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Ecological Effects of Fire Fighting Foams and Retardants

Robyn Adams and Dianne Simmons

School of Ecology and Environment, Deakin University (Rusden), Victoria, Australia.

radams@deakin.edu.au

Abstract

The use of fire fighting chemicals in Australia is increasing, yet few data are available to allow evaluation of their potential environmental effects on Australian ecosystems. These chemical retardants and foams are used extensively in natural areas with high environmental value, and there is a need to evaluate the effects of the fire compared with the effects of the fire retardants and foams. A summary of the data available suggests that there is significant potential for damage to terrestrial vegetation from fire retardants, and to aquatic ecosystems from fire fighting foams. There is a need to quantify the impacts of foams and retardants on native vegetation, and verify the effects of foams on aquatic organisms. Unnecessary use of retardants and foams for prescribed burning operations should be avoided, however foams may be the most appropriate and least damaging tool for bushfire suppression where the ecological costs of traditional suppression methods are high.

Introduction

Fire fighting retardants and foams are rapidly gaining acceptance as effective and efficient tools by fire management agencies in Australia (Rawet *et al.* 1996). In the United States during 1992, 91 million litres of ammonium based long-term retardant was used (McDonald *et al.* 1996), enough concentrate was sold to make 160 million litres of foam (Larson and Newton 1996), and in Western Australia 15% of the 1991/92 fire suppression budget was spent on fire fighting chemicals (Rawet *et al.* 1996). Within Australia, short-term fire suppressant foams (Class A foams) are gradually replacing long-term fire retardants. These foams are formulations composed principally of surfactants, and act by increasing water efficiency. The long-term fire retardants are effectively fertilizers, composed of ammonium phosphate and ammonium sulphate salts, which act by forming a combustion barrier between the fire and the fuel.

Worldwide, most fire fighting chemicals are used in natural areas, in areas of high wilderness value, or in areas of high landscape value, and in Australia, fire fighting chemicals are used almost exclusively in these contexts. The environmental effects of fire retardants have been of concern since the 1970s (Dodge 1970), but overall, little consideration has been given to the unwanted vegetation changes of weed invasion and reduced species diversity (Larson and Newton 1996) caused by additions of nitrogen and phosphorus to soils naturally low in these nutrients. In Australia, many of the most fire prone communities are comprised of sclerophyllous species adapted to very low nutrient levels (Specht 1981; Barlow 1994), and as early as 1977 concerns were

raised over the use of phosphate based retardants in these communities (Gill 1977). However, more than 10 years after Bradstock *et al.* (1987) wrote that "...the effects of retardant usage on Australian vegetation have not been determined...", few advances have been made in investigating the effects of fire fighting chemicals on vegetation.

Slightly more is known of the environmental impacts of these chemicals on fauna (eg. Gaikowski *et al.* 1996a; McDonald *et al.* 1996; Vyas and Hill 1994). The available data indicates that entry of fire fighting chemicals into aquatic environments could adversely affect aquatic invertebrates, and disrupt ecosystem functions (McDonald *et al.* 1997), but no studies have been carried out on Australian species, and little information is available to enable an assessment of the short-term fire suppression gains from these chemicals compared with their potential longer-term impacts on vegetation, wildlife or aquatic resources.

Detailed toxicity data for specific formulations are available on the product fact sheets and material safety data sheets produced by individual manufacturers, and in a number of summary reports and independent investigations (eg. Finger 1994; Labat-Anderson 1994; 1996; Hamilton *et al.* 1998). This paper aims to draw together the data on the environmental impacts of fire fighting chemicals, and present a summary which can form the basis for an evaluation of the impacts of fire retardants and foams in Australian ecosystems.

Long-Term Fire Retardants

Commonly used long-term retardants are Phos-Chek D75-F, Phos-Chek D75-R and Fire-Trol GTS-R. These are mixtures of diammonium sulphate, diammonium phosphate, monoammonium phosphate, gum thickeners, iron oxide colouring agent, and preservatives (Hamilton *et al.* 1998; Solutia 1998). Long-term fire retardants are typically fertilizer salts which are mixed with water to ensure uniform dispersal. Even after the water has evaporated, the retardant remains effective until it is removed by rain or erosion (USDA 1998a). They form a combustion barrier after the evaporation of the water carrier, and their effectiveness depends on the amount of retardant per unit surface area. The ammonium salts chemically combine with cellulose as the fuels are heated (Hamilton *et al.* 1998), effectively removing the fuel.

