Effects of fire retardants on vegetation in eastern Australian heathlands - a preliminary investigation

Research Report No. 68

T. L. Bell

Forest Science Centre
Creswick

November 2003

This report was commissioned by

Fire Management
Department of Sustainability and Environment

Victoria

For further information contact:
DSE Customer Service Centre 136 186

ISBN 1 74106 897 5

Department of Sustainability and Environment,
PO Box 500, East Melbourne, Victoria, 3002.

www.dse.vic.gov.au/fires

Cover photograph: Heathland, Stephen Muek (Biosis research Pty Ltd). Inset photograph: Fire retardant bomber, B.Rees/DSE

The full series of Fire Research Reports can be found on:
www.dse.vic.gov.au/fires (fire management; fire research)

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.

Gary Morgan AFSM

CHIEF FIRE OFFICER
Department of Sustainability and Environment

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

Contents

List of tables and figures

Executive summary

A preliminary study investigating the effects of the fire retardant, Phos-Chek D75-R (Phos-Chek) on typical heathland vegetation is described. Companion studies investigating the effects of the fire retardant on invertebrate communities and soil chemistry are reported elsewhere. Heathland ecosystems were chosen for this study as they are relatively low in nutrient availability and plants adapted to these conditions are likely to show greater growth response than plants from nutrient-rich ecosystems. Two sites in Victoria were selected; Victoria Valley in the Grampian Ranges and near Marlo in East Gippsland. Both sites were located adjacent to small airstrips and supported heathland vegetation that was long unburnt and relatively undisturbed. Plots were arranged in either a Latin square (Grampians) or randomised block design (Marlo) and subjected to either no addition of fire retardant ('control' and 'water only' treatments) or single applications of increasing concentrations of retardant (0.5, 1.0 and 1.5 L fire retardant m^{-2}).

A single application of Phos-Chek did not significantly change species composition or projected foliage cover of the major life forms of native vegetation which included herbs, moss, grasses, sedges and woody shrubs. It should be noted that assessments were limited in scope (i.e. broad vegetation classifications used with measures of cover, abundance, shoot growth and plant height) as this was considered to be a preliminary investigation and that data was only collected over a 12-month period. The application of Phos-Chek appeared to enhance weed invasion, particularly at higher levels of application. Death of shoots and whole plants of the targeted species, *Allocasuarina paludosa*, *Banksia marginata*, *Leptospermum continentale* and *L. myrsinoides* was recorded after application of fire retardant and was observed to affect other species including *Hakea teretifolia*, *Kunzea ericoides* and *Sprengelia incarnata*. The fire retardant had a 'fertiliser effect' and generally increased shoot growth of *Allocasuarina paludosa*, *Banksia marginata*, *Leptospermum continentale* and *L. myrsinoides* but did not significantly increase the overall height of target plants.

A number of recommendations are made including the need for a more detailed and longer-term study, glasshouse trials investigating response of heathland species to fire retardant, investigation of the potential for promotion of weed invasion in more remote locations and study of the interaction of fire and retardant on vegetation and soils.

Introduction

Fire retardants are widely used to assist in strategic containment of bushfires. They are classified as having either a short- or long-term effect according to how reactive they remain once the water carrier has evaporated (Chandler et al. 1983; van Meter et al. 1985). Long-term retardants are most often used when access by ground crews is difficult, conditions are unsafe or when there is a known delay in crews arriving at the fire scene. The dry retardant is mixed with water to form a thick slurry, and applied to unburnt vegetation by dropping from a fixed wing aircraft or from a helicopter. The retardant acts as a barrier in front of the bushfire and, as the fire burns into vegetation coated with the retardant, the chemical reaction that occurs modifies combustion (see below). This reaction largely prevents flaming combustion, significantly retarding the advance of the fire front for up to 18 hours or more (CSIRO 2000). Retardants also act to reduce fire intensity and are useful in controlling spot fires that have the potential to outflank established control lines. 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; covering about 10% of all fires on public land (CSIRO 2000).

Phos-Chek D75-R (hereafter referred to as Phos-Chek), the long-term retardant currently used by DSE, is a proprietary product manufactured by Solutia in the US and distributed through PhOZChem Pty Ltd in Australia. This product, and all other retardants used in Victoria, have been rigorously tested and approved by the United States Department of Agriculture (USDA) for effects on environmental and human health and, as such, is endorsed by the Australasian Fire Authorities Council. During 1998 and 1999 CSIRO Forestry and Forest Products conducted an assessment of the effectiveness and environmental risk of the use of fire retardants in Victoria. While the review concluded that "…the potential risk to human health is considered to be very small…" (CSIRO 2000), the consultants recommended that further research into the impacts of retardant on specific Australian ecosystems should be undertaken. Following publication of the CSIRO report in 2000, the-then Department of Natural Resources and Environment committed to examine the effect of retardants and foams on natural terrestrial and aquatic environments in Victoria.

Chemical and environmental effects

Long-term fire retardants are generally based on mixtures of ammonium sulphate or ammonium phosphate (Dodge 1970; Chandler et al. 1983). The principle component of Phos-Chek is diammonium sulphate—$(NH_4)_2SO_4$; it also includes diammonium phosphate—$(NH_4)_2PO_4$, monoammonium phosphate—$(NH_4)PO_4$, natural gum thickeners, iron oxide for colouring and certain preservatives and anti-corrosives (CSIRO 2000). The effectiveness of a retardant depends on the concentration of the salt in solution and the degree to which it adheres to the surface of fuel (Chandler et al. 1983). On heating, the ammonium salts of sulphate and phosphate convert to sulphuric and phosphoric acid (H_2SO_4 and H_3PO_4) with the release of sulphur dioxide (SO_2), ammonia (NH_3) and nitrogen oxides (NO_x). This reaction suppresses the flaming combustion of fuel and promotes charring and carbonisation (Chandler et al. 1983; CSIRO 2000).

Phos-Chek is delivered at an operational coverage of approximately 1 L m^{-2} to retard a fire of 2000 kW m^{-1} intensity. It has been estimated that about 10% of the total drop area may be covered with retardant at rates up to 2 L m^{-2} (CSIRO 2000). At this rate of coverage, nitrogen (N) and Phosphorus (P) inputs equal 337 kg N ha^{-1} and 94 kg P ha^{-1} (CSIRO 2000). The concentration of fire retardants at ground level is greatest in the core area with lower concentrations radiating outwards (Rees 1983). Centres of aerial drops may overlap, further increasing concentrations of retardant on fuels and the heterogeneity of the vegetation, particularly forests, will affect retardant coverage (Bradstock et al. 1987). Concentrations of retardant reaching the soil will depend on whether it has been chemically changed during the fire or remains unaltered and is subsequently washed from foliage. While it is often stated that the total area of application of retardant is generally small and that the effects are localised, there is the potential for a significant impact over a greater spatial scale through movement of retardant by leaching or surface run-off to nearby water sources.

The majority of research into the ecological effects of retardants has been conducted in the US and Canada (summarised by Adams & Simmons 1999; CSIRO 2000), with only one investigation by Bradstock et al. (1987) relating to Australian flora and fauna. The USDA has based the safe use of fire retardants on the former studies and, as a consequence, recommendations made by the USDA have been adopted by Australian agencies. For example, as retardants are known to have short-term adverse effects on aquatic life, practices to minimise entrance into watercourses are strictly followed both in Australia and the US (e.g. http://www.fs.fed.us/rm/fire/The_Environment.html). There are codes of safe practice that are strictly followed when handling and distributing Phos-Chek in order to promote human safety.

Phos-Chek can act as a source of nitrogen, phosphorus and sulphur for vegetation and soils whether in the burnt or unburnt form (CSIRO 2000). The effects of nutrient additions on soil processes will depend on rates of application, post-fire rainfall and soil properties—e.g. clay content, soil acidity (pH). Given the generally low nutrient status of forest and heathland soils in Australia, the effects of adding nutrients to the environment in this manner are likely to be significant. In the US, vegetation of annual grasslands and oak woodlands increased in biomass after application of fire retardant (Larson & Duncan 1982; Larson & Newton 1996; Larson et al. 1999) and would be expected for other vegetation types. In addition, direct application of Phos-Chek is likely to cause death of foliage. Field and glasshouse application of ammonium sulphate by Bradstock et al. (1987) resulted in leaf death with high concentrations leading to more rapid and widespread necrosis. Little published information is available on the effects of ammonium phosphate on foliage, but this chemical could potentially be as harmful as ammonium sulphate. The effect of nutrient addition via retardant application has yet to be considered in terms of changes in species diversity and weed invasion (Larson & Newton 1996; Adams & Simmons 1999).

The effect of fire retardant on fauna is better known than the effect on vegetation and soils. Toxicity data specifically for Phos-Chek ranges from non-toxic to slightly toxic when tested on small mammals and birds (Vyas et al. 1996, summarised in CSIRO 2000) and is considered to be non-toxic to livestock in relation to nitrate poisoning (Dodge 1970). Phos-Chek is also non-toxic to earthworms (Beyer & Olson 1996) and benthic invertebrates (McDonald et al. 1996; Poulton 1996) – two groups considered to be highly sensitive to environmental change. Again, most of the ecological research concerning the effects of fire retardants on aquatic systems has been carried out in the northern hemisphere and deal primarily with water quality and aquatic organisms.

Fire retardant impacts on vegetation direct through contact of chemicals with the foliage and stems and indirectly by the addition of toxic substances and nutrients to litter and soil. Little research has been performed to determine either the direct or indirect effect of fire retardant on native vegetation in Australia. To date, inferences regarding effects on flora and fauna and other components of the environment have been drawn from limited published research completed in the US. In these studies, annual grasslands in California and North Dakota and oak woodlands grading into riparian vegetation in Nevada have been the primary focus (Larson & Duncan 1982; Larson & Newton 1996; Larson et al. 1999). Such communities are different from eucalypt forests, coastal and inland heathlands and shrublands in eastern Australia in many respects, and comparisons with northern hemisphere ecosystems can only be valid up to a point.

Objectives of the study

While fire retardants may be the only viable and cost-effective means of combating fire spread under certain circumstances, the ecological effects need to be understood and considered. Additions of concentrated salts will affect plants and animals immediately through initial contact as well as over the longer term through changes in soil and water chemistry. Given the unique nature of Australian ecosystems, it is likely that responses to fire retardants may be quite different to ecosystems of the northern hemisphere and therefore require study.

Heathland ecosystems have been targeted in this study as they are particularly low in nutrient availability and are likely to show a greater response to addition of nutrients than other ecosystems with higher fertility. The larger study investigates components of the short-term direct and longer-term indirect effects of fire retardant on vegetation (this report), invertebrates (Collett & Schoenborn 2003) and soil chemistry (Hopmans & Bickford 2003) in Australian heathlands. Specific objectives of the study were to determine the effect of the fire retardant, Phos-Chek on:

- plant health and growth in heathland communities
- key litter and soil invertebrates such as collembola and annelids
- the nutrient status of soil in time and with depth.

Questions that could potentially be answered by such research include:

- What are the short-term impacts of fire retardant on selected plant types in wet and dry heathlands?
- What is the likelihood of weed invasion to heathland treated with fire retardant?
- What level of application of fire retardant has a visible or measurable impact on heathland flora?
- What short-term effects does fire retardant have on nutrient status of the soil?
- What short-term effect does fire retardant have on selected soil invertebrate populations?

In early 2001, Fire Management Branch of the-then Department of Natural Resources and Environment contracted the Forest Science Centre to conduct preliminary research on the effects of fire retardant in eastern Australian heathlands. The agreed timing was a 12-month period from February 2001 to February 2002. Certain aspects of field studies (e.g. soil and insect collection) were continued until later in 2002 and data analysis and the final report completed in mid-2003.

Previous studies in the USA indicated that nutrient increases from addition of the retardant result in a transient (1- to 2-year) increase in vegetation biomass and stem density (Larson & Duncan 1982; Larson & Newton 1996). A reduction in species richness has also been recorded, but this effect is also relatively short-lived (Larson & Newton 1996; Larson et al. 1999). Growth of woody vegetation, resprouting ability, flowering, herbivory, species evenness and diversity were not affected. In addition, Bradstock et al. (1987) noted changes in plant health and cover with direct application of fire retardant both in the field and glasshouse studies in Australia. Based on this information, three hypotheses dealing with effects of fire retardant on vegetation were tested in this project:

i) that the aboveground growth of dominant shrubs would be increased by addition of fire retardant

ii) that the health of foliage would be reduced by addition of fire retardant

iii) that addition of fire retardant would increase species richness of the vegetation.

