CONTROL BURNING IN THE ECOLOGY OF EUCALYPTUS AND PINUS FORESTS

by

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Except where otherwise acknowledged, this thesis is the author's own original work.

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CHAPTER 1

INTRODUCTION

The role of fire as a major operational factor in a very wide range of forest environments - tropical, temperate and sub-arctic - is well documented. For example, it has been amply demonstrated that the existing tropical African savanna woodlands are largely the result of repeated fires in the past (Gillon, 1971; Innes, 1971). In Australia, the genus Eucalyptus provides evidence of fire as a factor in natural selection; species of this genus owe their origin, distribution and survival largely to past fires (Jackson, 1968; Mount, 1964) but also to other site factors. The southern pine types of North America are generally considered fire sub-climax, having evolved over the centuries with fire as an integral part of the natural environment (Perkins, 1971). Again, evidence indicates that periodic past fires are responsible for the extensive development and survival of heath communities covering parts of Great Britain and neighbouring countries around the North Sea (Gimingham, 1971). In these areas, firing at more or less regular intervals, has prevented the encroachment of natural forest types. Finally, in the Canadian tundra, studies by Cochrane and Rowe (1969) indicate that evidence of past fires exist on well-drained slopes occupied by Alectoria lichen communities.

Forest fires are often the result of man's activities, although lightning and other natural causes are at times responsible for some fires. In places such as North America lightning-caused fires are frequent in the forests during the dry season (Black, 1968). However in other regions such as the humid tropics that have relatively short spells of dry weather, although thunderstorms are abundant, lightning-caused fires may be less frequent in the forests unless extensive and repeated drought occurs (Komarek, 1971).

The term "wildfire" as used in the forestry literature is synonymous with "forest fire" and both come under a common definition of "uncontrolled and freely-spreading combustion that consumes the natural fuels of a forest, i.e. litter, soil organic material and vegetation" - based on Davis (1959). Frequently, the combined effect of heavy fuel volumes and dry weather conditions cause many wildfires to burn with explosive violence, generating intense heat. The result usually is extensive damage to the forest communities and soils. Fire-caused damage may take the following forms:-

(1) Death of merchantable trees or serious degrade in tree quality.

(2) Provision of conditions favourable for tree-destroying insects and pathogens.

(3) Delays in, or sometimes prevention of, regeneration - especially when seeding time coincides with the fire incidence.

(4) Destruction of the soil's humus-forming litter and duff.

(5) Total or partial destruction of soil microfauna and flora in upper soil layers by direct killing or indirect destruction of shelter and source of food.

(6) Serious plant nutrient losses through combinations of excessive leaching, surface run-off and windblow.

(7) Removal of ground cover. This may produce the following effects:

(a) Overheating of surface soil under the influence of the increased solar radiation.

(b) Increased soil moisture losses through evaporation.

(c) Soil compaction and structural deterioration under the direct impact of rain drops.

(d) Reduced soil non-capillary porosity and aeration with resultant decline in aerobic microbial activities and oxidation-reduction reactions in the soil.

(e) Increased risk of surface run-off and erosion that may lead to flooding and siltation damage to nearby dams and stream channels.

Many reports demonstrate that wildfires have caused considerable economic losses through extensive devastation of forested lands (Black, 1968; Haines and Sando, 1969; Luke, 1961; McArthur *et al*., 1966).

Against these adverse effects of uncontrolled fires, there may be certain beneficial side effects. These include:

(1) Fertilizing action of the plant ash.

(2) Stimulation of mineralization processes in soils.

(3) Increase in the amount and quality of young growth available as food for browsing animals.

(4) Reduction of existing fuel volumes, hence reducing future fire hazards.

(5) Maintenance of existing fire sub-climax communities which may be of high commercial value. Apparently total exclusion of fire in some instances will result in significant, and probably unwanted, changes in species composition.

Thus, it becomes evident that fires can have both beneficial and detrimental effects on woodland ecosystems at the same time.

It is widely accepted that most of the devastating effects of wildfires could be reduced to a minimum if fires occurred under planned conditions (Lyons, 1971; McArthur, 1966; Perkins and White, 1969). In recent years, knowledge and understanding of factors that influence fire behaviour and intensity have greatly increased (Byram, 1959; Hough, 1968). Following this, it is now possible in many areas to forecast, with reasonable accuracy, the manner in which fire will behave under specified conditions of fuel, weather and topography. This has led to the development of "control burning" in forest management. McArthur (1966) has defined control burning as: "The planned application and confinement of fire to the vegetation of a pre-selected land area". The term "prescribed burning" was first used in connection with the understorey of forests (Biswell, 1967). Later, the term was employed synonymously with control burning as applied to brushlands. The primary objective of control burning is the skillful application of fire in order to realize maximum net benefits at minimal damage to the forest community and soil. Most control burning practices fall into four categories as follows (McArthur, 1966):

(1) Burning of buffer strips or fuelbreaks around areas of high value.

(2) Advanced burning prior to logging operations.

(3) Slash disposal burning for regeneration and hazard reduction following logging.

(4) Control burning of large areas, generally on a rotational system, to minimize wildfire severity.

Various types of control burning, as forest management techniques, have received widespread recognition in many parts of the world. In Australia, rapid fuel build-up is characteristic of the major forest types. As a result, interest has largely centred on area control burning, locally termed "fuel modification burning". Burning rotations are based on the rate of forest fuel accumulation in the particular vegetation types. In eastern Australia, a range of 5 to 7 years represents the common interval between burns while 4 to 6 years is the common rotation range in western Australia (Australian Conservation Foundation, 1970).

Despite the increasing use of control burning, the actual and potential effects of fire on forest ecosystems are still not well understood. For example, there are reports of increased, decreased and sometimes unchanged conditions in forest productivity after control fires. These conflicting reports make it almost impossible to generalize about the beneficial and detrimental effects of control burning. While very intense fires are frequently injurious to plants, excessively hot fires may be useful in some situations. For example, when a cleared forest is burnt in thick piles or windrows, "ashbeds" are formed. Numerous reports indicate that tree seedlings planted in these ashbeds have spectacular initial growth stimulus that may persist for several years (Cromer, 1970; Humphreys and Lambert, 1965; Hatch, 1960; Pryor, 1963).

Under a standing forest, it is generally accepted that any complete evaluation of net fire effects in specific situations must include consideration of type and age of the stand, forest fuel characteristics, fire intensity and duration, soil type, topography, weather conditions and the object in view. Of these, fire intensity appears to be of primary importance (Gilmour and Cheney, 1968). Byram (1959) expressed fire intensity in terms of energy output per unit of time, per unit length of fire front, and calculated it from the equation:

$$I = Hwr$$

where,

I = Fire intensity in B.T.U. per second per foot of fire front.

H = Heat yield in B.T.U. per pound of fuel.

w = Weight of available fuel in pounds per square foot.

r = Rate of forward spread in feet per second.

Ralston (1971) correlated fire intensity with forest floor removal and stressed the need to recognize the variations in forest floor removal by different kinds of heat. This is noteworthy because while a "heavy" slash burn and a "light" fuel modification burn are both forms of control burning, the former is relatively intense and long-lasting owing to greater fuel volumes. Most studies on fire effects, however, lack adequate descriptions of particular heat intensities involved. Some workers (e.g. Gilmour and Cheney, 1968) have expressed critical views on this neglect and suspect that this could be largely responsible for the inconsistency in the results of forest fire studies.

Many workers have warned that control burning involving frequent fires, such as annual burns, may progressively degrade soil fertility (Floyd, 1966; Lemon, 1967). Persistent fires of this nature usually prevent the establishment of forest floor cover needed to maintain stability of soil micro-climate and nutrient cycling. Disruption of nutrient cycling in forest ecosystems is particularly serious in young plantations where the bulk of the organic litter is derived from the ground flora (e.g. see Ovington, 1965). Hence it appears that possible benefits from such successive fires are often offset by the damage to the ecological system.

The wildfire situation in Australia is particularly serious and is responsible for considerable human and economic losses, perhaps as high as $200 million in a season of bad fires (Rural Fires Conference, 1969). The magnitude of this loss has stimulated a certain amount of research on forest fires, fire-fighting and ancillary aspects of the problem. Fire-fighting techniques will no doubt continue to improve, but nevertheless, once established wildfires will burn more or less uncontrolled, especially when large amounts of combustible fuel are available on the forest floor or in the understorey shrubs. In the present study, forest fuel modification burning is discussed in relation to its effects on certain soil physical and chemical properties, the floristic composition and nutrient levels of the ground vegetation and on tree growth and development during the first one year after the burn. Since fuel modification treatments are prescribed on rotational basis, it is important to evaluate such short-term post-fire effects on forest productivity. Much more work is needed in this field to provide a sound basis for the expansion of current knowledge and understanding of control burning effects.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Forest fires and forest ecosystems

The term "ecosystem" was introduced by Tansley (1935). By definition, an ecosystem is "the total sum of living organisms, their physical environment and the processes of interaction that occur between and within all parts of the system" (Gates, 1968).

Through natural selection primarily, over long periods of time, certain plant and animal communities have developed adaptations that allow them to live where fire is a factor of the environment (Komarek, 1962). These "fire-adapted" communities have become geared to periodic burning, including any adaptation to the properties of frequently burnt soils, as a normal feature of the environment (Lemon, 1968). Thus, it becomes apparent that total exclusion of fire would mean the removal of one of the most important environmental factors that had functioned over several years to maintain balance and stability in most forest ecosystems. In plant communities, the evolutionary adaptations comprise features that prevent the destruction of vital vegetative tissues and the production and efficient dissemination of reproductive bodies (Lemon, 1967). Recovery after fire occurrence is made possible through anatomical mechanisms such as thick bark, epicormic sprouting, etc., and reproductive mechanisms (e.g. rhizomes, root sprouting and serotinous cones).

As with most other environmental factors, man has greatly modified the influence of forest fire, increasing it in many cases and decreasing it in others (Odum, 1971). Some plant species are adapted to successional communities and are thus absent from, or occur at lower densities in, stable or climax communities (Whittaker and Woodwell, 1972). Likewise, there are certain animals that thrive best when the forest climax has been destroyed in some way, giving way to seral communities, while others prefer climax environments (Leopold, 1969).

In considering fire as an ecological factor, it is always important to note the different types of fire which differ in their effects on forest ecosystems (Odum, 1971). Davis (1959) has made the following distinctions:

(1) "Surface fires", that consume forest floor material (i.e. litter, herbs and shrubs),

(2) "Ground fires", that consume the bulk of the partly-decomposed forest floor material,

(3) "Crown fires", that burn tree canopies.

Severe scorching of tree foliage by crown fires may cause tree death. Ground fires proceed slowly but intensely and may adversely affect soil organic content, microbial life and feeding roots of plants. Surface fires, on the other hand, generally exert selective effects (Odum, 1971). These fires are more limiting to some forest organisms than to others and thus favour the development of organisms with relatively high tolerance to the fire factor.

2.2 Fire adaptations in the Australian vegetation

The important plant families of the Australian vegetation are the Myrtaceae, Leguminosae, Proteaceae, Casuarinaceae and Epacridaceae (Hall *et al.*, 1970). The eucalypts (*Eucalyptus*) and the wattles (*Acacia*) are two particularly prominent genera. *Eucalyptus* is by far the most important genus of Australian forest trees. Its members dominate 95 percent of the forest area and spread out over much of the remainder of the continent (Hall *et al.*, 1970).

Rainforest communities that cover areas which are moist for most of the year seldom accumulate much litter (Mount, 1964). However, the presence of eucalypts in mixed forest stands (i.e. eucalypt dominants with understorey of rainforest species) indicates the possibility of fierce fire outbreak in these stands after heavy fuel accumulation. The Australian sclerophyll vegetation consists of wet and dry types. Wet sclerophyll eucalypt communities occupy the deeper, commonly loamy soils of the higher rainfall zone (Hall *et al.*, 1970). While the foliage of the eucalypt dominants show some degree of inflammability, common understorey associates like *Bedfordia* spp., *Salicina* spp., *Pomaderris apelata* and *Acacia dealbata* are characterised by their relatively non-inflammable shoots (Mount, 1964). Dry sclerophyll eucalypt communities grow in habitats where soil moisture is markedly reduced in summers, although water supply may be ample in winters. Summer droughts are thus common. Understoreys associated with dry sclerophylls are normally low, harsh, xeromorphic shrubs with sclerophyllous microphylls (Cochrane, 1968). On very dry sites the shrub layer may be largely or entirely replaced by fibrous grasses even though there is no remarkable decrease in tree density. These factors suggest that dry sclerophyll communities will burn either more fiercely or more frequently than any of the other forest types.

The eucalypts in general produce abundant quantities of bark and other fuels. Species of this genus rarely occupy a site to the total exclusion of undergrowth since their crowns allow much penetration of light onto the forest floor (Cremer, 1960). Both pre-fire and post-fire climatic and seasonal conditions modify burning and regeneration patterns (Cochrane, 1968). Extremely dry conditions prior to a wildfire outbreak usually cause very intense fires with many ground species killed and much seed burnt. Some underground parts of plants may escape destruction from the intense heat and regenerate under favourable conditions. Also desiccation and dehiscence of many woody fruits by the heat of the fire result in great numbers of seedlings appearing after some fires.

The eucalypt genus has advantages over most of its competitors with regard to fire, in its resistance, regeneration and rapid growth of both seedlings and coppice (Mount, 1964). Eucalypts are generally considered one of the most fire resistant genera in the world (McArthur, 1968). Most eucalypt species have developed protective barks, bud strands and lignotubers that ensure survival after fire. Dormant (or epicormic) bud strands are shafts of bud-producing tissue that develop from the position of a leaf axil. On the trunks and branches of an Eucalyptus tree there exists at least one of these shafts for every leaf that developed as the tree gained height (McArthur, 1968). These bud strands can withstand progressive killing of the bark and phloem and may occasionally survive the death of the cambium. Lignotubers are woody swellings at stem bases which bear numerous dormant buds. From these buds, new shoots can be produced after the plant's shoot system has been damaged by fire, drought, or animals (Van Noort, 1960). Lignotubers commence in the axils of the cotyledons or the first few leaf pairs of a seedling. As the seedling ages the swellings in the individual leaf axils fuse to form a bulbous tissue. This tissue later folds down the stem, enveloping the upper part of the root system (McArthur, 1968). With increasing age and size the lignotuber becomes partly buried beneath the soil surface. Due to this partial underground nature of lignotubers, they are seldom completely damaged by fire and are the ultimate mechanism by which most eucalypt species can survive fires.

Pines, particularly <u>Pinus radiata</u>, are the major exotic conifers grown in Australia. Pryor (1940) noted that <u>Pinus canariensis</u> is one of the few conifers that approaches the eucalypts in its ability to recover from defoliation by fire. This species is capable of putting out vigorous epicormic shoots on stems and branches after fire. A similar characteristic was observed in <u>Pinus ponderosa</u>, <u>P. caribaea</u>, <u>P. laricio</u>, <u>P. patula</u> and <u>P. flexilis</u> although not as remarkable as in <u>Pinus canariensis</u>. Pryor (1940) presented the following classification of fire resistance for selected pine species:-

(1) Very resistant : *Pinus canariensis*.

(2) Resistant : *Pinus coulteri*, *P. ponderosa*, *P. caribaea*, *P. arizonica*, *P. apacheca*, *P. pinaster*, *P. montezumae*, *P. jeffreyi*.

(3) Susceptible : *Pinus radiata*, *P. densiflora*, *P. contorta*, *P. austriaca*, *P. sabiniana*, *P. sylvestris*, *P. patula*, *P. flexilis*, *P. laricio*, *P. torreyana*.

(4) Very susceptible : *Pinus lambertiana*, *P. strobulus*, *P. monticola*.

2.3 Principles and practices in control burning in Australia

Control burning as a forest management technique requires a clear-cut objective and skillful handling (Davis, 1959). The proper use of fire in any particular situation can only be recommended where adequate knowledge exists of the interrelationships between the many variables that affect fire behaviour and fire intensity, and hence fire damage (McArthur, 1962). The major variables recognized as affecting fire behaviour include the following:

(1) Type of fuel

(2) Quantity and arrangement of fuel

(3) Fineness of fuel

(4) Fuel moisture content

(5) Atmospheric temperature

(6) Relative humidity

(7) Wind velocity

(8) Topography.

The type and composition of the forest stand plays an important role in determining the "spot fire" potential of a particular fuel type (McArthur, 1962). Spot fires are burns initiated by glowing embers that are carried ahead of the main fire front under the influence of strong winds. In the Australian eucalypt forests the rough-barked species are generally more prone to spotting than are smooth-barked species (McArthur, 1962). The presence or absence of understorey species and their fire characteristics can also vitally affect the behaviour of a forest fire by providing additional fuel for combustion, and by microclimatic effects.

All studies of fire behaviour in eucalypt fuels have indicated that the amount of available fuel on the forest floor is a most significant variable affecting fire behaviour (McArthur, 1962). By "available fuel" is meant the quantity of fuel that actually burns in a forest fire (Van Loon, 1969). As the fire's heat intensity increases, more fuel becomes available for combustion. The term "total fuel" frequently refers to the quantity of fuel that would burn under the driest conditions to produce a fire with the highest intensity of heat (Byram, 1959). In control burning practice, however, the total fuel concept assumes little importance.

The degree to which a given fuel type is horizontally continuous is a very important aspect of forest fuels due to its direct relation to the rate of spread and difficulty of suppression (Davis, 1959). Both fuel continuity and fuel fineness are important in appraising fire spread potential, as the finer the fuel type, the higher the rate of spread (McArthur, 1967).

Fuel moisture content influences forest fire behaviour since combustibility generally decreases with increasing moisture content (Byram, 1959). Most control burning guides attempt to estimate fuel moisture regimes either by the use of hazard sticks or by reference to tables of temperature, relative humidity and recent rainfall (Van Loon and Love, 1973). Evidence derived by McArthur (1967) in a dry sclerophyll eucalypt forest indicated that fuel moisture content values in the narrow range around 15 percent are generally satisfactory for most control burns. In another study, Van Loon and Love (1973) compared fuel moisture content with the percentage fuel reduction on the one hand, and with fire intensity on the other. These workers noted that moisture regimes below 13 percent could produce heat intensities above the optimum range for control burns, while moisture contents above 20 percent could hinder efficient fuel reduction under certain conditions.

Weather information, which forms part of control burning prescriptions, is commonly recorded at the burning site. The data are collected in advance of the burning time in order to study the trends and daily variations (Schimke _et_. _al_., 1970). It is often necessary to record the daily weather information when atmospheric temperatures are near maximum and relative humidity near minimum (McArthur, 1962). During this time, the prevailing weather conditions are usually near the worst possible for the day from the view point of fire danger.

A wide range of temperatures - 30°F (-1°C.) to 80°F (27°C.) has been proposed as suitable for most fuel modification burnings, depending on other conditions. Under a 23 year old radiata pine plantation Gilmour and Cheney (1968) conducted a satisfactory control burn when the ambient temperature was 78^{o}F (25.6^{o}C.) and relative humidity 30 percent. Schimke et al. (1970) are of the opinion that relative humidities above 60 percent cannot effectively support most control fires.