Short-Term Retardants (foams)

Unlike the long-term retardants which remain effective after the water has evaporated, short-term fire retardants depend on the water they contain to retard or suppress the fire (USDA 1998a). Rural fire fighting foams (Class A foams) are a sub-category of short-term retardants (or suppressants). Commonly used foams include Ansul Silv-Ex, Angus ForExpan S, Fire Quench, 3M Firebreak and Phos-Chek WD-881, and all contain surfactants, foaming, and wetting agents. The foaming agents affect the rate at which water drains from the foam, and how well it adheres to the fuel. The surfactants and wetting agents increase the ability of the drained water to penetrate fuels thus reducing their ability to ignite. Fuels are insulated from heat, and air contact is also reduced. These retardants lose their effectiveness once the water has evaporated or drained from them (USDA 1998a). Foams are typically applied in the field at concentrations between 0.1% and 1.0%.

Effects of Fire Fighting Retardants and Foams on Vegetation

Very few studies into the ecological effects of fire retardants or foams on vegetation have been carried out. In Australia, retardant chemicals approved by the USDA Forest Service are used, but only Bradstock *et al.* (1987) have examined the responses of Australian plant species to retardants. Vegetation studies in North American ecosystems have indicated some potential causes for concern. For example, annual grassland in California doubled its biomass from approximately 6 t/ha to 12 t/ha following application of diammonium phosphate (DAP - high N and P) retardant (Larson and Duncan 1982). Native legumes germinated, but failed to establish on retardant-treated areas, and it was suggested that nitrogen from the ammonium based retardant was the limiting factor in legume re-establishment. Preferential grazing by cattle of retardant-treated areas was also reported (Larson and Duncan 1982). Phos-Chek G75-F, a long-term fire retardant containing monoammonium

phosphate and ammonium sulphate, produced similar biomass increases in prairie species in North Dakota (Larson and Newton 1996), and the weedy species *Poa pratensis* (Bluegrass) was the dominant grass at the site. Phos-Chek G75-F treatment appeared to inhibit leaf production in some species, and treated plots recorded depressed species richness (Larson and Newton 1996). Ammonium sulphate retardant tested on *Eucalyptus-Angophora* dominated vegetation in New South Wales (Bradstock *et al.* 1987) resulted in leaf death within a week of treatment, which continued for many months. No tree mortality was recorded. Foliage damage to understorey shrubs varied, and was related to the degree of retardant cover during treatment. Individuals of *Dodonaea triquetra* (Large-leaf hop-bush) and *Acacia longifolia* (Sallow Wattle) died, but no mortality of *Leptospermum attenuatum* (Paperbark tea-tree) was recorded. Decreases in cover were also recorded one year after treatment for 19 of 45 species in the understorey of retardant treated areas, compared with a decline in cover of four species in the untreated area (Bradstock *et al.* 1987). Mature individuals from the Myrtaceae, Poaceae, and most of the Proteaceae showed no overall decline in cover, but all five species from the Fabaceae showed decreases in cover in treated plots, and two of the three species from the Mimosaceae also decreased in cover. This is consistent with the decreases in native legumes reported by Larson and Duncan (1982) in response to ammonium-based retardants.

The response of prairie vegetation in North Dakota to the ammonium-based foam suppressant Silv-Ex, indicated a decrease in overall species richness in treated plots (Larson and Newton 1996), and Silv-Ex treated plants of *Symphoricarpos occidentalis* (Snowberry) showed shoot damage and symptoms of senescence. An increase in insect herbivory on Silv-Ex treated species was also recorded (Larson and Newton 1996). Silv-Ex also temporarily suppressed flowering in *Sprengelia incarnata* (Pink swamp-heath) (pers. com. T. Blanks, Parks & Wildlife Service Tasmania 1998) and ForExpan S, a similar ammonium-based foam, may cause leaf damage in *Banksia marginata* (Silver banksia) (pers. com. M. Loofs, Geography and Environmental Studies, University of Tasmania 1998) in Tasmanian heathy vegetation.

