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The Short Term Effects of a
Fire Fighting Foam and Fire Retardant
on Selected Flora from Australia's Southwest

BY

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ABSTRACT:

Chemical fire suppressants are used extensively throughout Australia's Southwest to contain and suppress wildfires. Despite several studies being conducted into their effects on terrestrial vegetation in North America and Eastern Australia, where a variety of significant effects were found, no such investigation has been carried out in Australia's Southwest. This study examined the short-term effects of a fire fighting foam and fire retardant on selected flora from Australia's Southwest.

Various concentrations of fire fighting foam and fire retardant were applied to seeds and seedlings of several native species. Native species were chosen for their high abundance and widespread distribution throughout Australia's Southwest. Seed germination was assessed over 28 days for the number of germinants, whilst the seedlings were assessed on numerous growth characteristics over a ten-week period.

Both the fire fighting foam and fire retardant treatments significantly reduced the germination of all seven species. Greater concentrations resulted in reduced seed germination. Both the 3.0% foam and 3.0% fire retardant treatments showed no sign of germination within the study period. The effect of the fire fighting foam on some native seedlings was significant, yet significant differences were inconsistent throughout the species examined and the variables applied. The fire retardant was far more influential on the growth characteristics measured and significantly affected all seven species. Significant responses included increases and decreases in biomass and improved and reduced plant health.

From these results, it was determined that the use of fire retardants to control and suppress wildfires should be avoided where possible. The use of fire fighting foams between 0.1% and 0.4% foam concentrate is recommended as an ecologically sound and effective fire suppressant tool.

DECLARATION:

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief does not contain any material previously published or written by any other person except where due reference is made in the text.

Signature... ·

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ACKNOWLEDGEMENTS:

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CHAPTER 1: INTRODUCTION

1.1. BACKGROUND:

Fire has long played an integral part in shaping the natural environment. It occurs over a wide range of plant communities and has produced numerous adaptations. These adaptations enable the survival and persistence of plant species within certain ranges of fire frequency, intensity and seasonal occurrence (Gill, 1975; Bond & Van Wilgen, 1996). Historically, the principal cause of fire in natural ecosystems was lightning. Today the leading source is anthropogenic (DeBano, Neary & Ffolliott, 1998).

On the Australian continent, Aborigines were the first to employ fire (Pyne, Andrews & Laven, 1996). It played an important role in their lives, including domestic, social, ritual and food gathering situations (Roberts & Attwood, 1992). This use of fire caused the receiving environment to adapt to a more open vegetation, void of any understorey and befitting to the pyrophytes. Hence, the eucalypt prevailed over much of Australia (Flannery, 1994).

Following European settlement, indigenous fire regimes were ignorantly suppressed. This resulted in an accumulation of forest understorey, adding to the ever-increasing fuel load, to which fire was inevitable (Roberts & Attwood, 1992; Flannery, 1994; Pyne 1995). Subsequent fires were far more intense, with economic demise and loss of life a common outcome (Luke & McArthur, 1978). In an effort to suppress such wildfire, traditional means of fire fighting were employed. These included firebreaks, hand tools, back burning and the use of water apparatus (Luke & McArthur, 1978; Roberts & Attwood, 1992; Overton, 1996).

Whilst traditional means of fire fighting were sufficient in dealing with low intensity fires, greater suppression was required for high intensity fires. In light of such requirements, fire-fighting foams were first evaluated during the 1930's and found to suppress 'A Class' fires (e.g. wood, paper and textiles) more effectively than plain water (Stern & Routley, 1996; Buhl & Hamilton, 2000). The evaluation of fire retardants followed shortly, with enterprises such as Angus, Monsanto, Chemonics and Solutia becoming leading manufactures in fire suppression (Anon, 2001).

The fire fighting foams used today, are principally composed of surfactants, foaming and wetting agents (McDonald, Hamilton, Buhl & Heisinger, 1995; Buhl & Finger, 2000). They act by reducing the surface tension of water, allowing greater water coverage and penetration over the fuel source (Gould, Khanna, Hutchings, Cheney & Raison, 2000; Larson & Newton, 1996). Fire fighting foams are supplied by the manufacturer as a liquid concentrate. They are typically applied at concentrations of 0.1 to 1.0 percent, rendering them more than 99 percent water (Larson, Newton, Anderson & Stein, 1999). This water dependency renders fire fighting foams ineffective once the water evaporates and they are consequently labelled as short-term fire suppressants (USDA, 1998b). Fire fighting foams are divided into two types: Class-A foams, which are suitable for extinguishing carbon compounds of an organic nature, such as wood, paper and textiles; and Class-B foams, for extinguishing flammable liquids and gases (Roberts & Attwood, 1992; Bryan, 1993). Fire fighting foams may be applied from the ground or the air (Hamilton, Larson, Finger, Poulton, Vyas and Hill, 1998; USDA 1998a).

Modern day fire retardants act by forming a combustion barrier between the fire and the fuel (Adams & Simmons, 1999). They are typically composed of diammonium sulphate, diammonium phosphate, monoammonium phosphate, gum thickeners, iron oxide colouring agent and preservatives (Gould *et al.*, 2000; Buhl & Finger, 2000). The ammonium salts retard the fire by chemically combining with cellulose as the fuels are heated (Hamilton *et al.*, 1998). Fire retardants may be supplied as liquid or powdered concentrates and applied at various concentrations (USDA, 1998a). Their effectiveness is dependent on the concentration deposited per unit area (McDonald *et al.*, 1995). Fire retardants may be applied from the ground or the air and remain effective after the water carrier has evaporated. They are therefore considered as long-term fire suppressants (Gould *et al.*, 2000; USDA, 1998a).

In light of the additional fire suppression that both fire fighting foams and fire retardants provide, their acceptance and application is now widespread (Luke & McArthur, 1978; Adams & Simmons, 1999; Gould *et al.*, 2000). In the United States, 91 million litres of ammonium-based fire retardant was used during 1992 (McDonald *et al.*, 1995) and enough foam concentrate was sold to make 160 million litres of foam (Larson & Newton, 1996). In Australia, the state of Victoria applied approximately 120, 000 litres of long term fire retardant to control wildfire in one year (Gould *et al.*, 2000). Moreover, the state of Western Australia

allocated 15 percent of the 1991/92 fire suppression budget to fire fighting chemicals (Rawet, Smith & Kravainis, 1996; cited in Adams & Simmons, 1999).

The application of these fire fighting chemicals is carried out by land management agencies. In Australia, these include the Department of Natural Resources and Environment (NRE) in Victoria and the Department of Conservation and Land Management (CALM) in Western Australia. Between these land management agencies a variety of short and long-term fire suppressants are employed. These include Angus ForExpan-S, Ansul Silv-Ex and Phos-Chek WD-881 fire fighting foams and Phos-Chek D75-F, Fire-Trol GTS-R and Amguard DSB Type-R Mop-Up fire retardants (Adams & Simmons, 1999; T. Maher, pers. comm., 2002). In Western Australia, the most commonly used fire fighting foam is Angus ForExpan-S, whilst the most common fire retardant is Amguard DSB Type-R Mop-Up (T. Maher, pers. comm., 2002).

To support the use of fire fighting chemicals, Australian land management agencies refer to the economic savings obtained by using fire fighting foams, where the amount of water required can be reduced by over 60 percent (McDonald *et al.*, 1995). They also point out that traditional means of fire fighting, such as the creation of fire breaks with heavy machinery, are ecologically damaging and often lead to edge effects, weed invasions and other types of environmental degradation (Adams & Simmons, 1999). Furthermore, the ability to control and suppress wildfires from the air with the use of fire fighting chemicals is advantageous to land management agencies, especially when wildfires are inaccessible by ground (Chandler *et al.*, 1983; cited in Bradstock, Sanders & Tegart, 1987; Adams & Simmons, 1999).

Despite the additional suppression that fire fighting foams and fire retardants provide, uncertainty remains on their environmental and human health effects (USDA, 1998b). This concern can be highlighted by the lack of ecological research and environmental evaluation of fire fighting chemicals prior to their widespread application (Adams & Simmons, 1999; Gould *et al.*, 2000; Larson *et al.*, 1999). At present, the United States Department of Agriculture (USDA) is the only approval system for chemical fire suppressants, to which all fire fighting foams and fire retardants applied in the USA must be tested. Approval involves a series of tests for product stability and storage, corrosion, health and safety, and operational evaluations (Stern & Routley, 1996). For Class-A foams to be approved by the USDA, 50 percent of the

foam must biodegrade in 28 days (Stern & Routley, 1996). In Australia, no such approval system exists, as fire fighting foams and fire retardants are not considered hazardous and are not classified as dangerous goods according to Work-Safe Australia (Chemwatch, 1997; cited in Hartskeerl, 1999; T. Maher, pers. comm., 2002; 3M Australia (Undated); Albright & Wilson, 2002).

1.2. ECOLOGICAL EFFECTS OF CHEMICAL FIRE SUPPRESSANTS:

As a result of their widespread application and chemical composition, fire fighting foams and fire retardants have the potential to be ecologically damaging, yet little investigation into their environmental effects has occurred (Bradstock *et al.*, 1987; Adams & Simmons, 1999; Hartskeerl, 1999; Gould *et al.*, 2000). Fire fighting foams and fire retardants are also applied in environmentally sensitive areas, which may contain rare or endangered species, providing further concern (Larson *et al.*, 1999; Buhl & Finger, 2000).

Of the limited research conducted on the ecological effects of fire fighting foams and fire retardants, the majority can be assigned to aquatic, vertebrate and invertebrate, and vegetative research. The bulk of this investigation has been carried out in North America, where the occurrence of wildfire is common (Adams & Simmons, 1999). In turn, the studies undertaken have focused on North American species (Hartskeerl, 1999). Comparative research in Australia is limited, with only two vegetation studies available, being Bradstock *et al.*, (1987) and Hartskeerl (1999).

Given the chemical composition of fire retardants, where the main ingredients are fertiliser salts (Gould *et al.*, 2000), it is quite possible that an adverse effect will result as the concentration deposited per unit area increases (McDonald *et al.*, 1995). This notion can be supported by the effects of fertilisers on Australian native plants, where nutrient availability is generally low (Flannery, 1994; Handreck, 1997).

In the same context, fire fighting foams are composed of surfactants, foaming and wetting agents (McDonald *et al.*, 1995). They act by reducing the surface tension of water, allowing greater water coverage and penetration over the fuel source (Larson & Newton, 1996; Gould *et al.*, 2000). How these physicochemical modifications affect the receiving environment is unknown, yet the literature suggests that a detrimental effect is possible to a variety of plant and animal species (Adams & Simmons, 1999; Gould *et al.*, 2000).

1.2.1. Aquatic organisms

In recent years, several studies have been conducted into the effects of fire fighting chemicals on aquatic organisms. The majority of these studies have focused on several species that play important roles in aquatic systems and allow comparability to other aquatic organisms (McDonald *et al.*, *1995*; Gaikowski, Hamilton, Buhl, McDonald & Summers, 1996; Hamilton *et al.*, *1998*; Buhl & Hamilton, 2000). These species include the Rainbow Trout (*Oncorhynchus mykiss*), Fathead Minnow (*Pimephales promelas*), Chinook Salmon (*Oncorhynchus tshawytscha*), daphnids (*Daphnia magna*), algae (*Selenastrum capricornutum*) and amphipods (*Hyalella azteca*).

The fire fighting foams applied to these study species include Fire-Trol FireFoam 103B, FireFoam 104, Fire Quench, Phos-Chek WD-881, Angus ForExpan-S, Ansul Silv-Ex and Pyrocap B-136. The fire retardants applied include Fire-Trol LCA-F, Fire-Trol LCM-R, Phos-Chek 259F and Phos-Chek D75-F (McDonald *et al.*, *1995*; Gaikowski *et al.*, *1996*; Hamilton *et al.*, *1996*; Hamilton *et al.*, *1998*; Buhl & Hamilton, 2000). These fire fighting chemicals are approved by the USDA and receive widespread application. The fire fighting foams Angus ForExpan-S, Ansul Silv-Ex, Phos-Chek WD-881 and the fire retardants Fire-Trol GTS-R and Phos-Chek D75-F are currently used in Australia for wildfire suppression (Adams & Simons, 1999; Gould *et al.*, *2000*).

The studies confirmed that a detrimental effect was evident to aquatic organisms, for both fire fighting foams and fire retardants (McDonald *et al.*, *1995*; Gaikowski *et al.*, *1996*; Hamilton *et al.*, *1998*; Buhl & Hamilton, 2000). For the Rainbow Trout (*Oncorhynchus mykiss*), Fathead Minnow (*Pimephales promelas*) and Chinook Salmon (*Oncorhynchus tshawytscha*), the fire fighting foams were found to be more toxic than the fire retardants (Hamilton *et al.*, *1996*; Hamilton *et al.*, *1998* Buhl & Hamilton, 2000). The study conducted by Gaikowski *et al* (1996) found that the fire fighting foams Phos-Chek WD-881 and Ansul Silv-Ex were 10 times more toxic to Rainbow trout and Chinook salmon, and between 10 to 258 times more toxic to Fathead minnow than the fire retardants Phos-Chek D75-F, Fire-Trol GTS-R and Fire-Trol LCG-R. This toxicity occurs as a result of the surfactant in the foams (Gaikowski *et al.*, *1996*; USDA 1998b). The surfactant reduces the surface tension of the water and interferes with the ability of the gills to absorb oxygen, causing the fish to suffocate (Gaikowski *et al.*,

1996; USDA, 1998b). As a general rule, the greater the reduction in surface tension, the greater the toxicity to aquatic organisms (Hamilton *et al., 1996*; Gaikowski *et al., 1996*).

The surfactants used in fire fighting foams also pose other problems to aquatic organisms. A reduction in surface water tension has been shown to adversely effect gill epithelia, ranging from epithelial swelling to complete destruction of the gill epithelia (Bock, 1967; cited in Hamilton *et al., 1996*). Surfactants also alter the permeability of biological membranes (Helenius & Simons, 1975; cited in Gaikowski *et al., 1996*; Hamilton *et al., 1996*). This cellular alteration may induce the chemical uptake of detrimental compounds by aquatic organisms. Therefore, in aquatic systems that contain inorganic or organic pollutants, the addition of fire fighting foam surfactants may increase the uptake of pollutants by aquatic organisms (Gaikowski *et al., 1996*).

The effect of the fire retardants on fish was far less toxic than the fire fighting foams, yet some mortality was observed. The studies confirmed that the toxic component was the active ammonium salts found in most fire retardant chemicals (McDonald *et al., 1995*; Hamilton *et al., 1996*). Amongst the fire retardants tested, the powered formulations showed greater toxicity to Rainbow Trout than the liquid compounds (Buhl & Finger, 2000). The studies suggested that a single retardant drop placed directly into a stream could cause the ammonium concentration in the water to be lethal to fish and other aquatic organisms (USDA, 1998b).

The *Daphnia magna* and *Hyalella azteca* responded to the fire fighting chemicals in a similar way to that of the fish. For the *Daphnia magna*, the toxicity of the fire fighting foams Silv-Ex and Phos-Chek WD-881 was 10 to 200 times greater than the fire retardants Phos-Chek D-75-F, Fire-Trol GTS-R and Fire-Trol LCG-R (Hamilton *et al., 1996*). For the *Hyalella azteca*, the toxicity of the Silv-Ex and Phos-Chek WD-881 was 10 to 50 times greater than the fire retardants Phos-Chek D-75-F, Fire-Trol GTS-R and Fire-Trol LCG-R (Hamilton *et al., 1996*). Again, this toxicity is due to the surfactants contained in the fire fighting foams, which lowers the surface tension of water and thus decreases the ability of aquatic organisms to obtain oxygen (McDonald *et al.* 1996).

In contrast to the greater toxicity of the fire fighting foams, the algae *Selenastrum capricornutum* showed the most toxic response to the fire retardant Fire-Trol LCG-R.

Somewhat confusingly, the fire fighting chemical least toxic to the algae was the fire retardant Phos-Chek D75-F (McDonald *et al.*, *1995*). In addition to the algae's toxicity response, an increase in biomass was observed for all fire fighting chemicals except Ansul Silv-Ex. The greatest biomass increase was associated with the fire retardant Phos-Chek D75-F, which produced a 43 percent biomass increase (McDonald *et al.*, *1995*). The studies attributed the biomass reactions to the chemical composition and nutritional properties of the fire fighting foams and fire retardants (Hamilton *et al.*, *1996*).

In consideration of the past studies into the ecological effects of fire fighting foams and fire retardants on aquatic organisms, a precautious nature would be of benefit to land management agencies when employing fire fighting chemicals in the vicinity of aquatic systems (Adams & Simmons, 1999). According to Hamilton *et al* (1996), for a typical fire fighting foam (0.1% to 1.0% foam concentrate) to reach a safe toxicity level, the foam would need to be diluted 50, 000 times to avoid the mortality of aquatic organisms. Unfortunately, this level of foam dilution would render the product ineffective. Despite the fact that these investigations were carried out in North America, the inherent similarities between North American and Australian aquatic organisms, justifies the extrapolation of these results to Australian aquatic systems, until further studies can prove otherwise.

1.2.2. Terrestrial vertebrates and invertebrates

Investigations into the effects of fire fighting foams and fire retardants on terrestrial vertebrates and invertebrates are extremely limited (Hartskeerl, 1999; Gould *et al.*, 2000). A study conducted by the Patuxent Wildlife Research Centre into the toxicity of fire fighting foams and fire retardants on terrestrial wildlife found no toxic effects to mammals and birds (Vyas, Spann & Hill, 1996). The fire suppressants tested were Ansul Silv-Ex and Phos-Chek WD-881 fire fighting foams and Fire-Trol GTS-R, Phos-Chek D75-F and Fire-Trol LCG-R fire retardants. During the investigation the fire fighting foam Silv-Ex caused periods of stupor and lack of co-ordination to the American kestrel (*Falco sparverius*) and Red-winged blackbird (*Agelaius phoeniceus*) (Vyas & Hill, 1994; cited in Adams & Simmons, 1999; Hartskeerl, 1999).

For fire fighting chemicals to be approved by the USDA, specific requirements must be met in regard to mammalian toxicity as determined by acute oral and dermal toxicity testing, as well as skin and eye irritation tests (USDA, 1998b). It should be noted, that with any chemical substance, a small percentage of the population may have an unusual reaction to the chemical, which will not be detected during the evaluation process (USDA, 1998b).

In relation to the effects of chemical fire suppressants on terrestrial vertebrates and invertebrates, Gould *et al* (2000) points out that large animals often have the ability to evacuate the area when threatened by fire and small animals can seek shelter in burrows. In comparison to the effects of a high intensity wildfire, where entire populations are incinerated or die from post-fire starvation and predation, the possibility of a short-term toxicity response to a chemical fire suppressant is far less severe (Gould *et al.*, 2000).

1.2.3. Plants and Vegetation

The ecological effects of fire fighting foams and fire retardants on terrestrial vegetation have been studied on a number of plant species. Studies undertaken in North America have resulted in similar findings to each other. Larson & Duncan (1982) investigated the effects of a diammonium phosphate (DAP) fire retardant on annual grassland in the San Joaquin Experimental Range, California. They found that the areas treated with DAP fire retardant produced twice the biomass then that of the control during the first year. However, in the second year the DAP fire retardant treated areas were not significantly different from the control treatments. A change in species composition was also observed during the study, with annual grasses becoming more prevalent with the addition of DAP fire retardant (Larson & Duncan, 1982).

The study carried out by Larson & Newton (1996) investigated the effects of a fire fighting foam (Ansul Silv-Ex) and fire retardant (Phos-Chek G75-F) on North Dakota Prairie vegetation. They found that the Silv-Ex foam application had little effect on the characteristics measured. The effects detected were subtle and included an increase in the number of insect chewed leaves per shoot, a reduction in mean shoot length and an increase in mean leaf length for some species (Larson & Newton, 1996). The application of Phos-Chek G75-F fire retardant resulted in an increase in biomass (Larson & Newton, 1996). However, the effect was only temporary, as biomass did not significantly differ the following year. Larson and Newton (1996) also note that the fertilisation effect was enhanced in the grass species *Poa pratensis*. The grass was not only longer on fire retardant treated plots, but the growth effect was enhanced over the course of the growing season (Larson & Newton, 1996). Of primary concern was a decrease in species richness after the application of both Silv-Ex fire fighting foam and Phos-Chek G75-F fire retardant (Larson & Newton, 1996).

The fire fighting foam Silv-Ex and fire retardant Phos-Chek G75-F were also applied by Larson, Newton, Anderson and Stein (1999) on shrub steep vegetation in Northern Nevada. Of the characteristics they measured, only species richness and the number of stems per metre square were significantly affected. The riparian plots treated with 1.0% Silv-Ex fire fighting foam had significantly fewer stems than the control during weeks 13 to 14 after treatment application (Larson *et al.*, *1999*). Species richness also declined in the riparian plots after

Phos-Chek G75-F application. However, by the end of the study, species richness did not significantly differ between treated and untreated plots (Larson *et al., 1999*).

On the Australian continent, Bradstock *et al.,* (1987) investigated the short-term effects of a chemical fire retardant on the foliage of a eucalypt forest in the Blue Mountains of New South Wales. "The effects of the fire retardant were considered to be striking" (Bradstock *et al., 1987,* p. 73). Leaf death was observed in the overstorey (*Eucalyptus gummifera, E. globoidea, Angophora costata, E. hybrid* and *E. notabilis*) and understorey (*Acacia longifolia, Dodonaea triquetra* and *Leptospermum attenuatum*) within one week of treatment application and continued for many months (Bradstock *et al., 1987*). The effect was greatest in areas where the fire retardant concentration was the highest. Recovery in the overstorey was quite rapid, yet the understorey was somewhat suppressed. Some mortality was observed for *Dodonaea triquetra* and *Acacia longifolia* individuals. Interestingly, *Leptospermum attenuatum* was less affected by the fire retardant and showed greater recovery (Bradstock *et al., 1987*). Following the fire retardant application, litterfall increased from trees and shrubs for the first few months. However, litterfall did not significantly differ over the year (Bradstock *et al., 1987*).