Wind velocity has considerable influence on control fires. Burning is generally found to be most satisfactory when the prevailing winds are fairly constant in direction and speed. According to McArthur (1967) the rate of forward spread of fires in most eucalypt forests varies approximately as the square of the wind velocity, except under very light winds of less than 2 m.p.h. Wind velocity effect is greatest at very low fuel moisture regimes. Wind velocity is generally expressed in terms of open station exposure, although the effective wind is that reaching the flame front on the forest floor (McArthur, 1967).

Slope appears to have a marked influence on the spread rate of fires. It has been reported that the rate of forward progress of fire in eucalypt fuels doubles on a 10 degree slope, and increases fourfold on a 20 degree slope (McArthur, 1967). On downslope directions fire spread is generally reduced.

Season of burning

Spring is generally accepted as the most satisfactory season for light-intensity burns (McArthur, 1962; Schimke et al., 1970). During this season the top soil and duff layers of the forest floor are often wet and do not hold fire for long periods. Thus fire escape is minimal and when it occurs suppression is often easy. Van Loon (1969) however pointed to rising hazards in spring burns in Australia following strong north-westerly winds of continental origin that prevail during this season. These winds are often hot and dry. Peet (1965) proposed that control burns carried out in autumn are generally "cleaner" and thus of greater protection value than most spring burns. Furthermore, some forest areas (for example flats) will not easily burn in the spring season. McArthur (1962) has warned that autumn burns, when they occur, are best delayed until the dry conditions have been broken by an adequately soaking rain. Great care is needed to ensure that excessive leaf scorch does not occur to young stands during autumn burns. Saplings that are badly scorched during this season may fail to recover until late the following spring (McArthur, 1962). This situation could adversely affect tree growth. In certain instances the timing of the prescribed burning is very important. For example, in regeneration burns knowledge of seed maturing period is often vital (Davis, 1959). Such burns are most effective when they closely precede seedfall.

Prediction of fire behaviour

McArthur (1967) has studied fire behaviour in eucalypt forests in some detail. The following account of fire behaviour prediction draws largely on the work of this author.

Data from experimental fire behaviour studies and wildfire analyses have been combined into a "forest fire danger meter", which guides the daily forecast of fire danger rating. Generally, more precise control burning tables are used for the predictions of low intensity fire behaviour. The fire danger meter integrates the combined effects of fuel dryness and wind velocity to produce a basic index which can further be modified by the inclusion of fuel quantity and slope for initial attack analyses. The fire danger index is directly related to rate of spread on a scale of 0 to 100. A rating of 100 represents "worst possible" conditions of :

(1) air temperature (100 to 105°F),

(2) relative humidity ($\leq$ 10 per cent),

(3) wind velocity ($\geq$ 35 m.p.h.),

(4) an extended prior drought period of 6 to 8 weeks or more, and

(5) unstable atmospheric conditions.

The index comprises fire divisions of : low; moderate; high, very high and extreme.

Control burning operations

The size of a control burning crew and the amount of equipment needed will depend on the extent of the burning. Since fire escape problems are relatively minimal in prescribed burns, a small crew is usually what is needed (Schimke *et al.*, 1970).

In Australia, the afternoon hours of 1300 to 1500 are recommended for fuel modification burns (McArthur, 1962). The meteorological and fuel moisture conditions at the time of burning will dictate whether the fire will be with or against the prevailing wind (i.e. headfire or backfire). These site conditions also decide the direction of the fire front with respect to slope (Van Loon, 1969). Ignition is carried out in a way that will ensure a systematic combustion of the fuel in the shortest possible time (McArthur, 1962). A grid system of fire spotting is commonly employed. Spot fire spacing is determined by fuel quantity and distribution, slope and weather conditions. Often a test fire is started in the ajoining area to provide a check of the prescription conditions before the burning treatment. Aerial ignition methods provide a remarkable improvement in area control burning particularly in steep mountainous country (McArthur, 1969).

Control burning practice in Australia

The current practice of area control burning in Australia dates back to the mid 1950's (McArthur, 1966). Initial programmes of prescribed burning operations were concentrated in the jarrah (*Eucalyptus marginata*) forests of Western Australia where wildfire hazards were greatest. In eastern Australia, fuel reduction burning in forest management has developed relatively slowly due to topographic and other difficulties (McArthur, 1966). Furthermore, some of the existing wet sclerophyll associations may only require fuel reductions at very infrequent intervals. For example, many wet sclerophyll and rainforest associations in Tasmania have a period of fuel scarcity lasting 10 to 20 years (Mount, 1964).

Radiata pine, the leading exotic conifer planted in Australia, is susceptible to intense fires (Pryor, 1940). There is little doubt therefore that, in view of considerable fuel build-ups under pine stands (McArthur, 1966), wildfires will cause serious damage when they occur. Thus the need for fuel modification under stands of pine becomes apparent. Considerable success has been reported under stands of Pinus radiata (Gilmour and Cheney, 1968; McArthur, 1966), Pinus ponderosa Laws and Pinus pinnaster Ait. (McArthur, 1966).

Area control burning has some beneficial side effects. In Australia, the following have been investigated in some detail:

(1) Eucalypt seedling regeneration.

(2) Elimination of competitive understorey and provision of easier access in the forest.

(3) Control of forest insects.

(4) Halting the ecological succession towards a less desirable forest type.

Reports indicate that fire plays an extremely important role in the regeneration of eucalypt forests throughout Australia (Cremer, 1962; Curtin, 1966; Florence, 1969; Gilbert, 1959; Harris, 1956). Field studies have shown that most species of Eucalyptus require relatively high light intensity (Florence, 1969; Gilbert, 1959) as well as mineral soil contact (Harris, 1956; Van Noort, 1960) in order to develop satisfactorily, although regeneration is also influenced by other factors. In addition to these two requirements, eucalypt regrowth is enhanced after burning following the readily available nutrients released in the plant ash and also changes that occur in microbial equilibrium in the soil which favour mineralisation(Florence, 1969). In the jarrah (*Eucalyptus marginata*) forests of Western Australia, regeneration burning is almost a routine silvicultural practice (e.g. Van Noort, 1960). Reports indicate that burning favours the initial establishment of *Eucalyptus pilularis* stands in eastern Australia, although it is not always essential to provide an exposed mineral seed bed for successful regeneration (Curtin, 1966; Florence, 1964). Generally, the unburnt and undisturbed forest floor is unsuitable for satisfactory regeneration of most eucalypts in the wet sclerophyll forests of New South Wales (Curtin, 1966). It has also been shown that eucalypts seldom invade or penetrate an unburnt rainforest except as a result of disturbance by logging or perhaps under conditions of extreme exposure (Cremer, 1960). Once satisfactory regeneration has been obtained then a period of complete protection from fire becomes necessary until the stand is old enough to resist fire (Curtin, 1966). Henry (1961) has suggested a fire-free period of 3-4 years as needed for the establishment of most eucalypt seedlings.

Weed species developing densely under forest stands can present serious silvicultural problems. In addition to suppressing regeneration, populations of undergrowth have a marked influence on soil water use, particularly in regions of prolonged dry season. In a 50 year old upland pine forest of North America, Zahner (1958) demonstrated that understorey hardwoods compete effectively with the forest crop for soil mosture. A similar finding was reported by Johnson and Kovner (1956) where mechanical removal of a dense undergrowth resulted in a 6 percent decrease in evapotranspiration. In Queensland, Henry (1961) reported that complete protection of spotted gum-iron bark associations over long periods causes gross invasion by weed species, notably Lantana camara and brush box. Studies have also indicated that in the blackbutt (Eucalyptus pilularis) region of New South Wales, hickory wattle (Acacia binervata D.C.), black wattle (Acacia irrorata), hop bush (Dodonaea triquetra Wendl.) and soldier vine (Kennedia rubicunda Vent.) are among the outstanding weed species that affect tree survival (Floyd, 1966). Control of understorey weed species has thus received some attention. In Queensland, Henry (1961) concluded from an 8 year annual and periodic prescribed burning programme that the general effect of fire on weed species appears to be a marked suppression of large individuals, thus improving visibility and access in the stand. These experimental burns gave considerable control of the major weed species, although coppice and seedling densities increased after the treatment. Control fires also have useful application, in range management, in the control of seedlings of woody species (Moore, 2969). However, a number of difficulties are encountered in the use of fire for weed control. For example, very dense thickets may be difficult to burn except under conditions which are likely to cause damage to valuable species (Henry 1961). Some members of the Myrtaceae, Proteaceae and the Casuarinaceae families possess hard woody fruits that remain attached to the plant for prolonged periods after maturing. Fire, in such cases, causes dehiscence of the fruits liberating viable seeds for colonization. For certain seeds with thick and impervious coats, notably the wattles, fire induces changes that permit imbibition of water thus promoting germination (Moore, 1969). Floyd (1966) concluded from field studies in Victoria and Tasmania that, under optimum soil and climatic conditions, Eucalyptus regnans F. Muell can suffer heavy mortality up to the age of 8 years in dense Pomaderris thickets that develop after a burn.

Many insect pests exist in the commercial forest areas of Australia. Throughout eastern Australia, the insect species Didymuria violescens of the family Phasmidae has been noted as a very effective defoliator of Eucalyptus trees (Campbell, 1959). In the coastal forests of northern New South Wales, the phasmid, Ctenomorphodes tessulata Gray is a serious pest attacking a wide range of species from the genera Eucalyptus, Syncarpia, Acacia and Casuarina (Hadlington and Hoschke, 1959). Under certain environmental conditions the Cypress pine jewel beetle, Diadoxus erythrurus White, whose larvae feed on conducting tissues of stems, is very detrimental to Callitris and Cupressus species in eastern Australia (Hadlington and Gardner, 1959). Also occurrence of massive ant populations under eucalypt stands has been related to widespread destruction of seed which affect seedling regeneration adversely (Campbell, 1959; Gilbert, 1959; Harris, 1956). Information about the possible use of fires in the control of forest insect pests is scanty. Studies by Campbell (1961) and Hadlington and Hoschke

(1959) led to the general conclusion that, properly timed, prescribed burns directly reduce insect populations. However, it appears that an alarming rate of re-invasion in the few years following the fire is the rule (e.g. Bornemissza, 1969; Hadlington and Hoschke, 1959). In Western Australia, Bornemissza (1969), while working on insects and mites, observed that recovery of insect numbers after fire is associated with the development of leaf litter on the forest floor as well as regrowth of herbs and shrubs in exposed areas. Some authors have stated that the removal of regulatory factors, such as parasites and predators, from the environment by fire partly explains the rapid rate of insect re-colonization after burns (Hadlington and Hoschke, 1959). The use of prescribed fires for forest insect control is further complicated by the fact that fires of sufficient intensity can predispose the forest trees to more severe insect attacks. For example, under favourable conditions adult insects of the Cypress pine jewel beetle, *Diadoxus erythrurus* White prefer slightly scarred bark surfaces for oviposition (Hadlington and Gardner, 1959). Again, evidence shows that colony-founding pairs of some serious tree destroying termites, notably *Porotermes adamsonii*, gain access to eucalypt host plants through decayed portions of fire scarred stem bases (Greaves *et al.*, 1965). It is thus apparent that full assessment of the role of control fires in insect pest control cannot be made until after further detailed investigation.

heat intensity, frequency as well as the presence or absence of adaptations to fire in the plant community (e.g. Ashton, 1969). Under conditions of prescribed burning, there may be no direct evidence of heat injury to most dominant trees. McArthur (1962) has investigated in detail the influence of different levels of fire intensity on wet and dry sclerophyll eucalypt communities. His work indicates that a fire intensity range of 13 to 50 B.T.U/ft./sec. is optimum for acceptable damage standards for most of these forests. Fire heat intensities above 50 B.T.U./ft./sec. may be too severe for some of the forest types.

Tree crowns frequently escape damage in fuel modification burns. The effects on butt degrade is not very clear and opinion varies on the extent of damage caused by prescribed fires (Henry, 1965). Various studies have shown that annual tree diameter increase is stimulated by control burning (e.g. Henry, 1961). Yet, it appears that burnt sites do not always stimulate growth and in some instances initial annual increments after control fires have been later reversed (Floyd, 1966). In a 12 year annual burning study, the annual diameter increments of Eucalyptus maculata on burnt land were significantly higher than those of control trees during the first five years. Subsequently, there was a decline in increment and total diameter increment for the 12 year period was found to be greater on the unburnt land (Queensland Forest Dept. 1964) In the jarrah (Eucalyptus marginata) forest type of Western Australia, fieldwork indicates that successive light burns have no significant effect on growth rates (Harris, 1956). A fire heat intensity of 11 B.T.U./sec./ft. had no marked effect on a pole-sized stand of Pinus pinaster during the first two years after a control fire (Forest Dept. of Western Australia, 1969). In North America, reports indicate that most prescribed burning in older stands of loblolly pine (Pinus taeda) cause no girth losses, even under frequent burning, so long as there is little or no needle scorch (Lotti, 1960). If a tree survives after its foliage is scorched by fire, however, growth losses frequently follow. A slash-disposal burning experiment under a North American Pinus taeda stand showed that height growth of trees is more sensitive to foliage scorch than is diameter growth (McCulley, 1950). A 30 percent needle scorch caused no significant loss in diameter growth to seedlings of this species three years after a control fire, while height growth was remarkably poor. Among the eucalypts, loss of annual growth increments due to crown scorch occurs more frequently in the fire-sensitive species (McArthur and Cheney, 1964). Young eucalypt regeneration up to 15 feet high may be severely affected by prescribed fires. During the first year of growth, seedlings of jarrah (Eucalyptus marginata) are commonly not fire-resistant (Harris, 1956). These seedlings are thus killed by even the lightest fire. With the development of lignotubers, however, resistance to fire is built up by the age of about three. Seedlings four years of age and older can readily recover from most light fires. Similarly, most seedlings of pine in their cotyledon stage and during their first two years of growth, are easily killed by light fires (Langdon, 1971).

Like tree seedlings, herbs and shrubs are liable to destruction by all forms of fire due to their low stature and small stems (Ahlgren and Ahlgren, 1960; McArthur, 1969). However, some fire-adapted species may coppice freely after fires. For example, in the high rainfall areas of Victoria, the ground species Atherosperma moschatum is fire prone and can be eliminated by fires whereas Nothofagus cunninghamii in the same community coppices readily after burns (Ashton, 1969).

2.4.2 Effects on soils

Fire creates a complex of changes in forest soils through physical, chemical and biological means (Davis, 1959). These changes in soils may cause a whole sequence of effects. The various effects are highly interrelated with each other and with the total site effects induced by the fire. For descriptive purposes, the effects of control burning on forest soils, although inseparably interrelated, are discussed below in their physical, chemical and biological aspects.

Physical effects :

Soil heating - The heating of the surface soil layers is an immediate and direct result of all forest fires. The mineral soil will be heated to a greater or lesser extent depending on the type of fire (Humphreys, 1966). The influence of heat on large volumes of soil is important mostly in fires of considerable intensity and duration. The high percentage of moisture in the mineral top soil and duff layer, which is part of the prescriptions for control burning, helps to retard the conduction of heat down the soil profile (Beadle, 1940; McArthur, 1969). It has been remarked that greater heat energy is required to raise the temperature of moist soil due to the extremely high specific heat of water (Kohnke, 1968). In area control burning, the mineral soil is little exposed to prolonged high temperatures, especially where the forest fuel is relatively fine thus ensuring rapid combustion (Hatch, 1959; Scotter, 1970). Among the early forest fire temperature studies is the work of Heyward (1938) conducted in a diversity of naturally occurring fuel types of North American longleaf pine forests. In this study, temperatures over 200°F (93°C.) were infrequent at a soil depth of $\frac{1}{8}$ to $\frac{1}{4}$ inch below the mineral soil surface. The majority of the temperature recordings ranged between 150°F (66°C.) and 175°F (79°C.). These temperatures generally persisted for 2 to 4 minutes only, after which they declined rapidly. In the same study, soil temperatures at the $\frac{1}{2}$ inch depths were much lower. Only slight increases in temperature were recorded at a depth of 1 inch from the mineral soil surface. Also Beadle (1940), while studying forest fires in the central coastline of New South Wales, recorded soil surface temperatures ranging from 81°C. to 213°C. At a depth of 1 inch from the mineral soil surface temperature hardly exceeded 67°C. On the other hand, Cromer (1970), while burning thick piles of eucalypt logs, recorded soil temperatures above 200°C. within the top $1\frac{1}{2}$ inches of the mineral soil. In the $1\frac{1}{2}$ to 3 inch layer, temperatures ranged between 100°C. and 200°C., while 50°C. to 100°C. were recorded in the 3 to 12 inch layer.

Generally, soil surface temperatures continue to be relatively higher for some period following a burn (Daubenmire, 1968; Lutz, 1956). Fire apparently affects post-burn surface soil temperatures indirectly through the removal of vegetation and litter that had previously intercepted much of the direct heating by sun rays (Scotter, 1963). It is also believed that increased light absorption by the blackened soil surface due to deposits of charred organic material and charcoal fragments partly explains the higher post-burn soil temperatures (Lutz, 1956). Under mature jack pine and black spruce forests in North America, soil temperatures on recently burnt land averaged 10.5^{o}F higher at 1 inch depth, and 9.7^{o}F. higher at 3 inch depth, compared with the temperatures in the soils of adjacent unburnt land (Scotter, 1963). These difference in temperature declined with increasing time after the burning treatment.

<u>Effects on mineral soil fractions</u> - Temperatures associated with light fires are often not high enough to cause significant changes in the properties of mineral soil particles (e.g. Ralston, 1971). The heat from more intense fires can, however, cause marked changes in the structure of soil clays as some of the outstanding properties of soil colloids are probably related to the presence of water of hydration. Thus, heating a soil sample to excessively high temperatures can destroy its colloidal properties (Puri and Asghar, 1940). Evidence by Kohnke (1968) shows that temperatures between 150^{o}C. and 250^{o}C. can drive off water that is

strongly absorbed between adjacent micelles of montmorillonite clays. At a temperature of 550°C., this group of clays as well as the kaolinites lose hydroxyl ions that form part of the crystal structure of clay minerals. Loss of gums and fine humic materials binding soil aggregates together is also apparent at this temperature. Ralston (1971) remarked that loss of structural water may alter the shrinking and swelling properties of montmorillonite clays to the extent that heat-treated clay aggregates may have soil moisture properties similar to those of sand. Again, Puri and Asghar (1940), while working with black cotton soils of 56 percent clay content, demonstrated that above the temperature of 400°C., the soil loses its plasticity and has properties similar to those of coarse silt or sand.

Effects on soil porosity and infiltration rate - Alterations in total porosity and infiltration rate of soil mostly depend on the intensity of fire and the amount of forest floor that remains after burning. Increases in soil macro-porosity and infiltration rate are reported after prolonged soil heating (Scott and Burgy, 1956). In a soil heating experiment with soils derived from shale, these workers found that temperatures of 100°C. and 300°C., maintained for 85 minutes and 30 minutes respectively, significantly increase infiltration rate. In the same experiment, however, data for soil samples derived from basic igneous rock failed to indicate similar results. Other studies have shown reduced porosity and infiltration rate where the mineral soil surface is completely stripped of cover (Stone, 1971; Tarrant, 1956 b). A severe slash burning experiment in a North American ponderosa pine forest demonstrated that the reduced porosity and infiltration rate are greatest in the upper 2 inches of the mineral soil (Fuller et al., 1955). It was suspected that the beating action of raindrops on the exposed soil surface after fire partly explains these effects. Frequently, when the surface organic soil horizons are not completely consumed by fire, changes in porosity and infiltration rate are too small to be detected. Thus, for coastal plain forest soils in North America, Metz et al.,(1961) reported unchanged pore space and infiltration rate after ten years of annual burning. Under a radiata pine stand in eastern Australia, a control fire of 18 B.T.U./sec./ft. heat intensity had no significant effect on infiltration rate of the soil (Gilmour and Cheney, 1968).