Materials and methods

General study area

In this study, low nutrient heathlands were investigated as they potentially show greatest response to disturbance and addition of nutrients. Two study sites were selected to represent typical Victorian heathland vegetation. The first, an inland sandy heathland assemblage, was located in Victoria Valley in the Grampian Ranges (37º 47' 27" S, 148º 36' 29" E), approximately 25 km west of Halls Gap, western Victoria (Fig. 1A). This heathland is associated with highly leached, seasonally waterlogged soils (Day et al. 1984). The second site, a wet coastal heathland assemblage, was located in Marlo (37º 11' 05" S, 142º 20' 28" E), approximately 20 km south-east of Orbost, East Gippsland, in eastern Victoria (Fig. 2A). In East Gippsland, large tracts of low treeless heathland occur from near the coast to 30 km inland at elevations less than 200 m (EGC 1985). Both sites are of low relief with the Grampians site situated at an elevation of 220 m above sea level and the Marlo site at an elevation of 20 m.

The climate at Victoria Valley is Mediterranean-like with cool, wet winters and warm, dry summers (Fig. 3A). Mean annual rainfall is 700 mm with the majority of rain (70%) falling from May to October. Elevation of the Grampians region (from 200 to 1168 m above sea level) creates orographic rainfall and the region receives between 550 mm to more than 1000 mm more rain than the surrounding plains (Day et al. 1984). This often results in periods of rapid runoff during winter. Despite this, drought has been experienced in more recent years (i.e. 1967–68, 1982–83, Day et al. 1984). Summer thunderstorms can occur and are often associated with lightning activity and little rainfall and therefore can create a severe fire hazard. Mean maximum summer temperatures are in the mid- to high-20s and mean winter temperature ranges from 3º to 12ºC. Evaporation from the soil surface (pan evaporation, Fig. 3A) and transpiration by plants is highest during summer due to higher temperatures being coupled with hot, dry northerly winds (Day et al. 1984).

Climate at the Marlo site is temperate with mild winters and warm summers mainly due to the nearby coastal influence. Mean annual rainfall for this site is approximately 925 mm and falls more or less equally in all months of the year (Fig. 3B). However, because of rates of evaporation, summer and autumn tend to be drier than winter and spring. During the study period, the soils of the Marlo site rarely dried out as rainfall averaged about 60 to 70 mm per month (G. McCarthy, pers. comm.). Maximum summer temperatures at this site are similar to those at Victoria Valley (25ºC) but winters are milder, ranging from 5º to 15ºC.

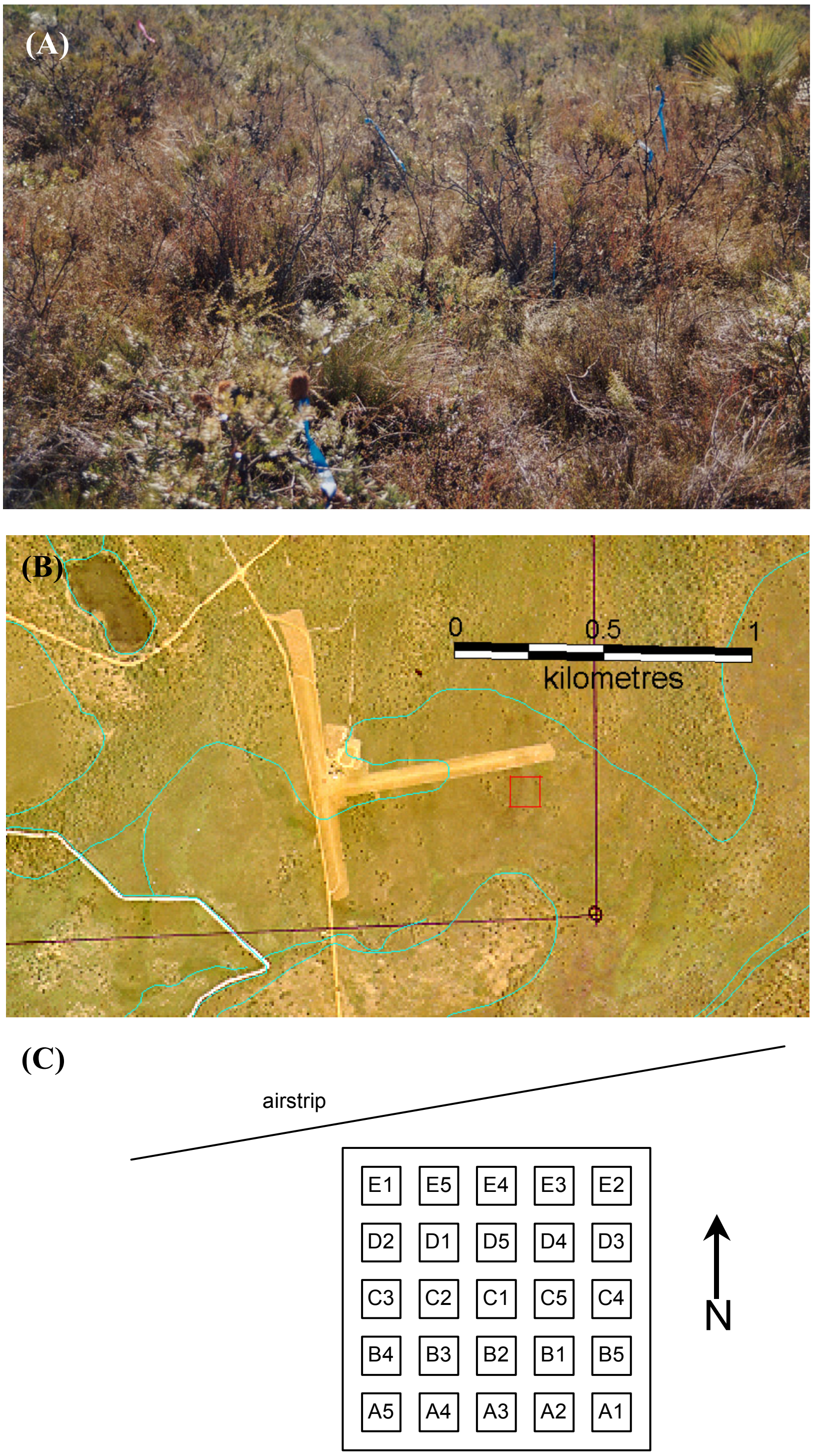

Figure 1 (A) Typical heathland vegetation, (B) location of research site and (C) plots in relation to the airstrip at Victoria Valley, Grampians

Notes:

Plots annotated with letters from A to E refer to replicates of treatments.

Plots annotated with the numbers '1' refer to untreated control plots, those with '2' refer to water-only treatments, '3' refer to fire retardant added at 0.5 L m^{-2}, '4' refer to fire retardant added at 1.0 L m^{-2} and '5' refer to fire retardant added at 1.5 L m^{-2}.

Photograph (A) supplied by M. Wouters and (B) sourced from Parks Victoria, Halls Gap (Ecological Vegetation Class Mapping Project).

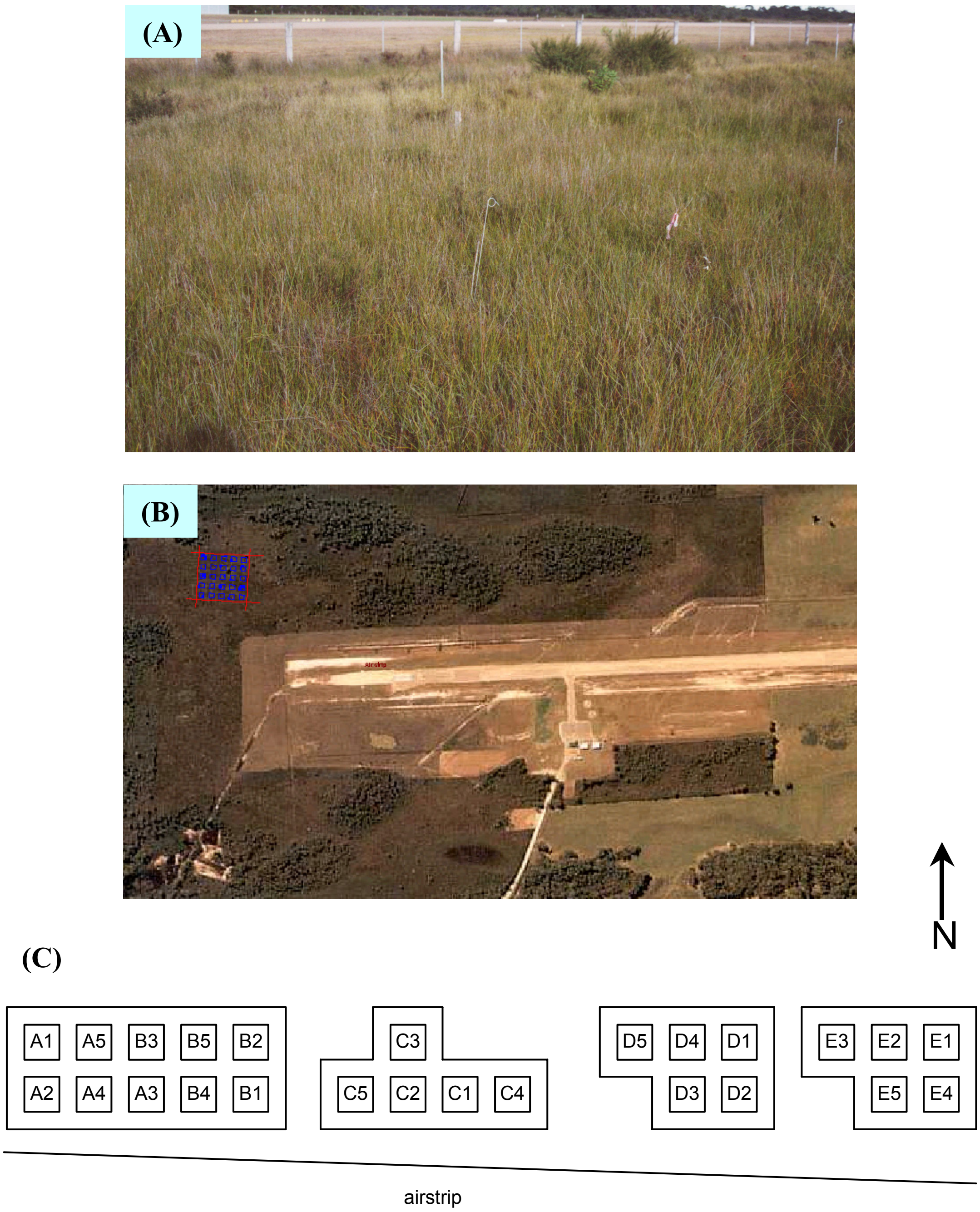

Figure 2 (A) Typical heathland vegetation, (B) location of research site and (C) plots in relation to the airstrip at Marlo

Notes:

Plots annotated with letters from A to E refer to replicates of treatments.

Plots annotated with the number ‘1’ refer to untreated control plots, those with ‘2’ refer to water-only treatments, ‘3’ refer to fire retardant added at 0.5 L m^{-2}, ‘4’ refer to fire retardant added at 1.0 L m^{-2} and ‘5’ refer to fire retardant added at 1.5 L m^{-2}.

Photographs supplied by G. McCarthy, Orbost.