Bradstock *et al.,* (1987) also studied the effects of the chemical fire retardant under glasshouse conditions on *Acacia longifolia, Leptospermum attenuatum* and *Banksia collina* seedlings. Treatments consisted of the chemical components of the fire retardant, being ammonium sulphate and kelzan (Bradstock *et al., 1987*). After 24 hours, all three species treated with ammonium sulphate or the full mixture, showed signs of leaf, phyllode, bud and branch tip damage. Further drying and browning continued over the first week. After six weeks, *Acacia longifolia* and *Leptospermum attenuatum* showed no sign of recovery and were considered dead. Alternatively, *Banksia collina* had almost fully recovered through the production of new leaves (Bradstock *et al., 1987*). Later analysis confirmed that foliar damage was solely caused by the ammonium sulphate component of the fire retardant. Washing to stimulate rainfall did not prevent foliar damage, even when carried out 24 hours after the fire retardant application (Bradstock *et al., 1987*).

More recently, Hartskeerl (1999) examined the effects of a Class-A foam (Angus ForExpan S) on the growth characteristics of selected Australian native terrestrial plants. A total of eight species were examined in the pot trial (seven being endemic to the Melbourne region): *Aotus*

ericoides, Hardenbergia violacea, Indigofera australis, Acacia melanoxylon, Eucalyptus polyanthemos, Poa labillardieri, Banksia integrifolia and *Grevillea sp.* Five treatments were applied to the seedlings using typical field concentrations. These were, 0% (control), 0.1% (foam solution), 0.3% (wet foam), 0.6% (fluid foam) and 1.0% (dry foam) of the foam concentrate (Hartskeerl, 1999). Species growth characteristics were examined every four weeks for a period of three months. An analysis of the results showed that Angus ForExpanS fire fighting foam did not significantly affect any of the study species. From these results, Hartskeerl (1999) concluded that the use of class A foams to control and suppress wildfires, was an ecologically effective tool for land management agencies throughout Australia (Hartskeerl, 1999).

In view of the past research conducted into the ecological effects of fire fighting foams and fire retardants on terrestrial vegetation, it seems fire retardants are far more influential to terrestrial vegetation then fire fighting foams (Larson & Newton, 1996; Larson *et al.*, 1999; Bradstock *et al.*, 1987). Not only do fire retardants affect plant growth, they also alter community characteristics such as species richness, but provide opportunistic species with a distinct advantage (Larson & Duncan, 1982; Larson & Newton, 1996). Given the direct and indirect effects of fire fighting foams and fire retardants, along with their economic and operational attributes, the decision to apply one or the other, at what concentration, to what extent and in which ecological setting is somewhat complex. Only through further research can land management agencies confidently apply chemical fire suppressants and successfully convince others of their ecological effects.

1.3. RESEARCH RATIONALE:

Chemical fire suppressants are used extensively throughout Australia's Southwest to contain and suppress wildfires. Despite several studies being conducted into their effects on terrestrial vegetation in North America and Eastern Australia, no such investigation has been carried out in Australia's Southwest (Adams & Simmons, 1999; Gould *et al.*, 2000). Given the high endemism of Australia's Southwest, where 79.2% of vascular plant species are endemic to Western Australia's Southwest Province (Beard, Chapman & Gioia, unpublished; cited in Paczkowska & Chapman, 2000) and hundreds of plant taxa are declared as endangered (Hopper, Van Leeuwen, Brown & Patrick, 1990), an investigation into how such chemicals affect Australia's Southwest native plants is needed.

Furthermore, seven of the plant species examined by Hartskeerl (1999), whilst investigating the effects of a fire fighting foam on the growth characteristics of Australian native terrestrial plants, are endemic to the Melbourne region of Eastern Australia. Given the geographical difference between Eastern and Western Australia, it is reasonable to suggest that Australia's Southwest native plants may react differently to those examined by Hartskeerl (1999). Thus, the extrapolation of Hartskeerl's (1999) results to Australia's Southwest should be precautionary until further research can show otherwise.

The life history stage of seed germination is crucial to species survival. Seed germination is dependent on factors such as temperature, moisture, nutrients, light and even fire (Hartmann, Kester, Davies & Geneve, 1997). There appear to have been no published research into the effects of chemical fire suppressants on seed germination. Given the chemical composition of both fire fighting foams and fire retardants, it is quite possible that seed germination will be affected by their application.

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1.4. SIGNIFICANCE:

This research will provide valuable information to land management agencies and fire managers to ensure that sound decisions are made concerning the use of chemical fire suppressants on Australia's Southwest native vegetation. An understanding of how fire fighting foams and fire retardants affect plant growth characteristics and native seed germination will assist fire managers in effectively suppressing wildfires without adversely affecting the receiving vegetation.

It is anticipated that this research will also assist in the protection of high value conservation areas from the threat of wildfire. In these areas the current policy is to use water only during wildfire suppression (T. Maher, pers. comm., 2002). The identification of a chemical fire suppressant that shows no significant effects to a variety of Southwest native plant species may lead to its eventual use in areas of high conservational value, adding to their protection.

1.5. AIMS:

This project investigates the effects of the fire fighting foam 'Angus ForExpan S' and fire retardant 'Amguard DSB Type R Mop-Up' on selected flora from Australia's Southwest. More specifically, this project aims to:

1. Examine the effects of the fire fighting foam and fire retardant on the germination of native plant species.

2. Assess the effects of the fire fighting foam and fire retardant on the growth characteristics of native plant species at the seedling stage.

2.2. *Eucalyptus calophylla* (Marri) Myrtaceae Family

Characteristics:

Reaching up to 40 metres in height (Marchant *et al., 1987*), *E. calophylla*, also known as *Corymbia calophylla* since reclassification, although this is still contested, is one of Western Australia's most popular tree species (Powell, 1990). Its bark is grey in colour, rough and tessellated, often exuding a reddish-brown gum from trunk or branches (French, no date; Western Australian Herbarium, 2002; Marchant *et al., 1987*). Its leaves are green to dark green above, paler below and often hairy in juvenile form. Flowering is from December to May (Marchant *et al., 1987*; Western Australian Herbarium, 2002). *E. calophylla* is a hardy tree species that competes well in disturbed areas (Powell, 1990).

Distribution:

Found abundantly throughout the lower southwest of Western Australia, *E. calophylla* extends from the Murchison River to Cape Riche. Its inland boundary is slightly greater than that of *E. marginata*, with Tincurrin being its most easterly location (Figure 2.2) (Gardner, 1979; French, no date; Marchant *et al.,* 1987). Frequently associated with *E. marginata*, it inhabits sandy soils on the coastal plain and heavier lateritic soils on the Darling Range (Marchant *et al., 1987*).
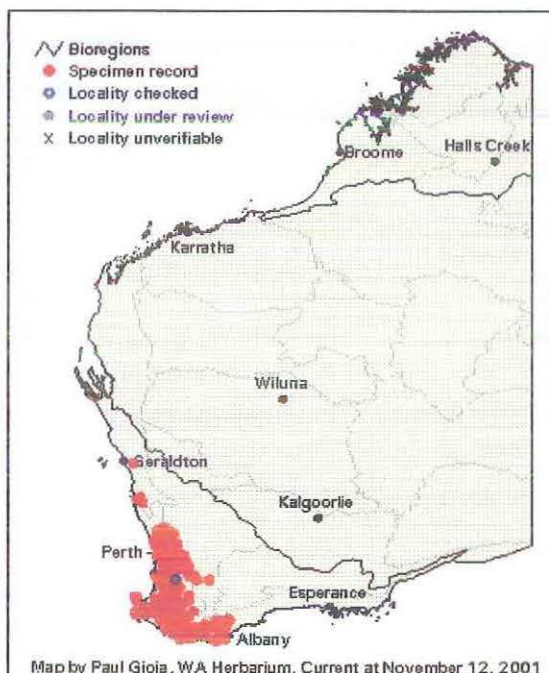
Figure 2.2: Distribution of *E. calophylla* (Western Australian Herbarium, 2002)

2.3.   *Banksia attenuata* (Slender Banksia) Proteaceae Family

Characteristics:

A lignotuberous tree or shrub with epicormic buds (Western Australian Herbarium, 2002). Standing 1 to 10 metres tall with thick fibrous bark, being red-brown underneath (Marchant *et al.*, 1987). Its leaves are narrow, being 40 to 270 mm in length and 5 to 16 mm in width. Flowering occurs between October and February, with bright yellow flower-spikes the product (Powell, 1990; Western Australian Herbarium, 2002). It is fire resistant and rarely killed by fire, allowing the species to dominate numerous woodlands (George, 1984). In areas north of Perth the species is usually a mallee-like shrub, with numerous stems arising from a lignotuber (Marchant *et al.*, 1987).

Distribution:

Ranges widely in the Southwest of Western Australia, from Kalbarri to Cape Leeuwin, extending inland to Wongan Hills and Lake Grace (Figure 2.3) (George, 1984; Powell, 1990). Often dominates sandplains and other deep sands, and sometimes over laterite or limestone. (George, 1984; Marchant *et al.*, 1987).
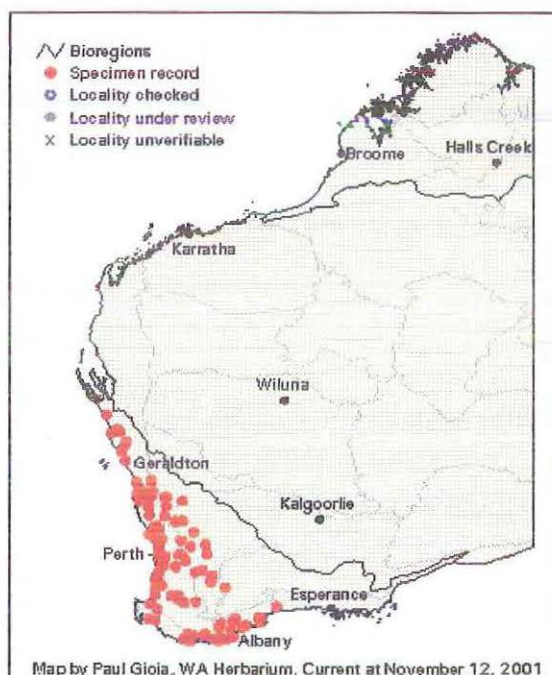
Figure 2.3: Distribution of *B. attenuata* (Western Australian Herbarium, 2002)

18

2.4.   *Xanthorrhoea pressii* (Grass tree) Xanthorrhoeaceae

Characteristics:

An endemic species to Australia (Powell, 1990), standing up to 5 metres tall (Western Australia Herbarium, 2001). Its growth is extremely slow, with a rate of 1.5 cm a year according to Powell (1990) and 4 cm a year according to Lewis (1955; cited in Missingham, 1978). Leaves are a square to rectangular shape, elongated, sharply pointed, hard and extremely brittle. Together they form a spherical bush (Missingham, 1978). *X. pressii* is highly adapted to fire and in turn it stimulates flowering between January and November (Powell, 1990; Missingham, 1978; Western Australian Herbarium, 2002).

Distribution:

X. pressii can be found from Geraldton to Walpole, with its inland boundary slightly west of *E. marginata* (Figure 2.4) (Powell, 1990; Missingham, 1978). It is often associated with Banksia and Jarrah stands (Powell, 1990), preferring grey sands to laterite (Western Australian Herbarium, 2002).
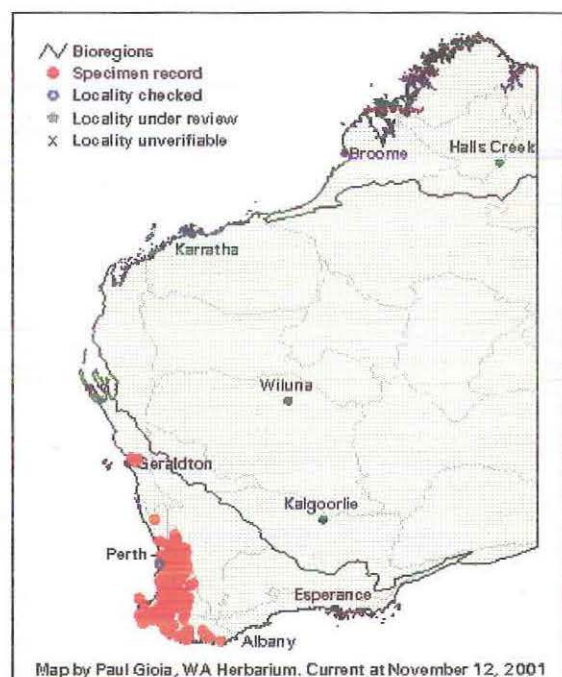
Figure 2.4: Distribution of *X. pressii* (Western Australian Herbarium, 2002)

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2.5. *Hakea lissocarpha* (Honey Bush) Proteaceae

Characteristics:

A lignotuberous understorey shrub up to 3 metres in height, yet more commonly 1 to 1.5 metres (Marchant *et al.*, 1987; Western Australian Herbarium, 2002). Leaves are divided into 3 to 15 lobes, 20 to 60 mm in length, elongated and spiny (Marchant *et al.*, 1987). Flowering occurs between June and October (Western Australia Herbarium, 2002).

Distribution:

Extends from Kalbarri to Israelite Bay, its inland boundary slightly greater than that of *B. attenuata* (Figure 2.5) (Marchant *et al.*, 1987). It can be found on limestone, white, grey, or yellow sands along the coastal plain and more lateritic soils on the Darling Range (Western Australia Herbarium, 2002; Marchant *et al.*, 1987). It is often associated with *E. calophylla*, *E. marginata* and Banksia on the Quindalup and Bassendean sands.
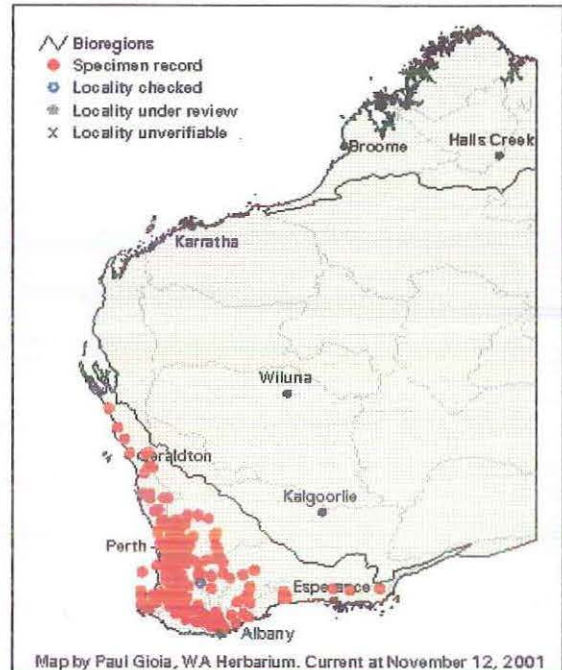
Figure 2.5: Distribution of *H. lissocarpha* (Western Australian Herbarium, 2002)

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2.6.   *Gompholobium tomentosum* (Hairy Yellow Pea) Papilionaceae

Characteristics:

An erect shrub that stands between 0.3 and 1 metre in height (Marchant *et al.*, 1987; Western Australia Herbarium, 2002). Its leaves are divided into 5 to 11 leaflets (Marchant *et al.*, 1987). Flowering occurs between July and January (Western Australia Herbarium, 2002).

Distribution:

Extends from Northampton to Mundijong and inland to York, Pingelly and Gnowangerup (Figure 2.6) (Marchant *et al.*, 1987). Found on Quindalup and Bassendean sands, limestone and lateritic soils on the Darling Range (Marchant *et al.* 1987).
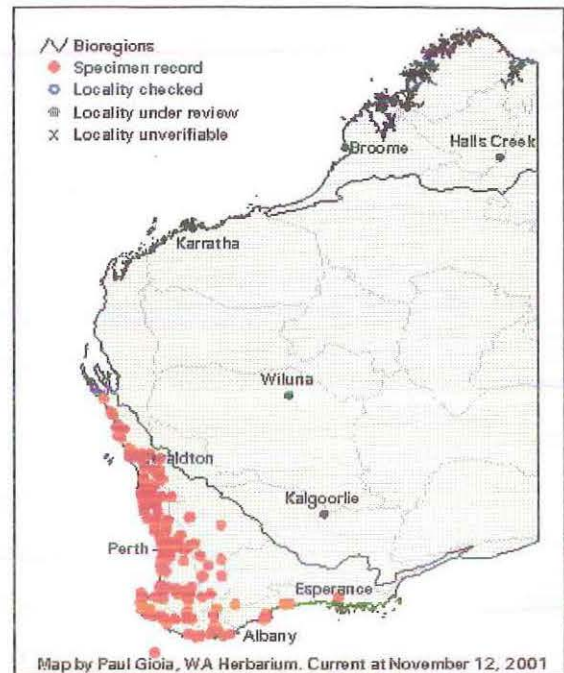
Figure 2.6: Distribution of *G. tomentosum* (Western Australian Herbarium, 2002)

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2.7.   *Acacia pulchella* (Prickly Moses) Mimosaceae

Characteristics:

An understorey shrub that stands 0.3 to 3 metres high (Simmons, 1981; Rippey & Rowland, 1995). It leaves are divided into 3 to 8 pairs of leaflets, housing one or two spines at the base of the leaf (Rippey & Rowland, 1995). Flowers are a golden yellow and arise between May and October (Simmons, 1981; Marchant *et al.,* 1987). Past research has shown *A. pulchella* is able to resist *Phytophthora cinnamomi*, a well-known fungus that attacks the roots of plants, causing the tree to dieback (Simmons, 1981).

Distribution:

Widespread throughout a variety of habitats, extending from Geraldton to Esperance, with remnants scattered throughout the wheat belt (Figure 2.7) (Simmons, 1981). Able to grow in coastal sands, limestone, clay-loam and lateritic soils of the Darling Range (Marchant *et al.,* 1987; Rippey & Rowland, 1995).
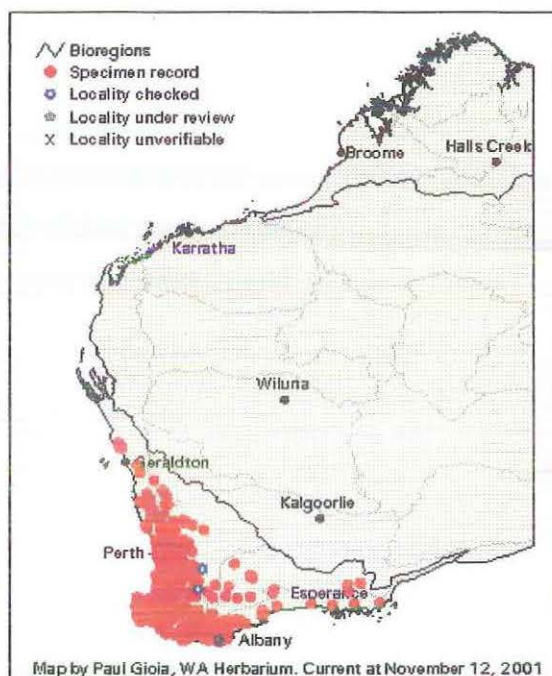
Figure 2.7: Distribution of *A. pulchella* (Western Australian Herbarium, 2002)

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CHAPTER 3: GERMINATION EXPERIMENT

3.1. MATERIALS AND METHODS:

This experiment utilised 385 Petrie dishes, pure agar, fire fighting foam concentrate, fire retardant concentrate and Ben-late ^{TM} fungicide. Foam treatments consisted of 0.1% (wet foam), 0.4% (fluid foam), 0.7% (fluid foam), 1.0% (dry foam) and 3.0% (extra dry foam) of the foam concentrate (v/v). These foam concentrations are typically applied in the field to suppress wildfire (B. Ingles, pers. comm., 2002). The fire retardant treatments consisted of 0.1%, 0.4%, 0.7%, 1.0% and 3.0% of the fire retardant concentrate (w/v). The seed was attained from Kimseed Environmental Seed Merchants, located in Osborne Park, Perth.

For each treatment, 1500 ml of 0.7% (10.5 g) agar solution was made up, to which the foam or fire retardant treatment was added. No chemical was added to the control. Prior to cooling, the agar/treatment media was poured into 35 Petrie dishes, where each dish received 40 ml. This procedure was repeated for each treatment, totalling 385 Petrie dishes.

Before the seeds were placed into the agar/treatment media, each seed species received the following pre-treatments to assist in germination:

E. marginata: Overnight in 0.2% KNO3 and water

E. calophylla: 30 minutes in cold water

B. attenuata: 30 minutes in cold water

X. pressii: 70% ethanol for 30 seconds, 2.0% Zephiran for 10 minutes, rinse off with autoclave water (reduces fungi)

H. lissocarpha: 30 minutes in cold water

G. tomentosum: heat to 80 – 90 degrees Celsius, then cool overnight

A. pulchella: Boil for 1 minute and cool for 10 minutes

For each species, 125 seeds were placed into 5 (replicate) petrie dishes, to which 25 seeds were allocated to each. Each seed was inserted into the agar/treatment media using sterilised pinchers. Each seed was inserted so that 25% of the seed remained above the agar/treatment media. The petrie dishes were then placed into a constant temperature room set at 19 degrees Celsius for a period of 28 days. The seeds were monitored every second day for the number of

new germinants, where germination is defined as a radicle greater than 2 mm in size (Hartman *et al.*, 1997). The fungicide Ben-late was used to suppress fungi when necessary.

The data collected from this experiment was initially tested for homogeneity of variances using Levene's Test ($p > 0.05$) with SPSS^{tm} (SPSS Inc.) software. This confirmed that variances were heterogeneous. The data was not transformed and a non-parametric (Kruskal-Wallis) analysis was performed to detect any significant differences between treatments.