Effect on water holding capacity of soil - It is generally agreed that soil organic matter improves the water holding capacity of soils (Kohnke, 1968; Neal et al., 1965). Hence it becomes evident that the effect of burning on the water holding capacity of soil is largely influenced by the amount of organic matter consumed by the fire. In a slash burning study in North America, Austin and Baisinger (1955) reported a 33.7 percent decrease in moistur holding capacity of the soil immediately after the burning treatment. Neal et al., (1965), while studying soil physical, chemical and microbiological changes associated with slash burns, noted that the water holding capacity of burnt land was lower during the first one year after the burning. The decline in moisture holding capacity was related to increasing heat intensity. A single fire of relatively low intensity had no marked influence on the absorptive and retentive capacities of the soil for water (Beadle, 1940).

Effect on surface run-off and erosion - The soil surface laid bare by burning is subject to water run-off and soil erosion by heavy rains or strong winds. Run-off and erosion are generally associated with severe fires (Fuller et al., 1955). The extent of surface run-off after burns is closely related to topography and the rate of vegetal recovery (Daubenmire, 1968). Generally, the steeper the slope and the longer the interval between burning and vegetal re-establishment, the greater the likelihood of run-off. It is also known that run-off and soil erosion characteristics of hilly areas are related to the ability of the soil to absorb water (Scott and Burgy, 1956). Field studies indicate that prescribed fires could cause little or no soil loss (e.g. Gilmour and Cheney, 1968) although soil loss could be very substantial after fires of very high intensity (Sampson, 1944).

Chemical effects of fire:

The effect of burning on soil chemical properties stems largely from the release of minerals in plant ash as well as changes in microclimatic conditions following fires (Davis, 1959). During the combustion of forest fuels much of the nitrogen and sulphur are volatilised and lost in smoke (Daubenmire, 1968; Humphreys, 1969). Allen (1964) has pointed out that these losses could be heavy. Under a loblolly pine stand, loss of nitrogen from litter and green needles averaged 62 percent after a prescribed fire (De Bell and Ralston, 1970). Although nitrogen losses by burning are well substantiated, relatively little is known of the chemical form in which this element escapes during the process of combustion (De Bell and Ralston, 1970). Nye and Greenland (1965) are of the opinion that nitrogen is lost to the atmosphere as ammonia, oxides of nitrogen and gaseous nitrogen. Despite this initial post-burn loss of nitrogen, it is widely believed that total nitrogen content is relatively higher on burnt land. Tarrant (1956 c) has noted that available nitrogen is generally increased after light fires. Studies by Humphreys (1966) showed that there is an apparent gain in total nitrogen content of soils heated up to 200°C. Above this temperature, a sharp decline follows until a very small amount of nitrogen remains at 500°C. In the same study, the ammonium nitrogen content of soil more than doubled at a temperature of 150°C. and continued to increase until a maximum value, which was about seven times the amount in the unheated soil, was reached at a temperature range of 250°C. and 300°C. Above 300°C. ammonium nitrogen showed a decline, reaching very low levels at 500°C. Also Neal et al., (1965), after burning Douglas fire slash, reported significant increases in ammonium nitrogen content of the soil. In this study the effect persisted for at least six months before a decline. Nitrate nitrogen was also found to be slightly higher (although not statistically significant) on burnt land.

It has been reported that total phosphorus content of soil is generally insensitive to light heating. Thus, Humphreys (1969), in a burning experiment, found that soil heating within the temperature range of 100^{o}C. and 600^{o}C. had no effect on total phosphorus content. In the same study, while organic phosphorus declined to zero at a temperature of 400^{o}C., aluminium and iron-bound phosphorus contents showed increases. Aluminium-bound phosphorus increased more rapidly than iron-bound phosphorus and the former was the major fraction between 100^{o}C. and 400^{o}C. Above 400^{o}C., the iron-bound phosphorus became the more abundant. In the study, calcium-bound phosphorus also increased with temperature, reaching twice its original content at 300^{o}C. Presumably, the increasing amounts of phosphorus bound to aluminium, iron and calcium were derived from the organic-phosphorus destroyed by ignition. It follows that very high soil temperatures, generally uncommon in most control burns, will enhance phosphorus availability.

Most studies show that available cations in soils are increased after burning (Stone, 1971; Scotter, 1963; Tarrant, 1956 c). Increases in exchangeable potassium, magnesium and sodium are particularly favoured by severe fires (Tarrant, 1956 c). In a land clearing and burning experiment, Nye and Greenland (1965) reported remarkable increases in exchangeable cations. The same authors noted that the amount of nutrients, notably calcium, released on savanna woodlands after fires are often much less than those on forest land. In a laboratory experiment, where samples of treated vegetation were ignited at various temperatures, Allen (1964) observed that most of the calcium and magnesium as well as all the potassium were retained in the plant material at a temperature of 500°C. At 900°C., the quantities of calcium and potassium were reduced.

The high conentrations of cations after burning are subject to losses through drainage and surface run-off since the mineral nutrients, particularly potassium, are readily soluble in water (Allen, 1964; Wells, 1971). The rates of nutrient losses by leaching depend largely on the extent of soil compactness. Humphreys (1969) remarked that under favourable topographical conditions, the cations released on heavy-textured soils after fires could be retained in the cation exchange complex for a few years after the fire. Immediate leaching losses are common only in siliceous sandy soils. A sandy soil developed over sandstone lost much of its potassium and other elements through leaching, while peat and clay soils retained substantial amounts following burning (Allen, 1964).

Corresponding to the post-fire increase in exchangeable cations, there is often a pH rise in the upper horizons of the soil (Daubenmire, 1968; Jorgensen and Wells, 1971; Nye and Greenland, 1965). Reduced soil acidity after fires probably results, in part, from the destruction of unincorporated organic material on the forest floor (Scotter, 1963). The importance of reduced acidity after burns was stressed for extremely acid soils in the tropics (Nye and Greenland, 1965). Reduced soil acidity are frequently related to more intense fires (Tarrant, 1956 c). Most fires of relatively low intensity show little or no pH increase in the soil (Hatch, 1959; Vlamis and Biswell, 1955). Humphreys (1966) examined soil nutrient changes associated with forest fires of various heat intensitites. In this study, there was little or no pH change in soils heated to 200^{o}C. Above this temperature samples showed marked pH increases, with the 400^{o}C. and 500^{o}C. samples showing a complete loss of acidic properties (i.e. pH values of approximately 7.2 and 7.6 respectively).

The "ashbed" effect - The significance of burning cleared forest debris prior to tree planting has received considerable attention (Applequist, 1960; Cromer, 1970; Loneragan and Loneragan, 1964; Pryor, 1963). When the debris of a cleared forest is heaped into windrows and burned, the residual plant ash forms ashbeds. It is generally agreed that tree seedlings planted in ashbeds have remarkable initial and perhaps long-lasting growth stimulus. Tree response to the ashbed effect is often greater on relatively poor soils (Pryor, 1963). A variety of forest trees, including the eucalypts, the wattles and the pines are known to respond to the ashbed treatment (Cromer, 1970). There are many suggestions as to precise reasons for the ashbed effect. Most reports indicate that the heat effect is of more importance than the ash nutrients in the production of the ashbed effect (Cromer, 1967; Loneragan and Loneragan, 1964). According to some workers, mild pre-heating of soil could produce a growth stimulus comparable to that of heavy fertilizer application (Loneragan and Loneragan 1964). It has been suggested that the elimination of competitive perennial shrubs with underground reproductive organs partly explains the ashbed effect (Pryor, 1963). Renbuss (1967) attributed the ashbed effect partly to the destruction of Actinomycetes by the intense heating of the soil. These soil organisms are known to produce certain antibiotics, several of which inhibit seedling germination and root growth (Brian, 1957). Cromer (1970) related the response largely to stimulated root growth due to the suppressed activities of competing soil organisms and plant pathogens. Another group of workers are of the opinion that the increased phosphorus availability associated with excessive soil heating mostly explains the ashbed effect (e.g. Attiwill, 1962; Humphreys and Lambert, 1965). It was reported for Pinus radiata that topsoil material transported into windrow areas during the heaping operation contributed in part to the increase in early height growth of the seedlings (Cromer, 1970). It is probable, however, that excessive removal of topsoil from areas between windrows causes a transformation of soil properties. This may be detrimental to soil fertility due to the destruction of soil aggregates and the weathering of soil structure in the non-ashbed areas.

Evidence by Hatch (1964) in Western Australia demonstrated the outstanding long-term effect of the ashbed treatment. He reported that a stand of 28 year old Eucalyptus diversicolor on an ashbed site attained a mean height of 115 feet and a girth at breast height of 53 inches. These values compared with 50 feet height and 14 inches girth on control plots. Generally, in south-western West Australia, the growth of young seedlings of Eucalyptus *diversicolor* in non-ashbed areas is so poor that deliberate creation of ashbeds has become part of the forest regeneration practice (Loneragan and Loneragan, 1964). Nine years after planting in ashbeds, a stand of *Pinus radiata* showed 1.2 to 1.4 times the height, and over 2 times the volume, of trees compared to non-ashbed areas (Humphreys and Lambert, 1965). In a similar study, Applequist (1960) reported highly significant differences in height growth of seedlings of *Pinus taeda* between burned and unburned plots two and three years after the burning treatment.

Maximum temperatures reached in the soil during ashbed treatments are often related to fuel quantity. A burning windrow of eucalypt logs gave a maximum temperature of 330°C. one inch below the soil surface and 56°C. at a depth of 12 inches (Cromer and Vines, 1966). In a similar study, temperatures remained above 212°F (100°C.) for 21 hours at a soil depth of about 4 inches from the surface (Roberts, 1965). Peak temperatures ranged from 1231°F (666°C.) just below the mineral soil surface to 233°F (112°C.) at a depth of $8\frac{1}{2}$ inches from the soil surface. Most windrow burns can smoulder for days, depending on weather conditions (Cromer, 1970).

Comparable to the ashbed effect is the burning phase of shifting cultivation. This traditional form of farming, common in humid tropics and monsoonal Asia, consists fundamentally of felling a forest undergrowth and small trees; burning the debris; cropping the land for a few years and abandoning the nutrient-depleted land for a new site. The former land then follows for many years to restore fertility for future re-cropping. Although this rotational "slash and burn" method of cultivation is wasteful of forest resources (Curry-Lindahl, 1972; Keay, 1971), its short-term beneficial effects on soil fertility and crop yields are remarkable.

Biological effects of burning:

The major groups of soil- or litter-inhabiting microflora are bacteria, Actinomycetes, fungi and algae. Among the soil fauna are protozoa, nematodes, annelids, arthropods and small burrowing mammals. These organisms contribute to soil fertility through their life activities, metabolic by-products or their dead remains.

The influence of soil heating on soil organisms may be related to environmental and chemical changes that follow burning (Davis, 1959). Losses of essential food and shelter for populations of some forest rodents could be catastrophic immediately after fires (Daubenmire, 1968). Organisms living near the surface of the soil are often directly affected by fires. In a control burning experiment, all insects within the litter layer of the soil were completely destroyed, while insects living in the upper 5 cm of soil suffered a mortality of 80 to 90 percent. (Bornemissza, 1969). The lowest temperature that killed insects was 55°C. This temperature was, however, insufficient to destroy insects or mites in their developmental stages.

Field studies have indicated that fires of sufficient intensity can affect soil microbial populations considerably (Miller *et al*., 1955; Nye and Greenland, 1965; Renbuss, 1967). Meiklejohn (1955) studied microbial changes in a Kenyan upland soil after clearing and burning. All three sites studied showed a drop in the population of microflora (determined by direct count) immediately after the fires. Populations were however back to pre-burn levels only 4 days after burning on one of the sites previously occupied by black wattle (*Acacia decurrens*). This site was burned 10 days after 1.32" of rain. Recovery was relatively slow on the other two sites, apparently due to dry conditions. Wright and Bollen (1961) produced similar evidence in North America after burning a logging slash of Douglas fir. In this study the microbial populations declined markedly immediately after the fire and approached original levels some 14 months after the treatment. Renbuss (1967) investigated nutrient changes associated with the ashbed effect. This worker recorded a maximum temperature of 660°C. at the soil surface. At depths of 1 inch, 2 inches and $3\frac{3}{4}$ inches, the maxima of 545°C., 365°C. and 210°C. respectively resulted in a complete kill of fungi and Actinomycetes in the top 10 inches of the soil. Only about 0.1 percent of the original bacterial population appeared to have survived the fire. A study by Neal *et al*., (1965) showed a significant increase in bacterial population six months after a slash burn. This increase was related significantly to the heat intensity of the fire; lightly-burned land showed the greatest bacterial numbers. In a scrub burning experiment, Miller *et al.*, (1955) reported an increase in bacterial numbers soon after the treatment, reaching a peak in one month. This peak corresponded with the highest ammonium nitrogen level in the soil. Increase in bacterial populations after burning are believed to be caused by a combination of factors. These factors include the stimulating effect of the increased soil temperatures (e.g. Neal *et al.*, 1965) and increased soil pH (Biswell, 1972). Furthermore, partial sterilization of soil frequently eliminates, at least temporarily, certain competing or antagonising organisms such as protozoa and nematodes, thus apparently favouring an upsurge of bacteria. Recovery rates of Actinomycetes (Neal *et al.*, 1965; Renbuss, 1967) and fungi (Jorgensen and Hodges, 1971; Renbuss, 1967) after forest fires are relatively slow. Fuller *et al.*, (1955) have noted that the ratio of bacteria to fungi increases in direct relationship with the extent of burning of the soil duff layer and organic matter.

Other effects of burning:

1. Effects on hydrology

Some workers do not favour any form of burning in mountain catchments due to the possibility of soil erosion and consequent threats of flooding and siltation (Costin, 1957). However, it appears that properly managed prescribed burning will not adversely affect either the quality or the quantity of ground or surface water (Cooper, 1971). This is particularly likely if relatively small areas are burnt at a time with burnt areas interspersed among protected tracts. According to Bower and Ferguson (1968), there is probably an advantage to understorey removal in forested catchments where moisture is deficient. In a North American hardwood watershed, the removal of a dense undergrowth by cutting decreased evapotranspiration and correspondingly increased stream flow (Johnson and Kovner, 1956). Perhaps disastrous post-fire effects are likely in brush-covered watersheds.

2. Effects on wildlife

Fire in the forest could be destructive to helpless young of ground-inhabiting forest animals. Likewise, seed and fruit crops of the current year, forming the food source of some forest animals, can be destroyed, at least temporarily, by fire (Stoddard, 1963). There are some forest animals that require dense climax vegetation particularly for shelter, and burned habitats may not be desirable (Burbidge, 1973). Other animals which have evolved in environments where fire is a factor can often persist in, and probably prefer, fire sub-climax vegetation types. Thus, populations of Western Grey kangaroos and brush wallabies in the northern jarrah (*Eucalyptus marginata*) forests of West Australia have not been affected by prescribed burning at 4 to 5 year intervals (Burbidge, 1973). Additionally, burning is known to enhance browse production by stimulating prolific sprouting from certain understorey plants. For example, dry season burning of sufficient heat intensity in some Australian dry sclerophyll forests produces in time dense undergrowth within which mammals such as rodents and wallabies can multiply beyond their original population levels (Heislers, 1973). The availability of post-fire herbage for browse is determined by the rate of vegetal recovery. Under a mixed pine-hardwood forest, two post-burn growing seasons were required before available browse production exceeded that on an adjacent unburned area (Dills, 1970). Stoddard (1963) thus points to the need for unburnt patches distributed over a wildlife land area in order to ensure alternative feeding ground for animals until herbage is restored on the burnt areas.

3. Effect on rangelands

It has been a long-standing practice in many parts of the world to burn grazing lands for pasture improvement. For instance, in parts of Great Britain, the burning of *Calluna vulgaris* heath has been in practice for many centuries towards maintaining the heathlands in their most productive forms for sheep and game animals (Kayll, 1965; Miller and Miles, 1970). It has been noted in North America that some rangelands are rendered relatively unproductive for grazing with long-term protection from fire (Lewis and Hart, 1972). Chaparral (scrub) burning in early spring is very effective in creating conditions favourable for sheep and game (Biswell, 1954). In parts of northern Australia, where the beef cattle industry is based largely on grazing of native vegetation, frequent burning of the range to provide a "green shoot" is a common practice (Smith, 1960). In tropical Africa, the fire-conditioned savanna woodlands are usually burnt by stockmen once or twice a year.

The advantages of periodic burning of pasturelands may include:

(1) Counteraction of bush encroachment;

(2) Removal of the mass of old herbage of low food value so that stock can crop the new growth easily;

(3) Increase in the quantity of forage;

(4) Improved nutrient levels in forage species;

(5) Fuel reduction, thus limiting the danger of accidental fires.

Although rational use of fire has a place in range management, most studies indicate that too frequent burning often deteriorates soil fertility. It has been remarked that gentle topography is more adaptable to the use of prescribed burning than is rough topography, due to lesser soil erosion hazard and more uniform condition of ground fuel (Hodgkins, 1958).

4. Effects on outdoor recreation

Outdoor recreational areas, such as National Parks and nature reserves, are often established with the aim of providing areas in which examples of the natural environment are preserved to be enjoyed by visitors (Wilhelm, 1972). Much controversy exists about the use of controlled fire in recreational areas. One group of authors remark that fire in the forest can hurt tourist and recreation activities since visitors are not likely to enjoy scenery that has been blackened by fire (Papenfus, 1971; U.S.D.A. For. Serv., 1964). Other workers believe that in habitats where existing plants and animals have evolved with fire as an integral part of the environment, periodic occurrence of fire is of vital importance (Klukas, 1972; Perkins, 1971). In some climates, it is well known that fire exclusion over lengthy periods results in accumulation of extreme quantities of dead fuel causing a very high degree of fire hazard. Thus, some National Park authorities strongly advocate programmes aimed at restoring fire to its natural role in the forest (McLaughlin, 1972; Schuft, 1972). This introduction of fire however involves a great deal of initial research in order to determine the way of using the fire constructively (Aust. Conservation Foundation, 1970). There are probably many reserve areas where total exclusion of burning would be highly desirable until a very compelling case for the use of fire become evident.

