire Management* **7**, 1-6.
Friend,G.R. (1994) Fire Ecology of Invertebrates – Implications for Nature Conservation, Fire Management and Future Research. In *Fire and Biodiversity – The Effects and Effectiveness of Fire Management*. pp. 155-62. Department of the Environment, Sport and Territories: Canberra.
Gaikowski, M.P., Hamilton, S.J., Buhl, K.J., McDonald, S.F. and Summers, C. (1996) Acute toxicity of three fire-retardant and two fire-suppressant foam formulations to the early life stages of Rainbow Trout *(Oncorynchus mykiss). Environmental Toxicology and Chemistry* **15**, 1365-1374.
Gould,J.S., Khanna,P.K., Hutchings,P.T., Cheney,N.P. and R.J. Raison (2000) *Assessment of the risk of the effectiveness and environmental risk of the use of retardants to assist in wildfire control in Victoria.* Report No. 50 CSIRO Forestry and Forest Products and Department of Natural Resources and Environment, Victoria.
Harvey,M.S., and Yen,A.L. (1995) *Worms to Wasps – An Illustrated Guide to Australia's Terrestrial Invertebrates*. Oxford University Press: South Melbourne.
Hartskeerl, K. (1999) The ecological effects of Class A foam on the growth of native Australian terrestrial plants. Honours thesis, School of Ecology & Environment, Deakin University, Victoria, Australia.
Hartskeerl,K., Simmons,D. and R. Adams (in press) Does firefighting foam affect the growth of some Australian native plants? *International Journal of Wldland Fire*
Inions,G.B., Tanton,M.T. and Davey,S.M. (1989) Effects of fire on the availability of hollows in trees used by the Common Brushtail Possum, *Trichosurus vulpecula* Kerr, 1792, and the Ringtail Possum, *Pseudocheirus peregrinus* Boddaerts, 1785. *Australian Wildlife Research* **16**, 449-458.
Keith,D.A., McCaw,W.L. and R.J.Whelan (2001) Fire regimes in Australian heathlands and their effects on plants and animals. In *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. (Eds RA Bradstock, JE Williams and AM Gill) pp199-237. Cambridge University Press: Cambridge.
Kim,K.C. (1993) Biodiversity, conservation and inventory: why insects matter. *Biodiversity and Conservation* **2**, 191-214.
Koehler,M.L. (2001) The effect of Class A foam on soil parameters and soil dwelling invertebrates. Honours thesis, School of Ecology & Environment, Deakin University, Victoria, Australia.
Larson,J.R., and D.A.Duncan(1982) Annual grassland response to fire retardant and wildfire. *Journal of Range Management* **35,** 700- 703.
Larson,D.L. and W.E.Newton (1996) Effects of fire retardant chemicals and fire suppressant foam on North Dakota prairie vegetation. *Proceedings of the North Dakota Academy of Science* **50**, 137-144.
Larsen,D.L., Newton,W.E. Anderson,P.J. and S.J.Stein (1999) Effects of fire retardant chemicals and fire suppressant foam on shrub steppe vegetation in northern Nevada. *International Journal of Wildland Fire* **9**, 115-127.
Lefroy,T. and Hobbs,R. (1992). Ecological indicators for sustainable agriculture. *Australian Journal of Soil and Water Conservation* **5**, 22-28.

Majer,J.D. and Greenslade,P. (1988). Soil and litter invertebrates. In 'Mediterranean-type Ecosystems. A Data Source Book'. (Ed. R. L. Specht.) pp. 197-226. Dordrecht: Kluwer.

McDonald,S.F., Hamilton,S.J., Buhl,K.J. and Heisinger,J.F. (1997) Acute toxicity of fire-retardant and foam-suppressant chemicals to *Hyalella azteca* (Saussure). *Environmental Toxicology and Chemistry* **16**, 1370-1376.

Mohr,F. (1994) M.I.S.T. - Putting the concept into practice. *Wildfire* **3(4)**, 4-15.

Morrison,D.A., Buckney,T.T. and Bewick,B.J. (1996). Conservation conflicts over burning bush in South-Eastern Australia. *Biological Conservation* **76**, 167-175.

Nature Conservation Council of New South Wales (2000) *Red Trucks: Green Futures. Ecologically Sustainable Bushfire Management*. Nature Conservation Council of NSW, Sydney.

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.

Norecol (1989) *Toxicological Review of Fire Fighting Foams*. Report prepared for Fire Management Forest Protection Branch, Ministry of Forests and Lands, Victoria, British Columbia by Norecol Environmental Consultants Ltd., Vancouver, British Columbia, Canada.

Norris,L.A. and Webb,W.L. (1989) *Effects of Fire Retardant on Water Quality* General Technical Report PSW-109 pp 79-86. U.S. Department of Agriculture Forest Service, USA.

Overcash,M.R. (1981) *Decomposition of Toxic and Nontoxic Organic Compounds in Soils*. Michigan, Ann Arbor. pp. 349-360.

Specht,R.L. (1963) Dark Island Heath (Ninety-Mile Plain, South Australia) VII. the effect of fertilizers on composition and growth, 1950-60. *Australian Journal of Botany* **11**, 67-94.

Specht,R.L. (1994). Heathlands. In *Australian Vegetation*. (Ed. R. H. Groves.) pp. 321-44. Cambridge University Press: Cambridge.

Sutton,F., Keats,J., Dowling,J. and Doig,C. (1999) *Bush Fire Management Conference Proceedings: Protecting the Environment Land, Life and Property*. Nature Conservation Council of NSW, Sydney, Australia 27-28 February 1998.

Vyas,N.B. and Hill,E.F. (1996). Toxicity of fire retardant chemicals and fire suppressant foams to vertebrate and invertebrate wildlife species. pp. 128- 131. In: G.S. Ramsey (ed) Proceedings International Wildland Fire Foam Symposium and Workshop. Natural Resources Canada, Petawawa National Forestry Institute, Information Report PI-X-123.

Vyas,N.B., Spann, J.W. and Hill,E.F. (1996) Effects of Silv-Ex on terrestrial wildlife. *Proceedings of the North Dakota Academy of Science* **50**, 150-1.

Williams,M.R. and Faunt,K. (1996) Factors affecting the abundance of hollows in logs in jarrah forest of south-western Australia. *Forest Ecology and Management* **95**, 153-160.