The persistence of effects of retardants and foams may be dependent on vegetation type (Larson *et al.* in press). Effects may be influenced by post-application weather patterns (Larson and Duncan 1982), particularly above (Larson and Newton 1996) or below (Hamilton *et al.* 1998) average rainfalls after retardant applications. Repeated applications of 1% Silv-Ex foam to birch, aspen and poplar resulted in minimal leaf damage to aspen only, and in trials of Silv-Ex on a stand of spruce and pine, lack of foliage damage was attributed to the washing effects of heavy rain (Stechishen 1988a in Norecol 1989).

Effects on Terrestrial Fauna

The toxicities of a number of retardants and foams were tested on American kestrel (*Falco sparverius*), Red-winged blackbird (*Agelaius phoeniceus*), and White-footed mouse (*Peromyscus leucopus*) (Vyas and Hill 1994). White-footed mouse showed no mortality or signs of sub-acute toxicity for any product tested. However, Silv-Ex foam caused periods of stupor and lack of coordination, but no mortality, in exposed kestrels, and some mortality of Red-winged blackbirds exposed to two retardants was recorded (Vyas and Hill 1994). Exposure to 0.3% Silv-Ex foam produced no effects on the survival rate or population size of Meadow mole (*Microtus pennsylvanicus*), and no effects on ants were recorded (Vyas *et al.* 1996).

Effects on Fish

Early life stages of Fathead minnow (*Pimephales promelas*), Rainbow trout (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*) were examined for acute toxicity to three fire retardants, Phos-Chek D75-F, Fire-Trol GTS-R and Fire-Trol LCG-R and two foams, Phos-Chek WD-881 and Silv-Ex (Gaikowski *et al.* 1996a; 1996b; Buhl unpublished). The two foams were 10 times more toxic for Rainbow trout and Chinook salmon, and between 10-258 times more toxic for Fathead minnow, than the fire retardants tested. The life stage of the exposed salmonids and

minnows had a significant impact on the toxicity of the formulation. Eggs and eyed-eggs were almost always more resilient than later life stages, and fry which were actively swimming in search of food were the most sensitive (Gaikowski *et al.* 1996a; 1996b).

Effects on Aquatic Invertebrates and Algae

The same three retardants and two foams which were tested on fish were also tested on two aquatic invertebrates *Daphnia magna* (*Daphnia*) (McDonald *et al.* 1996) and *Hyalella azteca* (an amphipod) (McDonald *et al.* 1997), and on the algae *Selenastrum capricornutum* (McDonald *et al.* 1996). The two foams were between 10 to 20 times more toxic to *Daphnia*, and 2 to 5 times more toxic to *Hyalella*, than the three long-term retardants. Results for the algae were inconsistent, but some increase in biomass was recorded. Mayfly nymphs (*Epeorus albertae*) have also been shown to be sensitive to Silv-Ex foam, but both Mayfly nymphs and Stonefly nymphs (*Hesperoperla pacifica*) were relatively unaffected by the retardant Phos-Chek D75-F (Poulton 1994).

Increased toxicities of fire retardants and foams over time have also been recorded for *Daphnia* (McDonald *et al.* 1996) and for *Hyalella* (McDonald *et al.* 1997), and although dilution and degradation is relatively rapid (Phos-Chek WD-881 80% in 21 days; Silv-Ex 37% for 0.5% solution in 20 days), successive *Daphnia* (Lesyuk *et al.* 1983) and algal generations may be exposed to toxic amounts (McDonald *et al.* 1996).

The toxic component of retardant chemicals in aquatic systems is ammonia (McDonald *et al.* 1996), and fish are less tolerant than are macroinvertebrates. In contrast, the higher toxicities of foams to aquatic invertebrates such as *Daphnia* and *Hyalella* is due to the surfactants they contain, which lower the surface tension of water and decrease the ability of aquatic organisms to obtain oxygen (McDonald *et al.* 1996). Surfactants also alter the permeability of biological membranes (Helenius and Simons 1975) and allow increased uptake of inorganic and organic pollutants already present in aquatic systems (Hamilton *et al.* 1998). Many fire retardant chemicals also contain flocculants such as guar gum which may inhibit respiration and egestion in bottom-dwelling invertebrates such as *Hyalella azteca* (Hargrave 1972; McDonald *et al.* 1997). No data are available on the effects of wetting agents on aquatic species, but it is likely that their effects are similar to those of foams (Labat-Anderson 1996).