CHAPTER 3

MATERIALS AND METHODS

3.1 The study area

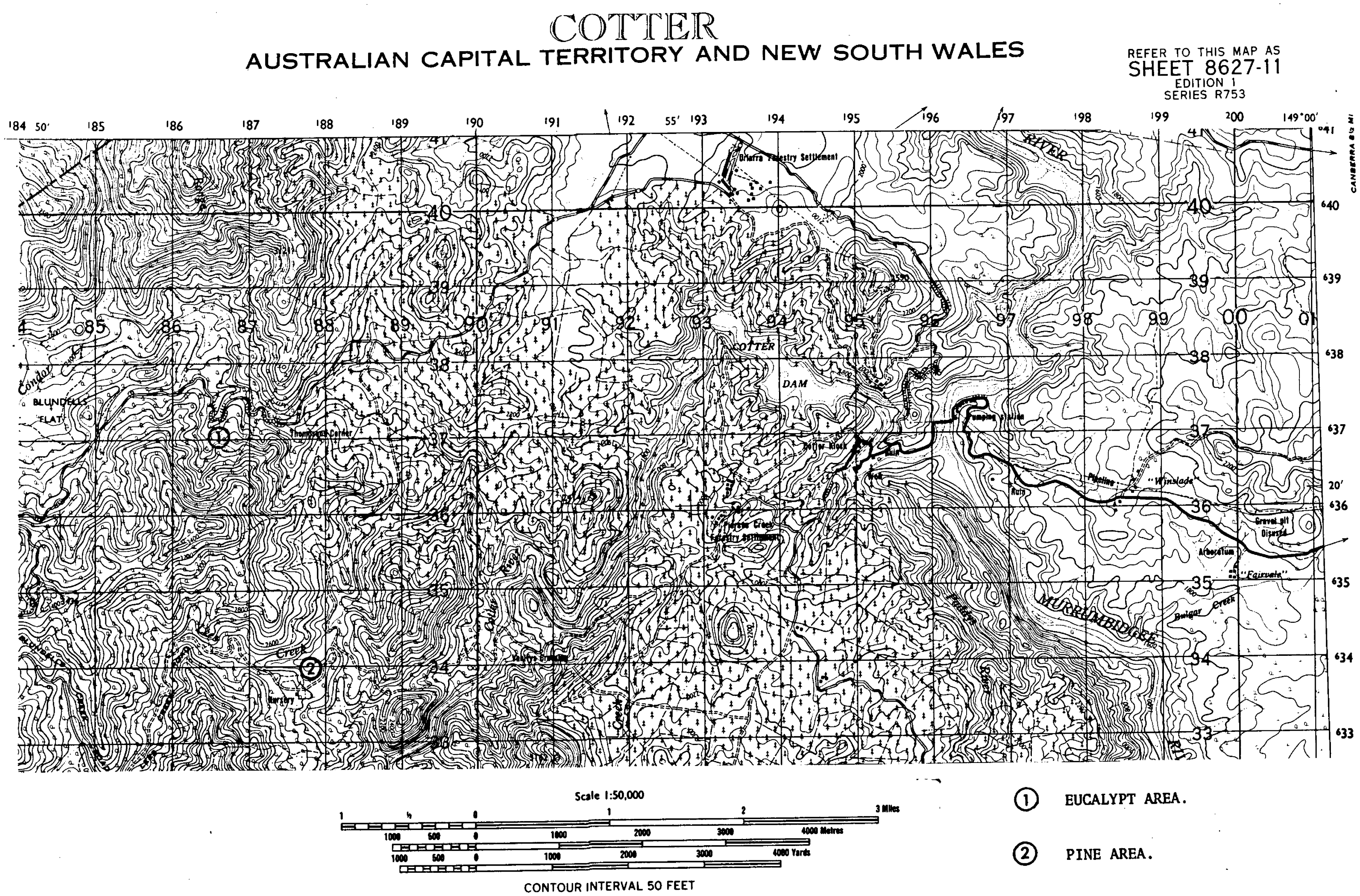
Two different vegetation types were chosen for the present study, namely: a dry sclerophyll eucalypt forest and a plantation of radiata pine. The eucalypt sampling area lies about 38 kilometres south-west of Canberra on the Brindabella Road. The radiata pine sampling area is located in Compartment 172 of Uriarra Forest about 3 kilometres to the south of the eucalypt sampling area (Fig. 1). The two sampling areas lie at elevations of approximately 2,400 feet (730 m) - pine, and 2,500 feet (760 m) - eucalypt, above sea level.

At each of the above study areas, five sample plots, each $50m^2$ were laid down on the basis of apparent homogeneity of vegetation, topography, aspect and soil type after careful examination. The five eucalypt plots were denoted by the letters A,B,C, D,E and the pine plots by F,G,H,I,J (Fig. 2). All plots were subdivided into grids of 10 m. square. At each sampling site the five plots were within 300 metres of each other.

3.2 Factors of the environment

3.2.1 Climate

The climate of the two study areas is of a continental type with warm to hot summers and severely cold winters. Winter



① EUCALYPT AREA.

② PINE AREA.

Fig. 1. - Location of study areas.

A:

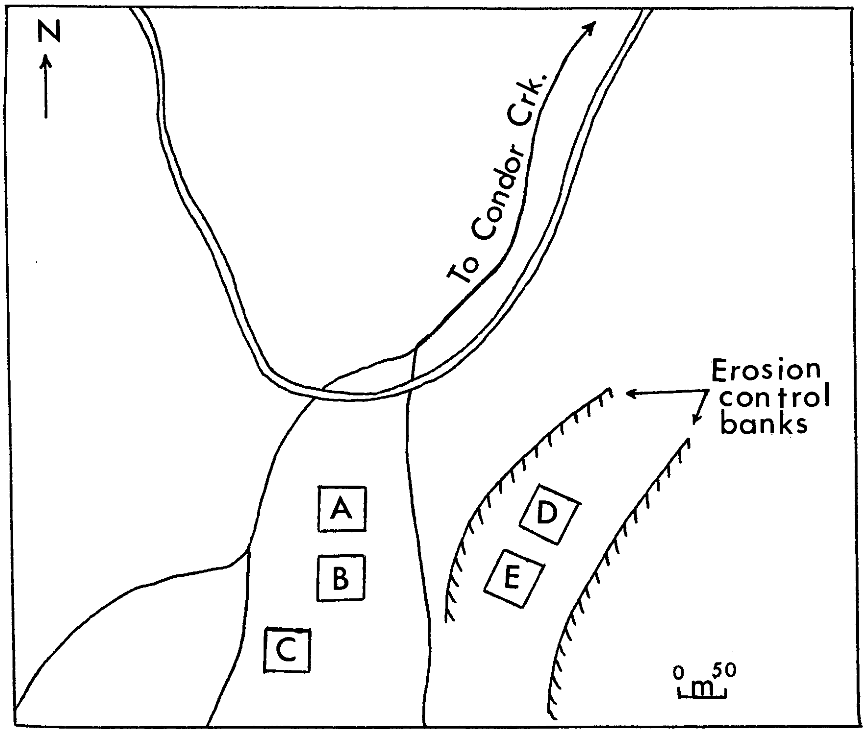
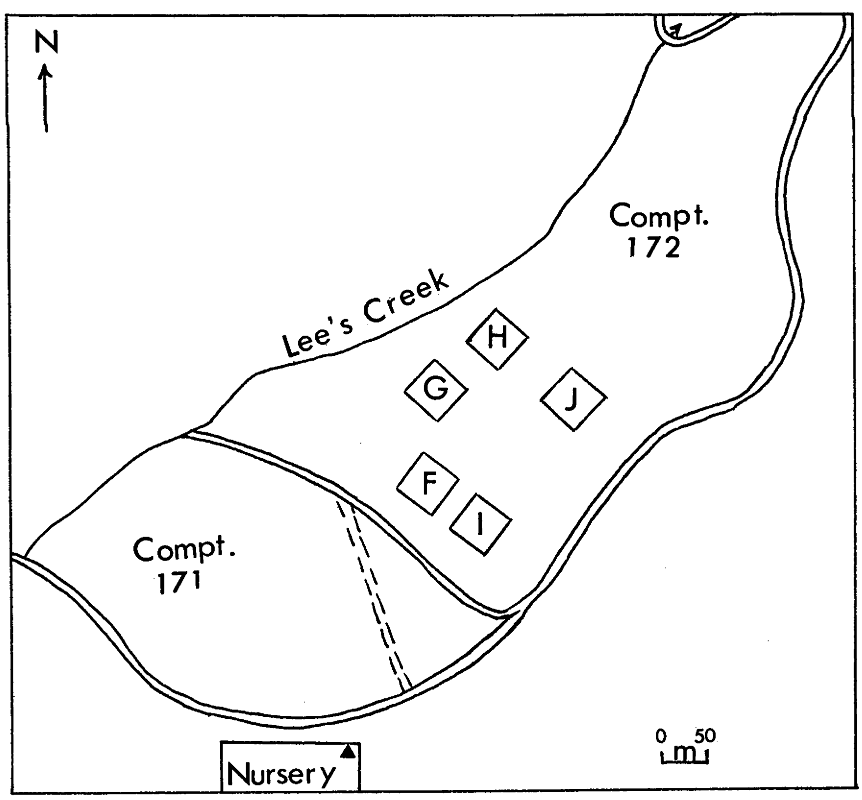


FIGURE 2: Layout of plots - (A) the Eucalypt area; (B) the Pine area

B:



▲ Meteorological station

temperatures are frequently below freezing and snowfall occurs in most winter seasons, although snow rarely lies for longer than a few hours.

The meteorological data kept at Lee's Creek Nursery site adjacent to the pine sampling area were applied for general purposes to both the pine and the eucalypt study areas since these two sites do not differ markedly in elevation.

(1) Temperature – The mean annual temperature at Lee's Creek Nursery for the period 1967 to 1972 is 11.6°C. (52.9°F). The highest monthly mean temperature of 25.3°C. (77.5°F) occurs in February and the lowest monthly mean of 0.2°C (32.4°F) occurs in July (Appendix 1).

(2) Precipitation – General aspects of rainfall distribution and intensity are presented in Appendix 1 where data on mean monthly rainfall are given for each month of the year over the period 1967 to 1972. The average annual rainfall, based on annual averages for the six year period, is 39.4 inches (1,000 mm.). Precipitation in the form of snow is recorded as equivalent rainfall. It can be seen in Appendix 1 that the rainfall is subject to considerable variation from year to year. During the period 1967 to 1972, the annual average ranged from a minimum of 20 inches (508 mm.) in 1967 to a maximum of 51.2 inches (1,300 mm.) in 1970.

(3) Wind – Although the prevailing winds are easterly, the study areas are subject to frequent severe desiccating westerly and north westerly winds. These latter wind systems may occur at any time of the year and are an important factor of the plant

environment. Occasionally, cold southerly winds blow steadily and strongly for 2 or 3 days in succession.

3.2.2 Soils

The soils of the two study areas belong to the red-yellow podzolics described in detail by Pryor and Brewer (1954). This great soil group covers most of the Australian Capital Territory below an elevation of 3,000 feet (900 m). The occurrence of the red-yellow podzolics can be correlated with geology, topography and climate but there seems to be little or no correlation with vegetation. Within this soil group, profile morphology varies considerably in regard to the depth of the A horizon, the sharpness of boundary between the A and B horizons, the amount of ferruginous concretions and the colour and structure of the B horizon.

The soils at the eucalypt site are derived from shale and have predominantly well drained profiles with diffuse to distinct horizon boundaries and humified A_1 horizons ranging in thickness from 0.5 cm. to 5.0 cm. (Appendix 5). The coarse to medium granular soil varies from sandy loam in the dark brown A_1 horizon to clay loam in the yellowish-red (5 YR 5/8) to reddish-brown (2.5 YR 5/4) B horizon. The B horizon has friable to firm consistence and contains few to many mottles of ferruginous origin. The A and B horizons extend to a depth of about 90 cm. beyond which clay pan or weathering material is reached. Stones are common over some areas. Soils have field-moist a pH range of 4.0 to 5.0.

At the pine sampling site, soil horizons show more evidence of podzolization. The dark brown organic A_1 layer, 2.0 to 4.5 cm. thick, overlies a bleached A_2 horizon which in most cases is a distinct light gray (5 YR 7/1) or almost white (5 YR 8/1) layer. The B horizon ranges in colour from pale yellow (2.5 Y 8/4) to yellowish-red (5. YR 4/6) and consists of very friable silty loam to clay loam soil with coarse to fine granular structure (Appendix 5). The B horizon contains a high proportion of mottles (chiefly ferruginous) and quartz fragments. The solum extends to a depth of about 110 cm. Rock outcrops are present on some upper slope positions. pH of the field-moist soil ranges between 5.0 and 5.5.

3.2.3 Vegetation

(a) Eucalypt area - The tree flora of the open dry sclerophyll forest is dominated by *Eucalyptus dives* Schau, *E. mannifera* Mudie sub sp. *maculosa* (R.T. Bak.) L. Johnson and *E. macrorhyncha* F. Muell. ex Benth. in that order of abundance (Appendix 2a). The average height of the dominant trees ranges between 10 and 25 metres and tree canopy cover ranges from 44.8 to 52.8 percent. Tree form of the co-dominant *Eucalyptus dives* is generally poor and some boles show evidence of past fires - the area having been burnt by wildfire in 1939 and again control-burnt as a fuel modification measure in 1956.

Table 1. Understorey species - Eucalypt plots

Species	Family
MAJOR SHRUBS:	
Leucopogon microphyllus	Epacridaceae
Monotoca scoparia	"
Brachyloma daphnoides	"
Dillwynia retorta	Papilionaceae
Daviesia mimosoides	"
Daviesia uliciformis	"
Acacia buxifolia	Mimosaceae
Hibbertia calycina	Dilleniaceae
Tetratheca ericifolia	Tremandraceae
MINOR SHRUBS:	
Acacia vomeriformis	Mimosaceae
Hovea heterophylla	Papilionaceae
Hardenbergia sp.	"
Hibbertia obtusifolia	Dilleniaceae
Lomandra longifolia	Xanthorrhoeaceae
HERBS:	
Stylidium graminifolium	Stylidiaceae
Poa caespitosa	Gramineae

Beneath the tree stratum is a relatively well developed undergrowth. 16 ground species were recorded (Table 1). Details about the condition of the undergrowth prior to burning are given in Appendices 3.1 to 3.4.

(b) Pine area - The 20 year old unthinned stand of *Pinus radiata* has a closed canopy with 82 to 86 percent cover. The trees are spaced at 8ft by 8ft (2.4 m by 2.4 m) and have a mean breast height diameter range of 21cm. to 23 cm. During site preparation prior to planting the original dry sclerophyll eucalypt forest covering this area was felled by bulldozer and chain, and broadcast-burnt.

The dense canopy of the stand allows little penetration of sunlight to the forest floor, and ground vegetation is almost absent. There are scattered occurrences of Australian meadow grass (*Poa caespitosa*), *Lomandra longifolia* and seasonally occurring low herbs mainly of the genera *Cryptostemma* and *Hydrocotyle*. Values of relative frequency, relative density and percentage of ground covered are given for these species in Appendices 3.1, 3.2 and 3.4. The eucalypt forest surrounding the pine plantation has a high diversity of ground species mostly of the genera *Melichrus*, *Acacia*, *Dillwynia*, *Hibbertia*, *Hovea*, *Lomandra* and *Poa*.

3.3 Sampling methods and sample preparation

3.3.1 The tree vegetation

Introduction - In the present study, stand composition is described quantitatively in terms of relative density, relative frequency, relative dominance, cover and importance value as defined below:

(1) "Relative density" refers to the number of individuals of a given species present per unit area. Calculation involves determining what percentage the actual number of individuals of a species is of the total number of individuals of all species in the sample plot.

Thus :

$$\text{Rel. density} = \frac{(\text{No of individuals of a sp.})}{(\text{No of individuals of all spp.})} \times 100$$

(2) "Relative frequency" implies the degree of uniformity of individuals of a species within the sample plot. Relative frequency is estimated as the percentage of the total number of sampling units per plot in which a particular species is found.

Hence :

$$\text{Rel. freq.} = \left\{\frac{\text{No of sampling units containing a sp.}}{\text{Total No of sampling units}}\right\} \times 100$$

Frequency classes of 0 to 20 percent (rare); 21 to 40 percent (occasional); 41 to 60 percent (frequent); 61 to 80 percent (abundant) and 81 to 100 percent (very abundant) were used.

(3) "Relative dominance" is indicated by stem basal area and applies only to the eucalypt area where the stand is composed of different species of trees. Relative dominance designates the important species of the stand from the viewpoint of tree size. Dominance figures for the various eucalypt species are given on sample plot basis:

$$\text{Rel. dominance} = \left(\frac{\text{Total basal area of a sp.}}{\text{Total basal area of all spp.}}\right) \times 100$$

(4) "Cover" signifies the area of ground occupied by the downward vertical projections of the aerial parts of the vegetation. The area of ground covered by a particular plant species is expressed in relation to the total ground surface. Tree canopy cover is considered separately from the cover afforded by the ground vegetation.

(5) "Species importance value" was introduced by Curtis and McIntosh (1951) as an index of the vegetational importance of a tree species within a stand. It is calculated by adding relative density, relative frequency and relative dominance values.

Sampling of trees - Tree parameters were estimated by the "point-centred quarter method" of sampling described by Cottham and Curtis (1956). Procedure: On each plot, 16 sampling points were arranged at fixed intervals of 10 metres along 4 randomised lines traversing the stand. Crossed sticks were used to define four quadrants above each sampling point. From a sampling point, the nearest tree inside each quadrant was measured for distance and diameter at breast height (d.b.h.). The diameter values were used to determine relative basal areas for the various species.

Tree canopy cover was estimated from 125 points per plot located on 5 randomly placed 25 metre transects. Canopy cover was expressed for each species separately.

Sampling of ground vegetation - Relative densities and frequencies of ground species were estimated from counts in 25 random quadrats within each plot. Quadrat dimensions were 1m x 1m.

Ground cover was determined by means of 25 metre transects each bearing 100 points. Determinations were completed for 5 randomly located transects in the eucalypt plots and six transects in the pine plots.

Above ground biomass of the ground vegetation was estimated from 15 randomised $1m^2$ quadrat positions per plot. Aerial parts of all plants rooted within the quadrat were clipped at ground level. The flora clipped for each quadrat was sorted out into species in the field and bagged. All samples were dried in an oven maintained at 80^oC. for 24 hours and weighed. Biomass was calculated for each species on plot basis (Appendix 3.3). Sampling for biomass was carried out twice, immediately before and soon after burning. This enabled estimation of the amount of live fuel consumed by the fire. Subsequent sampling was omitted as it was likely to interfere with the post-burn vegetal cover estimation.

The above plant samples were bulked, species by species and sub-sampled by quartering. The sub samples were ground to fine powder in a Christy and Norris mill to pass a 2mm. sieve and stored in plastic bottles for nutrient analyses.

3.3.2 Ground litter

Data on ground litter weights are presented in this study (Appendix 4) by permission of Dr M.T. Tanton. Sampling was by a 31.6cı quadrat with an internal area of 1/10 sq. m. 40 random samples were collected per plot at the two sites.