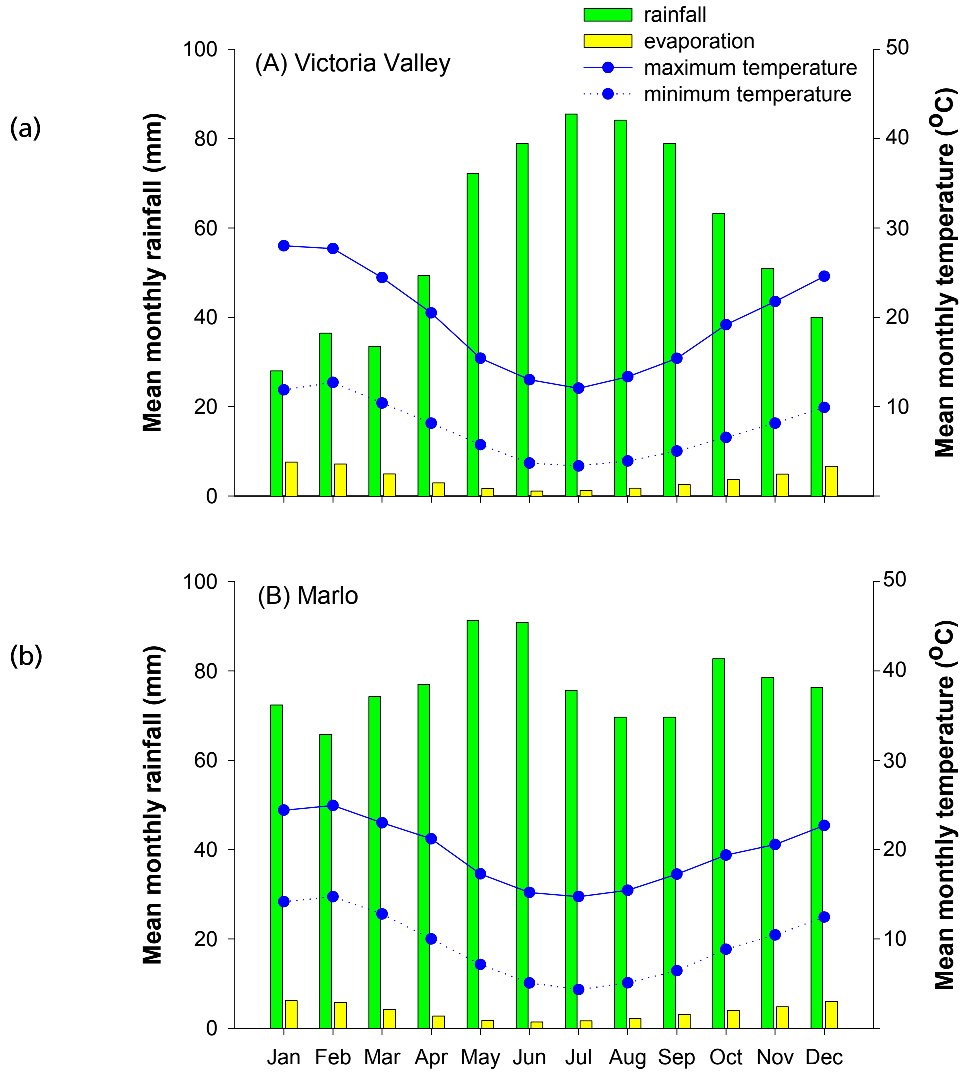

Figure 3 Mean monthly rainfall, pan evaporation and maximum and minimum temperatures for sites at (a) Grampians, (b) Marlo

Climatic data supplied by Bureau of Meteorology, 2002.

Vegetation at the Grampians site is dominated by larger shrubs including *Leptospermum continentale* Joy Thomps. (prickly tea-tree), *L. myrsinoides* Schltdl. (heath tea-tree), *Banksia marginata* Cav. (silver banksia), *Allocasuarina paludosa* Sieber ex Spreng. (scrub sheoak) and *Brachyloma daphnoides* Sm. Benth. (daphne heath). The understorey is dominated by *Hypolaena fastigiata* R. Br. (tassel rope bush) and *Lomandra multiflora* R. Br. (many flowered mat rush). Ephemeral species are uncommon; as are grasses, with the exception of *Amphipogon caricinus* F. Muell. (grey beard grass). As with all heathlands, trees are generally absent (Day et al. 1984).

All plant nomenclature is based on Walsh and Entwistle (1994, 1996) and status of species as weeds was based on Randall (2002).

Vegetation at Marlo is dominated by *Leptospermum continentale*, *Allocasuarina paludosa* and *Bossiaea prostrata* R. Br. (creeping bossiaea) and dominant understorey species include *Panicum simile* Domin. (hairy panic) and *Poa clelandii* Vickery (tussock grass). The coastal heathland community at Marlo is thought to support more rare or restricted species than anywhere else in east Gippsland and therefore has high conservation value (EGC 1984).

Soils at the Grampians site are composed of Cainozoic sediments (Spencer-Jones 1965). These soils contain 1 mg kg^{-1} extractable phosphorus, 0.3–0.5 g kg^{-1} total nitrogen, 5-10 mg kg^{-1} mineralisable nitrogen and 5–10 g kg^{-1} total carbon; mean pH is 5.3 (Hopmans & Bickford 2003). Soils at the Marlo site are also Cainozoic sediments (McAndrew & Marsden 1973). These soils contain 1 mg kg^{-1} extractable phosphorus, 0.4–1.0 g kg^{-1} total nitrogen, 10–20 mg kg^{-1} mineralisable nitrogen and 15–20 g kg^{-1} total carbon; pH ranges from 5.4–5.7 (Hopmans & Bickford 2003).

Both study sites were long unburned (>15 years) and relatively undisturbed despite being located adjacent to small airstrips (Figs. 1B, 2B). Since relevant records commenced at the Grampians, the Victoria Valley site has been prescribed burned in 1963 and 1985 (M. Wouters, pers. comm.). The Marlo site was last burned in the mid-1960s and the vegetation 'slashed' some time prior to the set up of the experiment (this practice ceased in 1986, G. McCarthy, pers. comm.), but was relatively intact at the time of study.

Experimental design

At the Grampians site, 25 large plots (20 m x 20 m) were established in a Latin square design (one control plus four treatments, five replicates each; Fig. 1C). Smaller experimental plots (10 m x 10 m) were centred within these larger plots to provide 5-m buffer zones, allowing easier access and to avoid trampling of the plot vegetation. At the Marlo site, plots of similar size and number were arranged in a randomised block design (Fig. 2C).

At both sites the 'control' plots were effectively unchanged with no addition of retardant or water (plots numbered as '1' in Figs. 1 and 2) and the four treatment plots consisted of retardant (12% w/v solution) applied at the following rates:

- 0 L m^{-2} ('water only', i.e. no retardant, water added at an equivalent volume to chemical application, plots numbered as '2' in Figs. 1 and 2)
- 0.5 L m^{-2} ('low' retardant, plots numbered as '3' in Figs. 1 and 2)
- 1.0 L m^{-2} ('medium' retardant, plots numbered as '4' in Figs. 1 and 2)
- 1.5 L m^{-2} ('high' retardant, plots numbered as '5' in Figs. 1 and 2).

Fire retardant was prepared at the mixing ratio of 0.144 kg Phos-Chek per litre of water (CSIRO 2000) and was applied from the ground using a slip-on delivery unit fitted with a spray nozzle to ensure consistency of application (Figs. 4A & 4B). Output from the unit was calibrated to deliver water at 1.0 L m^{-2} and fire retardant at approximately 0.5, 1.0 and 1.5 L m^{-2}. To measure rates of application of the fire retardant, three plastic drinking cups were placed randomly in each of the plots prior to spraying. Once spraying was completed the contents were weighed and retardant coverage calculated according to the dimensions of the cup (Fig. 4C). Actual rates of delivery are presented in Table 1. Retardant was applied during summer months (in February 2001 at the Grampians and in March 2001 at Marlo) to attempt to imitate time of peak use of fire retardant for fire control.

Table 1 Mean rates of application of the fire retardant, Phos-Chek, to treatment plots at the Grampians and Marlo sites

Treatment (L fire retardant m^{-2})	Mean rates of application	
	Grampians	Marlo
0 (control)	0	0
0 (water only)	0	0
0.5	0.51 ± 0.20	0.51 ± 0.30
1.0	0.96 ± 0.26	1.07 ± 0.26
1.5	1.68 ± 0.45	1.63 ± 0.79

Values represent mean ± standard deviation, n = 15

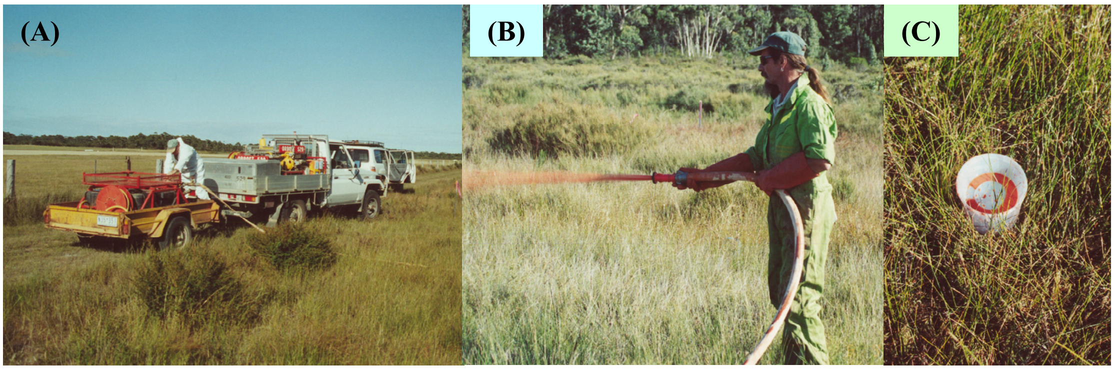

Figure 4 Application of the fire retardant, Phos-Chek, at Marlo:
(A) the slip-on delivery unit, (B) spraying of experimental plots and (C) cups used for determination of rate of application of fire retardant

Photographs supplied by G. McCarthy.

Vegetation sampling

Vegetation sampling consisted of measurement or estimates of:

- diversity of plant species (changes in total number of species present per plot, including number of weed species)
- percentage projected foliage cover—visual estimate of each species present (Grampians site) or of vegetation types (Marlo site) per plot
- plant health (visual assessment of all species present using leaf colour and brittleness)
- relative growth rate (plant height and length of leading shoot of dominant species in each plot).

Number of species present and estimates of foliage cover were determined using 10 x 10 m permanent plots located in the centre of each experimental plot. Projected foliage cover values for each species were estimated using the Braun-Blanquet scale (Kent & Coker 1996). Assessment of health of individual plants was based on changes in leaf colour, leaf loss and brittleness and signs of shoot regeneration from stem or basal buds. Plant height and length of the leading shoot of three individual plants per plot of the dominant species (*Allocasuarina paludosa*, *Banksia marginata*, *Leptospermum continentale* and *L. myrsinoides*) were measured repeatedly on tagged plants. If tagged shoots had died or were broken or eaten by insects, replacement shoots were selected for subsequent measurements. At the Grampians site, growth and health of dominant species were assessed immediately after the application of fire retardant (March 2001) then 4 months (June 2001) and 9 months (December 2001) later. Vegetation cover and abundance was measured in March and December 2001. At the Marlo site, shrub growth, health, cover and abundance was assessed immediately after application of fire retardant (February 2001) and 9 months later (November 2001).

Statistical analyses

Braun-Blanquet scores for percentage projected foliage cover of individual species from the Grampians site were replaced by the mid-point of their respective cover ranges for statistical analyses (i.e. 0.001 – 1.000 = 0.5; 1.001 – 5.00 = 3.0; 5.001 – 25.000 = 15.0; 25.001 – 50.000 = 37.5; 50.001 – 75.000 = 62.5; 75.001 – 100.000 = 87.5). Data relating to projected foliage cover were compared using two-way analysis of variance (ANOVA) followed by Tukey's multiple comparisons of means using 95% confidence levels. Data for plant height and shoot length were compared using two-sided Welch's paired t-tests and one-way ANOVA followed by Tukey's multiple comparisons of means using 95% confidence levels.

Results

Species abundance and percentage projected foliage cover

Basic information detailing the number of plant species, projected foliage cover of vegetation types (shrubs, grass/sedges and herbs/forbs) and physical components within plots at both sites is given in Tables 2 and 3. With up to twice the number of species recorded in individual plots (87 species, see Appendix 2), the Marlo site was much richer in terms of number of species than the Grampians site (43 species, see Appendix 1). In all but one plot at the Grampians (i.e. control treatment, replicate 5) and in all plots at Marlo, the number of species present increased in the nine months between application of fire retardant and final vegetation assessment. In the exceptional plot (control treatment, replicate 5), *Leptospermum continentale*, *Lomandra multiflora*, *Persoonia juniperina*, *Austrostipa mollis*, *Brachyloma daphnoides* and *Burchardia umbellata* were recorded during the first assessment in March but not during the second in December. Species which 'replaced' these included *Brunonia australis*, *Calectasia intermedia*, *Drosera auriculata* and *D. pygmaea* together with a heavily-grazed and therefore unidentifiable sedge (M. Wouters, pers. comm.). In two plots at the Grampians site (water-only treatment, replicate 2 and 0.5 L m^{-2} treatment, replicate 3) there was no net increase in species numbers but, in one of these plots, species composition changed. In the water-only treatment, *Persoonia juniperina* and *Brachyloma daphnoides*, both woody perennials, were recorded during the first inventory but were absent in the second. *Drosera auricularis*, an annual geophyte, was present only during the second assessment.