3.2. RESULTS:

3.2.1. *Eucalyptus marginata* (Jarrah) Myrtaceae Family

Results of Kruskal-Wallis test showed that mean percent germination of *E. marginata* treatments differed significantly (Chi-Square 44.010, df 10, Asymp. Sig <0.001). Both control and 0.1% fire retardant differed significantly from all other treatments (Figure 3.1). This result is also shown in Figure 3.2, where both control and 0.1% fire retardant show a gradual increase in the number of germinants over 28 days.
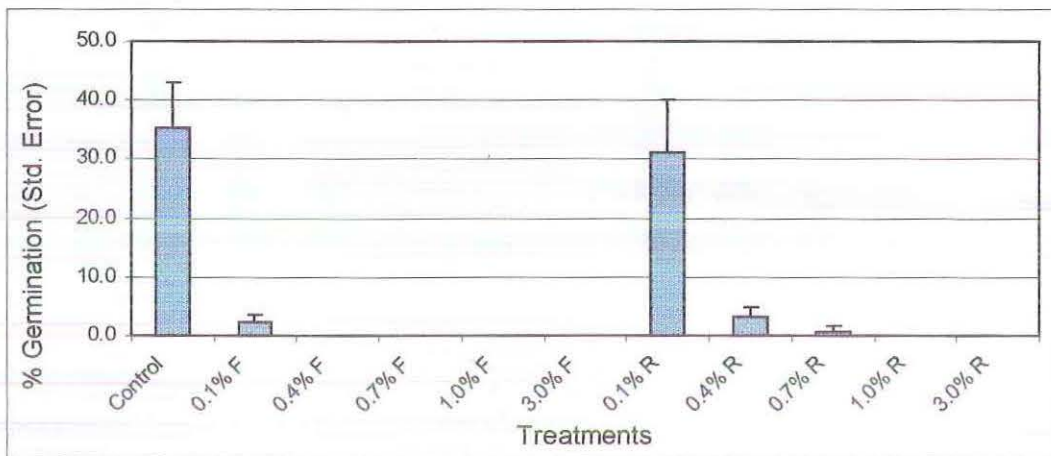
Figure 3.1: *E. marginata* mean percent germination (+ SE, n=5)
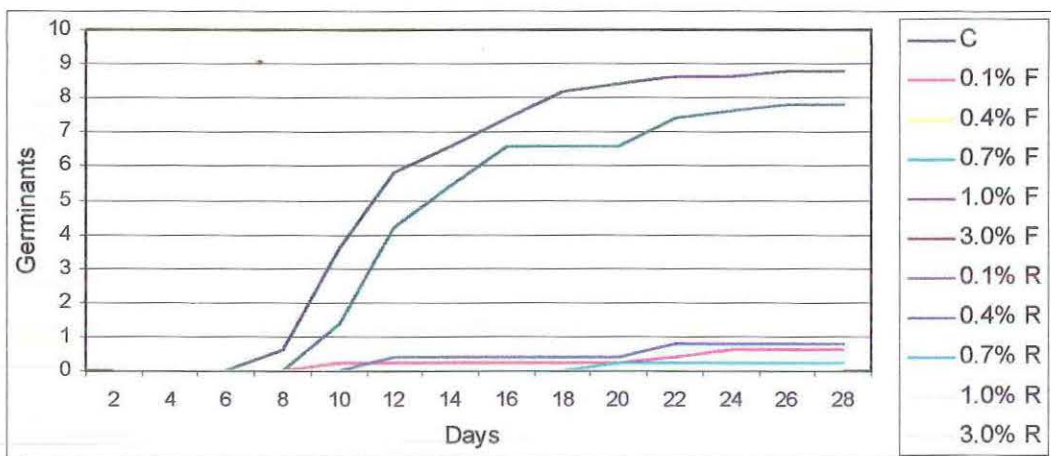
Figure 3.2: *E. marginata* mean number of germinants over 28 days

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3.2.2. *Eucalyptus calophylla* (Marri) Myrtaceae Family

The germination of *E. calophylla* significantly decreased (Chi-Square 45.77, df 10, Asymp. Sig. <0.001) as the concentration of both fire fighting foam and fire retardant treatments increased. Both control and 0.1% fire retardant treatment significantly differ from all other treatments. No germination was observed for 3.0% foam or 3.0% fire retardant treatments (Figure 3.3). Germination distinctively commenced at day 6 for all treatments and reached a maximum at approximately day 22 (Figure 3.4).
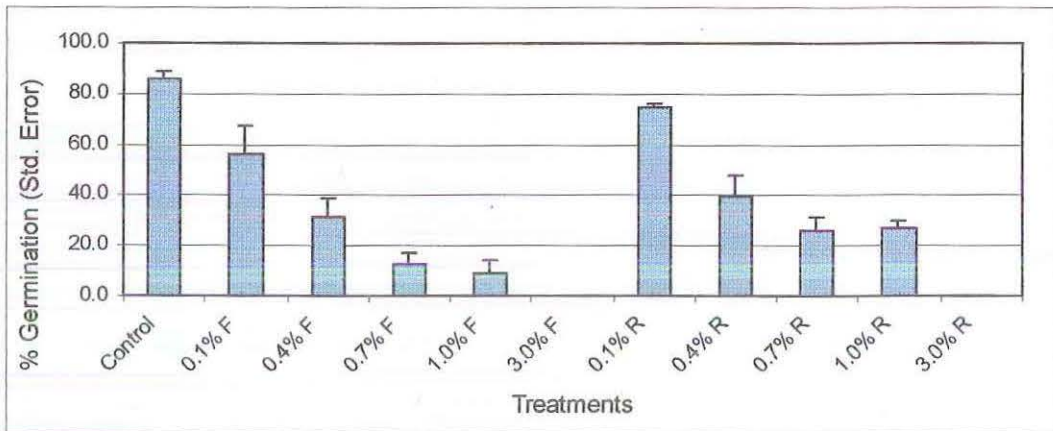
Figure 3.3: *E. calophylla* mean percent germination (+ SE, n=5)
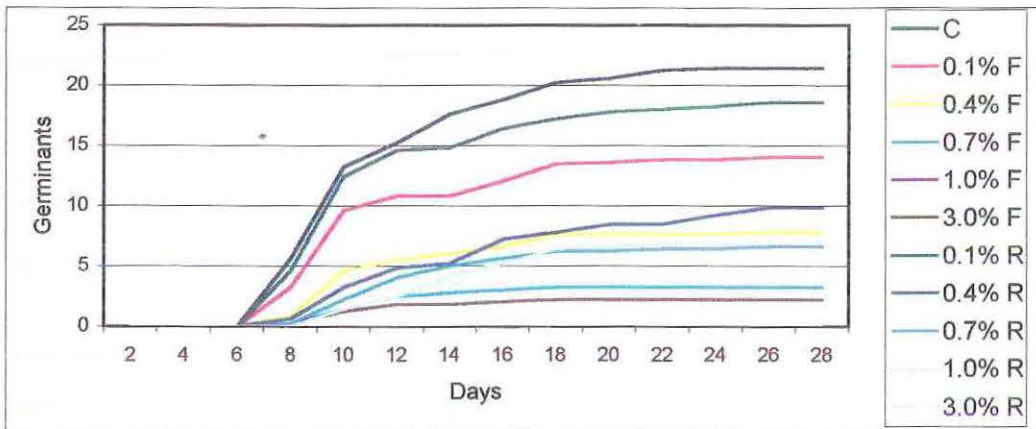
Figure 3.4: *E. calophylla* mean number of germinants over 28 days

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3.2.3. *Banksia attenuata* (Slender Banksia) Proteaceae Family

Results of Kruskal-Wallis test showed that mean percent germination significantly decreased as foam and fire retardant concentrations increased (Chi-Square 44.531 df 10 Asymp. Sig. <0.001). No germination was observed in the 3.0% foam and 3.0% fire retardant treatments (Figure 3.5). Figure 3.6 clearly shows the majority of treatments germinating between 6 and 8 days, before reaching a maximum at approximately 26 days. It is also evident that the higher concentration foam and fire retardant treatments are the last to begin initial germination (Figure 3.6).
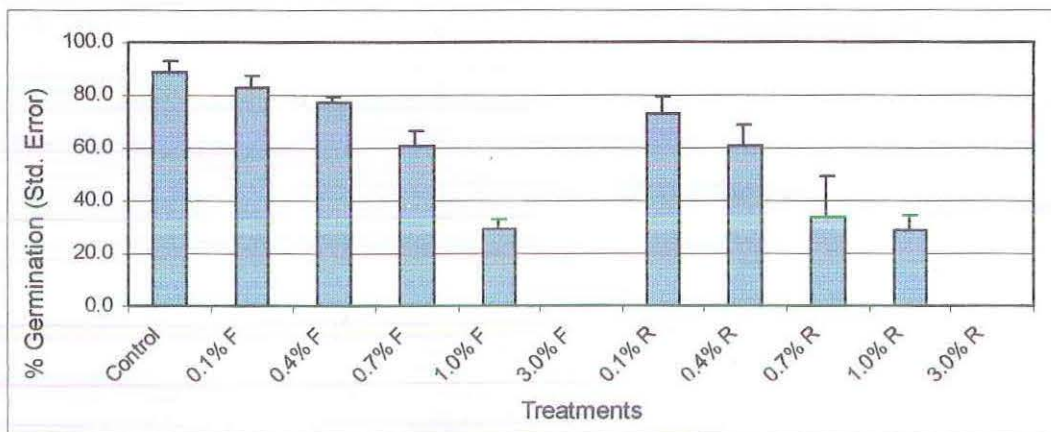
Figure 3.5: *B. attenuata* mean percent germination (+ SE, n=5)
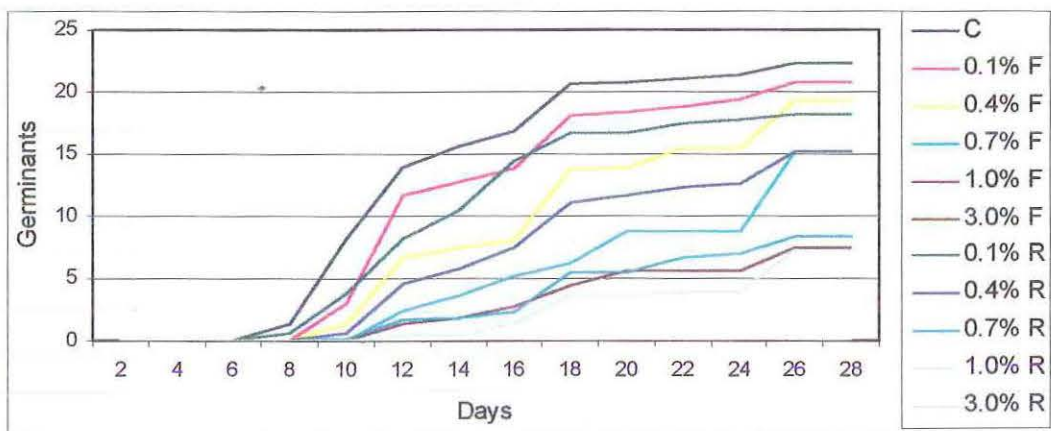
Figure 3.6: *B. attenuata* mean number of germinants over 28 days

3.2.4. *Xanthorrhea pressii* (Grass tree) Xanthorrhoeaceae Family

Germination of *X. pressii* treatments differed significantly, with 0.1% fire retardant showing 63% germination and 1.0% fire retardant showing only 4% germination (Chi-Square 53.922, df 10, Asymp. Sig. <0.001) (Figure 3.7). No germination was observed in any other treatments. These results are verified in Figure 3.8.
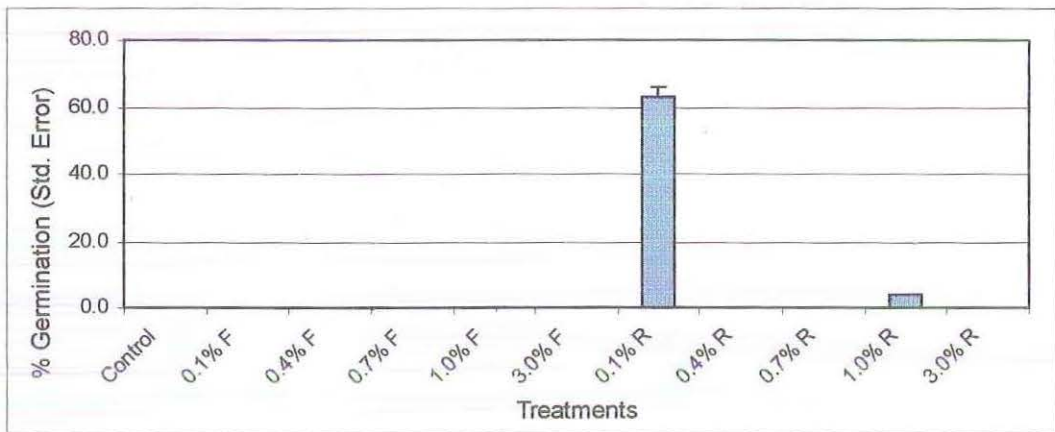
Figure 3.7: *X. pressii* mean percent germination (+ SE, n=5)
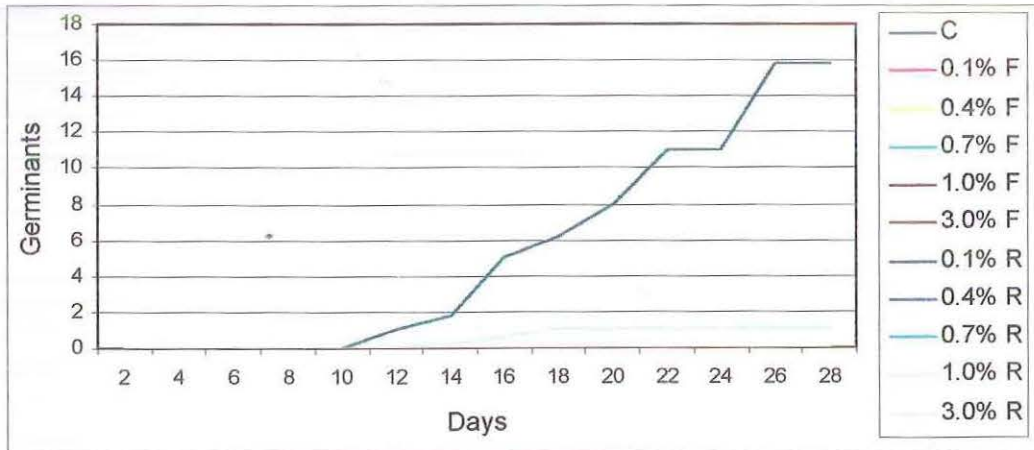
Figure 3.8: *X. pressii* mean number of germinants over 28 days

3.2.5. *Hakea lissocarpha* (Honey Bush) Proteaceae Family

Results of Kruskal-Wallis test for H. *lissocarpha* mean percent germination showed a significant decrease in percent germination as both foam and fire retardant treatment concentrations increased (Chi-Square 46.285, df 10, Asymp. Sig. <0.001). No germination was observed in the foam treatments above 0.1% foam concentrate and above 0.4% fire retardant concentrate for the fire retardant treatments (Figure 3.9). A distinct difference in initial germination is also evident in Figure 3.10. Germination in the control treatment begins at 10 days, where the 0.1% fire retardant begins at 12 days, the 0.4% retardant at 18 days and the 0.1% foam treatment at 24 days.
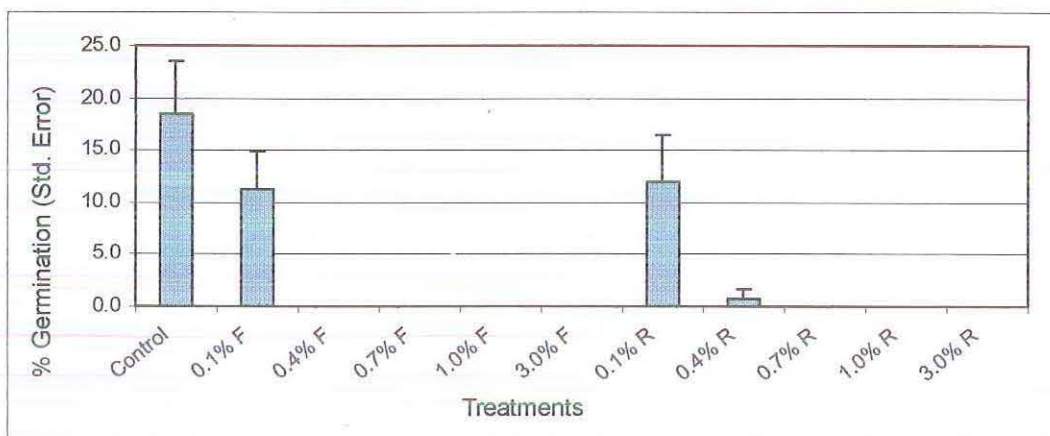
Figure 3.9: *H. lissocarpha* mean percent germination (+ SE, n=5)
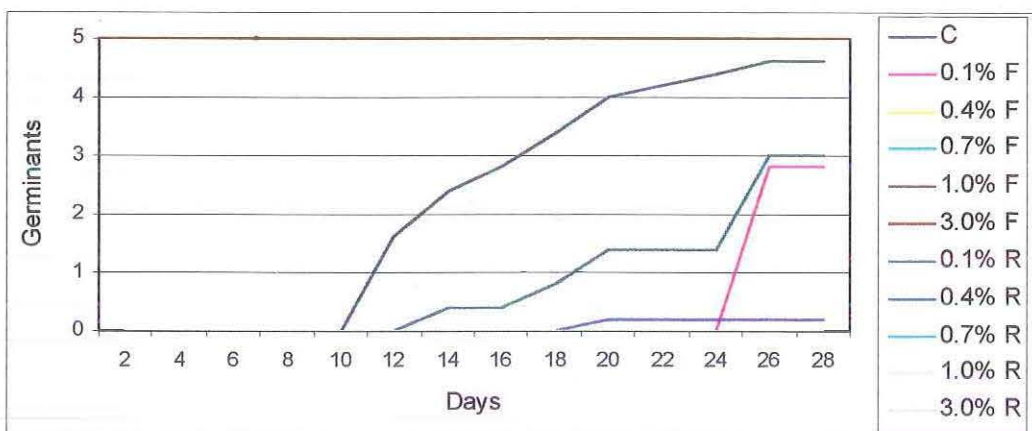
Figure 3.10: *H. lissocarpha* mean number of germinants over 28 days

3.2.6. *Gompholobium tomentosum* (Hairy Yellow Pea) Papilionaceae Family

Results showed that mean percent germination of *G. tomentosum* treatments differed significantly (Chi-Square 53.415, df 10, Asymp. Sig. <0.001). Only the control (16%) and 0.1% fire retardant (23%) treatments showed any germination (Figure 3.11). Germination was first observed in the control treatment on day 7 and the 0.1% fire retardant treatment on day 8 (Figure 3.12).
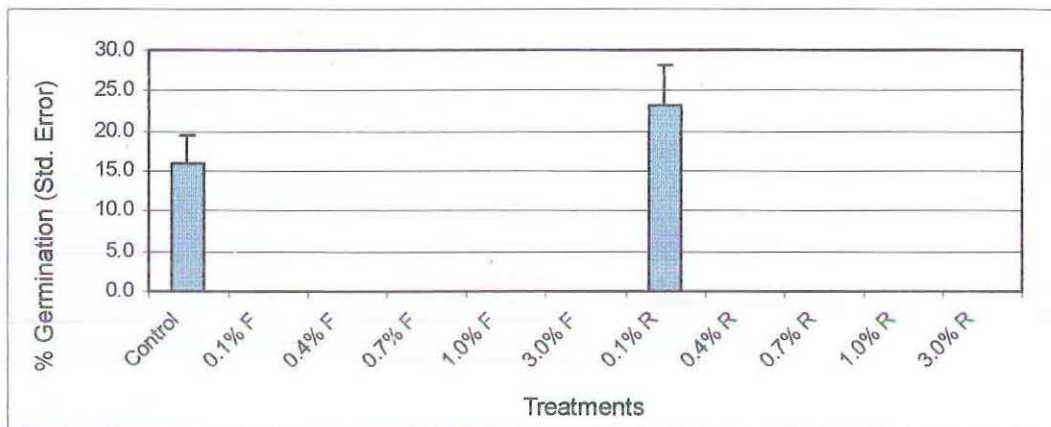
Figure 3.11: *G. tomentosum* mean germination percentage
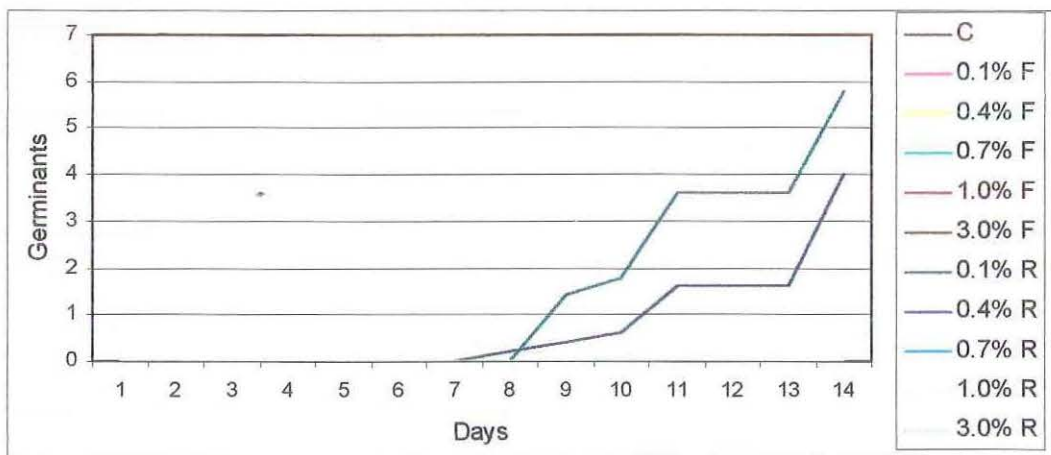
Figure 3.12: *G. tomentosum* mean number of germinants over 28 days

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3.2.7. *Acacia pulchella* (Prickly Moses) Mimosaceae Family