3.3.3 Soils

Soil profile characteristics were examined using a 3 inch soil auger. 8 auger holes were dug at random positions per plot. Each profile was carefully studied and described in terms of texture, structure, colour, consistence, stone content and degree of mottling (Appendix 5). The Munsell book of colour chips was used to describe the soil colour. Rough values of soil pH in field-moist conditions were determined for the top 10cm. of soil using Morgan's pH kit with a wide-range indicator liquid. For each auger hole, the thickness of th humified A_1 horizon and the depth of the solum to hard pan were recorde

Samples for bulk density determination were obtained by means of a steel corer measuring 10cm. by 10cm. by 15cm. With minimal soil disturbance the corer was driven into the soil by a heavy hammer until the top was level with the mineral soil surface. The corer with contents was then carefully dug out with a spade. The ends of the core were trimmed with a sharp knife and the contents were emptied into a large plastic bag. The bag was firmly tied to prevent soil moisture loss by evaporation. Samples were quickly weighed in the laboratory and transferred into labelled paper bags for oven drying for 24 hours at 80°C. They were then allowed to cool prior to weighing. Bulk density (Db) was expressed on an oven-dry basis as:

$$Db = \frac{\text{Weight of corer contents}}{\text{Internal volume of corer}}$$

Soil moisture losses after oven-drying the bulk density samples were expressed as percentages of the original weights of the corer contents.

The above bulk density samples were further used for the estimation of gravel percentage and soil particle density. The samples were passed through a 2mm. sieve. Roots and charcoal fragments were removed from the coarse material left over the sieve and the remaining gravel was collected and weighed. Percentage gravel was calculated for each soil sample relative to the total oven dry weight of the original corer contents. Particle density was determined on the fine earth material. This factor was needed in the calculation of soil porosity. The procedure is outlined in Appendix 6.

In order to study changes in soil nutrient elements at various depths of the topsoil, samples were collected from the following levels down the profile: 0 to 1 cm.; 1 to 3 cm.; 3 to 5 cm. This was achieved by means of 8 small pits, each about 20 cm.^{3}, randomly placed in each plot. Using a sharp spade and a steel ruler, the soil samples were taken in blocks from the pits.

Each block of soil was bagged and labelled to form a sample. All samples were air-dried in the laboratory and passed through a 2mm. sieve. The fine earth portions were stored temporarily for chemical analyses.

Separate soil samples were collected for pH studies. A soil auger, 4.5cm. in diameter and 12 cm. in internal length, was used. Eight soil cores per plot were randomly sampled into labelled paper bags. These were air-dried in the laboratory and sieved. The fine earth fractions were used for the analysis.

3.4 Analytical procedures

(1) Soil reaction was determined in the laboratory on a 1:2.5 soil:water suspension using a glass electrode pH meter. The soil suspension was stirred with a glass rod, stoppered and left to stand for 24 hours in a constant temperature room. The soil suspension was then well shaken and duplicate determinations made. Mean values were recorded.

(2) Total nitrogen and total phosphorus contents of soil were determined using a Technicon Auto Analyser. Air-dry samples were further dried overnight at $80^{\circ}C$. and 0.5000 g. (0.2000 g. for plant material) extracted with concentrated sulphuric acid (using potassium sulphate and selenium as catalysts) at about $250^{\circ}C$. on a hot plate. Total nitrogen and total phosphorus in the extract were determined simultaneously by the Auto Analyser by colometric methods using alkaline phenate and sodium hypochlorite for nitrogen and ammonium molybdate and ascorbic acid for phosphorus.

(3) Total amounts of potassium, calcium, magnesium, iron, zinc and manganese were determined by Atomic Absorption Spectrophotometer (Varian Techtron Model AA5). Air-dry samples were further dried overnight at $80^{o}C$. and 0.5000 g. (0.2000 g. for plant material) extracted with 7:1 perchloric acid:sulphuric acid solution at a maximum temperature of $230^{o}C$. on a hot plate, with 15 ml. concentrated nitric acid.

3.5 Experimental burning operations

The experimental burning of the plots was originally planned for October-November, 1971, but weather conditions were not satisfactory for a low intensity burn until June, 1972.

Preparation for burning - Prior to burning, fire breaks about 1m. wide were established around all plots intended for burning (i.e. eucalypt plots A, C and D and pine plots F, G and H). On the day of the burn, 40 steel bars treated with thermocolour crayon lines were randomly placed per plot on the mineral soil surface to measure fire temperatures. Details of the thermocolour crayons are given by Smith and Sparling (1966). Table 2 shows the dates and times of burning of the various plots. The burning operations were carried out by the Fire Behaviour research branch of the Forest Research Institute, Forestry and Timber Bureau.

Ignition - Just before the plots were ignited, meteorological and various site conditions were recorded (Appendix 7). Small test fires were started in areas adjacent to the plots to ensure satisfactory burning conditions. Fires were lit by mechanical flame throwers, following a rectangular grid pattern.

Table 2. Burnt plots - date and time of burning

Plot Number	Date of burning	Time of burning
A	November 26, 1972	1320 hours
C	June 15, 1972	1345 hours
D	June 15, 1972	1250 hours
F	September 28, 1972	1350 hours
G	September 28, 1972	1350 hours
H	September 28, 1972	1350 hours

Fire behaviour on eucalypt plots - Plots D and C were burnt on the same day. Most shrub species burned readily in the green state along with the dead litter, although ignition of a few species (e.g. *Daviesia mimosoides* and *D. uliciformis*) was poor. At some spots fire had difficulty in penetrating deep fuel beds. To ensure a satisfactory burn, particularly on plot D, further ignition of unburnt patches became necessary. Despite this re-spotting, burning was patchy on plot D. Flame heights were generally between 15 cm. and 30 cm. on plot D and between 15 cm. and 90 cm. on plot C. On the latter plot, the fire was faster-spreading due to the almost continuous layer of the very flammable shrub, *Hibbertia calycina*, and also greater wind flow. The bark of some *Eucalyptus dives* trees, particularly on plot C, were slightly charred but the tree canopies showed no visible leaf scorch.

Eucalypt plot A was burnt in late spring. Since burning was patchy on eucalypt plots C and D, 100 temperature measuring steel bars were randomly placed on plot A instead of 40 in order to give a better representation of surface temperatures. Plot A showed the greatest heat output and the longest duration of heat (Appendix 7). Although burning was relatively intense on this plot, with flames climbing many boles of Eucalyptus dives trees, no fire spotting occurred in the adjoining stands. Two trees of E. dives were burned down on plot A, two on plot C and one on plot D. These were apparently trees bearing deep fire scars from previous fires. Stand condition before and after burning is given for plot D in Plate 1. Progress of the fire is shown in Plate 3.

Fire behaviour on pine plots - The pine plots were burnt in early spring (Table 2). Burning proceeded in a relatively uniform manner (Plate 3) because of the continuous nature of the forest fuel. Soil surface temperatures were lower compared to the eucalypt plots (Appendix 7) and most of the lower litter layers were left unconsumed after the fire (Plate 2). Flame heights ranged between 23 cm. and 30 cm. on plot G and 30 cm. and 60 cm. on plot H. The pine trees showed no visible evidence of bark scorch. Due to the apparent homogeneity of the forest fuel, fire behaviour characteristics were not recorded for plot F but assumed to be in the range of data for plots G and H.

PLATE 1.

A. A view of eucalypt plot D prior to the burn, showing the dense undergrowth of shrubs typical of the area.

B. A post-burn view of the same plot. Note the almost complete consumption of the undergrowth by the fire.

PLATE 2.

A. A typical condition of the pine plots before the burn. Note the scarcity of ground vegetation and the continuous nature of the litter bed.

B. A post-burn condition typical of the pine site. Incomplete removal of the litter mat by fire is evident.

CHAPTER 4

RESULTS

Data analysis

A basic statistics programme developed from that of Sokal and Rohlf (1969) was applied to all sample data. The programme determined the mean, variance, standard deviation and confidence limits at 95 percent level. All statistical analyses were also given in square root transformations for the purposes of normalizing the distributions. The transformed statistics were mostly applied in graphical illustrations.

Experimental burning

Appendix 7 summarizes meteorological and fuel conditions as well as fire behaviour and fire intensity for the burnt plots at the two study sites. The fire intensity values are in terms of the rate of heat energy produced per metre of fire front. This was calculated after conversion of factors in the formula :

$$I = Hwr.$$

Thus,

I = fire intensity in K/joules per sec. per metre of fire front;

H = heat yield in k/joules per kg of fuel;

w = weight of available fuel in kg per square foot;

r = rate of forward spread in m per second.

It may be noted in Appendix 7 that the weather and fuel moisture data for eucalypt plot A provides a contrast to all other burnt eucalypt and pine plots. A comparison of the two sites indicate that burning was less intense at the eucalypt site, eucalypt plot A being an exception.

The tree vegetation

The effect of the relatively light intensity burning on tree diameter growth was apparently slight at both the eucalypt and the pine sites (Figs. 3a and 3b). Throughout the sampling period, trees of Eucalyptus dives and Pinus radiata showed an uninterrupted diameter growth rate. At the eucalypt site, the initial mean diameter at breast height (d.b.h.) for E. dives for all plots was 32.1 cm. This value increased slightly but steadily to 32.9 cm. at the end of the 18 month period (Appendix 9). At the pine site, the initial mean d.b.h. of 21.8 cm. for all plots increased slightly to 22.5 cm. at last sampling.

Similar to tree diameter growth, the canopy development showed only slight changes over the period of the experiment at both the eucalypt and the pine sites (Appendix 10). Figures 4a and 4b show trends in canopy cover at the two sites. For the duration of the experiment, canopy cover fluctuated between 44 and 55 percent for all plots at the eucalypt site, and 81 and 88 percent for plots at the pine site.

The undergrowth

The greatest effect of the experimental fire appeared to have been on the ground flora. Relative to control plots on both

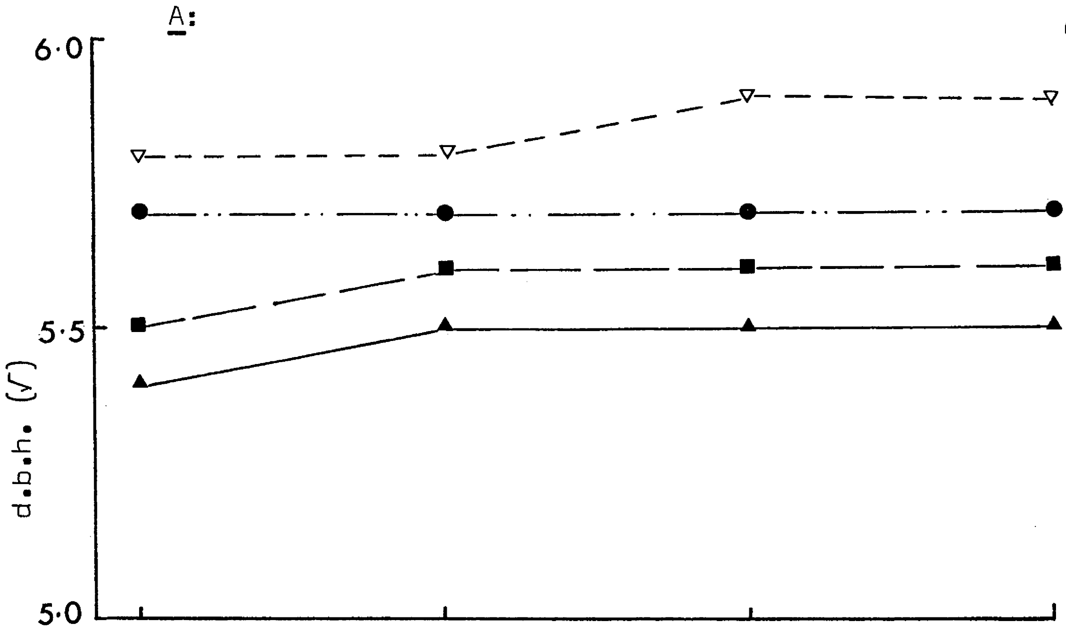
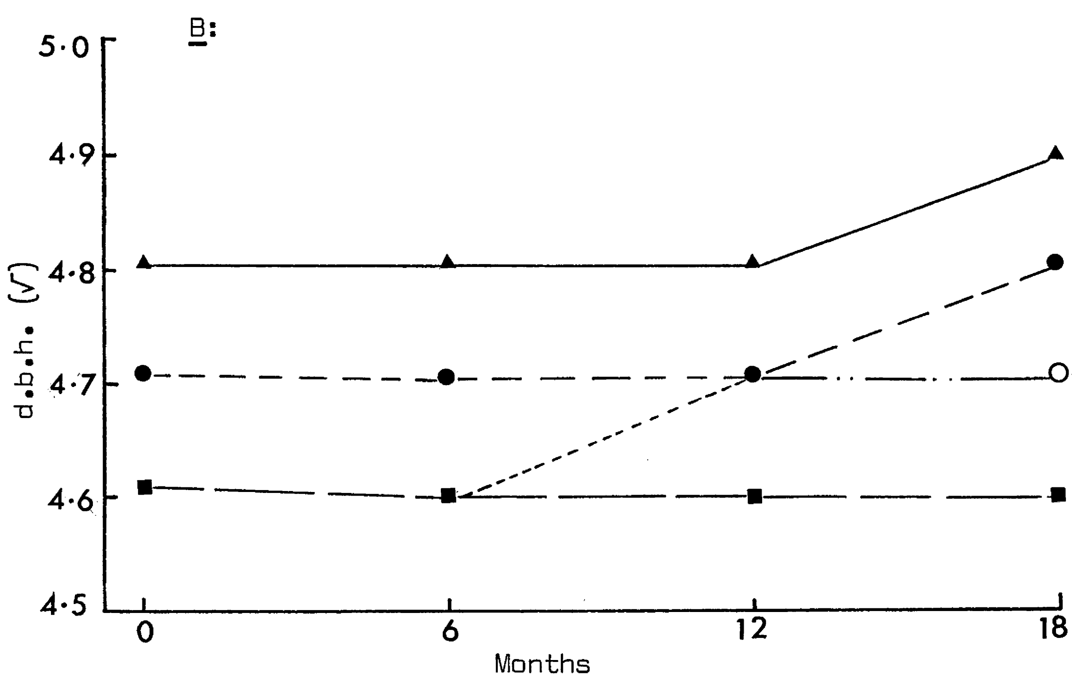


FIGURE 3: Trends in tree diameter growth during the first 12 months after a prescribed burn* – (A) Eucalypt Stand; (B) Pine stand.

Plot A
" B
" C
" D
" E



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H
Controls – B,E; I,J

Plot F
" G
" H
" I
" J

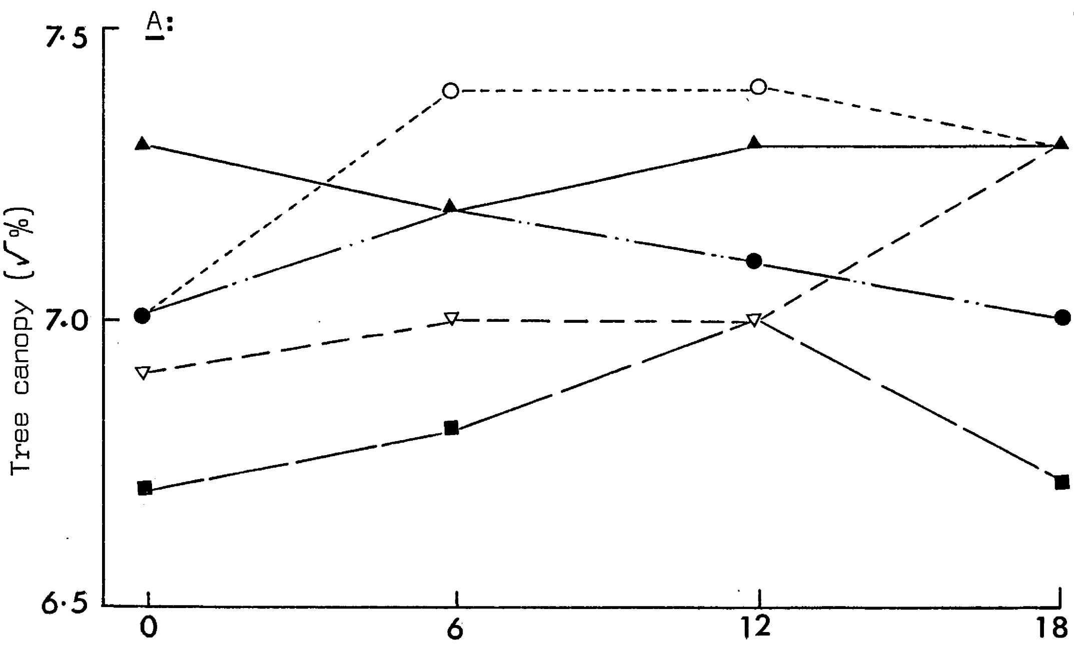
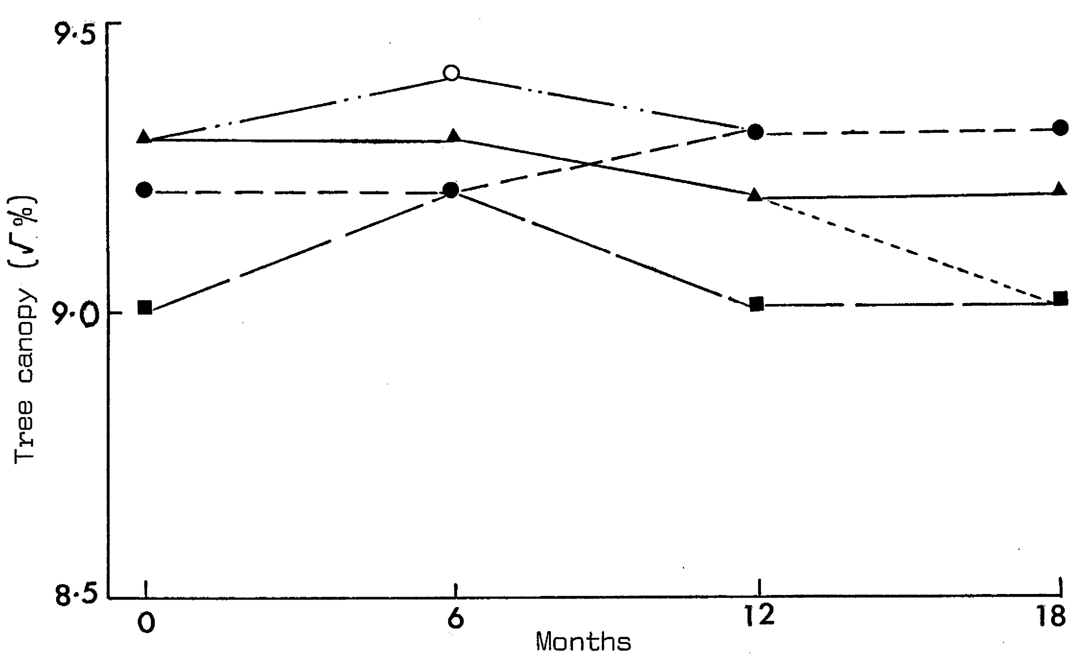


FIGURE 4: Patterns of tree canopy development 12 months after prescribed burning* –
(A) Eucalypt Stand;
(B) Pine stand



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H

the eucalypt and the pine areas, ground cover was significantly reduced immediately after burning (Figs. 5a and 5b). It follows that the proportion of bare ground was significantly increased on all burnt plots immediately after burning. Eucalypt plot A was reduced in ground cover from 44.4 percent to 6.0 percent, while plots C and D dropped from 72.2 and 59.8 percent to 15.2 and 19.4 percent respectively in ground cover immediately after burning (Appendix 11). At the pine site, the sparse cover of vegetation was completely removed by the fire. This elimination of ground vegetation was the result of the uniform spread of the fire (Plate 3).