Complete species lists for both Grampians and Marlo sites are provided in Appendixes 1 and 2. At the Grampians site, all of the species that were present during the first inventory in March 2001 were native taxa. Weeds (defined as taxa not native to the area) were present in the general area but were not recorded within the control or treatment plots. Regular mowing and high grazing pressure from kangaroos tends to keep the obvious seed sources from the nearby airstrip at low levels (M. Wouters, pers. comm.). At the time of the second assessment (referred to as '2 only'), six newly-recorded species were weeds—*Carthamus* sp. (Thistle 1), *Carthamus* sp. (Thistle 2), *Sonchus* sp. 1, *Sonchus* sp. 2, Weed 1 and *Stellaria media* (Randall 2002). Two species remained unidentified as they were heavily grazed ('Grazed grass' and 'Grazed sedge') but were suspected to be *Austrostipa* sp. and *Lepidosperma* sp. respectively. Eight new native species were recorded in the second vegetation assessment (2 only), six of which were herbaceous (*Craspedia glauca*, *Brunonia australis*, *Drosera auricularis*, *D. pygmaea*, *Pattersonia* sp. and *Lomandra* sp.) and are most likely to represent seasonal regrowth from underground storage organs. Adult plants of two new shrub species were recorded in the second vegetation assessment, suggesting that they were missed in the first assessment. Eighteen species were present during both assessments (referred to as '1 & 2'). Six species were recorded in the first assessment (referred to as '1 only') and not the second, but there was no evidence to suggest that they were killed by the application of fire retardant or by some other disturbance (potentially true for *Brachyloma daphnoides* and *Persoonia juniperina*, see Weste et al. 2002), were seasonally absent from plots (potentially *Burchardia umbellata* and *Austrostipa mollis*) or were poorly recognised by data collectors.

A different situation was observed at Marlo with eight introduced weed species (Anthoxanthum odoratum, Eragrostis brownii, Hypericum gramineum, Hypochoeris radicata, Imperata cylindrica, Paspalum dilatatum, Pentapogon quadrifidus and Plantago coronopus) present in several plots at the beginning of the study. Two additional species (Iridaceae sp. and Liliaceae sp.) may be potential weeds but their status cannot be determined due to lack of reliable identification. A further five weed species (Briza minor, Cicendia filiformis, Cyperus tenellus, Holcus lanatus and Juncus bufonius) were present in plots nine months later during the second assessment (2 only). Forty-three native species were present during both assessments (1 & 2) and 24 new native species were identified in November (2 only). Most of these new species were grasses, sedges, annuals or geophytes (e.g. Drosera peltalta ssp. peltata, D. pygmaea and Diuris punctata). The list of new species also included two new woody shrubs

(Hakea decurrens and Sphaerolobium vimineum) – these were likely to have been missed or incorrectly identified in the first assessment as they were present as adult specimens.

Broad estimates of projected foliage cover of the vegetation were made for plots at both sites at the beginning of the experimental period (February and March 2001) prior to treatment application and again at the Marlo site in November 2001. In general, projected foliage cover of grasses and sedges in plots at the Marlo site (0 to 105%) were more variable than in plots at the Grampians site (30 to 60%)—Tables 2 and 3. Woody shrubs represented greater cover at Marlo (15 to 75%) than at the Grampians (0 to 30%) and herbs and forbs were more prevalent in terms of cover in plots at the Grampians site (10 to 50%) than in plots at the Marlo site (<1 to 20% cover). At the Marlo site, percentage projected foliage cover of vegetation types (shrubs, sedges and grasses, herbs and forbs) generally remained stable during the sampling period with increases (and no decreases) recorded in three plots only (0.5 L retardant m^{-2} treatment, replicates 3 and 4; Table 3). The percentage of ground covered by leaf litter was relatively high at the Marlo site (50 to 70%) and there was little bare ground (<1 to 5%). Percentage cover of litter and bare ground was not assessed at the Grampians site.

Table 2 Number of species and percentage projected foliage cover of vegetation types for individual plots at the Grampians experimental site

Treatment (treatment no.)	Replicate	Total number of plant species	Shrub cover (%)	Grass and sedge cover (%)	Herb and forb cover (%)
Control	A	12/15	25	30	40
(1)	B	11/14	20	50	30
	C	10/11	0	50	30
	D	8/10	10	50	20
	E	16/15	0	50	30
Water only	A	13/14	5	50	20
(2)	B	9/9	0	50	30
	C	9/10	0	50	30
	D	8/11	10	50	10
	E	9/15	0	50	40
0.5 L retardant m^{-2}	A	10/12	30	40	20
(3)	B	9/13	0	50	20
	C	9/15	10	50	30
	D	10/15	0	50	30
	E	9/9	0	60	10
1.0 L retardant m^{-2}	A	9/14	0	50	20
(4)	B	8/12	20	50	20
	C	10/15	10	50	20
	D	8/12	0	50	50
	E	7/15	10	50	30
1.5 L retardant m^{-2}	A	9/11	15	50	30
(5)	B	8/12	10	50	30
	C	10/13	20	10	20
	D	7/11	10	60	10
	E	9/14	0	50	40

Notes:

1. The first value in the 'Total number of plant species' column indicates the number of species recorded in March 2001, the second value indicates the number of plant species recorded in December 2001.
2. Percentage projected foliage cover (referred to in the table as 'cover') for the broad vegetation types were only recorded at the beginning of the experiment in March 2001. Data for percentage cover of litter and bare ground are not available.

Table 3 Number of species and percentage projected foliage cover of vegetation and percentage area of litter and bare ground for individual plots at the Marlo experimental site

Treatment (treatment no.)	Replicate	Total number of plant species	Shrub cover (%)	Grass/ sedge cover (%)	Herb/ forb cover (%)	Litter cover (%)	Bare ground (%)
Control	A	16/20	55	80	25	50	<5
(1)	B	14/20	15	85	60	50	<1
	C	18/31	15	0	40	70	<5
	D	16/20	15	35	75	60	5
	E	20/27	15	35	55	70	1
Water only	A	14/21	75	75	90	60	<5
(2)	B	14/17	15	15	85	60	<5
	C	14/22	40	35	60	50	<5
	D	12/21	50	40	90	50	<5
	E	12/21	30	15	60	70	5
0.5 L retardant m^{-2}	A	14/20	75	105	45	60	<1
(3)	B	16/22	30	35	15	60	<5
	C	15/28	<5/<6	35	25	50	<1
	D	13/24	50	30	105/120	60	5
	E	12/20	40	30	50	70	5
1.0 L retardant m^{-2}	A	12/16	50	100	40	60	<5
(4)	B	13/19	45	20	15	60	<1
	C	20/35	15	45	20	60	<1
	D	16/31	15	0	65	70	5
	E	13/25	30	30	85	70	<1
1.5 L retardant m^{-2}	A	12/26	55	80	<1	70	<1
(5)	B	15/26	<1	50	10	50	<5
	C	15/25	30	65	35	70	<1
	D	19/34	15	40	60/95	60	<1
	E	14/25	30	40	60	70	<1

Notes:

1. The first value in the 'Total number of plant species' column indicates the number of species recorded in February 2001 before treatment, the second value indicates the number of plant species recorded in November 2001, 9 months after treatment.
2. Percentage projected foliage cover of each vegetation type was recorded in February 2001 and November 2001. A single value indicates no change in cover between the two sampling times and two values indicates change in cover.

Mean percentage canopy cover was assessed for each species in the experimental plots at the Grampians site in March and December 2001 and is represented in Fig. 5. Herbaceous and woody shrub cover was initially low for all treatments and remained low in December regardless of treatment (<5%). Cover represented by the moss, *Campylopus australis*, was variable with relatively high cover (5 to 10%) in control plots and plots treated with the highest level of fire retardant (1.5 L m^{-2}) and low cover (<2%) in all other plots. Percentage cover of moss did not change between March and December 2001 in any of the plots. In contrast, cover of sedges and grasses decreased and that for weed species increased with the addition of fire retardant. A comparison of projected foliage cover of weeds in control and water only plots with that in retardant plots suggests that there may be increased 'weediness' with the addition of nutrients via the fire retardant. Despite this, there was no significant difference between percentage cover of vegetation types measured in March and again in December for any of the treatments (two-way ANOVA, $p = 0.857$). Unfortunately, no statistics relating to percentage cover of vegetation can be reported for the Marlo site, as similar data for each species were not available.

Plant health

Obvious visual changes in the vegetation of plots treated with fire retardant included initial pink discolouration, shoot dieback and whole plant death at both sites (Fig. 6). Of the targeted taxa, the most consistently affected species at the Grampians site included *Banksia marginata* and *Leptospermum myrsinoides*. The number of plant deaths of *B. marginata* increased with increased concentration of fire retardant applied (Table 4). *Allocasuarina paludosa* was relatively unaffected by the application of fire retardant. In addition, death of shoot tips in plots treated with fire retardant was observed for *Hakea teretifolia* and *Kunzea ericoides* but not for *Acacia longifolia* (data not shown). At the Marlo site, both *Allocasuarina paludosa* and *Leptospermum continentale* suffered shoot dieback, however whole plant death was recorded only for *L. continentale*. The relatively high numbers of shoot deaths of *Allocasuarina paludosa* and *L. continentale* in untreated control plots are hard to account for, as little or no insect or other damage due to disturbance (e.g. kangaroo travel lines) was recorded (M. Wouters, pers. comm.). Although not formally measured, death of several individuals of *Sprengelia incarnata* was observed, but there appeared to be little effect on survival of other common epacrids—*Epacris impressa* and *E. obtusa* (G. McCarthy, pers. comm.). Similarly, there was little noticeable effect of retardant on the health, height or projected cover of *Xanthorrhoea* spp. at either site.