Results of Kruskal-Wallis test showed that mean percent germination of *A. pulchella* differed significantly (Chi-Square 49.909, df 10, Asymp. Sig. <0.001). Percent germination decreased as the foam and fire retardant concentrations increased (Figure 3.13). Figure 3.14 shows the majority of treatments initially germinating between 6 and 10 days and reaching their maximum around 24 days. Initial germination of the higher concentration foam and fire retardant treatments occur somewhat after the lower concentrations (Figure 3.14).
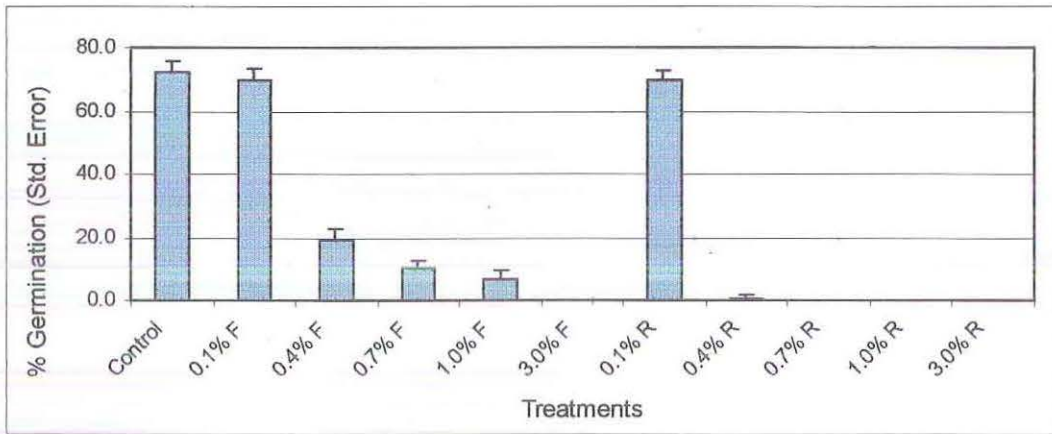
Figure 3.13: *A. pulchella* mean percent germination (+ SE, n=5)
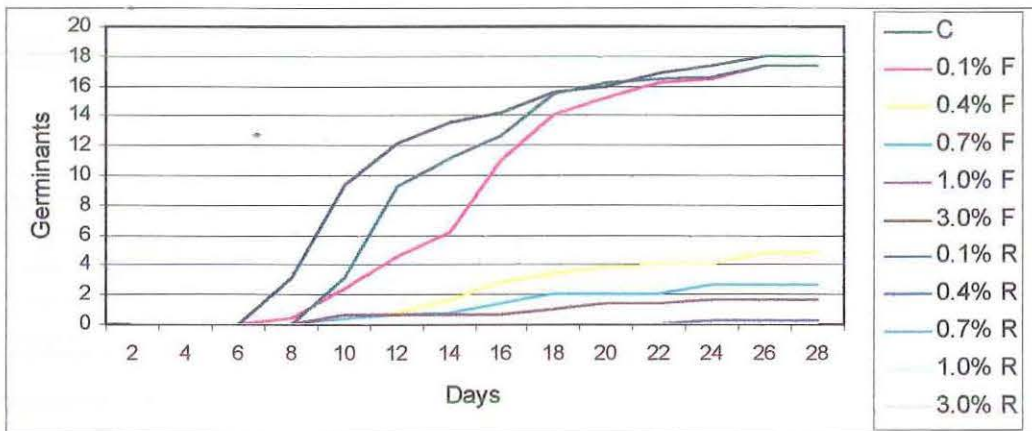
Figure 3.14: *A. pulchella* mean number of germinants over 28 days

Figure 3.15 shows the total mean percent germination for the study species combined. A distinct trend is apparent, where total mean percent germination decreases as foam and fire retardant concentrations increase. In addition, the total mean percent germination for the 0.1% fire retardant treatment is considerably greater than the control and all other treatments.
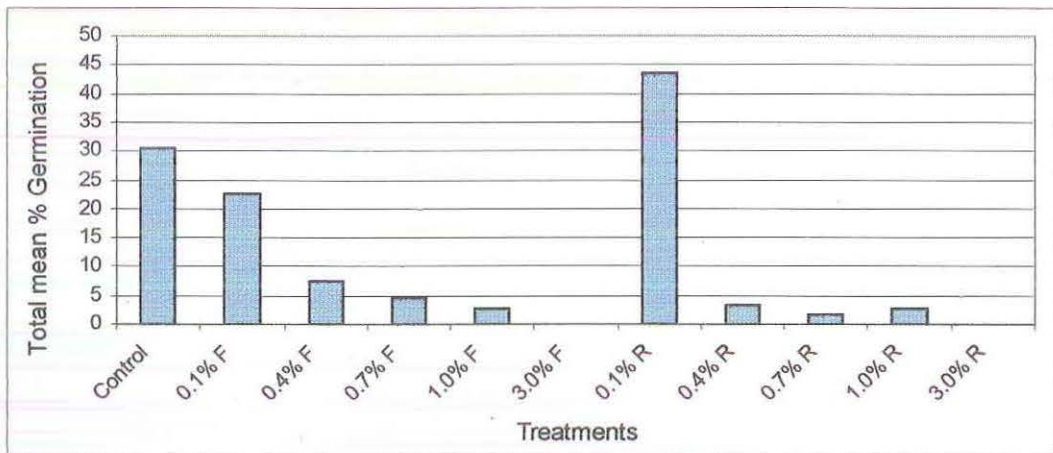
Figure 3.15: Total species mean percent germination over 28 days

Figure 3.16 shows the total mean percent germination at days 8, 14, 20 and 26 for the study species combined. For each observation the total mean percent germination decreases as both foam and fire retardant treatment concentrations increase. The total mean percent germination increases at each successive observation. Delay in germ
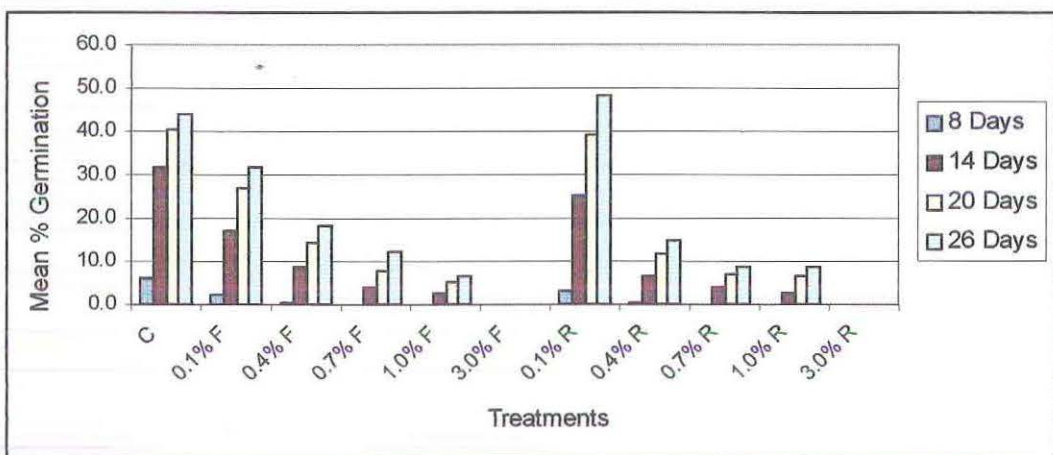
Figure 3.16: Total species mean percent germination between eight and twenty six days

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3.3. DISCUSSION:

The fire fighting foam and fire retardant significantly affected the germination of the species examined. Germination was significantly suppressed in both foam and fire retardant treatments for all species, other than *X. pressii*, where germination was significantly greater in the 0.1% fire retardant treatment (Figure 3.7). The results obtained for *E. calophylla* and *B. attenuata*, showed a distinct decrease in the mean percent germination, as both foam and fire retardant treatment concentrations increased (Figure 3.3 and Figure 3.5). This trend was also evident for *E. marginata*, *H. lissocarpha* and *A. pulchella*. Comparative research by Mandak and Pysek (2001) found that the addition of potassium nitrate to the germination of different fruit types showed similar effects. For each species examined germination was reduced at the highest treatment concentrations.

The results also determined that initial germination was considerably affected by foam and fire retardant treatments. As a general rule, the control and lower treatment concentrations were the first to germinate, followed by treatments of an increasing foam and fire retardant concentration. This trend is clearly defined in Figure 3.16, which shows the total mean percent germination for all species examined. The observations made on days 8, 14, 20 and 26, show a distinct negative correlation between the total germination and treatment concentrations. This suggests that the fire fighting foam and fire retardant not only suppress the number of germinants, but also inhibit seed germination by a number of days. Unfortunately, no prior research into the effects of chemical fire suppressants on seed germination is available for comparison.

In contrast to the overall suppression of seed germination, is the mean percent germination of the 0.1% fire retardant treatment. For the study species examined, germination for the 0.1% fire retardant treatment was substantial in comparison to the control. In particular, mean percent germination for *X. pressii* and *G. tomentosum* was greater in the 0.1% fire retardant treatment than the control. These results suggest that a small amount of fire retardant actually assists in seed germination for a number of species. Comparative research into the effects of nutrients on seed germination confirms this observation (Langkamp, 1987; Handreck, 1997; Hartmann *et al.*, 1997; E. van Etten, pers. comm., 2002).

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CHAPTER 4: GLASSHOUSE EXPERIMENT

4.1. MATERIALS AND METHODS:

The seedlings were purchased from commercial nurseries in the Perth metropolitan area, where possible, 100 individuals of each species were obtained. For *Banksia attenuata* and *Acacia pulchella*, only 50 individuals were available at the commencement of the study. The study species were placed in a glasshouse, located at Edith Cowan University's Joondalup Campus, Perth, Western Australia. Watering occurred daily for a period of 10 minutes. Measurable variables were assigned to each species based on their morphological characteristics. The variables assigned to each species are shown in Table 4.1, whilst further description of how each was undertaken is provided below.

Table 4.1: Plant variables measured for each species.

Plant variables	*E. marginata*	*E. calophylla*	*B. attenuata*	*X. pressii*	*H. lissocarpha*	*G. tomentosum*	*A. pulchella*
Stem length	●	●	●		●	●	●
Stem width	●	●	●		●	●	●
N° of leaves	●	●		●			
% health	●	●	●	●	●	●	●
Leaf / Branch Variables							
Length	●	●	●	●	●	●	●
Width	●	●	●	●	●		●
N° of leaflets						●	
% Health	●	●	●	●	●	●	●

Stem length:

Stem length was measured from the soil base to the growing tip or apical bud of the longest shoot using a rule. These stems were tagged with visible white wire. This procedure was applied to *E. marginata, E. calophylla, G. tomentosum* and *A. pulchella*.

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Stem width:

Stem width was taken approximately 10 mm above the soil base using callipers. In instances where there was more than one stem, the stem measured for stem length was used. This procedure was applied to *E. marginata* and *E. calophylla*. For the species *B. attenuata, H. lissocarpha* and *G. tomentosum*, stem width was measured immediately below the tagged random leaf. For *A. pulchella*, stem width was measured below the tagged random branch, or to where it joined the stem used for stem length.

Number of leaves:

The number of leaves were attained by counting the leaves greater than 10 mm in length and was applied to *E. marginata, E. calophylla* and *X. pressii*.

Plant and leaf percentage health:

This was an observational measure used as an indicator of plant health. The percentages were applied in relation to a completely healthy plant. To avoid unnecessary complexity, increments of five percent were applied. This variable was applied to all species.

Leaf length:

Measuring from the base of the leaf to the tip of the central axis attained the leaf length. This variable was applied to *E. marginata, E. calophylla, B. attenuata* and *X. pressii*. Two tagged leaves were used. For *H. lissocarpha* and *G. tomentosum*, leaf length was determined by measuring the length of the central midrib of the divided leaves.

Leaf width:

Measuring the widest part of the tagged leaf, which was usually found at half the length, attained the leaf width. This procedure was carried out for *E. marginata, E. calophylla* and *B. attenuata*. For *X. pressii*, leaf width was taken at the narrowest point at approximately half the length. Leaf stem width was conducted for *H. lissocarpha* and no leaf width measurement was carried out for *G. tomentosum* due to its morphological characteristics.

Number of leaflets:

This variable was applied to *G. tomentosum* and was determined by the number of leaflets on tagged leaves.

The species were randomly arranged and then divided into fire fighting foam treatments and fire retardant treatments. Ten individuals/replicates (five individuals/replicates for *B. attenuata* and *A. pulchella*) were allocated to each treatment and subsequently labelled. Prior to treatments, an initial measure was conducted on the 15th of December 2001, according to the species variables shown in Table 4.1. The foam treatments consisted of 0.1% (wet foam), 0.4% (fluid foam), 0.7% (fluid foam), 1.0% (dry foam) and 3.0% (extra dry foam) of the foam concentrate (v/v) (Angus ForExpan S: water). These foam concentrations are typically applied by CALM to control and suppress wildfires throughout Australia's Southwest (B. Ingles, pers. comm., 2002). It is expected that the examination of the above concentrations, will render the study more applicable to fire managers and the application of fire fighting foams in the field. The fire retardant treatments consisted of 0.1%, 0.4%, 0.7% and 1.0% of the fire retardant concentrate (w/v) (Amguard DSB Type R Mop-Up: water). They were obtained by manually adding the fire retardant concentrate to the fire unit's water tank.

The application of the foam and fire retardant treatments took place on the 24th of December 2001, at Edith Cowan University, Joondalup. The treatments were applied by CALM Fire personnel under standard procedure. A 'standard foam branch' was used to apply the treatments at a rate of 175 Litres per minute at 500 Kpa. In turn, each treatment was applied for approximately 20 seconds, resulting in 58.3 Litres of fire fighting foam or fire retardant applied to the study species. After treatment application, the study species were returned to the glasshouse and arranged in a randomised block design. They were not watered for a period of 48 hours to prevent the dilution of the treatments. The seedlings were rearranged on a fortnightly basis. A watering regime of 10 minutes per day then resumed. Subsequent measures were conducted two weeks, six weeks and ten weeks after treatment application.

Samples of the foam treatments applied were later analysed by Angus Fire Pty Ltd (2002) for a more precise account of their foam concentrate. Results were:

0.1% foam treatment = 0.58% foam concentrate

0.4% foam treatment = 0.69% foam concentrate

0.7% foam treatment = 0.96% foam concentrate

1.0% foam treatment = 1.13% foam concentrate

3.0% foam treatment = 2.42% foam concentrate

In addition, both foam and fire retardant samples were provided to the Australian Government analytical Laboratories (AGAL) (2002) for total nitrogen and total phosphorus analysis. Results were:

10% foam concentrate = 2 mg/L Total N and 5.4 mg/L Total P

100% foam concentrate = 120 mg/L Total N and 13 mg/L Total P

0.1% fire retardant concentrate = 140 mg/L Total N and 240 mg/L Total P

1.0% fire retardant concentrate = 1650 mg/L Total N and 2900 mg/L Total P

The data collected from this experiment was analysed using analysis of variance (ANOVA) with SPSS^{tm} (SPSS Inc.) software. The data was initially tested for homogeneity of variances using Levene's Test ($p > 0.05$). This confirmed that variances were homogenous and parametric analysis was performed. Significant differences between treatments were subsequently analysed using Tukey's testing procedure to determine which treatments differed from others, in combination with the examination and comparison of standard error bars on graphs.

4.2.   RESULTS:

Upon resumption of daily watering, following treatment applications, it was noted that fire fighting foam was still evident upon the soil base of 0.4%, 0.7% 1.0% and 3.0% foam treatments, throughout all study species for several days. In addition, a film was evident on the soil base of all fire retardant treatments, across all study species.

4.2.1. *Eucalyptus marginata* (Jarrah) Myrtaceae Family

Results of ANOVA for mean percentage change of the variables measured for *E. marginata*, showed that percentage health, leaf length, leaf width and leaf percentage health did not significantly differ within treatments (Table 4.1). ANOVA showed that mean stem length percentage growth was significantly different, with 1.0% fire retardant greater than all other treatments (Figure 4.1). The majority of growth for the 1.0% fire retardant treatment occurred between 2 and 6 weeks after treatment application (Figure 4.2).

Table 4.2: Summary table of ANOVA for mean percentage change over study duration

Variables	df	F	P	Comments
Stem Length	9, 84	5.57	<0.001	Significant
Stem Width	9, 84	2.60	0.01	Significant
Number of leaves	9, 84	4.52	<0.001	Significant
Percentage Health	9, 84	0.92	0.51	Not Significant
Leaf Length	9, 56	0.76	0.65	Not Significant
Leaf Width	9, 56	1.40	0.21	Not Significant
Leaf Percentage Health	9, 56	1.34	0.24	Not Significant
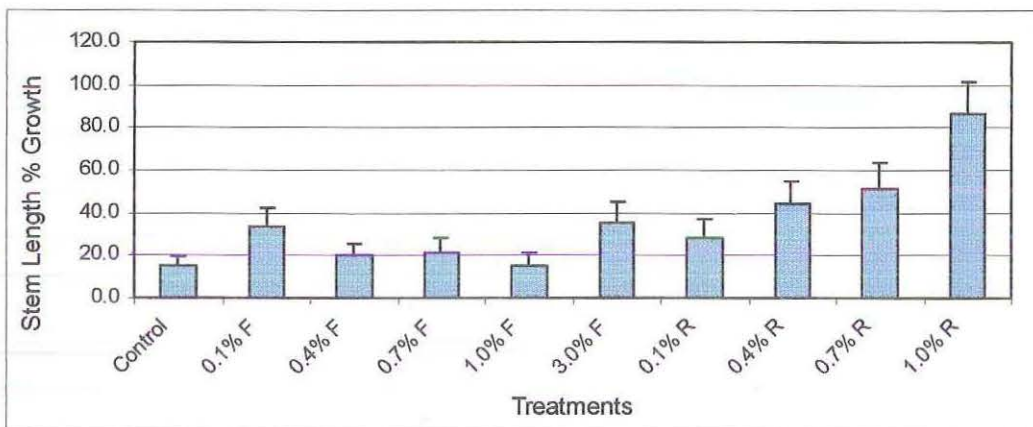
Figure 4.1: *E. marginata* mean stem length percentage growth (+ SE, n=10)
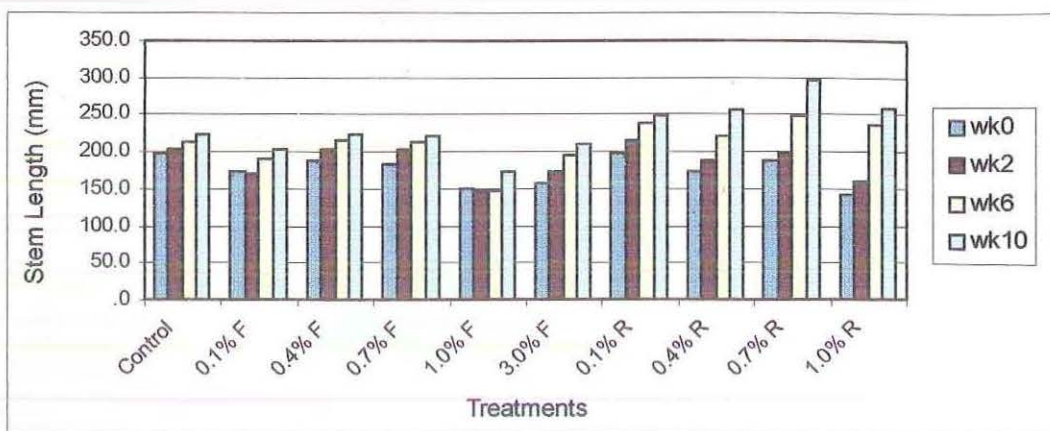
Figure 4.2: *E. marginata* mean stem length over study duration

Results of ANOVA showed that mean stem width percentage growth was significantly different, with the 1.0% fire retardant treatment significantly greater than the control (Figure 4.3). Figure 4.3 also illustrates that mean stem width percentage growth for the fire retardant treatments were greater than all foam treatments.
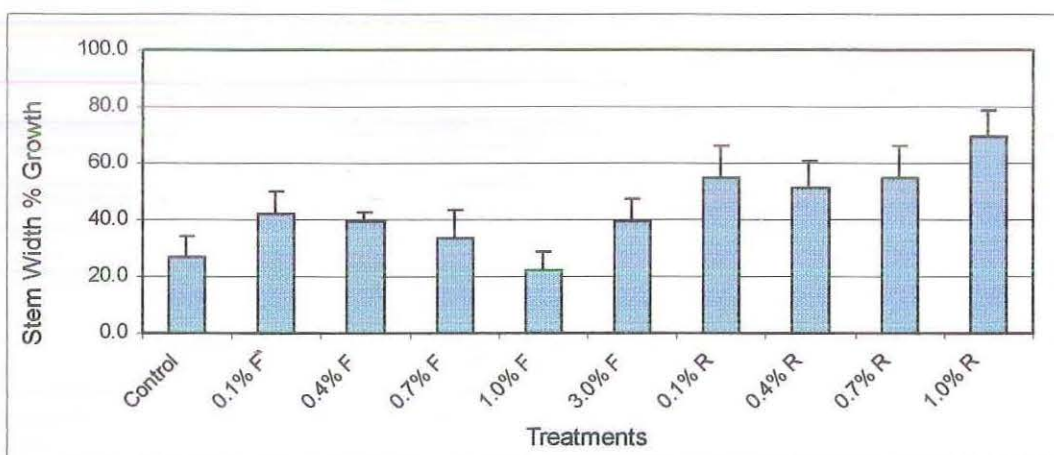
Figure 4.3: *E. marginata* mean stem width percentage growth (+ SE, n=10)

The mean number of leaves percentage change for *E. marginata* showed that 0.7% and 1.0% fire retardant treatments were significantly greater than all other treatments (Figure 4.4). Figure 4.5 illustrates that 0.7% and 1.0% fire retardant treatments underwent a considerable increase in the number of leaves between 2 and 6 weeks after treatment application.
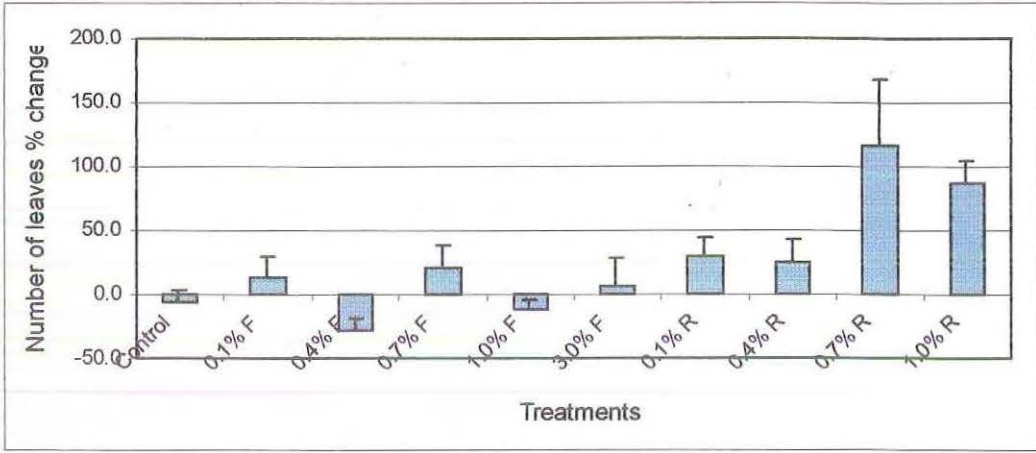
Figure 4.4: *E. marginata* mean number of leaves percentage change (+ SE, n=10)
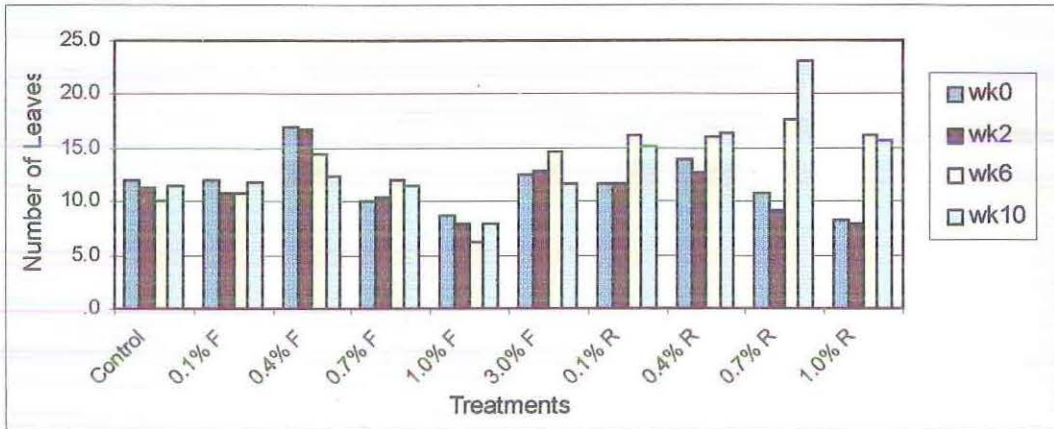
Figure 4.5: *E. marginata* mean number of leaves over study duration

4.2.2. *Eucalyptus calophylla* (Marri) Myrtaceae Family

Results of ANOVA for mean percentage change of the variables measured for *E. calophylla*, showed that leaf length and leaf width did not significantly differ between treatments (Table 4.3). The variable stem length differed significantly, with 0.4%, 0.7% and 1.0% fire retardant treatments significantly greater than all other treatments (Figure 4.6). The majority of stem length growth for 0.4%, 0.7% and 1.0% fire retardant treatments occurred between 2 and 6 weeks after treatment application (Figure 4.7).