Post-fire succession of the ground species was very remarkable at the two sites. Table 3 presents re-establishment trends at the eucalypt site. The table gives a typical pattern of recovery of ground species for all burnt plots since post-fire succession between plots were closely comparable. The observations indicate that re-establishment of almost all the pre-burn ground species occurred during the first six months after the fire. Most species showed a consistent trend of recovery, increasing in most cases to their pre-burn levels of relative frequency one year after the burning treatment (Tables 4a and 4b). Figures 6a – 6h give relative frequency trends for the most widespread ground species at the eucalypt site. It may be noted that the grass species Stylidium graminifolium and Poa caespitosa as well as the suckering low shrub Tetratheca ericifolia were particularly favoured by the burning. It is also evident that the shrub species Leucopogon microphyllus and Dillwynia retorta which were major pre-burn components of the

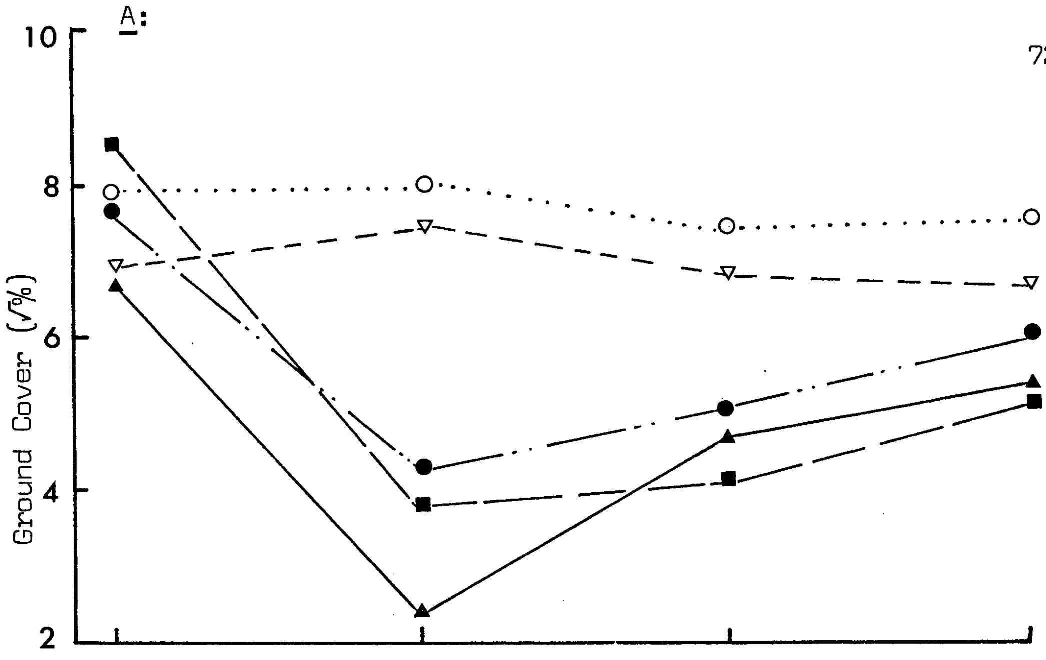
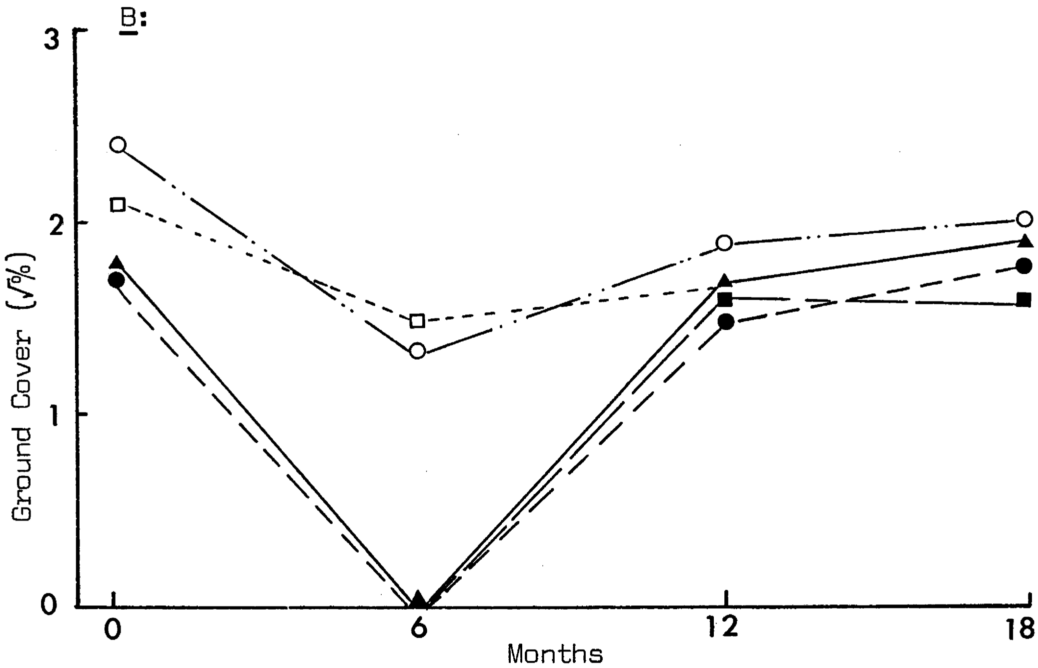


FIGURE 5: Development of ground vegetation cover after a prescribed burn* – (A) Eucalypt stand; (B) Pine stand

Plot A
" B
" C
" D
" E



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H
Controls – B,E; I,J

Plot F
" G
" H
" I
" J

TABLE 3: Re-establishment trends of the ground species - eucalypt plots

Period after burning	Observation
3 months	(i) The grass species *Poa caespitosa* and *Stylidium graminifolium* sprout from their burnt root stocks. (ii) *Lomandra longifolia* begins to emerge from burnt shoot bases. (iii) *Tetratheca ericifolia* regenerates abundantly from suckers. (iv) Fresh shoots develop from the bases of burnt eucalypt seedlings
4 months	(i) *Hovea heterophylla* emerges. It is difficult to judge whether this growth is from seed or an underground organ. (ii) New shoots of *Hibbertia calycina* and *H. obtusifolia* sprout from the bases of burnt shoots. (iii) *Daviesia minosoides* shows recovery from bases of scorched shoots. (iv) *Monotoca scoparia* regenerates from burnt shoot bases.
6 months	(i) *Daviesia uliciformis* sprouts from burnt shoot bases. (ii) *Acacia buxifolia* regenerates from burnt shoot bases.
18 months	(i) *Dillwynia retorta* shows signs of regrowth from burnt root bases. This is noted only on plot D which received a relatively light burn. (ii) One unidentified shrub species, of relatively rare occurrence, emerges on plots A and C.

TABLE 4a: Trends in relative frequency of ground species – burnt and unburnt eucalypt plots*

SPECIES	Pre-burn					Immediately after burn					6 months after burn					12 months after burn				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Leucopogon microphyllus	60	40	32	12	32	4	28	12	8	36	0	24	0	0	28	0	16	0	0	20
Monotoca scoparia	24	24	8	24	48	8	32	0	24	40	16	12	8	40	32	28	24	16	40	36
Dillwynia retorta	36	32	84	4	16	0	36	16	0	8	0	36	0	0	4	0	32	0	4	12
Daviesia mimosoides	44	8	4	36	36	12	20	8	20	32	8	36	12	12	36	28	44	12	32	44
Daviesia uliciformis	0	20	4	40	20	0	0	0	28	44	0	16	0	32	48	0	0	0	44	52
Acacia buxifolia	0	12	0	48	72	0	0	0	20	56	0	12	8	48	52	0	8	8	52	48
Acacia vomeriformis	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachyloma daphnoides	32	36	0	44	16	8	48	8	20	24	16	32	12	16	24	28	20	16	28	36
Hibbertia calycina	0	16	88	68	36	0	12	32	24	40	0	8	72	44	32	0	12	80	52	28
Hibbertia obtusifolia	0	48	28	56	44	4	36	16	24	52	24	52	52	64	48	28	44	48	60	40
Tetratheca ericifolia	68	80	56	48	56	8	76	24	40	64	80	76	84	72	76	92	60	68	80	64
Hovea heterophylla	0	4	4	8	0	0	32	0	8	8	36	24	20	16	36	48	16	12	8	16
Hardenbergia sp.	4	8	0	0	4	0	0	0	0	0	4	0	0	0	0	0	0	0	4	0
Lomandra longifolia	12	8	0	24	32	0	12	0	8	36	8	16	12	20	24	24	16	16	20	32
Stylidium graminifolium	16	64	12	12	12	4	48	4	24	20	40	40	8	40	32	52	32	16	40	32
Poa caespitosa	36	20	4	28	8	0	12	0	16	16	20	24	16	36	24	44	16	16	40	36
Eucalypt seedlings	48	36	52	40	32	12	48	8	24	40	40	36	36	28	36	44	40	40	32	44

* Burnt plots – A, C, D
Unburnt plots – B, E.

TABLE 4b: Trends in relative frequency of ground species – burnt and unburnt pine plots*

SPECIES	Pre-burn					Immediately after burn					6 Months after burn					12 Months after burn				
	F	G	H	I	J	F	G	H	I	J	F	G	H	I	J	F	G	H	I	J
Lomandra longifolia	3	0	7	10	7	0	0	0	7	13	3	0	0	0	7	3	0	3	0	0
Poa caespitosa	17	13	17	20	20	0	0	0	33	43	10	20	40	53	37	17	37	20	50	43
Hydrocotyle sp.	30	27	43	33	17	0	0	0	30	27	43	60	53	47	23	50	77	63	60	50
Cryptostemma sp.	17	10	7	20	13	0	0	0	20	17	10	17	27	30	10	7	20	17	37	17
Hardenbergia sp.	0	3	0	0	3	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Pine seedlings	7	7	3	0	7	0	0	0	23	27	50	43	37	77	63	43	50	27	60	53

* Burnt plots – F, G, H
Unburnt plots – I, J.

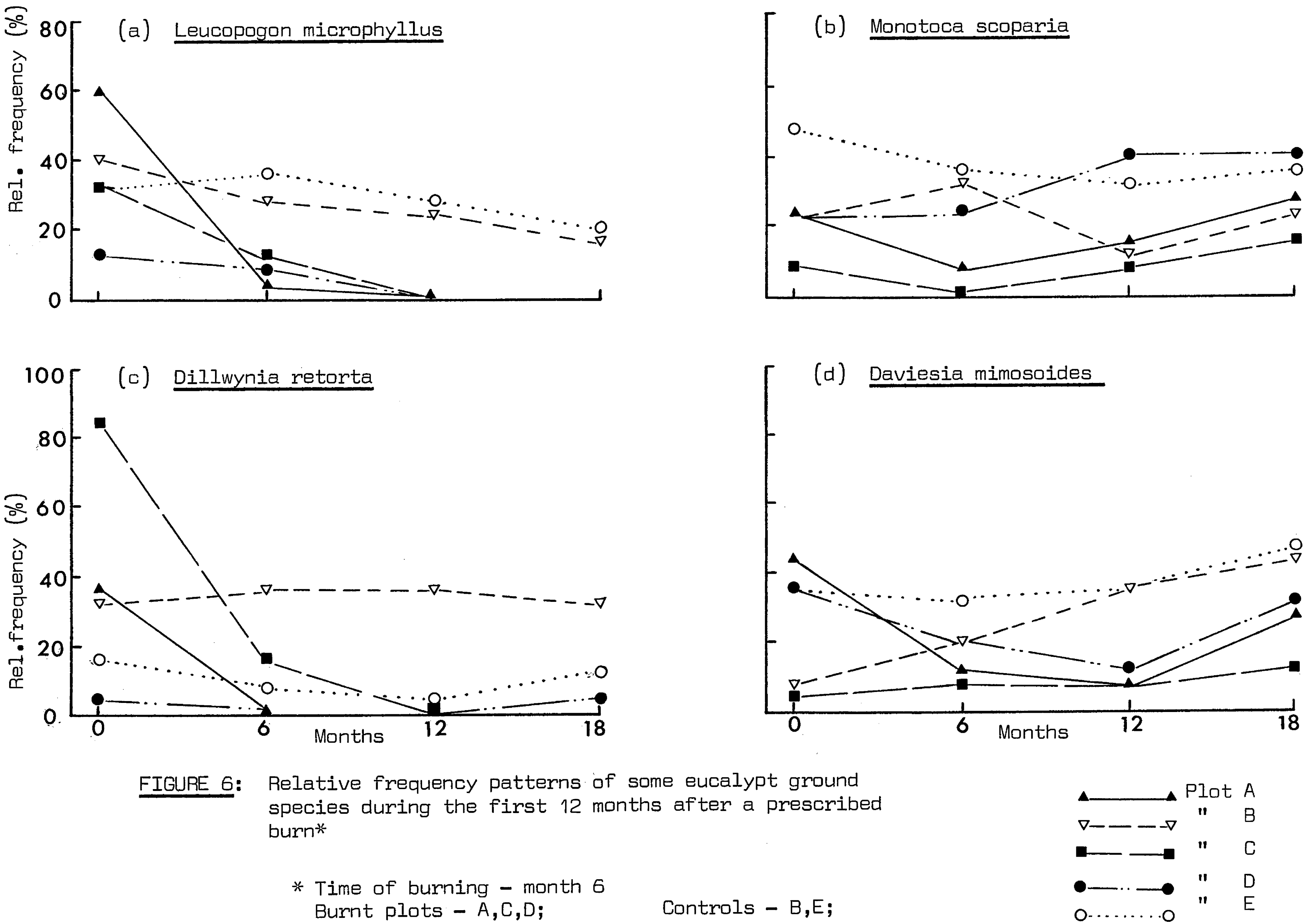


FIGURE 6: Relative frequency patterns of some eucalypt ground species during the first 12 months after a prescribed burn*

* Time of burning – month 6
Burnt plots – A,C,D; Controls – B,E;

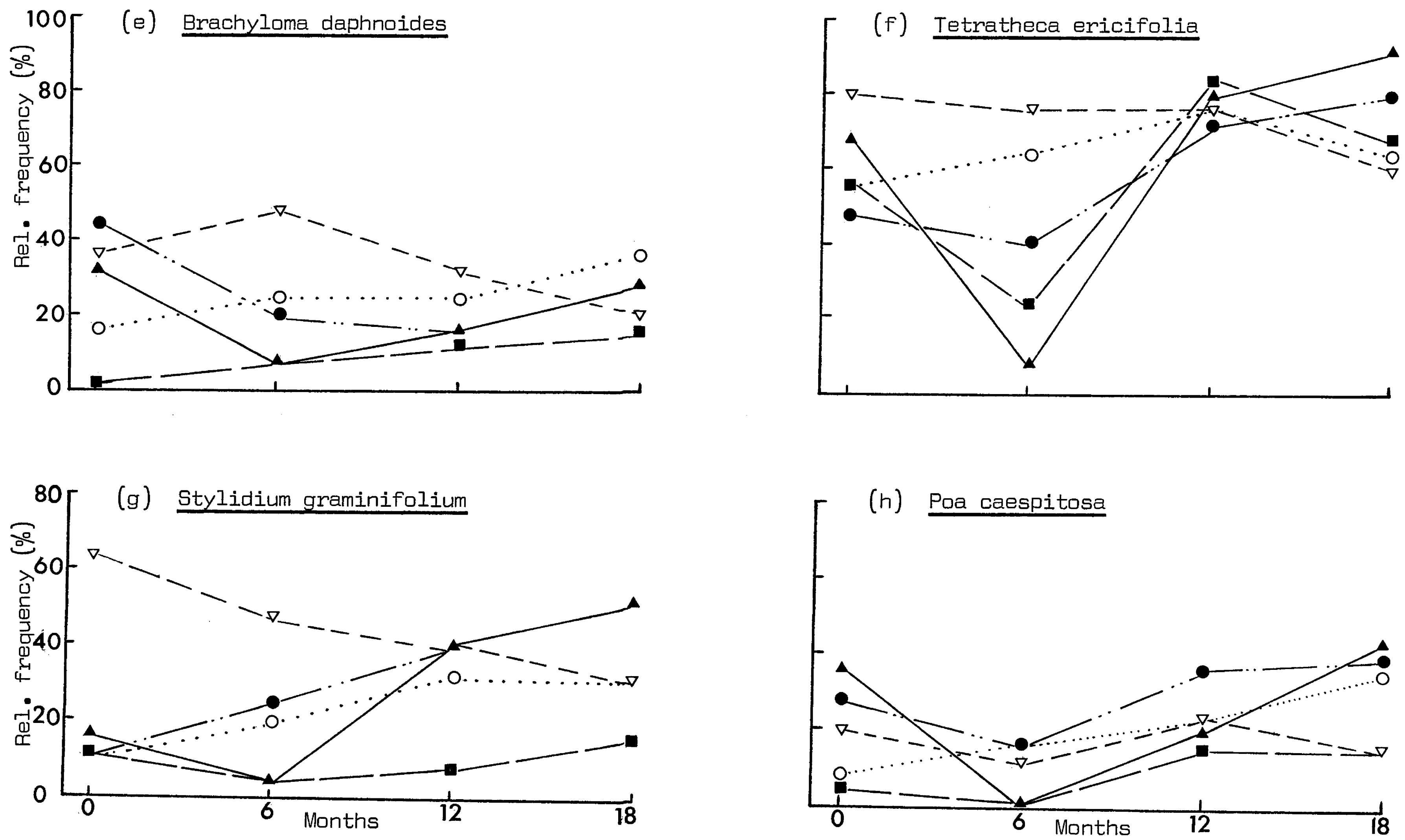


FIGURE 6: (Cont'd) Relative frequency patterns of some eucalypt ground species during the first 12 months after a prescribed burn*

* Time of burning – month 6
Burnt plots – A,C,D; Controls – B,E;

ground flora are sensitive to fire since these species showed little recovery during the first year after the burn. Despite the rapid re-sprouting of most of the ground species after the burning treatment, percentage recovery in terms of ground cover was below 60 percent on all burnt plots (Fig. 5a). The precise recovery time (i.e. the period following the burn after which no remarkable difference could be noticed between conditions on the burnt and nearby unburnt areas) could not be determined for the eucalypt ground species in the present study since the time of the post-fire observations was relatively short. At the pine site, however, full recovery had occurred on all burnt plots six months after the burn. Species of the genera Cryptostemma and Hydrocotyle are likely to have sprouted from seed. Evidence also existed of pine regrowth from seed. For the eucalypt ground species, however, there was no clear evidence of post-fire regeneration from seed during the entire 12 months after the burning.

Soil physical properties

Soil moisture : Over the 18 month sampling period, soil moisture fluctuated between 8.6 and 17.2 percent at the eucalypt site, and 6.7 and 20.4 percent at the pine site (Table 5). Moisture regimes of all eucalypt plots were slightly low six months after the burning. This was particularly so for plot C. An increasing trend was then apparent during the following 6 months. At the pine site, soil moisture levels in the treated plots F,G and H were slightly high relative to those of the control plots immediately

TABLE 5: Mean values of soil moisture for eucalypt and pine plots. 95 percent confidence limits given in brackets.