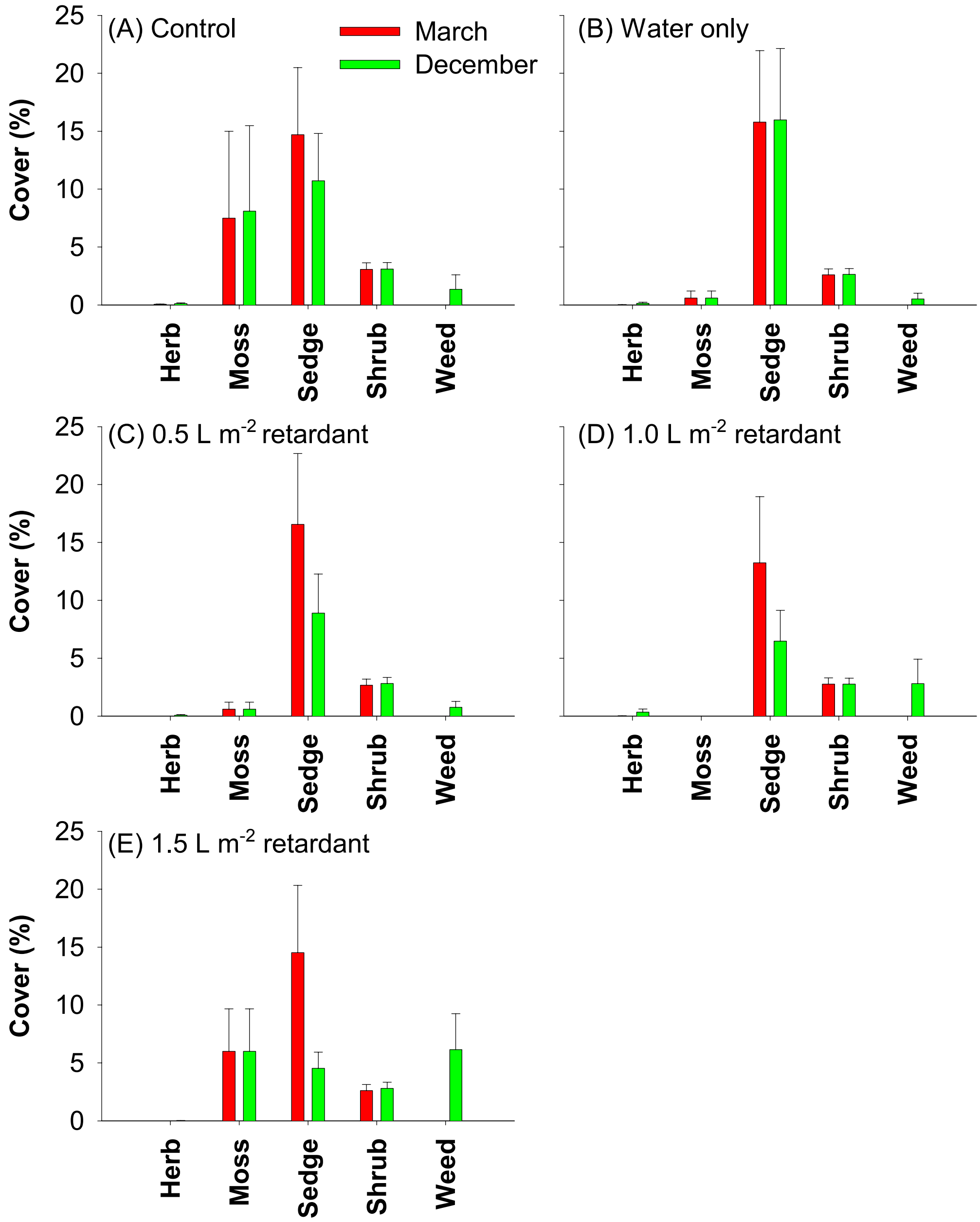

Figure 5 Change in percentage projected foliage cover of major vegetation types at the Grampians for (A) untreated control, (B) water only and (C-E) fire retardant treatments

Notes:

1. Vegetation types represented are herbs (including forbs), moss, sedges (including grasses), woody shrubs and weeds.
2. Bars represent mean values and error bars are + 1 standard error.

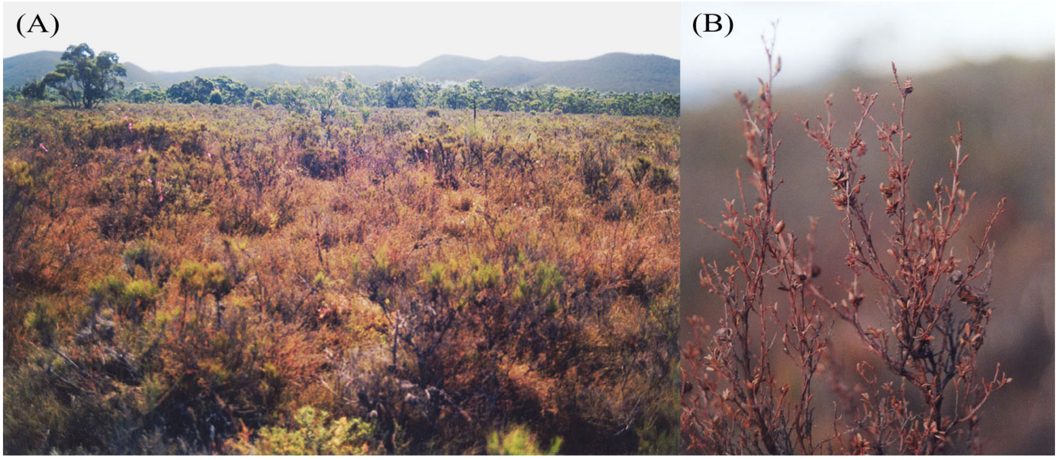

Figure 6 (A) General pink discolouration and (B) shoot death of *Leptospermum myrsinoides* after application of the fire retardant Phos-Chek to plots at the Grampians

Photographs supplied by M. Wouters.

Table 4 Incidence of death of shoots and whole plants of dominant species at the Grampians and Marlo sites after application of the fire retardant, Phos-Chek

Study site and species	Treatment									
	Control (1)		Water only (2)		0.5 L m^{-2} retardant (3)		1.0 L m^{-2} retardant (4)		1.5 L m^{-2} retardant (5)	
	whole plant	shoot	whole plant	shoot	whole plant	shoot	whole plant	shoot	whole plant	shoot
Victoria Valley										
Allocasuarina paludosa	0	0	0	0	1	1	0	0	0	0
Banksia marginata	0	2	0	3	0	1	1	1	0	1
Leptospermum myrsinoides	1	0	1	0	2	3	3	6	5	1
Marlo										
Allocasuarina paludosa	0	7	0	4	0	4	0	2	0	0
Leptospermum continentale	0	10	0	12	0	9	4	5	6	2

Note: A total of 15 plants were tagged for each treatment (3 individuals per plot).

Plant growth

Plant height and shoot lengths of three dominant shrub species at the Grampians are presented in Fig. 7. In most instances, plants (including those in untreated control plots) decreased in height during the three months after application of fire retardant. This is most likely due to a change in measuring technique or people making the measurements rather than any ecological or physiological cause. For this reason, data from June 2001 are disregarded in further analyses. During the following six months until final measurements in December 2001, *Allocasuarina paludosa* and *Banksia marginata* increased in height slightly or remained the same height. Comparisons of heights of shrubs measured at the beginning of the experiment (March 2001) with those at the end of the experiment

(December 2001) using two-sided Welch's paired t-tests showed all treatments for all species, apart from one, to be unchanged (Table 5). The only significant increase in height was for *Leptospermum myrsinoides* in plots with fire retardant added at a rate of 1.5 L m^{-2}. Treatment differences for heights of each species were tested using one-way ANOVA with mean heights at the beginning and end of the experiment used as the dependent variables. No significant differences were found between treatments (p = 0.871 for *Allocasuarina paludosa; p* = 0.648 for *Leptospermum myrsinoides; p* = 0.889 for *Banksia marginata*).

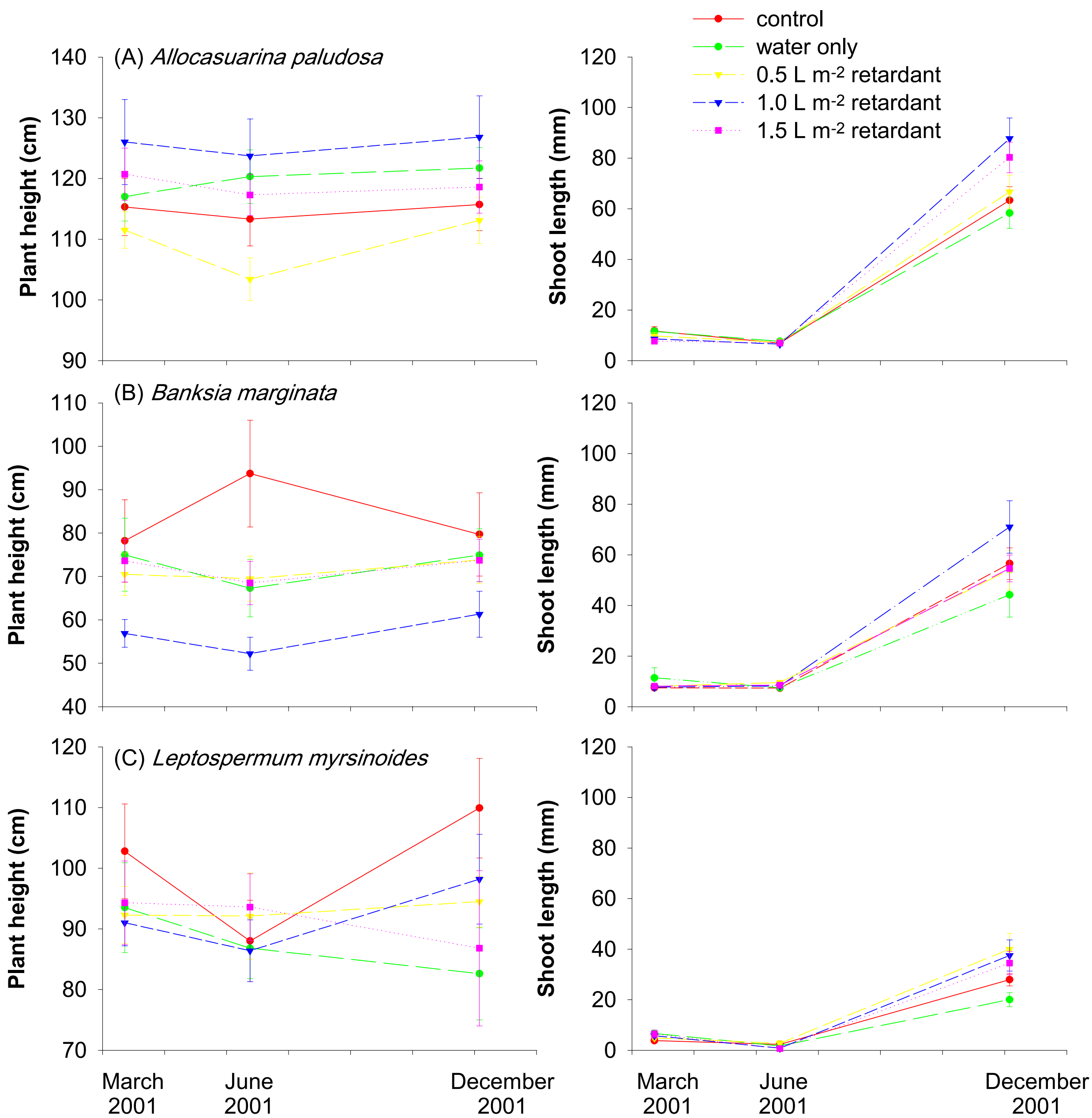

Figure 7 Mean plant height and shoot length of (A) *Allocasuarina paludosa*, (B) *Banksia marginata* and (C) *Leptospermum myrsinoides* in control and treatment plots at the Grampians site

Points represent means ± standard error.

Table 5 Significance differences (*p* values) between mean plant heights and shoot lengths of *Allocasuarina paludosa*, *Banksia marginata* and *Leptospermum myrsinoides* at the Grampians site

Treatment (treatment no.)	*Allocasuarina paludosa*		*Banksia marginata*		*Leptospermum continentale*	
	Plant height	Shoot length	Plant height	Shoot length	Plant height	Shoot length
Control (1)	NSD	<0.001	NSD	<0.001	NSD	<0.001
Water only (2)	NSD	<0.001	NSD	0.008	NSD	<0.001
0.5 L m^2 (3)	NSD	<0.001	NSD	<0.001	NSD	0.016
1.0 L m^2 (4)	NSD	<0.001	NSD	<0.001	NSD	0.046
1.0 L m^2 (5)	NSD	<0.001	NSD	<0.001	0.030	<0.001

Notes:

1. Two-sided Welch's paired t-tests were used.

2. Measurements were made in March and December 2001; one month and 11 months after treatment respectively.

NSD Means no significant difference ($p > 0.050$)

Shoot growth for *Allocasuarina paludosa*, *Banksia marginata* and *Leptospermum myrsinoides* at the Grampians site increased very little in the first three months after application of fire retardant but increased significantly in the following six months (Fig. 7; Table 5). Plants in plots treated with fire retardant tended to have longer shoots than those in the control and water-only plots, however this was only significant (using one-way ANOVA with mean heights at the beginning and end of the experiment as the dependent variables) for *Allocasuarina paludosa* ($p = 0.003$) and *Leptospermum myrsinoides* ($p = 0.008$). Using the Tukey multiple comparison of means test, significant differences were found between plots with 1.0 L m^{-2} of fire retardant added and untreated control plots and water only plots for *Allocasuarina paludosa* and between water-only plots and plots with 0.5 and 1.0 L m^{-2} of fire retardant added. No significant differences were found between control and water-only plots and the highest additions (1.5 L m^{-2}) of fire retardant.

Mean change in shoot length for *Allocasuarina paludosa* and *Leptospermum continentale* growing in plots at the Marlo site is presented in Fig. 8. Data for plant height were only available for the February 2001 assessment, as plants were not remeasured in November. During nine months of growth, all tagged shoots increased in length. Shoot data from both species were compared using two-sided Welch's paired t-tests to test whether there were differences in mean shoot lengths measured in February and November. For *Allocasuarina paludosa* the only significant difference found was for plots with fire retardant added at 1.0 L m^2 (Table 6). For *Leptospermum continentale*, all treatment and control plots were significantly different (Table 6). One-way ANOVAs indicated that there were no significant differences between treatments within each species ($p = 0.357$ for *Allocasuarina paludosa* and $p = 0.684$ for *Leptospermum continentale*).