Table 4.3: Summary table of ANOVA for mean percentage change over study duration

Variables	df	F	P	Comments
Stem Length	9, 83	15.68	<0.001	Significant
Stem Width	9, 83	3.33	<0.001	Significant
Number of Leaves	9, 83	8.64	<0.001	Significant
Percentage Health	9, 83	5.27	<0.001	Significant
Leaf Length	9, 68	0.55	0.83	Not Significant
Leaf Width	9, 68	0.45	0.90	Not Significant
Leaf Percentage Health	9, 68	6.14	<0.001	Significant
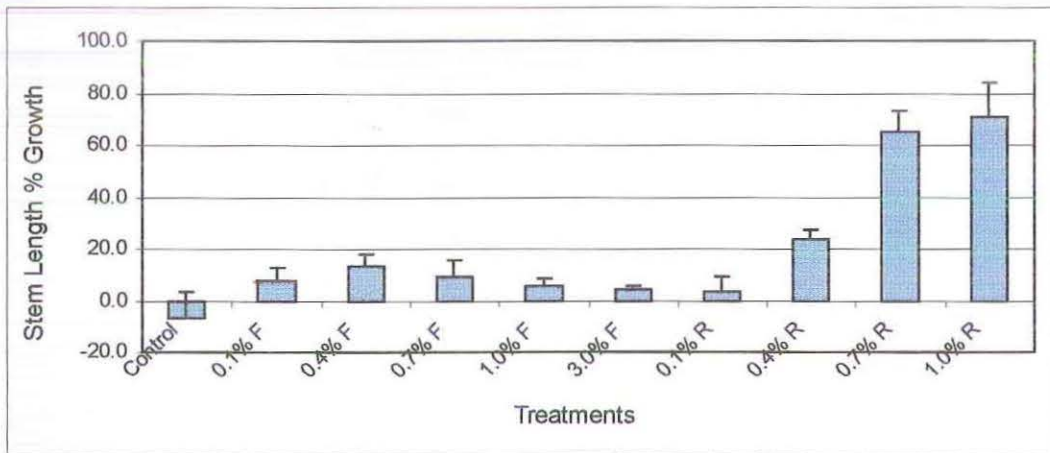
Figure 4.6: *E. calophylla* mean stem length percentage growth (+ SE, n=10)
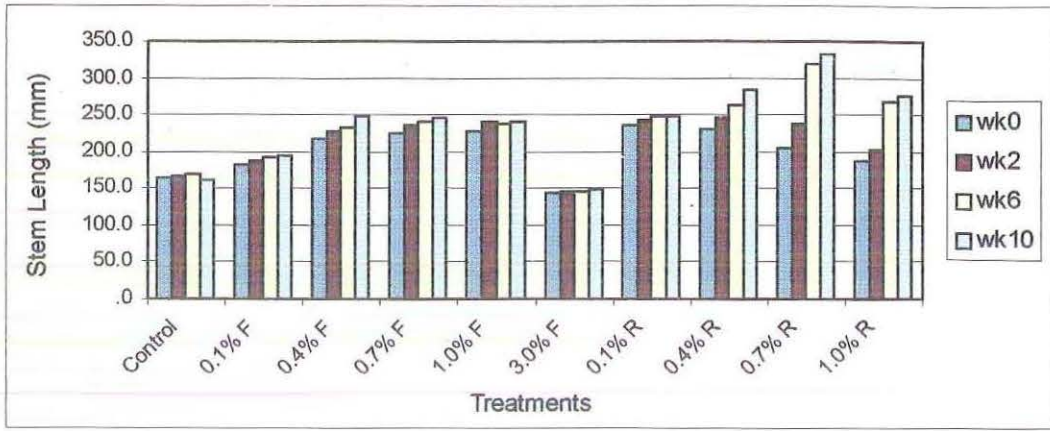
Figure 4.7: *E. calophylla* mean stem length over study duration

ANOVA showed that treatments were significantly different for *E. calophylla* mean stem width percentage health. The 1.0% fire retardant treatment differed significantly from the control (Figure 4.8). Actual stem width growth for the 1.0% fire retardant treatment was fairly consistent throughout weeks 0 to 10 (Figure 4.9).
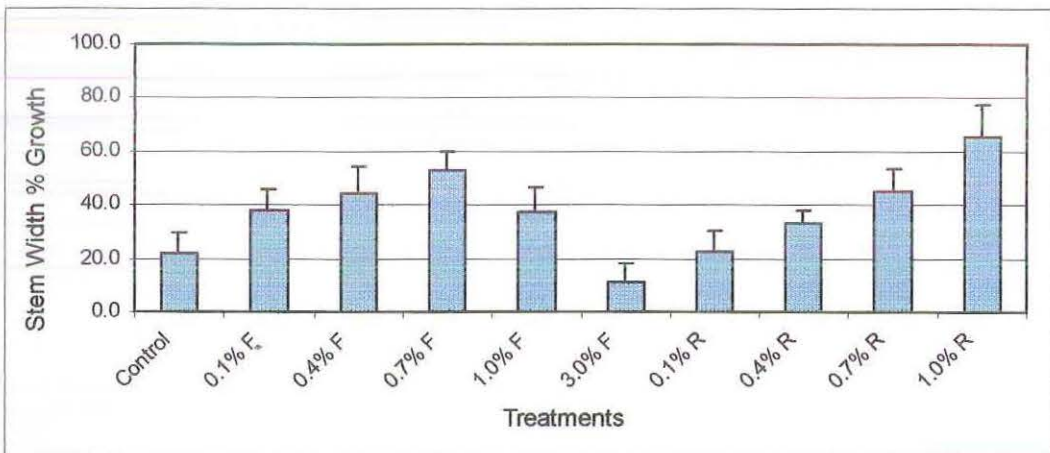
Figure 4.8: *E. calophylla* mean stem width percentage growth (+ SE, n=10)
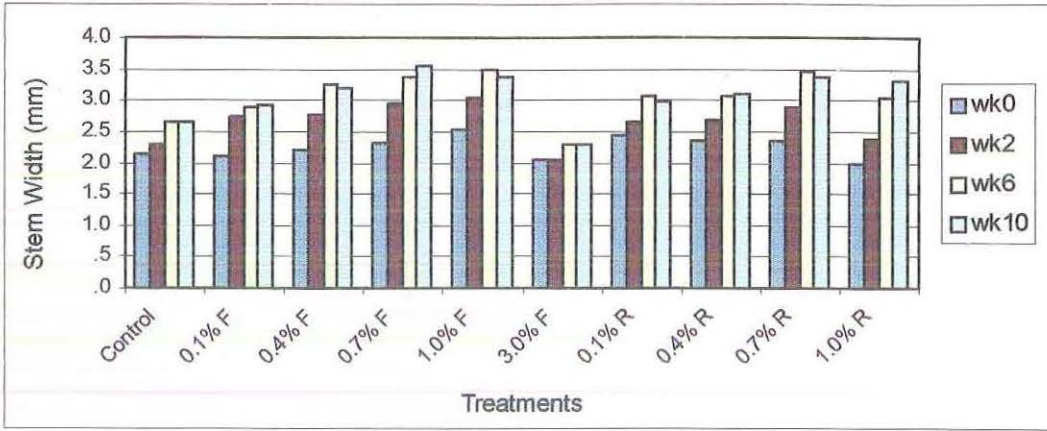
Figure 4.9: *E. calophylla* mean stem width over study duration

The analysis of the mean number of leaves percentage change for *E. calophylla* showed that 0.4%, 0.7% and 1.0% fire retardant treatments were significantly greater than all other treatments. The significant fire retardant treatments actually gained leaves throughout the study, whilst the other treatments showed an overall loss (Figure 4.10). The overwhelming change in the number of leaves throughout all treatments occurred 2 weeks after treatment applications (Figure 4.11).
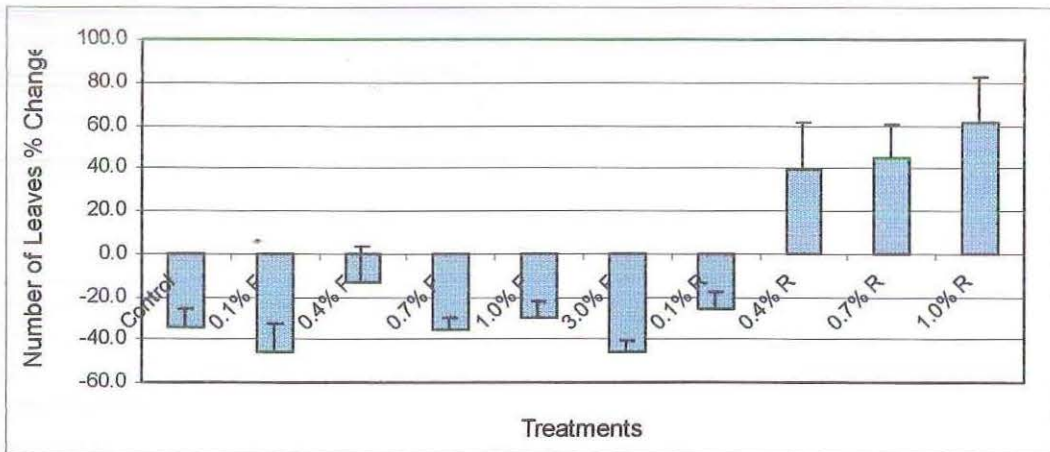
Figure 4.10: *E. calophylla* mean number of leaves percentage change (+ SE, n=10)
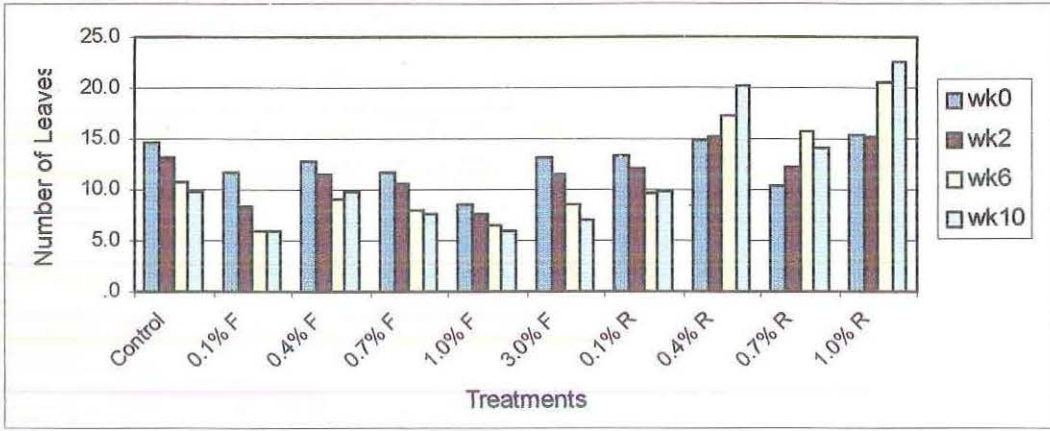
Figure 4.11: *E. calophylla* mean number of leaves over study duration

Results of ANOVA showed that mean percentage health for *E. calophylla* differed significantly across treatments. The 0.1% 0.4% and 0.7% foam and 0.7% fire retardant treatments were significantly less affected in comparison to the control (Figure 4.12). This reduction occurred consistently over the study period and affected all treatments (Figure 4.12 and Figure 4.13).
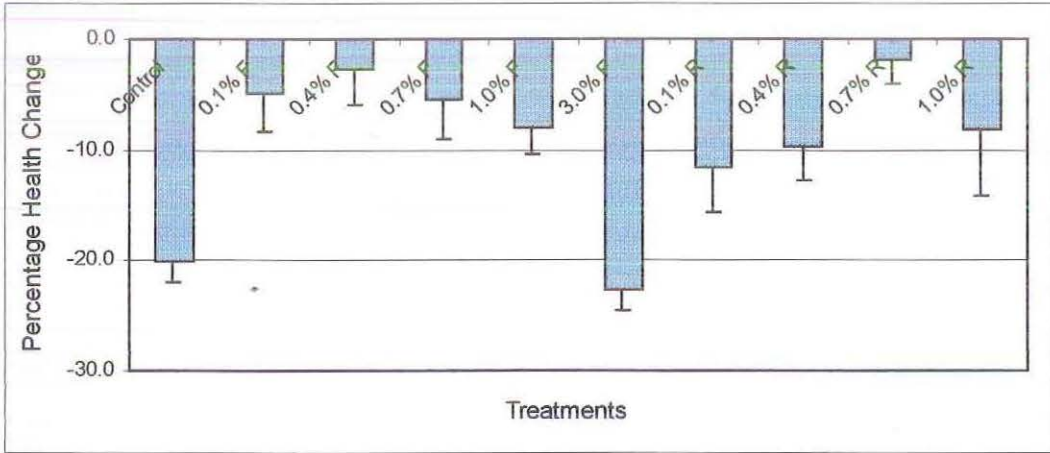
Figure 4.12: *E. calophylla* mean percentage health change (+ SE, n=10)
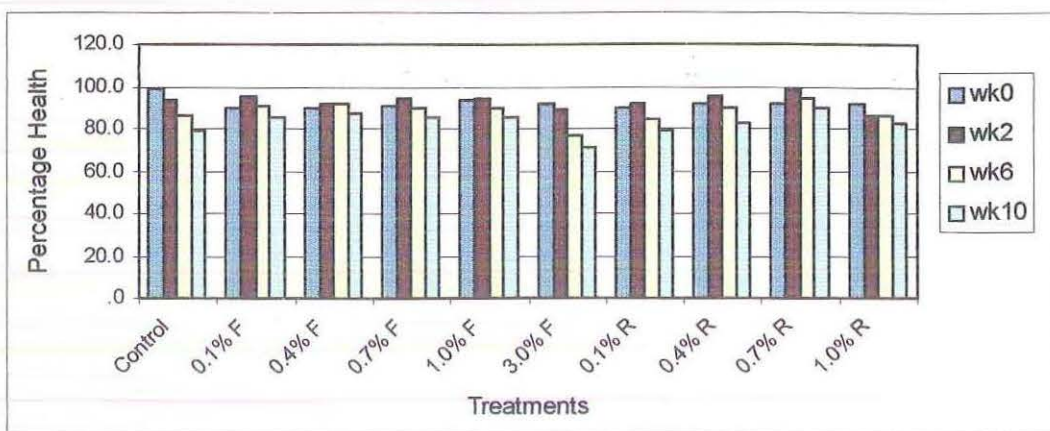
Figure 4.13: *E. calophylla* mean percentage health over study duration

Results for *E. calophylla* mean leaf percentage health change, showed that the 1.0% fire retardant treatment was significantly reduced by 70% (Figure 4.14). Observations were made of a mottled reduction in leaf colour and distinct leaf brittleness. The major reduction in the 1.0% fire retardant treatment occurred 6 weeks after the treatment application (Figure 4.15). A similar reduction was shown for all other treatments (Figure 4.14).
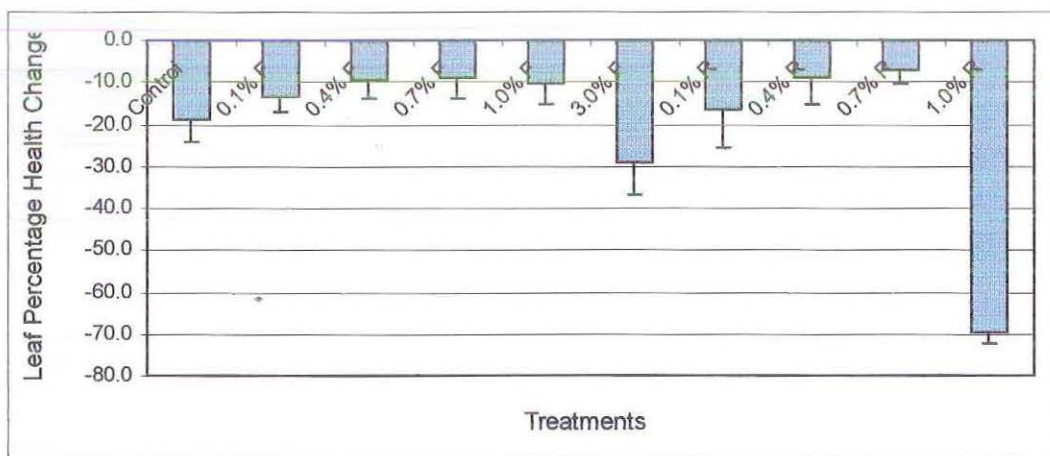
Figure 4.14: *E. calophylla* mean leaf percentage health change (+ SE, n=10)
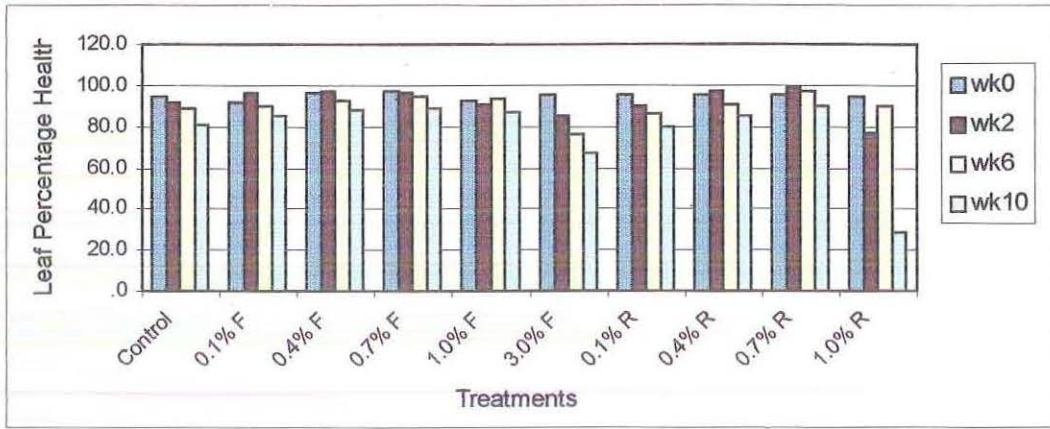
Figure 4.15: *E. calophylla* mean leaf percentage health over study duration

4.2.3. *Banksia attenuata* (Slender Banksia) Proteaceae Family

ANOVA showed that for the variables measured for *B. attenuata*, leaf length, leaf width and leaf percentage health did not significantly differ between treatments (Table 4.4). For the variable stem length, treatments were significantly different. The 0.7% fire retardant treatment was significantly greater than all other treatments (Figure 4.16). Mean stem length percentage growth was consistent across all treatments throughout the study period (Figure 4.17).