Discussion

Angus ForExpan S fire suppressant foam is probably the most widely used foam at present in Australia. However, no independent quantitative data on its effects on either terrestrial flora and fauna, or on aquatic organisms has been published. However, the chemical compositions of the foams Silv-Ex and ForExpan S appear quite similar (Ansul 1998; Angus Fire Armour 1997; Hamilton *et al.* 1998) and the environmental effects recorded experimentally for Silv-Ex (eg. Gaikowski *et al.* 1996a; 1996b; Larson and Newton 1996; McDonald *et al.* 1996; 1997; Vyas and Hill 1994) are likely to be similar for Australian plants and animals exposed to ForExpan S.

Foams have been assumed to be non-toxic to vegetation as they are principally composed of surfactants, however the reports of shoot damage, suppressed flowering, and foliage death in response to Silv-Ex and ForExpan S foams are cause for caution in their use. Changes in species richness and the possible inhibition of leguminous species recovery in responses to retardants need to be verified for Australian plant communities, especially as fire is a primary regeneration stimulus in these species. The increases in biomass of terrestrial plants and algae in response to ammonium based retardants is not unexpected and is explained by the increase in available nitrogen. However, the competitive advantage of weedy species such as *Poa pratensis* in response to long-term retardant application is cause for concern where these fire fighting chemicals are used to combat fires in natural areas.

Although no toxicological studies appear to have been carried out on any Australian native vertebrates, the long-term effects of fire retardants and foams appear to be minimal. Environmental risk assessments for fire fighting chemicals carried out for seven north American ecoregions (Labat-

Anderson 1996) indicated no adverse effects of foams on terrestrial vertebrates, and that long-term retardants posed risks to only two bird species (blue jay and wild turkey) and one mammal species (rabbit).

However, the potential for adverse impacts on aquatic species appears to be high. Fire fighting chemicals, particularly foams, are applied in the field at concentrations in the range 0.1% to 1.0%, which are greater than the acutely toxic concentrations reported for a range of organisms, and Hamilton *et al.* (1998) calculate that a 1% field application of Silv-Ex foam would need to be diluted up to 50,000 times to reach safe concentrations. Dilution may occur rapidly in fast flowing streams, but toxic levels are likely to persist for some time in static water bodies (USDA 1998b). Norris and Webb (1989) suggest that applications of fire retardants which fall outside the riparian zone will have minimal long-term effect on water quality, and recommend that stream protection and application plans be included as part of overall fire management pre-planning.

Accidental applications and spills of fire retardants into streams have been implicated in fish kills (Minshall and Brock 1991), and simulated exposures of aquatic species in the U.S. to accidental spills, indicated that both foams and retardants would have adverse effects in all ecosystems (Labat-Anderson 1996). An assessment of the impacts of fire fighting chemicals, especially foams, on aquatic systems in Australia appears to be a very high priority given their widespread, and increasing use, and their generally negative impacts on aquatic invertebrates.

Summary

The increasing use of fire retardants and foams in natural areas with high conservation value highlights the need for a comprehensive evaluation of their potential ecological impacts in unique Australian ecosystems. The use of fire retardants in Australia is relatively limited, but the overall low toxicity and effectiveness of the foam suppressants makes them valuable tools for bushfire fighting. However, they have an ecological cost which must also be considered (Larson and Duncan 1982). The likelihood of vegetation damage from retardants is high, and Larson and Newton (1996) suggest that the use of both fire retardant chemicals and foams be avoided for prescribed burns because of the high potential for weedy grass invasion and the possibility of reduced species richness. The potential for disruption of aquatic ecosystems by foams is also high (McDonald *et al.* 1996). On the other hand, fire fighting foams may be the most appropriate and least damaging tool for bushfire suppression where the ecological costs of traditional fire suppression techniques such as rakehoe lines and bulldozer trails are too high (Mohr 1994), or where rapid aerial suppression is the only alternative.

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