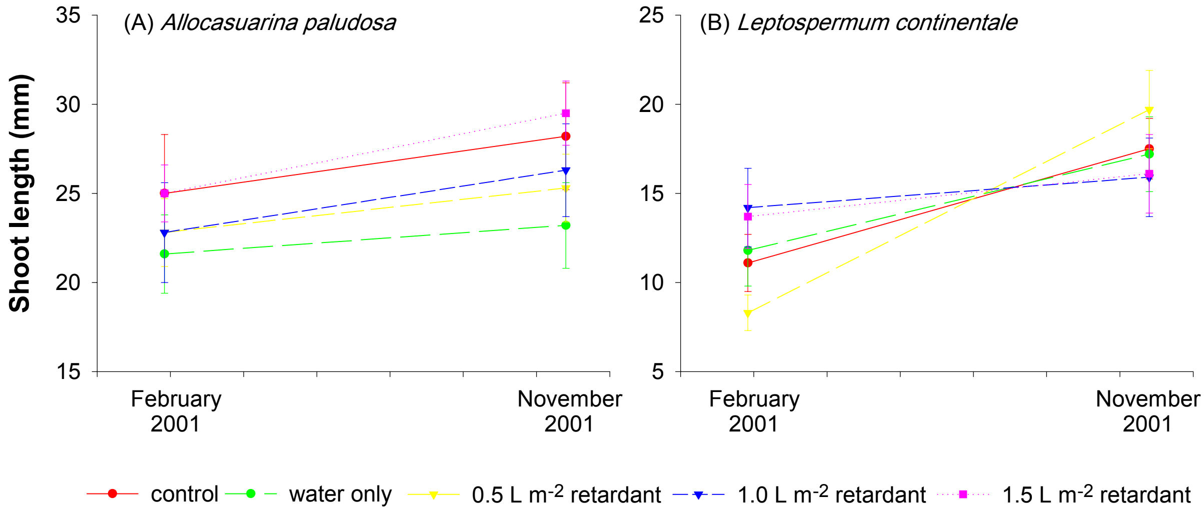

Figure 8 Mean shoot length of (A) *Allocasuarina paludosa* and (B) *Leptospermum continentale* in control and treatment plots at Marlo

Points represent means ± standard error.

Table 6 Significance differences (*p* values) between mean shoot lengths of *Allocasuarina paludosa* and *Leptospermum continentale* growing in experimental plots at the Marlo site

Treatment (treatment no.)	*Allocasuarina paludosa*	*Leptospermum continentale*
Control (1)	NSD	0.002
Water only (2)	NSD	0.002
0.5 L m^{-2} (3)	NSD	<0.001
1.0 L m^{-2} (4)	0.020	0.015
1.0 L m^{-2} (5)	NSD	0.014

Notes:

Two-sided Welch's paired t-tests were used.

Measurements were made in February and November 2001l; immediately before treatment and eight months after treatment respectively.

NSD Means no significant difference ($p > 0.050$)

Discussion

Chemical effects

The response of heathland vegetation to application of fire retardant of increasing strength was variable when treatment plots were compared with each other and to plots which received no fire retardant (untreated control and water only plots). For some measured variables the effect of application of fire retardant was obvious. For example, whole plant and shoot death tended to increase with application of fire retardant at both sites, as did cover and abundance of a number of species at the Grampians site. Similarly, the number and percentage projected foliage cover of weed species increased with the addition of fire retardant. Despite this, an overall increase in species numbers could not be attributed directly to the application of fire retardant as the majority of plots at both sites had increased species numbers regardless of treatment. This was most likely due to the seasonal appearance of perennial geophytes (e.g. *Drosera* sp. and *Burchardia umbellata*) and annual herbs (e.g. *Brachyscome* sp. and *Austrodanthonia* sp.). For most native taxa there was little change in projected foliage cover with the application of fire retardant (e.g. *Allocasuarina paludosa*, *Hibbertia virgata*, *Leucopogon glacialis* and *Xanthorrhoea minor*). The addition of fire retardant did not affect the height of *Allocasuarina paludosa*, *Banksia marginata* and *Leptospermum myrsinoides* at the Grampians site or the shoot length of *Allocasuarina paludosa* and *Leptospermum continentale* at the Marlo site. Shoots of *Allocasuarina paludosa*, *Banksia marginata* and *Leptospermum myrsinoides* plants from the Grampians site did increase in length over the experimental period, however there were no obvious differences between treatments.

The lack of strong response by vegetation to the application of fire retardant does not necessarily mean that the retardant had no effect. Other measurements may be needed to indicate subtle changes in vegetation, as the imprecise nature of measures used in this study (e.g. visual estimates of percentage cover) would have been unable to detect small changes in plant attributes. The measures used were chosen to minimise disturbance to vegetation, to be cost-effective and as a preliminary means of assessment. It must be remembered that this study was envisaged to be an initial investigation to identify key elements of the vegetation that would then be targeted for more detailed investigation. Some of the inaccuracies of the data were due to the nature of the management of the project (i.e. changes in people recording data from one period to the next; different types of data collected from each site) but other gaps could have been avoided with a little more care (i.e. damage to tagged plants). Different methods of assessment, such as removal of small blocks of above-ground vegetation for determination of biomass of grasses, sedges and forbs (e.g. as described in Larson & Duncan 1982), may have been more precise but would have caused unacceptable disturbance of the plots. Additionally, with the repeated measurements required for such a technique, the original plots would have needed to be much larger. Similarly, an indication of the effect of increased nutrients on fungal and microbial biomass in the soil may have been useful but, again, this type of sampling would have been disruptive and post-collection analyses would be particularly time-consuming and costly. Recommendations for future research should include collection of more accurate and informative data sets. However, to achieve this, a greater allocation of time and money would obviously be required.

Anecdotal evidence suggested that there was a distinct fertilisation effect for some components of the vegetation in response to added nitrogen and phosphorus from the salts contained in the fire retardant. The growth of the grasses *Poa clelandii*, *Deyeuxia quadriseta*, *Paspalum dilatatum*, *Austrostipa* sp. and *Austrodanthonia* sp. was more prolific on the treated plots at Marlo (G. McCarthy, pers. comm.). *Xanthorrhoea resinifera* also appeared very green and healthy on the treated plots, but this may be an effect of a particularly wet winter, spring and summer in Gippsland. There was certainly an increase in soil nitrogen and phosphorus immediately after application of fire retardant at both sites (Hopmans & Bickford 2003). However, nutrient availability and uptake by plants was not formally assessed. Despite these observations, there was little significant effect on plant height and shoot length for target species in fire retardant treatment and control plots at either site. Similarly, in US studies, no significant effect was found for application of fire retardant or foam on growth, flower production, insect herbivory and galling insect activity for dominant shrubs (*Artemisia tridentata* and *Chrysothamnus* spp.—Larson et al. 1999) or grass species (*Poa pratensis*—Larson et al. 1996). Herbaceous vegetation from a Californian oak–savanna rangeland showed increased growth with the addition of fire retardant one year after application but not two years later (Larson & Duncan 1982). Regardless, future research should aim to detect changes in plant biomass and nutrient status with addition of fire retardant, bearing in mind the inherently slow-growing nature of native, sclerophyllous Australian vegetation (Pate & Dell 1984; Specht & Moll 1983).

Species diversity and plant health

Arguably the greatest problem associated with the use of fire retardant is its potential to support the establishment of weed species. There was a marked increase in cover and number of introduced species at both sites, particularly at the Grampians site in which numbers of weeds increased from 0 to 19% of the total species present. Admittedly the experimental sites were situated close to public areas (airstrips) and a larger seed bank of exotic species would be present in the soil than in more remote areas generally targeted for use of such fire suppression techniques. Nevertheless, weed invasion is likely to be an important consideration if fire retardant is considered for use in the control of wildfire in native vegetation of the ever-increasing urban–rural interface.

The relatively short length of time of this study did not allow the effects of seasonal and inter-annual climatic variation to be differentiated from effects of fire retardant. This was also highlighted as a limitation in the investigation into the effects of retardant on invertebrates (Collett & Schoenborn 2003). A longer period of study would have been particularly useful for determining the effect of fire retardant on annual germination and regrowth of native and introduced herbaceous species. For example, the introduction of weed species discussed above may have been transitory and, by the second or third year after application of retardant, numbers, vigour and cover of weed species may have diminished substantially with gradual reduction in soil nitrogen and phosphorus. Despite this, if a longer-term study were to be undertaken, a new research project incorporating the interaction of fire and retardant would be of greater use rather than simply extending the collection time of the current project.

Extensive damage to foliage and death of plants after application of fire retardant was obvious from this study. Similar results were recorded by Bradstock et al. (1987) in which leaf death occurred within a week of application of fire retardant and continued for several months. Some species were unable to recover after leaf death and the damage resulted in whole plant death (e.g. *Leptospermum continentale*, *L. myrsinoides*, *Sprengelia incarnata*) while other species showed little observable damage and strong resprouting (e.g. *Allocasuarina palludosa*, *Banksia marginata*, *Epacris impressa*, *E. obtusa*). Bradstock et al. (1987) also found variable response to leaf death, but much of this variability was accounted for by an uneven coating of the vegetation as a result of dropping retardant from an aircraft. However, in the current project, fire retardant was applied to vegetation relatively evenly by ground delivery so this argument seems unlikely. As discussed by Bradstock et al. (1987), there appears to be no pattern in susceptibility to retardants relating to taxonomic or life-form groupings, but further testing of this statement is recommended. It must be remembered that the fire retardant was applied in the summer months when many of the small herbaceous species did not have above-ground vegetation present for exposure to the retardant. If fire retardant is used to control a wildfire in spring or autumn, the effect on foliage of herbaceous vegetation may be considerably different to that on sclerophyllous, perennial vegetation. It is likely that the delicate leaves of herbaceous species such as *Drosera* and *Lomandra* would be adversely affected. This could be tested with direct application of Phos-Chek to leaves of selected species under field or glasshouse conditions as outlined in Bradstock et al. (1987).

Other considerations

To date, no research has been done on the effect of fire retardant on seed germination. Parallel studies must therefore be used to get some indication of what the effect of fire retardant, particularly increases in nutrient availability, may have on promoting or inhibiting germination. For fire-prone, sclerophyll communities in Australia there is a common understanding that fire increases germination of soil-stored seed. This has been termed the 'fire effect' and combines the effects of heat from fire (Christensen & Kimber 1975; Warcup 1980; —1981; Bell et al. 1987), chemicals from smoke (Brown et al. 1993; Baxter et al. 1994; Dixon et al. 1995; Tieu et al. 1999) and changes in soil chemistry (Weston & Attiwill 1990; Siddique et al. 1976), with triggers that are not unique to fire, such as changes in light regimes and diurnal temperature ranges and reduction in levels of soil carbon dioxide (Baker 1989; Whelan 1995; Auld & Bradstock 1996). In the context of this research, increases in surface soil pH, exchangeable cations and availability of nitrogen and phosphorus (Bell 1999; Chambers & Attiwill 1994) may or may not account for the marked increase in the number of new species germinating after the application of fire retardant. While these features did not act as triggers for germination of species in *Eucalyptus* woodlands in the Grampians National Park (Enright et al. 1997) they may do for species in adjacent vegetation types. It is possible that application of fire retardant would also have little effect on germination of heathland species as approximately only 20% of the heathland vegetation in the Grampians region comprises obligate seeders and a dense ground cover of grass and Restionaceae prohibits germination (M. Wouters, pers. comm.). As with many fire-prone vegetation types, mass germination events are synchronised with large-scale disturbance. In the current study, many of the species germinating after the application of fire retardant were introduced weeds and, according to their life history strategy, need minimal triggers for annual germination in the form of seasonal increases in soil moisture, light or temperature.