Table 4.4: Summary table of ANOVA for mean percentage change over study duration

Variables	df	F	P	Comments
Stem Length	9, 39	2.76	0.01	Significant
Stem Width	9, 39	2.33	0.03	Significant
Percentage Health	9, 39	4.28	<0.001	Significant
Leaf Length	9, 38	1.39	0.23	Not Significant
Leaf Width	9, 38	1.41	0.22	Not Significant
Leaf Percentage Health	9, 38	1.67	0.13	Not Significant
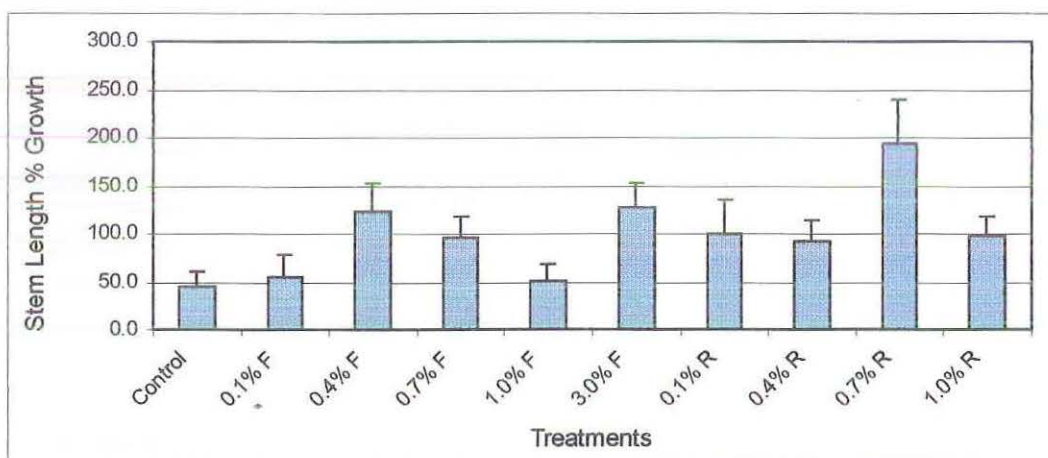
Figure 4.16: *B. attenuata* mean stem length percentage growth (+ SE, n=5)
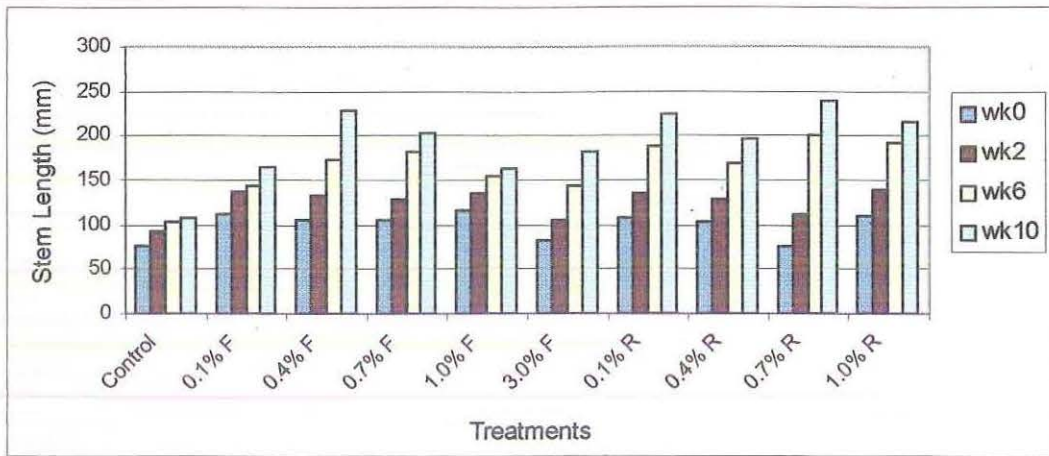
Figure 4.17: *B. attenuata* mean stem length over study duration

ANOVA conducted for mean stem width percentage growth, showed that 0.4% foam and 0.4% and 0.7% fire retardant treatments were significantly greater than the control (Figure 4.18). The majority of this growth occurred 2 weeks after the treatment applications (Figure 4.19).
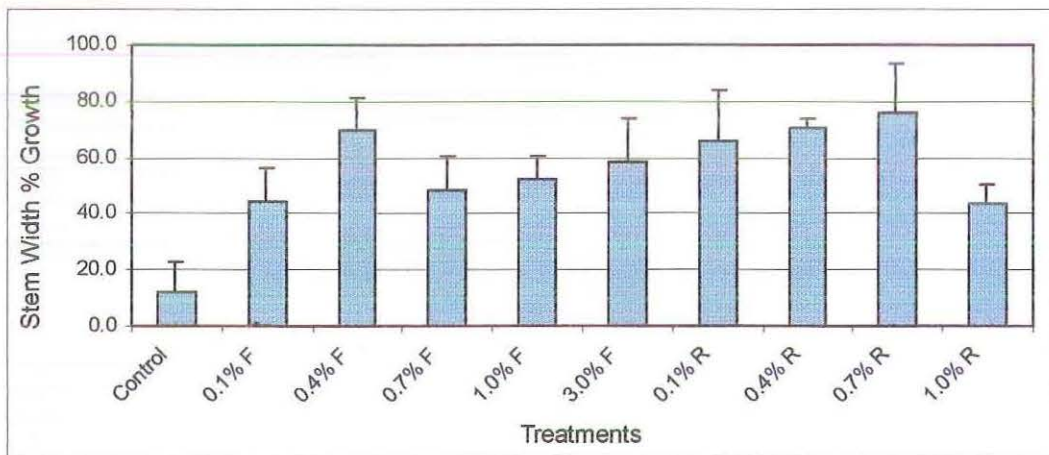
Figure 4.18: *B. attenuata* mean stem width percentage growth (+ SE, n=5)
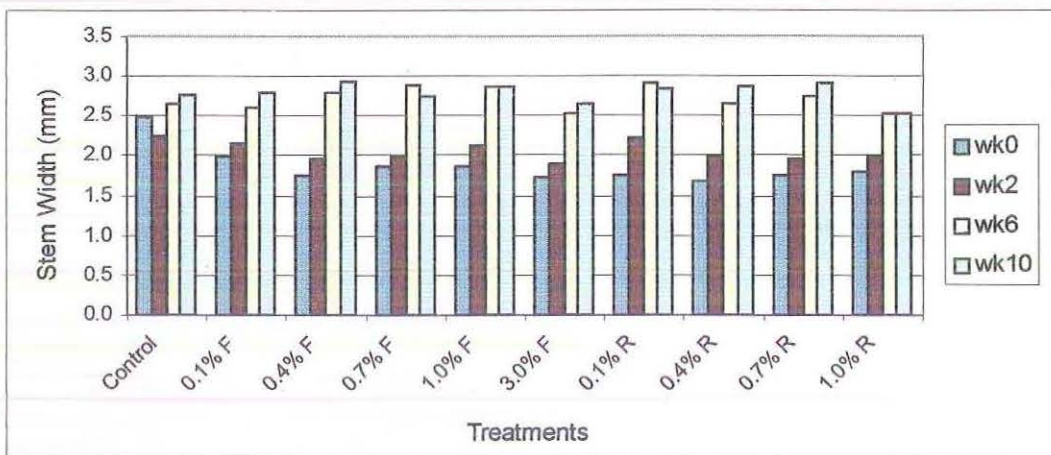
Figure 4.19: *B. attenuata* mean stem width over study duration

Analysis of the variable mean percentage health change, showed that 0.4% foam and 0.4% fire retardant treatments were significantly greater than the control. The treatments 1.0% foam, 0.7% fire retardant and control, showed a considerable decrease in mean percentage health (Figure 4.20). The change in mean percentage health occurred unevenly throughout all treatments, with dramatic changes in health status over a relatively short period of time (Figure 4.21).
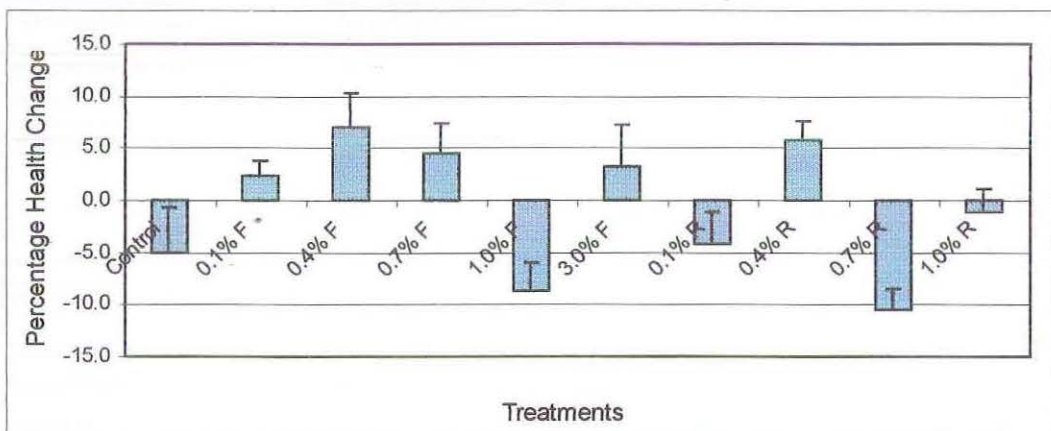
Figure 4.20: *B. attenuata* mean percentage health change (+ SE, n=5)

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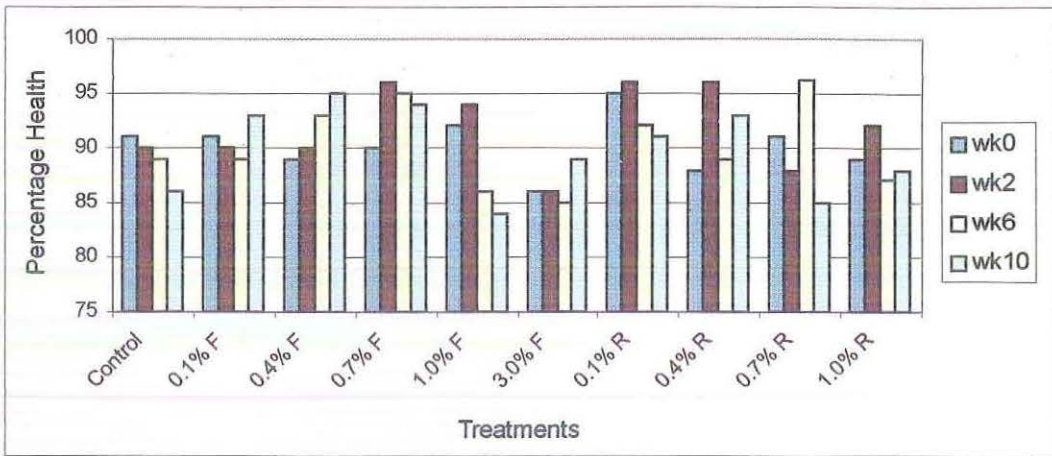
Figure 4.21: *B. attenuata* mean percentage health over study duration

4.2.4. *Xanthorrhea pressii* (Grass tree) Xanthorrhoeaceae

Results of ANOVA for the variables measured for *X. pressii*, showed that the mean number of leaves did not significantly differ between treatments (Table 4.5). The variable mean percentage health was significantly different, with all treatments except the 1.0% foam being significantly less than the control (Figure 4.22). This health reduction was erratic throughout the study period (Figure 4.23).

Table 4.5: Summary table of ANOVA for mean percentage change over study duration

Variables	df	F	P	Comments
Number of Leaves	9, 56	0.51	0.86	Not Significant
Percentage Health	9, 59	3.50	<0.001	Significant
Leaf Length	9, 59	6.55	<0.001	Significant
Leaf Width	9, 59	3.58	<0.001	Significant
Leaf Percentage Health	9, 59	4.64	<0.001	Significant
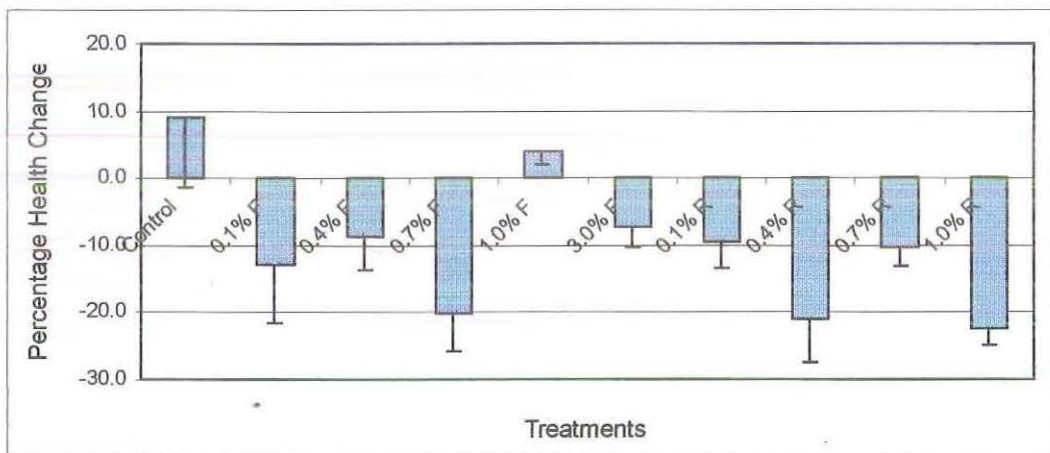
Figure 4.22: *X. pressii* mean percentage health change (+ SE, n=10)

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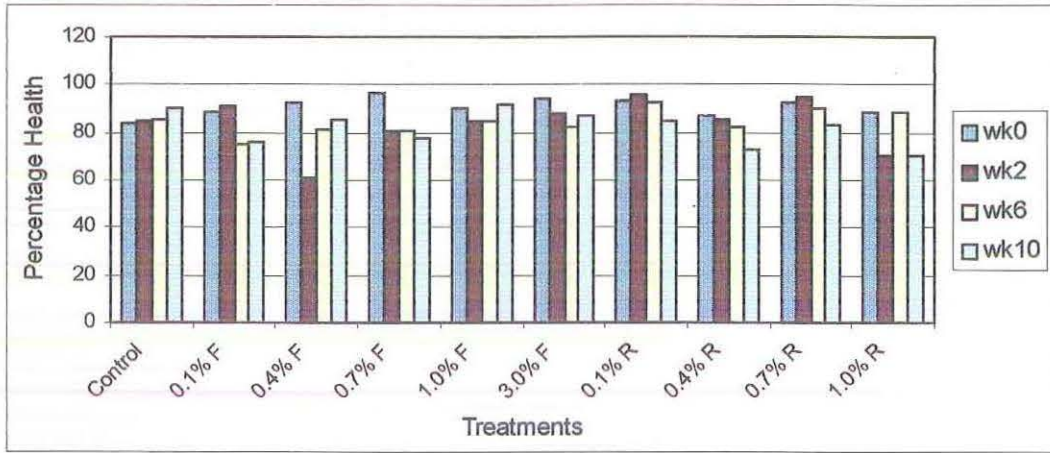
Figure 4.23: *X. pressii* mean percentage health over study duration

Results of ANOVA showed the control for mean leaf length percentage growth was significantly greater than all other treatments. Both foam and fire retardant treatments showed a considerable decrease in mean leaf length (Figure 4.24). The majority of this decrease occurred 6 weeks after the treatment applications (Figure 4.25).
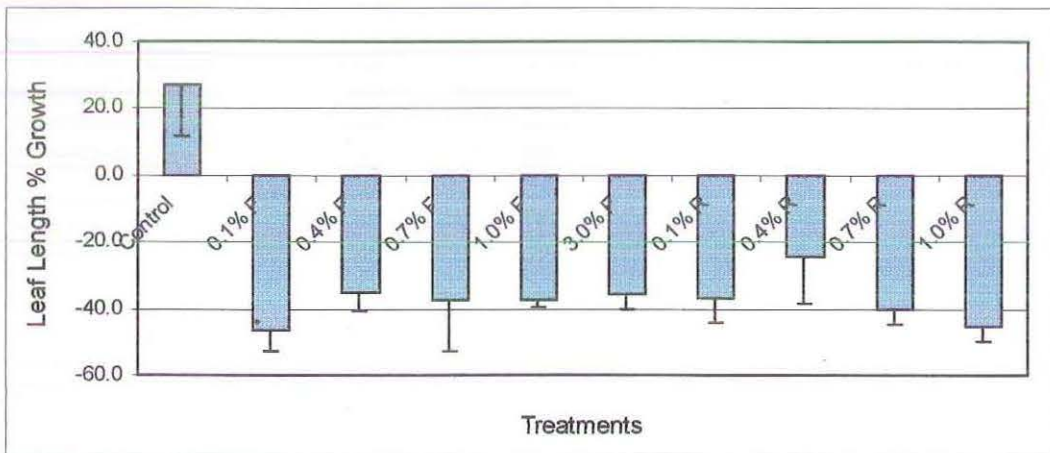
Figure 4.24: *X. pressii* mean leaf length percentage growth (+ SE, n=10)
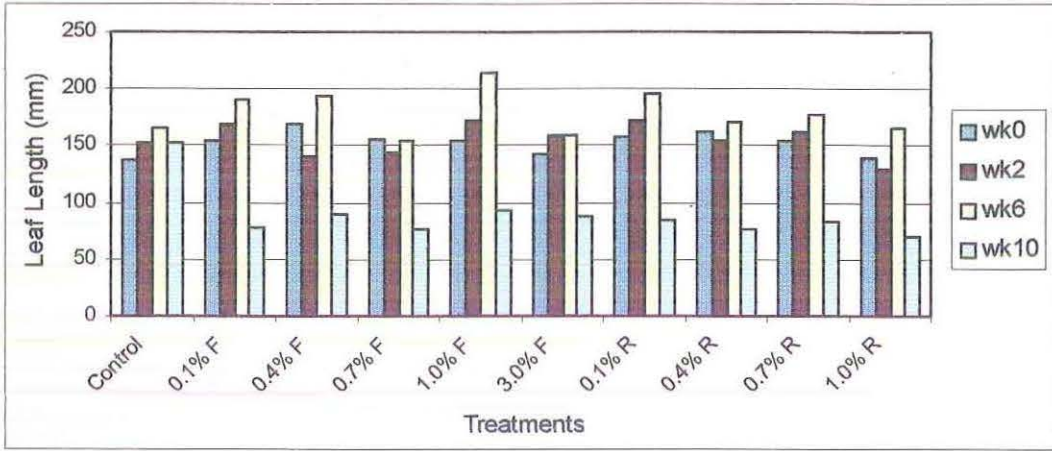
Figure 4.25: *X. pressii* mean leaf length over study duration

The analysis of mean leaf width percentage growth for *X. pressii*, showed that 0.4%, 0.7% and 1.0% fire retardant treatments were significantly reduced in comparison to the control. The majority of foam treatments showed an overall increase (Figure 4.26).
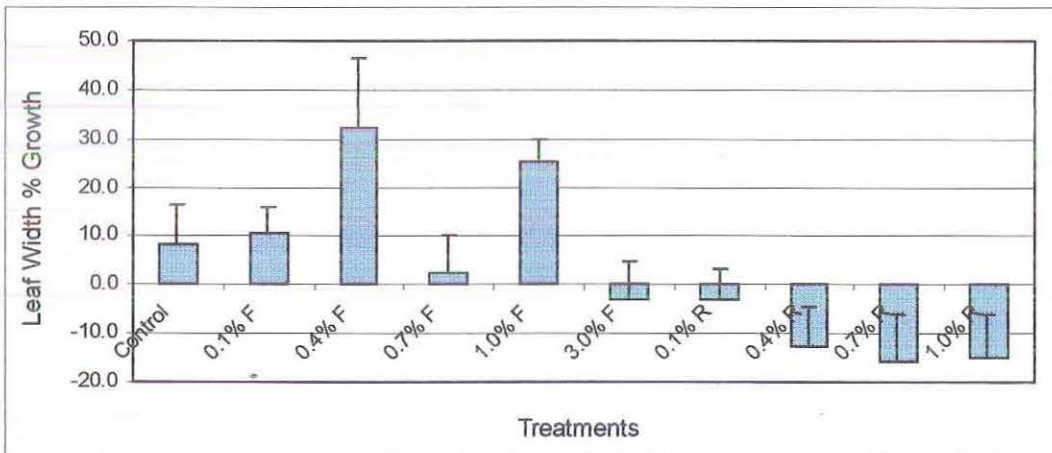
Figure 4.26: *X. pressii* mean leaf width percentage growth (+ SE, n=10)

The analysis of *X. pressii* mean leaf percentage health percentage change, showed that all treatments were significantly reduced in comparison to the control (Figure 4.27). An overwhelming reduction in mean leaf percentage health occurred 6 weeks after treatment applications. The control did not undergo this level of reduction (Figure 4.28).
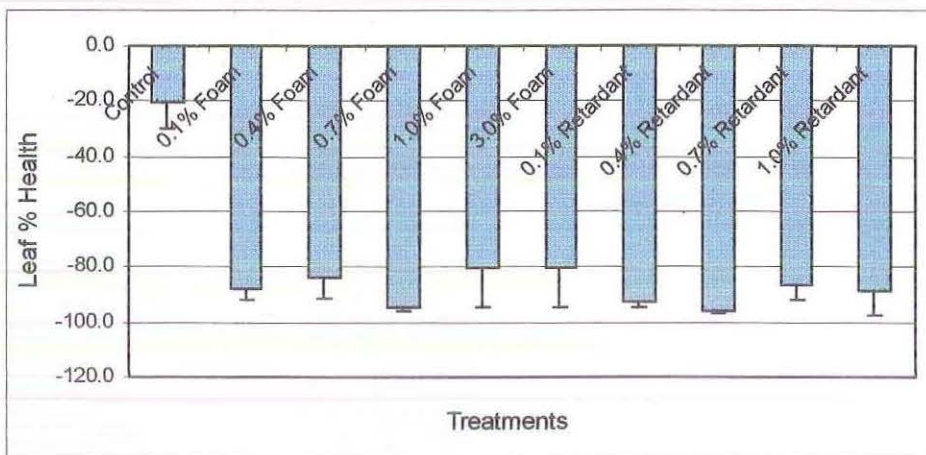
Figure 4.27: *X. pressii* mean leaf percentage health change (+ SE, n=10)
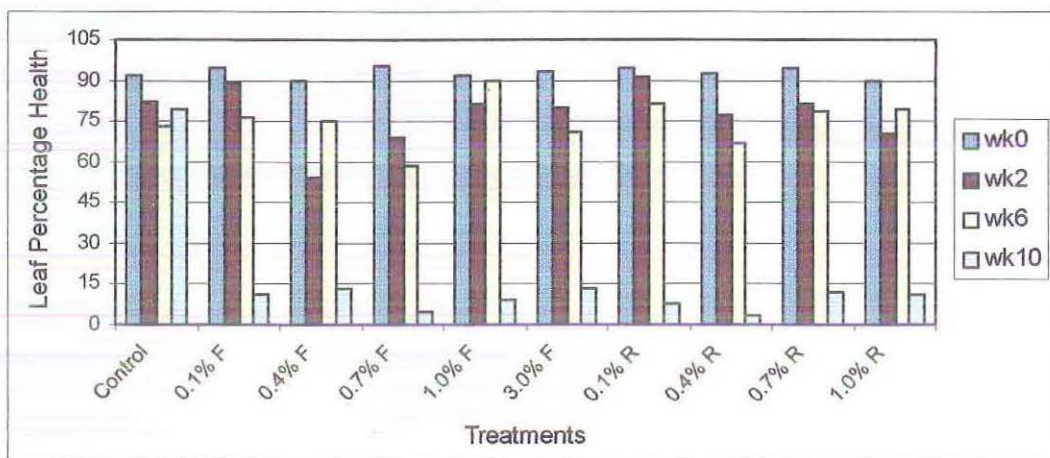
Figure 4.28: *X. pressii* mean leaf percentage health over study duration

4.2.5. *Hakea lissocarpha* (Honey Bush) Proteaceae

ANOVA of the variables measured for *H. lissocarpha*, showed that stem width, leaf length, leaf width and leaf percentage health were not significantly different between treatments (Table 4.6). The variable mean stem length percentage growth differed significantly between treatments, with the 0.1% fire retardant significantly greater than the control (Figure 4.29). During this experiment, all individuals/replicates of the 0.7% and 1.0% fire retardant treatments died 2 weeks after treatment applications (Figure 4.30). Consequently, they no longer appear in Figure 4.29.