Plot No.	Pre-burn	Immediately after burn*	6 months after burn	12 months after burn
A	16.8 (15.0 - 18.6)	11.6 (9.6 - 13.5)	11.3 (9.6 - 13.0)	14.8 (12.2 - 17.4)
B	17.2 (14.0 - 20.5)	12.9 (11.2 - 14.7)	10.6 (8.9 - 12.3)	13.4 (11.4 - 15.3)
C	15.9 (13.6 - 18.2)	11.4 (10.3 - 12.5)	8.6 (7.1 - 10.0)	10.6 (8.9 - 12.3)
D	15.4 (13.9 - 16.8)	12.5 (11.5 - 13.5)	10.0 (8.6 - 11.4)	11.9 (10.0 - 13.7)
E	15.4 (13.8 - 17.1)	13.4 (11.5 - 15.4)	12.9 (11.0 - 14.8)	13.7 (11.3 - 16.1)
F	11.2 (9.4 - 13.0)	17.5 (14.7 - 20.2)	10.0 (7.9 - 12.1)	18.2 (16.0 - 20.3)
G	11.5 (8.8 - 14.2)	13.8 (9.0 - 18.6)	9.8 (8.2 - 11.4)	19.9 (16.9 - 22.9)
H	11.3 (9.4 - 13.1)	10.9 (7.9 - 13.9)	8.4 (7.7 - 9.2)	15.8 (13.6 - 18.0)
I	11.8 (9.3 - 14.2)	7.3 (5.5 - 9.2)	10.5 (9.1 - 11.9)	20.4 (17.8 - 23.1)
J	10.5 (9.1 - 11.9)	6.7 (5.3 - 8.1)	8.1 (7.3 - 9.0)	14.0 (11.7 - 16.2)

* One to two days after the burning

Note: Burnt plots - A,C,D (eucalypt); F,G,H (pine)
Control plots - B,E (eucalypt); I,J (pine)

after the burning (Fig. 7b). While the burnt plots showed slight drops during the first 6 months after the burn, the control plots showed an increasing trend. Highest levels of soil moisture were recorded for all plots at last sampling. Over the 12 month post-fire period there were no significant differences in soil moisture between burnt and unburnt plots at the two sites.

Soil bulk density: On the two study areas, irrespective of the burning treatment, the values for soil bulk density remained almost unchanged throughout the sampling period (Figs. 8a and 8b). Bulk density ranged from 1.0 to 1.2 on the eucalypt plots and 1.1 to 1.3 on the pine plots (Table 6).

Soil porosity: The apparent uniformity in bulk density was reflected in total soil porosity which, for all plots, ranged between 47 and 57 percent at the eucalypt site, and 46 and 55 percent at the pine site (Table 7). A noticeable drop was observed for burnt plot C at the eucalypt site 6 months after the burning (Fig. 9a). This was followed by an increase during the following 6 months. Burnt plot A decreased slightly in total porosity during the first six months after the burn while burnt plot D showed a slight increase during the same period. At the pine site, burnt plots F and H increased slightly during the first 6 months after burning. These increases were followed by slight decreases during the following 6 months. Burnt plot G showed the opposite trend by declining slightly in porosity during the first 6 months after the burn and increasing thereafter.

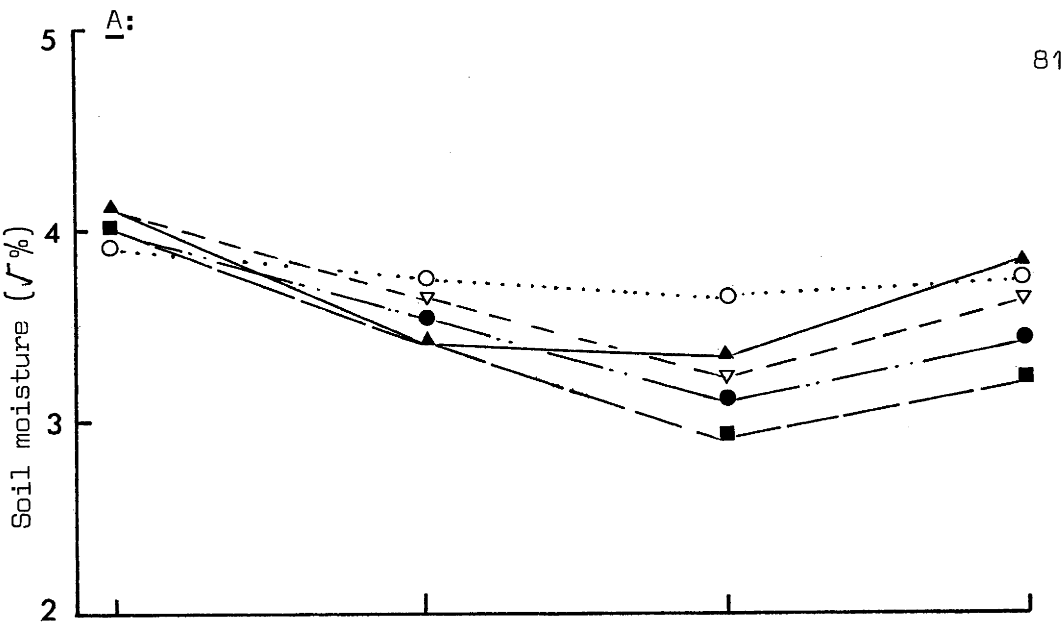
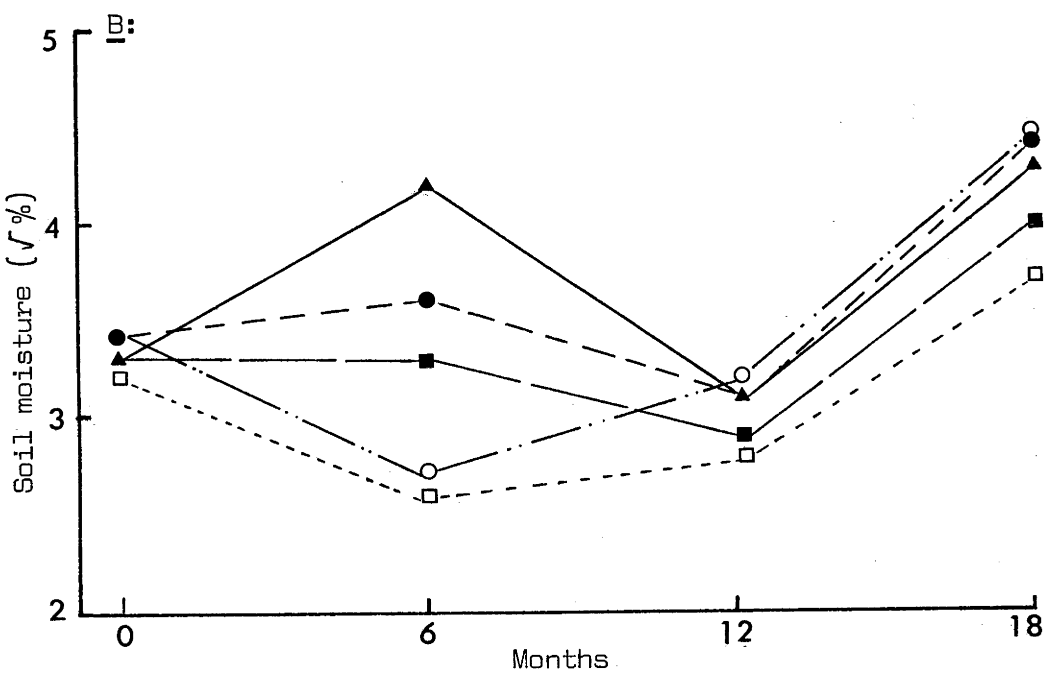


FIGURE 7: Influence of prescribed burning on soil moisture regimes during the first 12 months after the treatment* – (A) Eucalypt stand; (B) Pine stand



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H

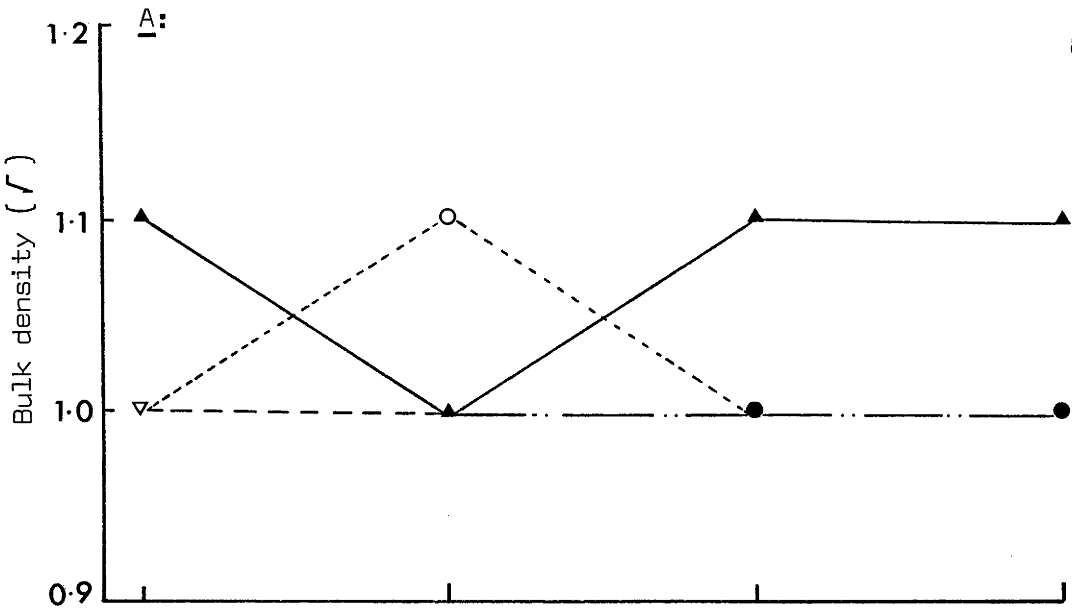
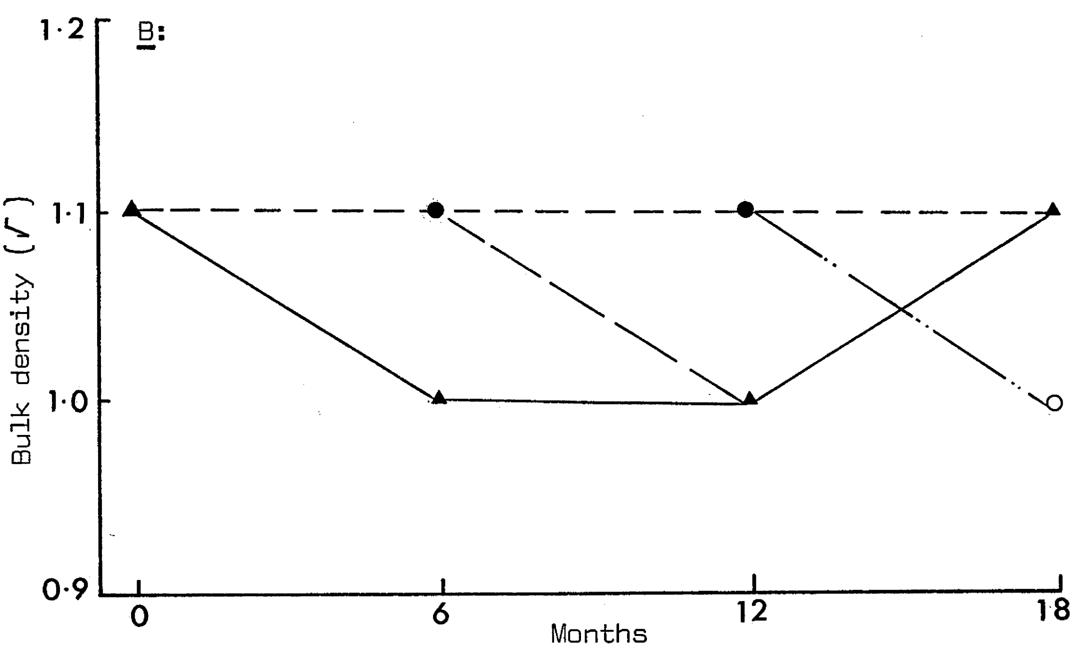


FIGURE 8: Variations in soil bulk density during the first 12 months after a prescribed fire* – (A) Eucalypt stand; (B) Pine stand

Plot A
" B
" C
" D
" E



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H
Control plots – B,E; I,J

Plot F
" G
" H
" I
" J

TABLE 6: Mean values of soil bulk density for eucalypt and pine plots. 95 percent confidence limits given in brackets.

Plot No.	Pre-burn	Immediately after burn *	6 months after burn	12 months after burn
A	1.1 (1.1 - 1.2)	1.1 (1.0 - 1.2)	1.2 (1.0 - 1.3)	1.2 (1.0 - 1.3)
B	1.1 (0.9 - 1.2)	1.1 (1.0 - 1.2)	1.2 (1.0 - 1.3)	1.2 (1.0 - 1.4)
C	1.0 (1.0 - 1.1)	1.0 (1.0 - 1.1)	1.2 (1.0 - 1.4)	1.2 (1.0 - 1.3)
D	1.1 (1.0 - 1.2)	1.1 (1.0 - 1.2)	1.0 (1.0 - 1.2)	1.1 (1.0 - 1.2)
E	1.1 (1.0 - 1.1)	1.1 (1.1 - 1.2)	1.1 (1.0 - 1.3)	1.1 (1.0 - 1.2)
F	1.3 (1.2 - 1.3)	1.1 (1.0 - 1.1)	1.1 (1.0 - 1.2)	1.2 (1.1 - 1.3)
G	1.3 (1.2 - 1.3)	1.2 (1.1 - 1.3)	1.2 (1.1 - 1.4)	1.2 (1.1 - 1.3)
H	1.3 (1.2 - 1.3)	1.2 (1.1 - 1.2)	1.1 (1.0 - 1.2)	1.3 (1.2 - 1.3)
I	1.2 (1.2 - 1.3)	1.2 (1.2 - 1.3)	1.3 (1.2 - 1.3)	1.1 (0.9 - 1.2)
J	1.2 (1.1 - 1.2)	1.2 (1.2 - 1.3)	1.2 (1.1 - 1.4)	1.2 (1.1 - 1.3)

* One to two days after the burning

Note: Burnt plots - A,C,D (eucalypt); F,G,H (pine)
control plots - B,E (eucalypt); I,J (pine)

TABLE 7: Mean values of soil porosity for eucalypt and pine plots. 95 percent confidence limits given in brackets.

Plot No.	Pre-burn	Immediately after burn *	6 months after burn	12 months after burn
A	48.1 (42.9 - 53.3)	55.0 (51.0 - 59.1)	50.2 (44.0 - 56.5)	54.8 (49.9 - 59.7)
B	50.4 (46.2 - 54.5)	52.4 (50.3 - 54.5)	50.3 (45.6 - 55.0)	51.1 (44.0 - 58.2)
C	55.8 (52.2 - 59.5)	56.2 (53.1 - 59.4)	47.3 (42.5 - 52.0)	55.2 (50.5 - 60.0)
D	53.1 (48.7 - 57.4)	48.2 (45.0 - 51.5)	50.7 (46.8 - 54.7)	48.7 (45.0 - 52.3)
E	49.5 (45.5 - 53.5)	53.0 (50.2 - 55.8)	47.4 (41.9 - 52.9)	52.9 (48.0 - 57.7)
F	54.1 (48.4 - 59.8)	48.7 (44.6 - 52.8)	49.4 (44.2 - 54.6)	46.1 (41.1 - 51.2)
G	52.3 (48.3 - 56.3)	49.9 (44.9 - 54.8)	47.9 (43.1 - 52.7)	51.5 (47.1 - 55.9)
H	50.3 (48.2 - 52.3)	48.1 (43.5 - 52.7)	54.0 (50.5 - 57.6)	50.2 (45.0 - 55.4)
I	50.4 (46.4 - 54.3)	50.7 (46.5 - 54.9)	49.4 (44.6 - 54.1)	46.8 (42.9 - 50.8)
J	53.9 (49.8 - 58.1)	50.6 (45.3 - 55.9)	51.9 (46.9 - 56.8)	53.6 (47.8 - 59.3)

* One to two days after the burning

Note: Burnt plots - A,C,D (eucalypt); F,G,H (pine)
Control plots - B,E (eucalypt); I,J (pine)

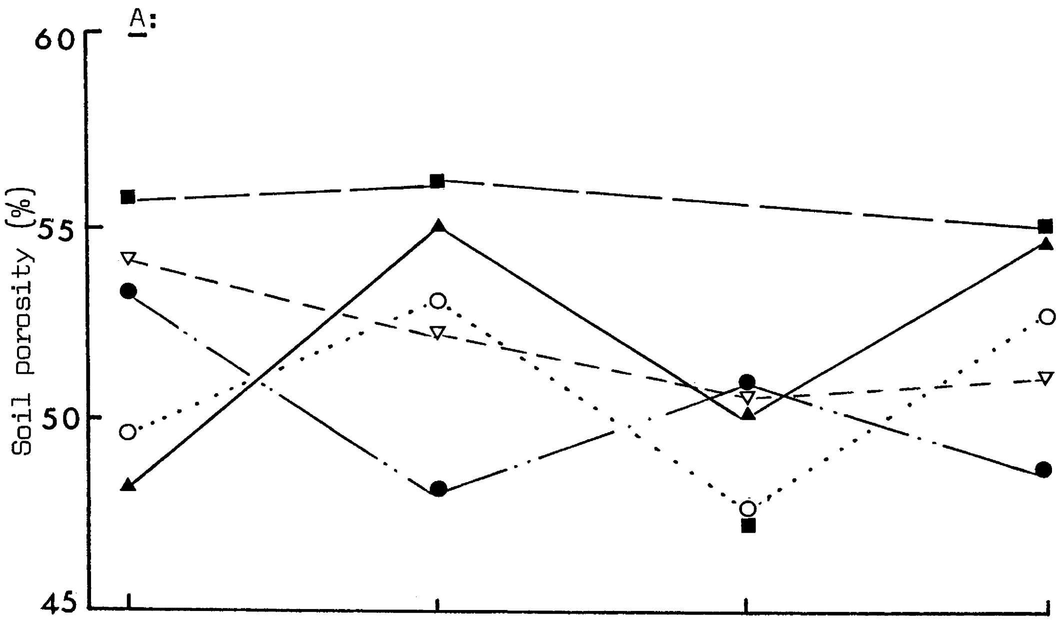
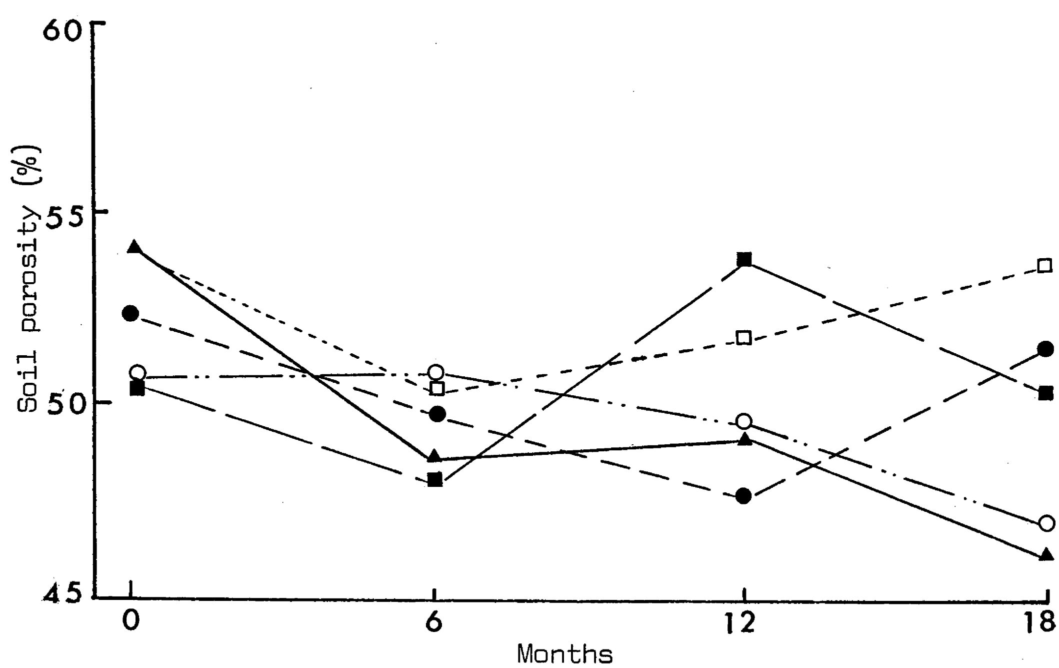