In this study the effect of fire retardant on healthy and long undisturbed vegetation has been investigated. Little consideration has been given to the potentially greater effect it may have on weakened, declining or otherwise disturbed vegetation. Since the mid-1970s there has been widespread reporting of 'dieback' in areas of the Grampians caused by *Phytophthora cinnamomi* (Kennedy & Weste 1977). In heathland, woodland and forested sites in the Grampians over 50% of understorey vegetation has been found to be susceptible to dieback (Weste & Kennedy 1997) and changes in vegetation composition and structure here and elsewhere have been strongly linked to *Phytophthora* infestations (Weste 1981; Kennedy & Weste 1986; Podger & Brown 1989; Shearer & Tippett 1989; Shearer & Dillon 1996). Certain species may be susceptible to infection but are able to regenerate as seedlings or recovering individuals after an infestation (e.g. *Persoonia juniperina*, *Banksia marginata* and *Lomandra* spp.) while other species (e.g. *Leptospermum* spp. and *Hypolaena fastigiata*) are resistant to dieback (Weste & Kennedy 1997; Weste et al. 2002). While Weste et al. (2002) found in their long-term study that there was little significant change in the overall plant density, cover and species richness in infested and uninfested areas, susceptible species were replaced by resistant species in number and biomass. A similar situation has been illustrated in this study, where little change in species richness and plant cover has masked a reduction in native species and an increase in weed species after application of fire retardant. It is suggested by the current study and others (e.g. Marks et al. 1977; Kormorek et al. 1994; Pilbeam et al. 2000) that, in areas already weakened by dieback or other disturbance, additional stress caused by the addition of fire retardant may be extremely detrimental. Similarly, application of fire retardant in areas that are still recovering from a previous fire may preclude effective regeneration. This must always be kept in mind when the use of fire retardant is considered.

The preliminary research presented here has investigated the effects of fire retardant alone on vegetation. The potentially important interaction between fire and the retardant that would occur under normal circumstances was not investigated. For example, retardant would be sprayed onto unburnt vegetation with the strategy that the fire will burn up to and be contained by the chemical barrier. The remaining unburnt vegetation of the barrier is likely to react in a similar way to vegetation targeted in this study but the surrounding burnt area has the potential to react very differently. Burnt areas near the chemical barrier may be subjected to increased nutrient inputs from non-combusted retardant combined with additional nutrients from the ash bed. This may facilitate weed invasion, as demonstrated in this study, and push nutrient availability to toxic levels for nearby native plants. Larson and Duncan (1982) found that legume species germinated but did not survive on plots after addition of fire retardant followed by burning due to increased levels of soil nitrogen. It is recommended that, if a future experiment investigating the effect of fire retardant on vegetation were to be devised, it would investigate the combined variables of addition of fire retardant and burning.

Conclusions

A single application of Phos-Chek to relatively undisturbed Victorian heathland vegetation:

- did not appear to significantly change species composition or projected foliage cover of the major life forms of native vegetation (herbs, forbs, mosses, grasses, sedges and woody shrubs), although it should be noted that data collection was limited in scope and time
- provides an environment more conducive to weed invasion, particularly at higher levels of retardant application
- causes whole plant and/or shoot death of *Allocasuarina paludosa*, *Banksia marginata*, *Leptospermum continentale* and *L. myrsinoides* and may affect other species such as *Hakea teretifolia*, *Kunzea ericoides* and *Sprengelia incarnata*, particularly in areas where coverage may exceed 1.0 L m^{-2}
- appears to generally increase the shoot growth, but not the overall plant height of *Allocasuarina paludosa*, *Banksia marginata*, *Leptospermum continentale* and *L. myrsinoides*
- may potentially affect growth rates of native grasses and sedges and weed species.

Recommendations

- A longer-term study (2 to 3 years) with well-defined experimental design and rigorous sampling techniques to provide more ecologically and physiologically meaningful data sets.
- Glasshouse trials involving a subset of heathland species for investigation of specific response to addition of Phos-Chek, including analyses of growth and nutrient uptake.
- Investigation of potential for weed invasion in more remote locations. Heathland sites in the current study were located close to sites of human activity and already contained weed species or were in close proximity to weedy areas.
- An investigation of the effects of the interaction of fire and retardant on vegetation and soils.

Acknowledgments

The author of this report wishes to thank the people responsible for design (Nick Collett, Peter Hopmans, Kevin Tolhurst and Mike Wouters) and initial set-up of the experiment (Greg McCarthy and Mike Wouters), for data collection (Karen Chatto, Paul Clements, Glenn Dooley, Greg McCarthy, Carolien Schoenborn, David Smith, Richard Stokes and Mike Wouters) and plant identification (Alan Trumble-Ward and Mike Wouters). Albertus Smit kindly completed statistical analysis of the data.

References

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

Auld, TD & Bradstock, RA 1996, Soil temperatures after the passage of a fire: do they influence the germination of buried seeds?, *Australian Journal of Ecology* 21: 106–09.

Baker, HG 1989, Some aspects of the natural history of seed banks, in MA Leck, VT Parker & RL Simpson (eds.), *Ecology of Soil Seed Banks,* Academic Press, San Diego, US, pp. 9–21.

Baxter, BJM, van Staden, J, Granger, JE & Brown, NAC 1994, Plant-derived smoke and smoke extracts stimulate seed germination of fire-climax grass, *Themeda triandra*, *Environmental and Experimental Botany* 34: 217–23.

Bell, DT 1999, Turner Review No. 1 - The process of germination in Australian species, *Australian Journal of Botany* 47: 475–517.

Bell, DT, Vlahos, S & Watson, LE 1987, Stimulation of seed germination of understorey species of the northern jarrah forest of Western Australia, *Australian Journal of Botany* 35: 451–58.

Beyer, WN & Olsen, A 1996, Can earthworms survive fire retardants?, *Fire Management Notes* USDA Forest Service, Volume 56, No. 1: 26–27.

Bradstock, R, Sanders, J & Tegart, A 1987, Short term effects on the foliage of a eucalypt forest after an aerial application of a chemical fire retardant, *Australian Forestry* 50: 71–80.

Brown, NAC, Kotze, G & Botha, PA 1993, The promotion of seed germination of Cape *Erica* species by plant-derived smoke, *Seed Science and Technology* 21: 573–80.

Chambers, DP & Attiwill, PM 1994, The ash-bed effect in *Eucalyptus regnans* forest: chemical, physical and microbiological changes in soil after heating and partial sterilization, *Australian Journal of Botany* 42: 739–49.

Chandler, C, Cheney, P, Thomas, P, Trabaud, L & Williams, D 1983, *Fire in Forestry* Volume II, *Forest Fire Management and Organization*, John Wiley and Sons, New York, US, 298 pp.

Christensen, PE & Kimber, PC 1975, Effects of prescribed burning on the flora and fauna of south-west Australian forest, *Proceedings of the Ecological Society of Australia* 9: 85–106.

Collett, N & Schoenborn, C 2003, Effects of fire retardant on heathland invertebrate communities in Victoria, *Research Report* No. 69, Fire Management, Department of Sustainability and Environment, Victoria.

CSIRO 2000, Assessment of the Effectiveness and Environmental Risk of the Use of Retardants to Assist in Wildfire Control in Victoria, *Research Report* No. 50, prepared by CSIRO Forestry and Forest Products for the Department of Natural Resources and Environment, 43 pp.

Day, JC, McGregor, GA & Johnstone, PD 1984, *Grampians National Park – Inventory of Resources and Uses*, National Parks Service, Melbourne, Victoria, 136 pp.

Dixon, KW, Roche, S & Pate, JS 1995, The promotive effect of smoke derived from burnt native vegetation on seed germination of Western Australian plants, *Oecologia* 101: 185–92.

Dodge, M 1970, Nitrate poisoning, fire retardants and fertilizers – any connection? *Journal of Range Management* 23: 244–47.

EGC 1985, *East Gippsland Coalition Proposal for National Parks in East Gippsland – A Greenprint for Forests*, East Gippsland Coalition, Melbourne, Victoria, 48 pp.

Enright, NJ, Goldblum, D, Ata, P & Ashton, DH 1997, The independent effects of heat, smoke and ash on emergence of seedlings from soil seed bank of a healthy *Eucalyptus* woodland in Grampians (Gariwerd) National Park, western Victoria, *Australian Journal of Ecology* 22: 81–88.

Hopmans, P & Bickford, R 2003, Effects of fire retardant on soils of heathland in Victoria, *Research Report* No. 70, Fire Management, Department of Sustainability and Environment, Victoria.

Kennedy, J & Weste, G 1977, *Phytophthora cinnamomi* in the Grampians, *Australian Plant Pathology Newsletter* 6: 23–24.

Kennedy, J & Weste, G 1986, Vegetation changes associated with invasion by *Phytophthora cinnamomi* on monitored sites in the Grampians, Western Victoria *Australian Journal of Botany* 34: 251–79.

Kent, M & Coker, P 1996, *Vegetation Description and Analysis: A Practical Approach*, John Wiley and Sons, Chichester, United Kingdom, 363 pp.

Kormorek, B, Shearer, BL, Smith, B & Fairman, R 1994, Phosphonate offers a practical measure for the control of *Phytophthora cinnamomi* in native plant communities, in RT Wills & WA Cowling (eds), *Handbook of the Symposium of Plant Diseases in Ecosystems*, Royal Society of Western Australia and the Ecological Society of Australia, Perth Western Australia, p. 28.

Larson, JR & Duncan, DA 1982, Annual grassland response to fire retardant and wildfire, *Journal of Range Management* 35: 700–03.

Larson, DL & Newton, WE 1996, Effects of fire retardant chemicals and fire suppressant foam on North Dakota prairie vegetation, *Proceedings of the North Dakota Academy of Science* 50: 137–44.

Larson, DL, Newton, WE & Ramsey, GS 1996, Effects of fire suppressant foam on vegetation in North Dakota prairie *Proceedings of the International Wildland Fire Foam Symposium and Workshop*, Thunder Bay, Ontario, 3–5 May 1994, Petawawa National Forestry Institute, Canadian Forest Service, No. PI X 123, pp. 123–27.

Larson, DL, Newton, WE, Anderson, PJ & Stein, SJ 1999, Effects of fire retardant chemical and fire suppressant foam on shrub steppe vegetation in northern Nevada, *International Journal of Wildland Fire* 9: 115–27.

Marks, GC, Kassaby, FY & Fagg, PC 1977, Variation in population levels of *Phytophthora cinnamomi* in *Eucalyptus* forest soils of Eastern Victoria, *Australian Journal of Botany* 23: 435–49.

McAndrew, J & Marsden, MAH 1973, *Regional Guide to Victorian Geology*, School of Geology, University of Melbourne, Melbourne, Victoria, 224 pp.

McDonald, SF, Hamilton, SJ, Buhl, KJ & Heisinger, JF 1996, Acute toxicity of fire control chemicals to *Daphnia magna* (Straus) and *Selenastrum capricornutum* (Printz), *Ecotoxicology and Environmental Safety* 33: 62–72.

Pate, JS & Dell, B 1984, Economy of mineral nutrients in sandplain species, in JS Pate & JS Beard (eds.), *Kwongan – Plant Life of the Sandplain*, University of Western Australia Press, Nedlands, Australia, pp. 227–52.

Pilbeam, RA, Colquhoun, IJ, Shearer, B & St J. Hardy, GE 2000, Phosphite concentration: its effect on phytotoxicity symptoms and colonisation by *Phytophthora cinnamomi* in three understorey species of *Eucalyptus marginata* forest, *Australasian Plant Pathology* 29: 86–95.

Podger, FD & Brown, MJ 1989, Vegetation damage caused by *Phytophthora cinnamomi* on disturbed sites in temperate rainforest in western Tasmania, *Australian Journal of Botany* 37: 443–80.

Poulton, BC 1996, Effects of two fire suppressant foams on benthic invertebrates colonizing artificial substrates in portable limnocorrals, *Proceedings of the North Dakota Academy of Science* 50: 145–51.

Randall, R 2002, *A Global Compendium of Weeds*, Department of Agriculture of Western Australia, http://www.hear.org/gcw/.

Rees, B 1983, Retardant distributions from six agricultural aircraft, *Research Report* No. 18 Fire Management Branch, Department of Conservation & Environment, Victoria, p. 16.

Shearer, BL & Dillon, M 1996, Impact and disease centre characteristics of *Phytophthora cinnamomi* infestations of *Banksia* woodlands on the Swan Coastal Plain, Western Australia, *Australian Journal of Botany* 44: 79–90.