Table 4.6: Summary table of ANOVA for mean percentage change over study duration

Variables	df	F	P	Comments
Stem Length	7	2.66	0.02	Significant
Stem Width	7	0.66	0.70	Not Significant
Percentage Health	7	2.70	0.02	Significant
Leaf Length	7	0.55	0.79	Not Significant
Leaf Width	7	1.93	0.09	Not Significant
Leaf Percentage Health	7	0.54	0.80	Not Significant
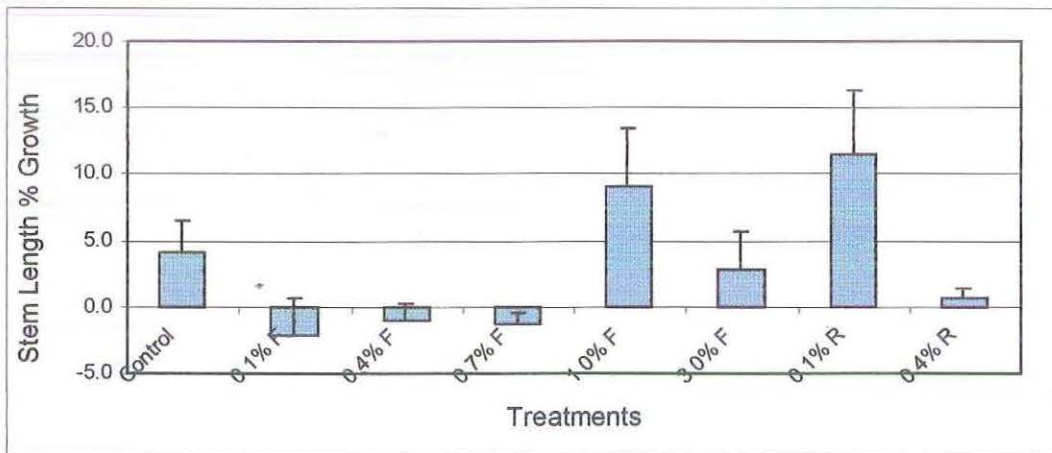
Figure 4.29: *H. lissocarpha* mean stem length percentage growth (+ SE, n=10)
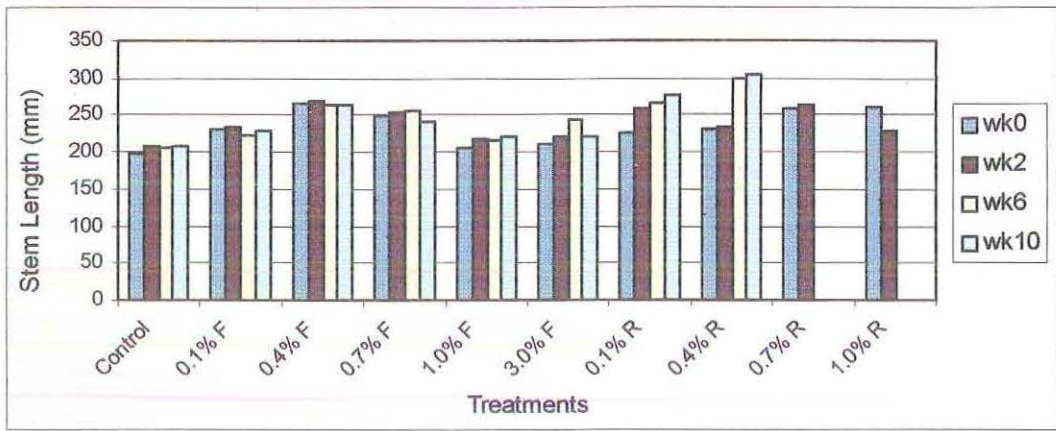
Figure 4.30: *H. lissocarpha* mean stem length over study duration

For mean percentage health in *H. lissocarpha*, all treatments showed a significant reduction in percentage health in comparison to the control (Figure 4.31). The majority of the health reduction occurred 2 weeks after the treatment applications (Figure 4.32). The 0.7% and 1.0% fire retardant treatments died two weeks after treatment application as mentioned above.
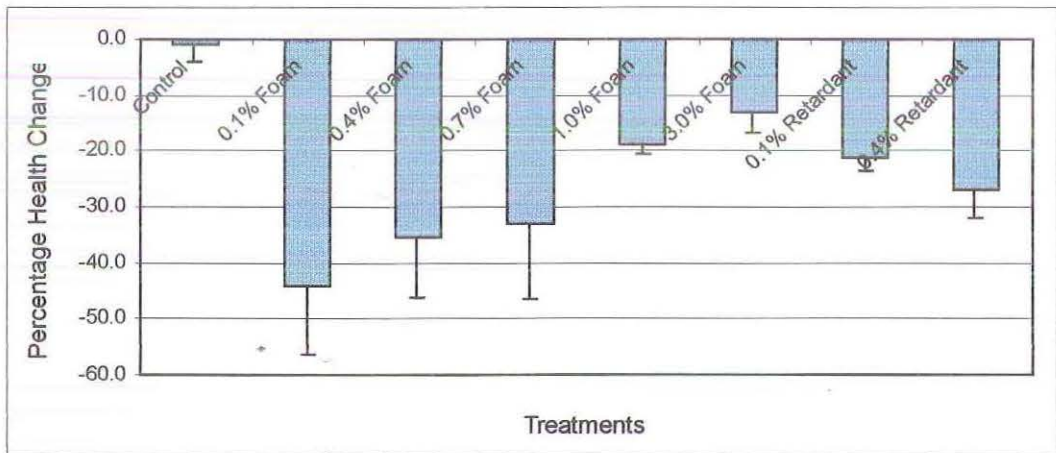
Figure 4.31: *H. lissocarpha* mean percentage health change (+ SE, n=10)
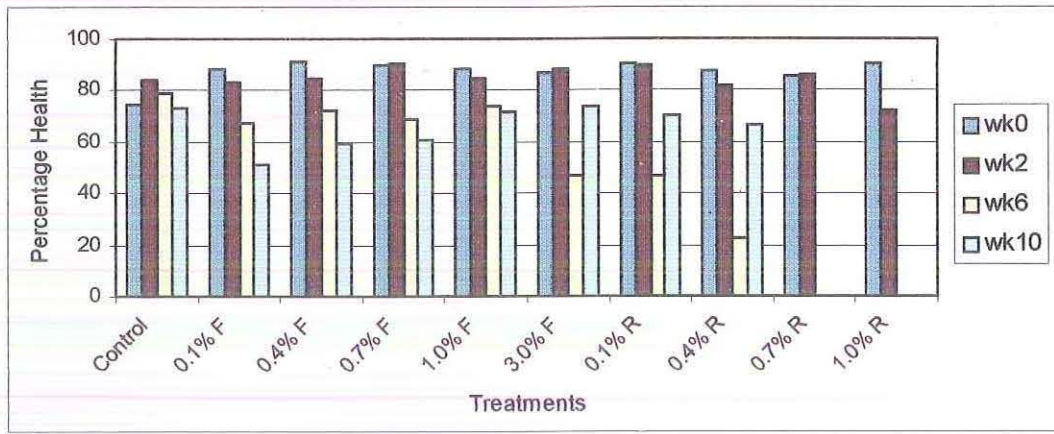
Figure 4.32: *H. lissocarpha* mean percentage health over study duration

4.2.6. *Gompholobium tomentosum* (Hairy Yellow Pea) Papilionaceae

Results of ANOVA showed that the variables measured for *G. tomentosum*, being stem length, number of leaflets and leaf percentage health, did not differ significantly between treatments (Table 4.7). The variable stem width showed significant differences between treatments, with 0.4% foam and 1.0% fire retardant significantly less than the control (Figure 4.33). The majority of growth throughout the treatments occurred 2 weeks after the treatment applications (Figure 4.34).

Table 4.7: Summary table of ANOVA for mean percentage change over study duration

Variables	df	F	P	Comments
Stem Length	9, 87	0.61	0.79	Not Significant
Stem Width	9, 86	2.93	<0.001	Significant
Percentage Health	9, 87	4.59	<0.001	Significant
Leaf Length	9, 64	2.42	0.02	Significant
Number of Leaflets	9, 64	0.33	0.96	Not Significant
Leaf Percentage Health	9, 65	0.74	0.67	Not Significant
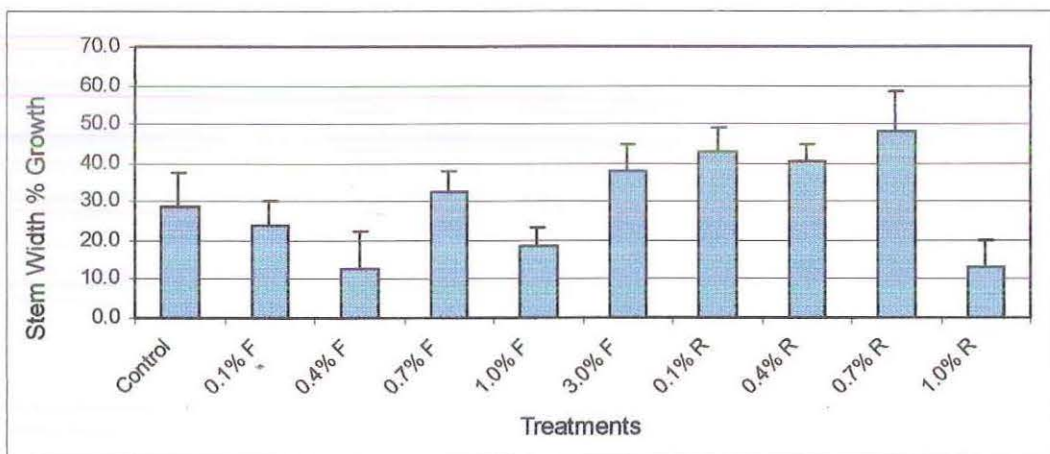
Figure 4.33: *G. tomentosum* mean stem width percentage growth (+ SE, n=10)
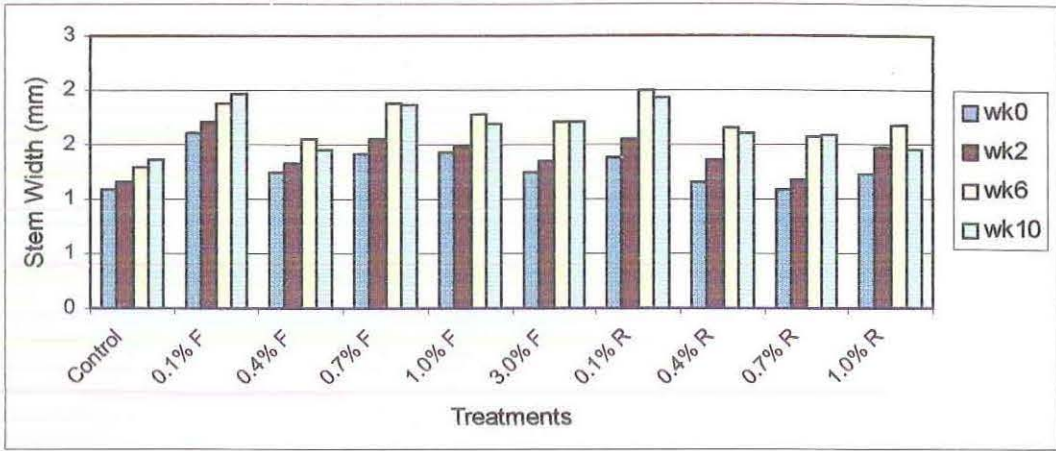
Figure 4.34: *G. tomentosum* mean stem width over study duration

For the variable mean percentage health, the 0.4%, 0.7% and 1.0% fire retardant treatments were significantly less than the control (Figure 4.35). A considerable decrease was observed for all treatments, occurring consistently throughout the study period, although there was some improvement in health after the first week (Figure 4.36).
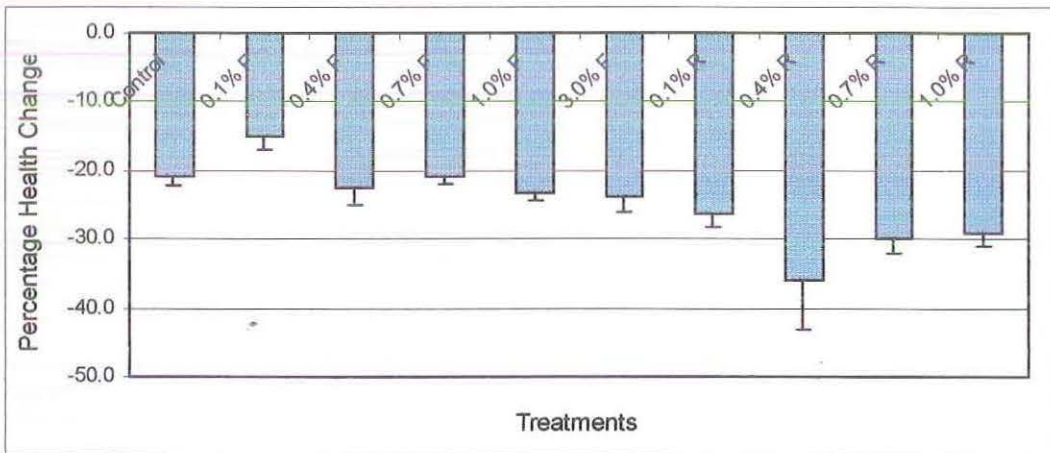
Figure 4.35: *G. tomentosum* mean percentage health change (+ SE, n=10)

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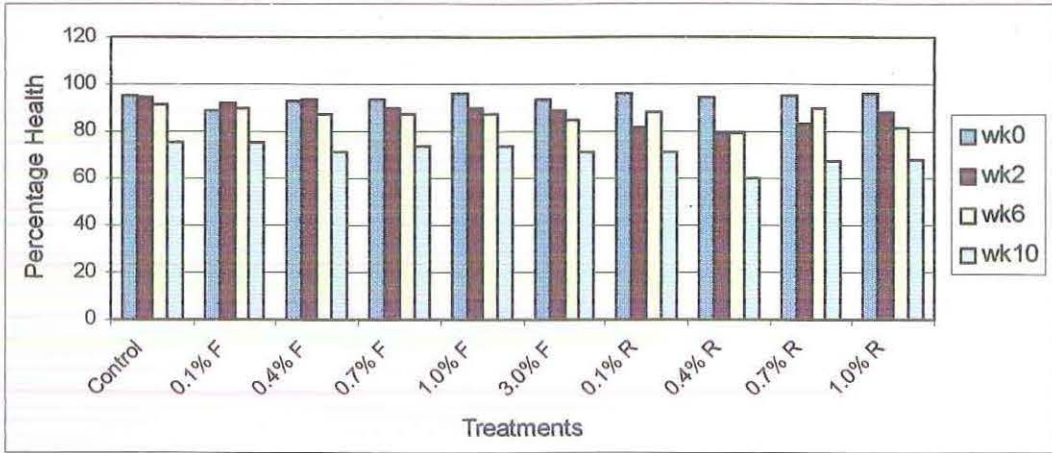
Figure 4.36: *G. tomentosum* mean percentage health over study duration

Results of ANOVA for *G. tomentosum* leaf length percentage growth, showed that the 0.4% and 1.0% fire retardant treatments were significantly greater than all other treatments (Figure 4.37). The majority of increased growth for 0.4% and 1.0% fire retardant treatments occurred 2 weeks after the treatment applications (Figure 4.38).
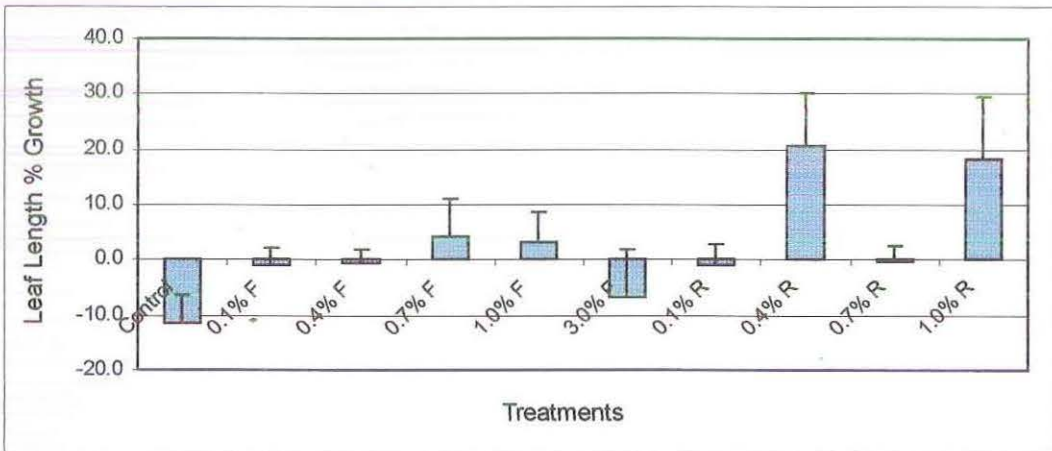
Figure 4.37: *G. tomentosum* mean leaf length percentage growth (+ SE, n=10)
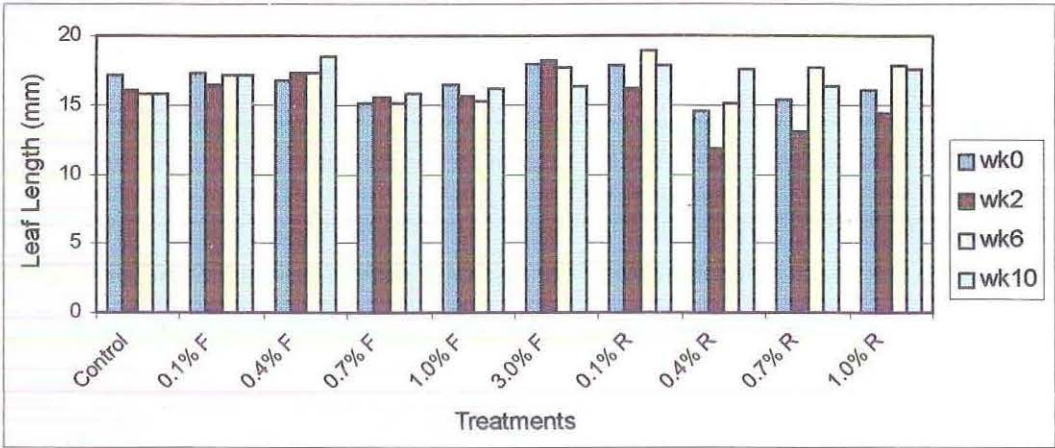
Figure 4.38: *G. tomentosum* mean leaf length over study duration

4.2.7. *Acacia pulchella* (Prickly Moses) Mimosaceae

ANOVA was conducted for the variables applied to *A. pulchella*. Table 4.8 shows that branch length and branch width did not significantly differ between treatments. The variable stem length showed significant differences between treatments, with the 0.7% and 3.0% foam and 0.7% fire retardant treatments significantly less than the control (Figure 4.39). An overwhelming growth period was shown by most treatments approximately 2 weeks after treatment applications (Figure 4.40).

Table 4.8: Summary table of ANOVA for mean percentage change over study duration

| Variables	df	F	P	Comments
Stem Length	8, 34	2.82	0.02	Significant
Stem Width	8, 34	4.84	<0.001	Significant
Percentage Health	8, 34	4.86	<0.001	Significant
Branch Length	8, 34	1.04	0.42	Not Significant
Branch Width	8, 34	1.05	0.42	Not Significant
Branch Percentage Health	8, 34	3.76	<0.001	Significant
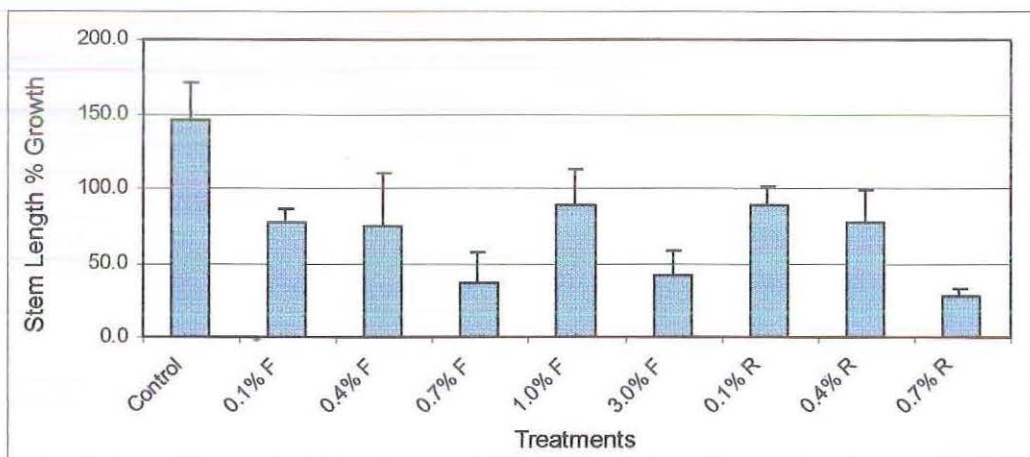
Figure 4.39: *A. pulchella* mean stem length percentage growth (+ SE, n=10)
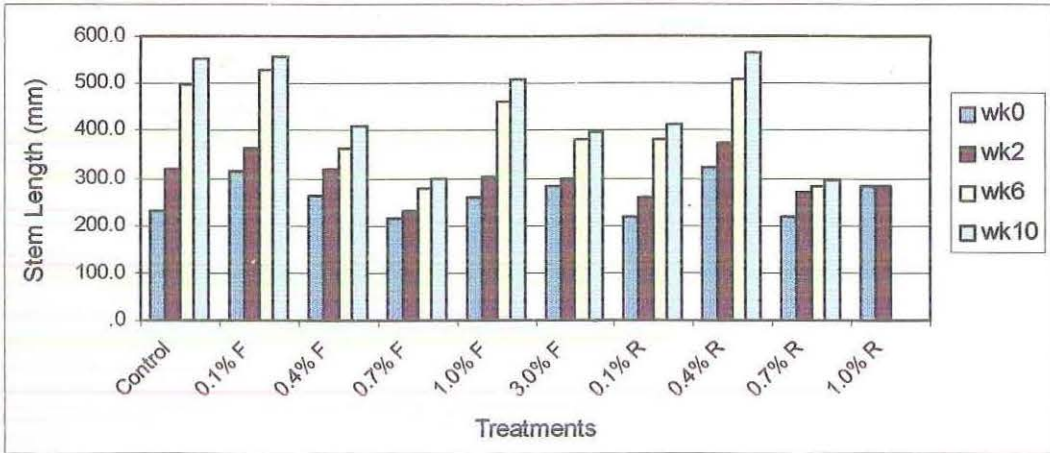
Figure 4.40: *A. pulchella* mean stem length over study duration