Shearer, BL & Tippett, JT 1989, Jarrah dieback: the dynamics and management of *Phytophthora cinnamomi* in the jarrah (*Eucalyptus marginata*) forest of south-western Australia, *Research Bulletin* No. 3, Conservation and Land Management, Como, Western Australia, 76 pp.

Siddiqui, MY, Carolin, RC & Myerscough, PJ 1976, Studies in the ecology of coastal heath in New South Wales. III. Regrowth of vegetation after fire, *Proceedings of the Linnean Society of New South Wales* 101: 53–63.

Spech,t RL & Moll, EJ 1983, Mediterranean-type heathlands and sclerophyllous shrublands of the world: an overview, in FJ Kruger, DT Mitchell & JUM Javis (eds.), *Mediterranean-Type Ecosystems. The Role of Nutrients*, Springer-Verlag, Berlin, pp. 41–65.

Spencer-Jones, D 1965, *The Geology and Structure of the Grampians Area, Western Victoria*, Geological Survey of Victoria, Memoir 25, Department of Mines, Melbourne, Victoria, 92 pp.

Tieu, A, Dixon, KW, Sivasithamparam, K, Plummer, JA & Sieler, IM 1999, Germination of four species of native Western Australian plants using plant-derived smoke, *Australian Journal of Botany* 47: 207–19.

van Meter, WP, George, CW & Johnson, CW 1985, Chemical analysis procedures for four fire retardant constituents, *USDA Forest Service General Technical Report* INT-181, 25 p.

Vyas, NB, Hill, EF & Ramsey, GS 1996, Toxicity of fire retardant chemicals and fire suppressant foams to vertebrate and invertebrate wildlife species, *Proceedings of the International Wildland Fire Foam Symposium and Workshop*, Thunder Bay, Ontario, 3–5 May 1994, Petawawa National Forestry Institute, Canadian Forest Service, No. PI X 123, pp. 128–131.

Walsh, NG & Entwistle, TJ 1994, *Flora of Victoria,* Volume 2, *Ferns and Allied Plants, Conifers and Monocotyledons*, National Herbarium of Victoria, Inkata Press, Melbourne, Victoria.

Walsh, NG & Entwistle, TJ 1996, *Flora of Victoria,* Volume 3, *Dicotyledons: Winteraceae to Myrtaceae*, National Herbarium of Victoria, Inkata Press, Melbourne, Victoria.

Warcup, JH 1980, Effect of heat treatment of forest soil on germination of buried seed, *Australian Journal of Botany* 28: 567–71.

Warcup, JH 1981, Effect of fire on the soil microflora and other non-vascular plants, in AM Gill, RH Groves & IR Noble (eds.), *Fire and the Australian Biota*, Australian Academy of Science, Canberra, Australia, pp. 203–14.

Weste, G 1981, Changes in the vegetation of sclerophyll shrubby woodland associated with invasion by *Phytophthora cinnamomi*, *Australian Journal of Botany* 29: 261–76.

Weste, G, Brown, K, Kennedy, J & Walshe, T 2002, *Phytophthora cinnamomi* infestation – a 24-year study of vegetation change in forests and woodlands of the Grampians, Western Victoria, *Australian Journal of Botany* 50: 247–74.

Weste, G & Kennedy, J 1997, Regeneration of susceptible native species following a decline of *Phytophthora cinnamomi* over a period of 20 years on defined plots in the Grampians, western Victoria, *Australian Journal of Botany* 45: 167–90.

Weston, CJ & Attiwill, PM 1990, Effects of fire and harvesting on nitrogen transformations and ionic mobility in soils of *Eucalyptus regnans* forests of south-eastern Australia, *Oecologia* 83: 20–26.

Whelan, RJ 1995, *The Ecology of Fire*, Cambridge University Press, Cambridge, UK, 346 pp.

Appendix 1

Species list with respective life form and introduced status for plots at the Victoria Valley, Grampians

'Presence' refers to the sampling dates when each of the species were recorded: 1 = March 2001 sampling, 2 = December 2001 sampling. Status of species as weeds according to Randall (2002).

Family	Species	Life form	Weed	Presence
Asteraceae	*Carthamus* sp. (Thistle 1)	Herb	yes	2 only
	Carthamus sp. (Thistle 2)	Herb	yes	2 only
	Craspedia glauca	Herb		2 only
	Sonchus sp. 1	Herb	yes	2 only
	Sonchus sp. 2	Herb	yes	2 only
	Weed 1	Herb	yes	2 only
Brunaceae	*Brunonia australis*	Herb		2 only
Caryophyllaceae	*Stellaria media*	Herb	yes	2 only
Casuarinaceae	*Allocasuarina paludosa*	Shrub		1 & 2
Campanulaceae	*Wahlenburgia stricta*	Herb		2 only
Cyperaceae	*Lepidosperma carphoides*	Sedge		1 & 2
	Grazed sedge *(Lepidosperma* sp.*)*	Sedge		2 only
Dasypogonaceae	*Calectasia intermedia*	Shrub		2 only
Dicranaceae	*Campylopus australis*	Moss		1 & 2
Dilleniaceae	*Hibbertia riparia*	Shrub		1 & 2
	Hibbertia virgata	Shrub		1 & 2
Droseraceae	*Drosera auricularis*	Herb		2 only
	Drosera pygmaea	Herb		2 only
Epacridaceae	*Brachyloma daphnoides*	Shrub		1 only
	Epacris impressa	Shrub		1 & 2
	Leucopogon glacialis	Shrub		1 & 2
	Leucopogon virgatus	Shrub		1 & 2
	Monotoca scoparia	Shrub		1 & 2
Iridaceae	*Pattersonia* sp.	Herb		2 only
Leguminosae	*Dillwynia glaberrima*	Shrub		1 & 2
Liliaceae	*Burchardia umbellata*	Herb		1 only
	Lomandra multiflora ssp. *multiflora*	Herb		1 only
	Lomandra sp.	Herb		2 only
	Xanthorrhoea minor ssp. *lutea*	'Grass'		1 & 2
Myrtaceae	*Calytrix tetragona*	Shrub		1 & 2
	Eucalyptus willisii	Shrub		1 & 2
	Leptospermum continentale	Shrub		1 only
	Leptospermum myrsinoides	Shrub		1 & 2
	Micromyrtus ciliata	Shrub		1 & 2
Poaceae	*Austrostipa mollis*	Grass		1 only
	Grazed grass *(Austrostipa* sp.*)*	Grass		2 only
Proteaceae	*Banksia marginata*	Shrub		1 & 2
	Hakea sp.	Shrub		2 only
	Persoonia juniperina	Shrub		1 only
Restionaceae	*Hypoleana fastigiata*	Sedge		1 & 2
	Lepidobolus drapetocoleus	Sedge		1 & 2
Scrophulariaceae	*Euphrasia collina*	Herb		2 only

Appendix 2

Species list with respective life form and introduced status for plots at the Marlo site, East Gippsland

'Presence' refers to the sampling dates when each of the species were recorded: 1 = February 2001 sampling, 2 = November 2001 sampling. Status of species as weeds according to Randall (2002).

Family	Species	Life form	Weed	Presence
Adiantaceae	*Lindsaea linearis*	Herb		1 & 2
Anthericaceae	*Chamaescilla corymbosa* var *corymbosa*	Herb		2 only
Apiaceae	*Centella cordifolia*	Herb		1 & 2
	Xanthosia dissecta	Herb		2 only
Asteraceae	*Brachyscome* sp.	Herb		2 only
	Hypochaeris radicata	Herb	yes	1 & 2
	Lagenifera gracilis	Herb		2 only
	Leptorhynchos nitida	Herb		2 only
Campanulaceae	*Wahlenbergia* sp.	Herb		1 & 2
Casuarinaceae	*Allocasuarina paludosa*	Shrub		1 & 2
Centrolepidaceae	*Centrolepis strigosa* var *strigosa*	Herb		2 only
Clusiaceae	*Hypericum gramineum*	Herb	yes	1 & 2
Cyperaceae	*Baumea acuta*	Sedge		1 & 2
	Baumea juncea	Sedge		1 & 2
	Baumea tetragona	Sedge		1 & 2
	Cyperus tenellus	Sedge	yes	2 only
	Lepidosperma laterale	Sedge		1 & 2
	Lepidosperma longitudinale	Sedge		1 & 2
	Lepidosperma neesii	Sedge		1 & 2
	Schoenus apogon	Sedge		2 only
	Schoenus brevifolia	Sedge		1 & 2
	Schoenus lepidosperma var *lepidosperma*	Sedge		1 & 2
	Tetraria capillaris	Herb		2 only
Droseraceae	*Drosera pygmaea*	Herb		2 only
Epacridaceae	*Epacris impressa*	Shrub		1 & 2
	Epacris obtusa	Shrub		1 & 2
	Sprengelia incarnata	Shrub		1 & 2
Gentiaceae	*Cicendia filiformis*	Herb	yes	2 only
Goodeniaceae	*Dampiera stricta*	Herb		1 & 2
Haloragaceae	*Gonocarpus micranthus*	Herb		2 only
	Gonocarpus tetragynus	Herb		1 & 2
	Gonocarpus teucrioides	Herb		1 & 2
Iridaceae	*Iridaceae* sp.	Herb	yes?	1 & 2
	Patersonia fragilis	Herb		1 & 2
Juncaceae	*Juncus bufonius*	Herb	yes	2 only
Leguminoseae	*Acacia dealbata*	Shrub		1 & 2
	Acacia longifolia	Shrub		1 & 2
	Bossiaea prostrata	Shrub		1 & 2
	Dillwynia glaberrima	Herb		1 & 2
	Sphaerolobium vimineum	Shrub		2 only
	Viminaria juncea	Shrub		1 & 2

Appendix 2 (cont.)

Family	Species	Life form	Weed	Presence
Lauraceae	*Cassytha glabella*	Climber		1 & 2
Liliaceae	*Burchardia umbellata*	Herb		1 & 2
	Caesia parviflora var *parviflora*	Herb		2 only
	Hypoxis hygrometrica ssp. *hygrometrica*	Herb		2 only
	Liliaceae sp.	Herb	yes?	1 & 2
	Tricoryne elatior	Herb		2 only
	Thysanotus tuberosus	Climber		2 only
	Xanthorrhoea resinifera	'Grass'		1 & 2
Lobeliaceae	*Lobelia alata*	Herb		1 & 2
Myrtaceae	*Kunzea ericoides*	Shrub		1 & 2
	Leptospermum continentale	Shrub		1 & 2
Orchidaceae	*Cryptostylis subulata*	Herb		1 & 2
	Diuris punctata	Herb		2 only
	Orchidaceae sp.	Herb		1 & 2
	Prasophyllum brevilabre	Herb		2 only
	Thelymitra sp.	Herb		2 only
Phormiaceae	*Thelionema caespitosum*	Herb		2 only
Pittosporaceae	*Billardiera scandens*	Herb		1 & 2
	Rhytidosporum procumbens	Herb		1 & 2
Plantaginaceae	*Plantago coronopus*	Herb	yes	1 & 2
Poaceae	*Anthoxanthum odoratum*	Grass	yes	1 & 2
	Austrodanthonia sp.	Grass		2 only
	Austrodanthonia setacea var *setacea*	Grass		2 only
	Austrostipa sp.	Grass	yes?	1 & 2
	Briza minor	Grass	yes	2 only
	Deyeuxia quadriseta	Grass		1 & 2
	Eragrostis brownii	Grass	yes	1 & 2
	Holcus lanatus	Grass	yes	2 only
	Imperata cylindrica	Grass	yes	1 & 2
	Microleana stipoides	Grass		1 & 2
	Panicum simile	Grass		1 & 2
	Paspalum dilatatum	Grass	yes	1 & 2
	Pentapogon quadrifidus	Grass	yes	1 & 2
	Poa clelandii	Grass		1 & 2
Polygalaceae	*Comesperma ericinum*	Herb		1 & 2
Polypodiaceae	*Adiantum aethiopicum*	Herb		2 only
Proteaceae	*Banksia serrata*	Shrub		1 & 2
	Hakea decurrens	Shrub		2 only
	Hakea teretifolia	Shrub		1 & 2
Restionaceae	*Restio complanatus*	Sedge		1 & 2
Rubiaceae	*Opercularia varia*	Herb		2 only
Selaginellaceae	*Selaginella uliginosa*	Herb		1 & 2