Results of ANOVA for the variable mean stem width percentage growth, showed that the 0.4%, 0.7% and 3.0% foam, and 0.7% fire retardant treatments were significantly less than the control (Figure 4.41). The growth of each treatment was shown to be fairly consistent throughout the study period (Figure 4.42).
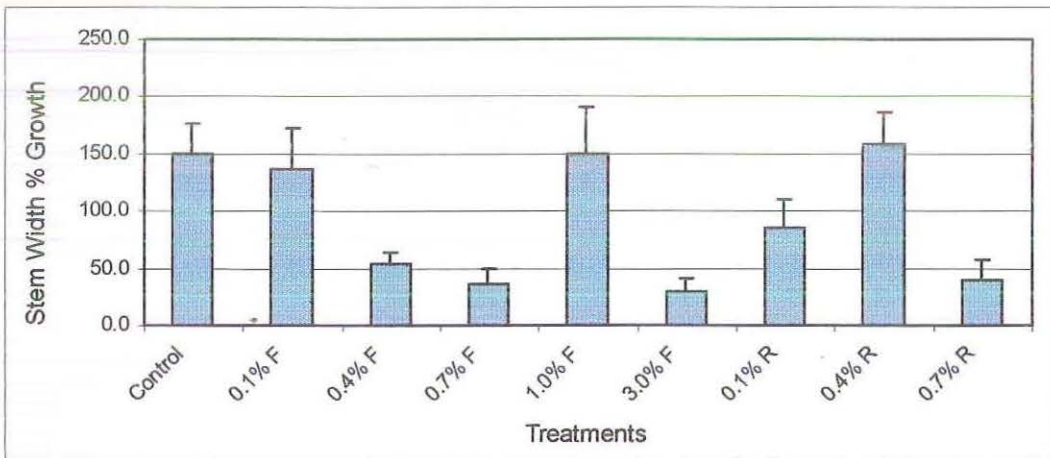
Figure 4.41: *A. pulchella* mean stem width percentage growth (+ SE, n=10)
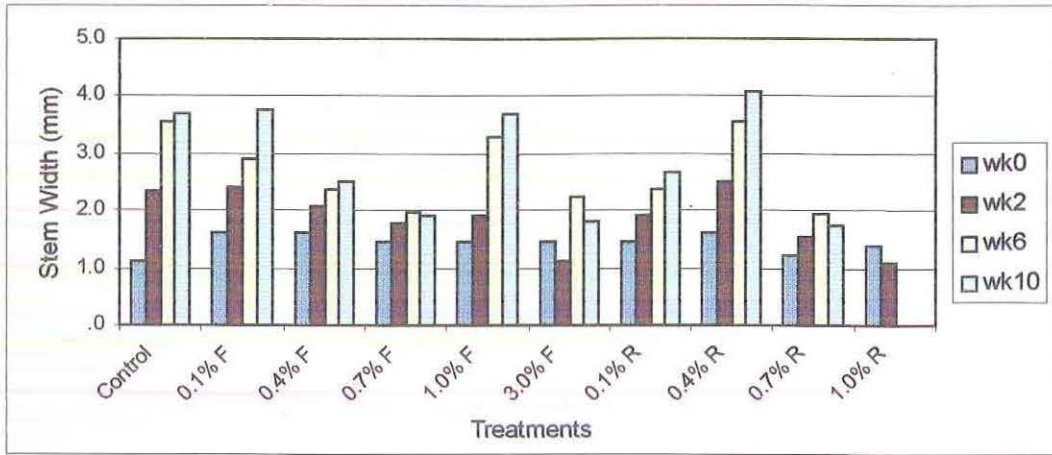
Figure 4.42: *A. pulchella* mean stem width over study duration

The analysis of mean percentage health for *A. pulchella*, showed that 0.4% and 3.0% foam, and 0.7% fire retardant treatments were significantly less than the control (figure 4.43). The main reduction of these significant treatments was not confined to a specific time period within the study (Figure 4.44). During the experiment, all individuals/replicates from the 1.0% fire retardant treatment died approximately 2 weeks after the treatment applications (Figure 4.43 and Figure 4.44).
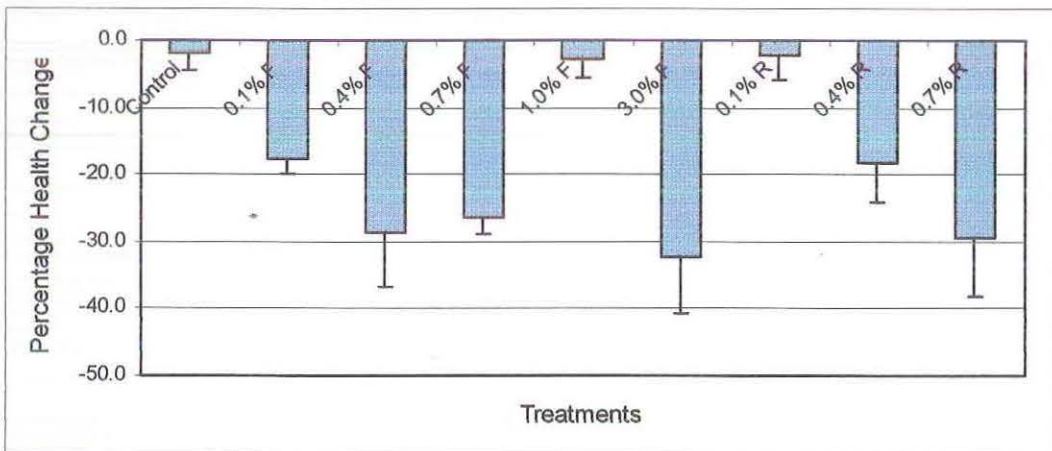
Figure 4.43: *A. pulchella* mean percentage health change (+ SE, n=10)
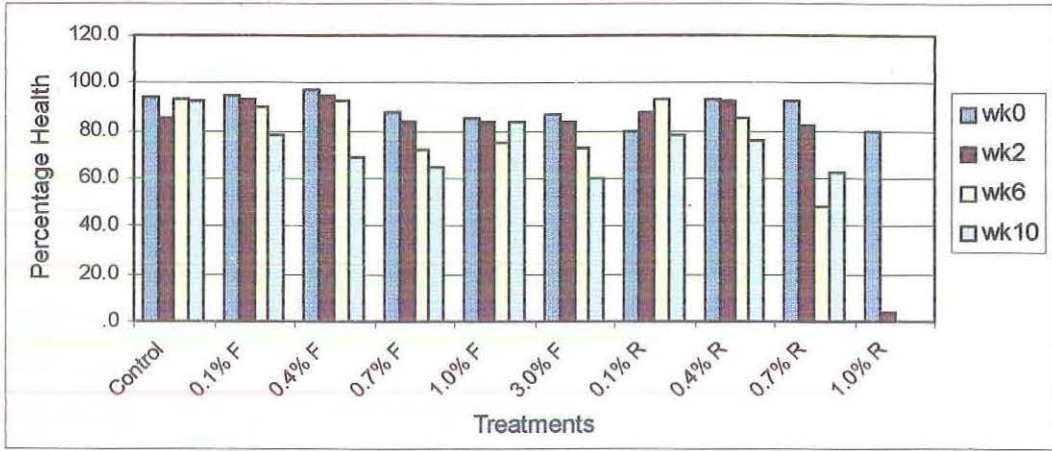
Figure 4.44: *A. pulchella* mean percentage health over study duration

The analysis of mean branch percentage health showed that the 1.0% foam treatment was significantly healthier than the control. It also showed that the 3.0% foam and 0.7% fire retardant treatments were significantly less than the control (Figure 4.45). The majority of mean branch percentage health reduction occurred 2 weeks after treatment applications (Figure 4.46).
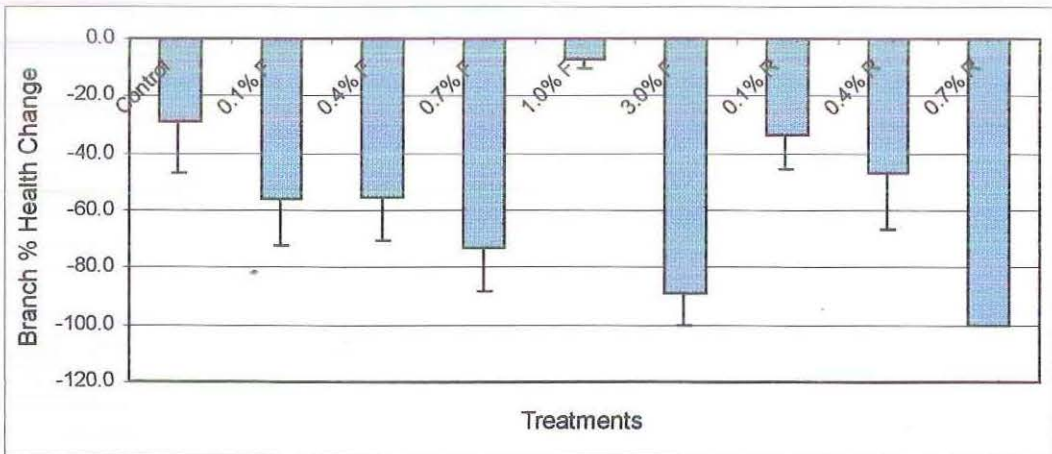
Figure 4.45: *A. pulchella* mean branch percentage health change (+ SE, n=10)
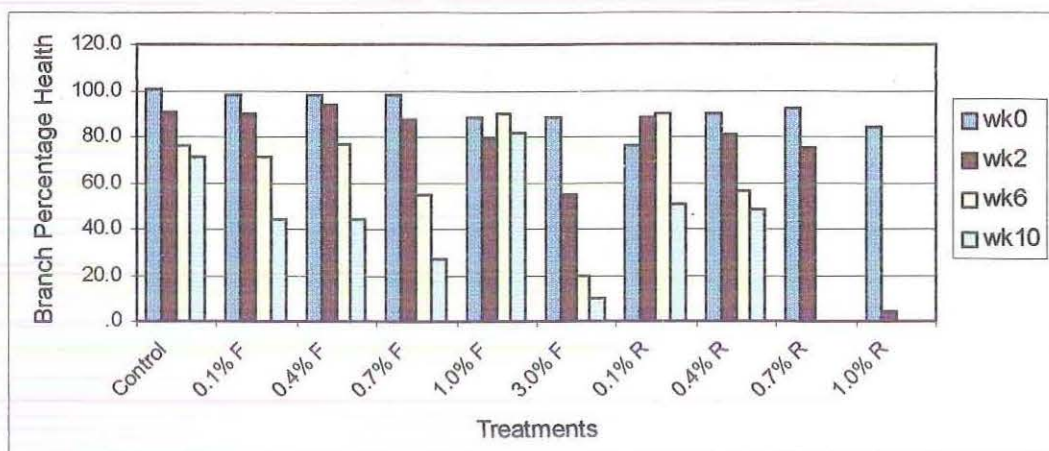
Figure 4.46: *A. pulchella* mean branch percentage health over study duration

A summary of the variables measured for each species is shown in Table 4.9. Also shown is the ANOVA result of each species variable. The occurrence of a significant result for each variable is shown. The significant results for the whole plant variables occur more frequently than the leaf and branch variables.

Table 4.9: ANOVA result for plant variables with significant percent occurrence

Plant variables	E. marginata	E. calophylla	B. attenuata	X. pressii	H. lissocarpha	G. tomentosum	A. pulchella	Sig. Different
Stem length	• Sig.	• Sig.	• Sig.		• Sig.	• Not	• Sig.	83%
Stem width	• Sig.	• Sig.	• Sig.		• Not	• Sig.	• Sig.	83%
N° of leaves	• Sig.	• Sig.		• Not				67%
% health	• Not	• Sig.	• Sig.	• Sig.	• Sig.	• Sig.	• Sig.	85%
Leaf / Branch Variables								
Length	• Not	• Not	• Not	• Sig.	• Not	• Sig.	• Not	28%
Width	• Not	• Not	• Not	• Sig.	• Not		• Not	17%
N° of leaflets						• Not		0%
% Health	• Not	• Sig.	• Not	• Sig.	• Not	• Not	• Sig.	43%

A summary of the significant variables for each study species is shown in Table 4.10. Dot points indicate that a significant difference occurred between treatment and control. Whether these differences are positive or negative is shown. Foam treatments accounted for 33 differences, whilst fire retardant treatments accounted for 47.

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Table 4.10: Summary of species variables that showed significant differences between treatments and control according to ANOVA and Tukey post hoc tests

	Treatments significantly different to control									Comments
	Foam					Retardant				Comments
	0.1	0.4	0.7	1.0	3.0	0.1	0.4	0.7	1.0	
E. marginata										
Stem length									•	Increased Biomass
Stem width									•	Increased Biomass
Number of leaves								•	•	Increased Biomass
E. calophylla										
Stem length							•	•	•	Increased Biomass
Stem width									•	Increased Biomass
Number of leaves							•	•	•	Increased Biomass
Percentage health	•	•	•						•	Increased Biomass
Leaf % health									•	Decreased Biomass
B. attenuata										
Stem length									•	Increased Biomass
Stem width		•						•	•	Increased Biomass
Percentage health		•						•		Increased Biomass
X. pressii										
Percentage health	•	•	•		•	•	•	•	•	Decreased Biomass
Leaf length	•	•	•	•	•	•	•	•	•	Decreased Biomass
Leaf width							•	•	•	Decreased Biomass
Leaf % health	•	•	•	•	•	•	•	•	•	Decreased Biomass
H. lissocarpha										
Stem length						•		D2	D2	Decreased Biomass
Percentage health	•	•	•	•	•	•	•	•	•	Decreased Biomass
G. tomentosum										
Stem width		•							•	Decreased Biomass
Percentage health							•	•	•	Decreased Biomass
Leaf length							•		•	Positive effect
A. pulchella										
Stem length			•		•			•	D2	Decreased Biomass
Stem width		•	•		•			•	D2	Decreased Biomass
Percentage health		•			•			•	D2	Decreased Biomass
Branch % health					•			•	D2	Decreased Biomass
Total	5	10	7	3	8	5	11	16	15	
Total F & R	33					47				

(D2= Death of all treatment individuals/replicates 2 weeks after treatment application).

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4.3. DISCUSSION

From the results presented, a variety of trends are evident. As summarised in Table 4.10, 24 (56%) of the 43 measurable variables applied to the study species, showed a significant difference between treatment and control. Further analysis of these significant variables, showed that foam treatments accounted for 41% of the significant differences between treatment and control, whilst fire retardant treatments accounted for 59%. This indicates that the fire retardant is far more influential upon the growth characteristics measured throughout this experiment. These results compare well to those found by Larson and Duncan (1982), Larson and Newton (1996) and Larson *et al.*, (1999). In all three cases, investigations into the effects of fire fighting foams and fire retardants on native plants showed foams had little effect in comparison to fire retardant.

Significant differences within the variables applied to *E. marginata, E. calophylla* and *B. attenuata,* were mainly due to the 0.7% and 1.0% fire retardant treatments. Significant foam treatments were few in comparison. The majority of these significant differences resulted in an increase in biomass. For example, stem length in all three species was greater in the 0.7% fire retardant treatment than any other, whilst the number of leaves in both *E. marginata* and *E. calophylla* were significantly greater in the 1.0% fire retardant treatment than the control. The results of investigations carried out by Larson & Duncan (1982) and Larson and Newton (1996) conform with these increases in biomass as a result of the fire retardant application. Both made similar observations of increased growth. They also found that the following year, biomass did not significantly differ between treated and untreated plots. This suggests that the effects of fire retardants are only temporary.

The results obtained for *X. pressii* and *H. lissocarpha* were distinctly different to the other species examined. Significant effects from both foam and fire retardant treatments were found. For the majority of variables applied, significant differences were found between all treatments and control. These differences occurred as a decrease in biomass. In addition to this, all treatment individuals within the 0.7% and 1.0% fire retardant treatments for *H. lissocarpha* died approximately 2 weeks after treatment application. These results suggest that both species are extremely susceptible to foam and fire retardant treatments in comparison to the others examined. Comparable results include those found by Bradstock (1987), where leaf

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death was apparent within one week of treatment application and continued for many months. Bradstock (1987) also noted that the effect was greatest in areas where fire retardant concentration was the highest.

The effects of the foam and fire retardant on *G. tomentosum* and *A. pulchella* were variable in comparison to the other species examined. On all accounts, except for leaf length for *G. tomentosum*, the significant variables showed a decrease in plant biomass. Percentage health in the 0.4%, 0.7% and 1.0% fire retardant treatments for *G. tomentosum* was significantly less than the control. Results showed that some recovery was made 2 weeks after treatment applications. The response shown by *A. pulchella* to the 3.0% foam and 0.7% fire retardant treatments was quite severe. In all significant variables the 3.0% foam and 0.7% fire retardant treatments adversely affected *A. pulchella*. Furthermore, all individuals of the 1.0% fire retardant treatment died 2 weeks after treatment applications. This reiterates that particular plant species are far more susceptible to the application of chemical fire suppressants than others. Further analysis conducted by Bradstock *et al.*, (1987) confirmed that foliar damage was solely caused by the ammonium sulphate component of the fire retardant. Washing to simulate rainfall did not prevent foliar damage, even when carried out 24 hours after the fire retardant application (Bradstock *et al.*, 1987).

The examination of the variables applied to each study species, as shown in Table 4.1 and Table 4.9, revealed that whole plant characteristics such as stem length, stem width and overall percentage health, were significantly affected more than within plant characteristics, such as leaf length, leaf width and leaf percentage health. This observation was compared to the results found by Hartskeerl (1999); the majority of variables she measured did not significantly differ between treatment and control, therefore no such comparison could be made. The confirmation of these observations requires further research.

A further trend within the results was the 'fertiliser effect' within the fire retardant treatments. As a general rule, the greater the fire retardant concentrations the greater the biomass increase. Prior nutrient analysis of both foam and fire retardant showed that the fire retardant was considerably greater in total nitrogen and total phosphorus. These nutrient components were clearly shown in plant response and were most evident in *E. marginata, E. calophylla* and *B. attenuata*. The investigation conducted by Larson and Newton (1996) also found that

particular species were able to tolerate and prevail with fire retardant application. The grass species *Poa pratensis* was of greater height on the fire retardant treated plots and growth was enhanced over the course of the growing season. Similarly, Bradstock *et al.*, (1987) found that the species *Leptospermum attenuatum* was far less affected by the fire retardant and showed greater recovery. In association with such species opportunity is the decline in species richness. Both Larson & Newton (1996) and Larson *et al.*, (1999) made observation of changes in community composition.

In summary, it can be determined that the effect of the fire fighting foam is subtle in comparison to that of the fire retardant. Significant effects shown by the foam include an increase in percentage health for *E. calophylla*, a decrease in percentage health for *X. pressii* and *H. lissocarpha*, and decrease in leaf length for *X. pressii*. Overall, the effects of the foam were variable and inconsistent, and affected individual plant species differently. Conversely, the effects of the fire retardant on the species examined were substantial. For each species examined the fire retardant had significant effects, although the significant variables were inconsistent across species. For *E. marginata, E. calophylla* and *B. attenuata* the fire retardant increased plant biomass and improved percentage health. For *X. pressii, H. lissocarpha, G. tomentosum* and *A. pulchella* the fire retardant treatments resulted in decreased biomass and reduced percentage health. In consideration of the past research conducted on fire retardants, it is expected that these significant effects found will be transitory only (Larson & Duncan, 1982; Bradstock *et al.*, 1987; Larson & Newton, 1996; Larson *et al.*, 1999).

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CHAPTER 5: GENERAL DISCUSSION AND CONCLUSIONS

The application of differing foam and fire retardant treatment concentrations to both seed and seedlings resulted in a variety of significant effects. The effect on seed germination was considered substantial. For all species except *X. pressii*, germination was significantly suppressed in both foam and fire retardant treatments. As a general rule, the greater the treatment concentrations, the greater the reduction in seed germination. Reason for this outcome is unknown, yet suggestion could be made towards the prevention of moisture into the seed capsule due to an impermeable barrier created by both foam and fire retardant treatments. It is also feasible that the elevated nutrient levels within the agar media were substantial enough to suppress seed germination. Further research is needed for clarification.

The implications of these results upon native seed germination within Australia's Southwest are severe. Seed germination is a crucial life history stage of every plant species and is dependent on factors such as temperature, moisture, nutrients, light and even fire (Hartmann *et al.*, 1997). The application of chemical fire suppressants during native seed germination could possibly inhibit the number of germinants and delay the onset of germination. This impact could adversely affect a plant species well being and jeopardize its ecological status. In particular, some endangered plant species could be particularly at risk due to low numbers of adults and seeds.

The effect of the foam and fire retardant treatment concentrations on the seedlings was far less severe. Despite significant effects being found for both suppressants, the fire retardant was far more influential on the plant characteristics measured. To concur with the prior research undertaken, the effect of the fire fighting foam was subtle in comparison to the fire retardant. Significant foam effects occurred inconsistently between study species and the applied variables. The fire retardant significantly affected all study species via an increase or decrease in plant biomass and improved or reduced percentage health. It was also evident that *X. pressii* and *H. lissocarpha* were adversely affected in comparison to the other species. Comparative research shows this is a frequent observation (Larson & Duncan, 1982; Larson & Newton, 1996; Larson *et al.*, 1999; Bradstock *et al.*, 1987).

In reflection of the results presented, in can be determined that the use of fire fighting foams to control and suppress wildfires is an ecologically sound and effective tool. This conclusion can

be supported by the available alternatives, including traditional methods of fire fighting, which are known to be ecologically damaging, lead to edge effects, weed invasions and other environmental degradation. More so, from the results presented it can be determined that fire retardants are significantly damaging in a variety of ways. Numerous accounts were made of fire retardant treatments resulting in a decrease in plant biomass and reducing overall plant health. In addition, fire retardant treatments significantly increased plant biomass for a number of species and improved their overall health. The implications of such opportunistic species growth are detrimental at the community level. In turn, a change in species richness could have numerous adverse effects on organisms dependent on the vegetation structure at hand.

Despite the effects of fire retardants being considered as temporary, numerous short-term effects have been observed by a number of independent studies. It is because of these short-term effects that land management agencies should avoid the use of fire retardants where possible and employ a precautious nature. Based on prior research into the effects of fire fighting foams on terrestrial vegetation, as well as the results presented in this study, it can be determined that the application of fire fighting foams between 0.1% and 1.0% foam concentrate, does not adversely affect the receiving vegetation as a whole. However, given the results of the germination experiment, the use of lower foam concentrations is advisable. Specifically, foam concentrations no greater than 0.4% is recommended to ensure seed viability.

This study recommends the use of fire fighting foams as opposed to fire retardants for the suppression of wildfire throughout Australia's Southwest. These conclusions are drawn from the overwhelming evidence presented by prior research and upon the results presented in this study. In light of the results obtained in the germination experiment, fire fighting foam concentrations of 0.1% to 0.4% foam concentrate are recommended.

Further research is required on the interaction between fire and fire fighting foams and fire retardants, as well their residual breakdown times in the soil environment. Field trials are needed to verify the effects of chemical fire suppressants on mature plants and their effects on seed germination. Attention should be given to the chemical constituents of fire suppressants and how each affects the various stages of terrestrial plant growth.

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