FIGURE 9: Trends in soil total porosity during the first 12 months after control burning* – (A) Eucalypt stand; (B) Pine stand



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H
Controls – B,E; I,J

Soil chemical properties

Soil reaction: A characteristic common to both burnt eucalypt and pine areas was a non-significant decrease in soil acidity immediately after the burning treatment (Figs. 10a and 10b). Pre-burn pH values of soil samples from both the eucalypt and the pine sites were fairly uniform (Table 8). At the eucalypt site, a non-significant rise in pH was observed for plot C immediately after the burn, from 4.1 to 4.4. The other burnt plots A and D showed non-significant increases of 0.2 and 0.1 units respectively immediately after burning. At the pine site, burnt plot H showed the highest but non-significant increase of 0.5 units from pH 5.6 to pH 6.1. Treated plots F and G increased by 0.3 units each from 5.3 to 5.6 and from 5.5 to 5.8 respectively. The higher pH values, although not statistically significant, were maintained on eucalypt plots A and C and on pine plots F and H during the first 12 months after the burning. Eucalypt plot D declined slowly in pH during the first 6 months after burning while pine plot G declined to pre-burn levels 12 months after the burn. At both sites, soil pH values were unusually high for all plots at last sampling.

Mineral nutrients: All the mineral elements under study here were analysed for total contents. A comparison of the initial soil samples from the eucalypt site and those from the pine site shows that the eucalypt area appears to be richer in calcium, zinc, and manganese. Mean differences are, however, non-significant. Contents of phosphorus, magnesium and iron were fairly comparable for the two sites (Tables 9a and 9b - 16a and 16b).

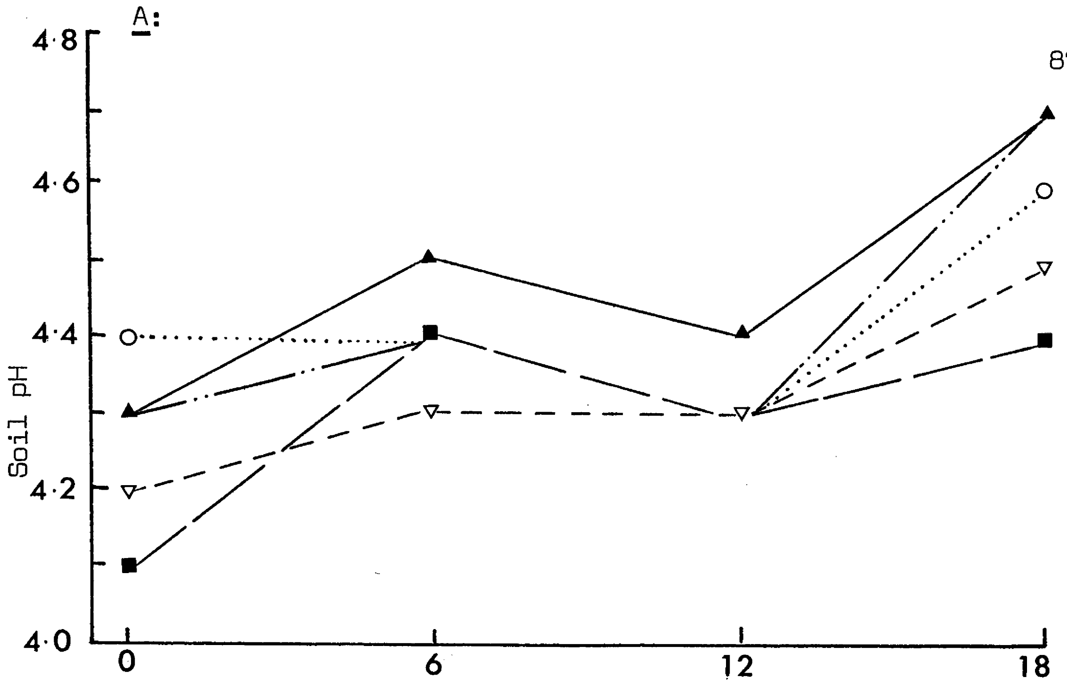
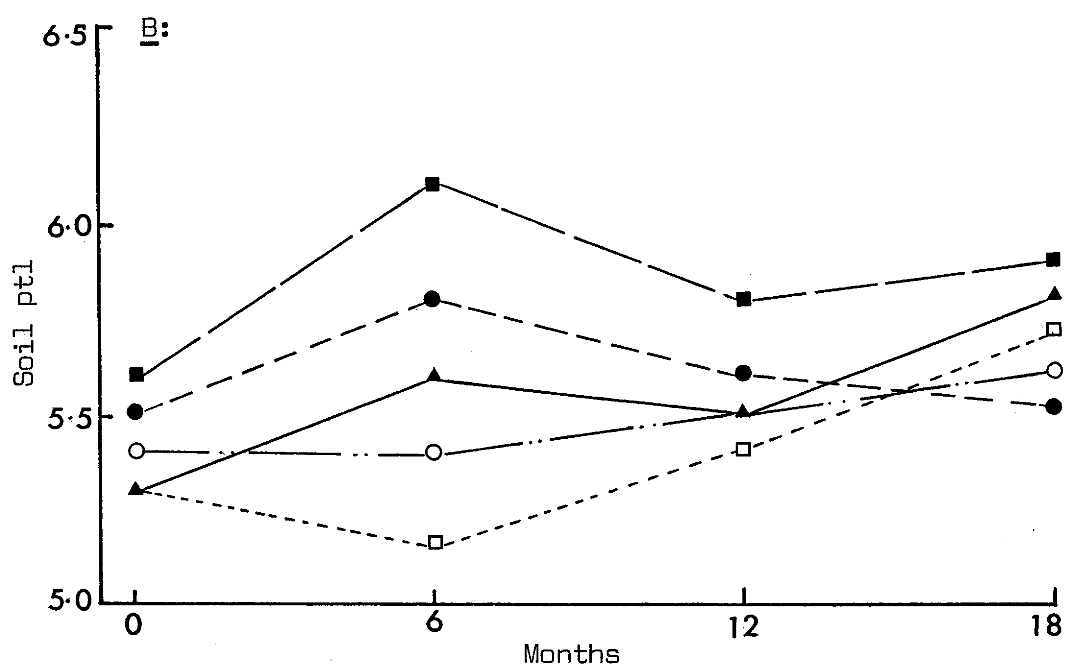


FIGURE 10: Response of soil reaction to prescribed burning * during the first 12 months after the treatment – (A) Eucalypt stand; (B) Pine stand

Plot A
" B
" C
" D
" E



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H
Controls – B,E; I,J

Plot F
" G
" H
" I
" J

TABLE 8: Mean values of soil pH for eucalypt and pine plots. 95 percent confidence limits given in brackets.

Plot No.	Pre-burn	Immediately after burn *	6 months after burn	12 months after burn
A	4.3 (4.2 – 4.4)	4.5 (4.4 – 4.6)	4.4 (4.3 – 4.4)	4.7 (4.5 – 4.9)
B	4.2 (4.1 – 4.3)	4.3 (4.2 – 4.4)	4.3 (4.2 – 4.4)	4.5 (4.3 – 4.7)
C	4.1 (4.1 – 4.2)	4.4 (4.3 – 4.4)	4.3 (4.2 – 4.3)	4.4 (4.2 – 4.6)
D	4.3 (4.2 – 4.4)	4.5 (4.4 – 4.5)	4.3 (4.2 – 4.4)	4.7 (4.4 – 4.9)
E	4.4 (4.4 – 4.5)	4.4 (4.3 – 4.5)	4.3 (4.2 – 4.4)	4.6 (4.4 – 4.7)
F	5.3 (5.0 – 5.6)	5.6 (5.5 – 5.7)	5.5 (5.3 – 5.7)	5.8 (5.7 – 5.8)
G	5.5 (5.1 – 5.8)	5.8 (5.5 – 6.1)	5.6 (5.4 – 5.8)	5.5 (5.3 – 5.6)
H	5.6 (5.3 – 5.9)	6.1 (5.8 – 6.4)	5.8 (5.7 – 5.9)	5.9 (5.8 – 6.0)
I	5.4 (5.4 – 5.5)	5.4 (5.3 – 5.5)	5.5 (5.2 – 5.8)	5.9 (5.8 – 5.9)
J	5.3 (5.1 – 5.4)	5.2 (5.0 – 5.3)	5.4 (5.3 – 5.6)	5.7 (5.6 – 5.8)

* One to two days after the burning

Note: Burnt plots – A,C,D (eucalypt); F,G,H (pine)
Control plots – B,E (eucalypt); I,J (pine)

TABLE 9a: Concentration of nitrogen in the upper soil horizons as determined by the Auto Analyser - Eucalypt plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets.

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	421 (213-629)	379 (272-485)	482 (332-632)	80 (43-117)	114 (93-135)	124 (101-146)	50 (31- 68)	74 (61- 86)	80 (62- 98)
B	313 (246-379)	222 (142-302)	236 (114-358)	119 (59-179)	106 (71-142)	102 (80-125)	68 (48- 88)	77 (57- 96)	75 (55- 94)
C	317 (170-463)	353 (133-573)	375 (240-509)	104 (58-151)	148 (91-204)	146 (106-185)	65 (51- 78)	66 (51- 80)	74 (56- 91)
D	246 (166-326)	257 (149-364)	250 (168-331)	79 (62- 96)	112 (81-143)	121 (94-147)	64 (45- 82)	72 (51- 92)	76 (56- 95)
E	232 (180-284)	272 (126-418)	264 (162-367)	108 (78-138)	112 (78-145)	122 (71-173)	62 (29- 99)	65 (47- 81)	77 (59- 94)

* Sampling one or two days after the burn

Note: Burnt plots - A,C,D
Control plots - B,E

Horizon 1 : 0 - 1 cm.
2 : 1 - 3 cm.
3 : 3 - 5 cm.

TABLE 9b: Concentration of nitrogen in the upper soil horizons as determined by the Auto Analyser – Pine plots. Sample means given (p.p.m.) with corresponding 95 percent confidence limits in brackets.

Plot No.	SOIL HORIZON 1			SOIL HORIZON 3			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	128 (85–171)	102 (55–148)	132 (94–169)	93 (43–143)	100 (57–143)	91 (69–113)	78 (39–117)	83 (59–107)	75 (55– 95)
G	119 (57–181)	131 (85–177)	102 (77–128)	84 (44–123)	108 (80–135)	85 (45–126)	71 (32–111)	63 (36– 89)	78 (52–103)
H	85 (38–131)	94 (67–122)	115 (75–156)	60 (38– 83)	79 (47–111)	81 (53–109)	37 (17– 57)	56 (29– 82)	43 (30– 56)
I	124 (48–199)	101 (60–141)	117 (50–183)	73 (38–107)	89 (58–120)	88 (51–125)	54 (26– 81)	66 (50– 81)	58 (32– 84)
J	107 (60–154)	120 (80–159)	91 (62–119)	79 (53–104)	63 (46– 80)	82 (45–119)	65 (43– 87)	71 (52– 91)	59 (30– 88)

* Sampling one or two days after the burn

Note: Burnt plots – F,G,H
Control plots – I,J

Horizon 1 : 0 – 1 cm.
2 : 1 – 3 cm.
3 : 3 – 5 cm.

TABLE 10a: Concentration of phosphorus in the upper soil horizons as determined by the Auto Analyser - Eucalypt plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets.

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	99 (80–118)	86 (55–116)	83 (49–117)	76 (55– 97)	56 (39– 73)	57 (37– 77)	52 (39– 65)	39 (27– 51)	40 (32– 49)
B	77 (56– 99)	59 (46– 72)	70 (46– 94)	83 (49–117)	40 (29– 51)	41 (30– 53)	54 (37– 71)	31 (26– 36)	35 (22– 47)
C	61 (45– 77)	81 (37–124)	76 (53– 98)	54 (38– 70)	38 (22– 53)	41 (28– 54)	32 (28– 36)	36 (28– 44)	38 (24– 51)
D	66 (59– 73)	76 (57– 95)	81 (50–112)	46 (32– 60)	37 (27– 47)	37 (25– 48)	34 (32– 36)	38 (25– 50)	33 (26– 41)
E	102 (85–119)	60 (39– 82)	83 (48–118)	60 (44– 75)	36 (23– 50)	37 (28– 45)	35 (23– 46)	35 (28– 42)	38 (27– 49)

* Sampling one or two days after the burn

Note: Burnt plots - A,C,D
Control plots - B,E

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 10b: Concentration of phosphorus in the upper soil horizons as determined by the Auto Analyser - Pine plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	101 (69-133)	85 (57-112)	96 (67-124)	84 (55-113)	67 (45- 90)	78 (42-113)	78 (59- 96)	81 (63- 99)	76 (55- 96)
G	70 (50- 91)	79 (61- 96)	87 (58-115)	60 (37- 83)	57 (30- 83)	58 (34- 83)	79 (54-105)	65 (42- 87)	68 (43- 92)
H	65 (45- 85)	73 (50- 95)	78 (45-111)	56 (40- 71)	51 (37- 65)	49 (24- 73)	52 (27- 77)	54 (31- 77)	51 (28- 73)
I	78 (43-113)	89 (64-114)	81 (52-111)	82 (55-108)	80 (44-116)	60 (40- 80)	88 (60-115)	84 (60-108)	81 (57-106)
J	73 (45-100)	80 (46-113)	65 (43- 86)	64 (48- 79)	58 (45- 72)	66 (37- 95)	57 (35- 79)	64 (42- 86)	55 (42- 67)

* Sampling one or two days after the burn

Note: Burnt plots - F,G,H
Control plots - I,J

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 11a: Concentration of potassium in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer - Eucalypt plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	8023 (3730-12315)	8743 (5828-11657)	8427 (5272-11583)	6309 (886-11731)	6365 (4458-8273)	7408 (4298-10519)	7433 (3552-11314)	7582 (4593-10570)	7099 (4847-9351)
B	6223 (1708-10739)	6839 (2127-11552)	6603 (3918-9287)	6425 (1220-11630)	5728 (1608-9847)	6442 (4701-8183)	7415 (3334-11497)	7353 (3076-11631)	7030 (4231-9829)
C	8178 (3954-12402)	9490 (7026-11954)	8599 (5597-11600)	8020 (4122-11919)	7529 (1922-13135)	7560 (3438-11681)	8488 (5404-11571)	8116 (5841-10391)	8475 (5771-11178)
D	7942 (4203-11681)	8238 (4320-12156)	7967 (4716-11218)	7450 (4478-10422)	8511 (5444-11578)	9261 (5099-13423)	8307 (4360-12254)	8203 (5589-10818)	7494 (3577-11410)
E	7120 (3377-11946)	7851 (3346-12356)	6978 (4159-9796)	8323 (3825-12820)	8639 (4696-12582)	9094 (6868-11320)	8053 (3895-12211)	8307 (3783-12830)	7729 (3313-12145)

*Sampling one or two days after the burn

Note: Burnt plots - A,C,D
Control plots - B,E

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 11b: Concentration of potassium in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer – Pine plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets.

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	5129 (3726–6532)	5431 (3022–7839)	4300 (2629–5970)	4803 (3602–6003)	3567 (2896–4238)	3169 (1514–4823)	4939 (3603–6275)	5351 (1935–8766)	4622 (2980–6264)
G	4174 (2777–5570)	4440 (3292–4487)	4045 (3136–4954)	4160 (3186–5134)	4044 (3018–5070)	3778 (2014–5542)	4242 (3084–5399)	3884 (2756–5013)	4049 (3431–4666)
H	4419 (2813–6026)	5685 (1923–9447)	4937 (2572–7303)	4137 (3038–5236)	4250 (3159–5341)	4414 (2173–6654)	4331 (2787–5875)	4370 (2865–5875)	4787 (2861–6712)
I	4601 (3346–5856)	4762 (2796–6727)	4201 (2008–6395)	4566 (3266–5866)	4170 (3169–4171)	4552 (2725–6380)	4659 (3832–5485)	3928 (2890–4965)	3687 (2311–5063)
J	6096 (4092–8101)	5097 (3833–6362)	5089 (3469–6709)	7880 (2561–13198)	5509 (3249–7768)	4827 (2970–6683)	5817 (4144–7490)	6164 (4332–7995)	4139 (2808–5469)

* Sampling one or two days after burn

Note: Burnt plots – F,G,H
Control plots – I,J

Horizon 1: 0 – 1 cm.
2: 1 – 3 cm.
3: 3 – 5 cm.

TABLE 12a: Concentration of calcium in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer – Eucalypt plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	1085 (538–1631)	1402 (933–1871)	1194 (911–1477)	332 (176–487)	308 (153–462)	450 (303–596)	201 (79–322)	205 (80–331)	255 (102–409)
B	817 (349–1285)	820 (326–1315)	950 (661–1238)	252 (173–330)	267 (187–347)	355 (207–502)	218 (110–326)	179 (125–234)	230 (141–318)
C	660 (398–922)	1211 (523–1898)	976 (606–1346)	378 (68–688)	312 (216–408)	376 (254–498)	263 (193–332)	302 (154–449)	374 (221–526)
D	505 (214–795)	1102 (330–1873)	919 (482–1355)	313 (176–449)	254 (183–325)	357 (154–561)	301 (209–392)	271 (171–371)	244 (145–342)
E	662 (364–960)	684 (316–1052)	806 (404–1209)	322 (188–455)	263 (252–273)	268 (194–342)	291 (190–392)	301 (179–422)	262 (169–354)

* Sampling one or two days after the burn

Note: Burnt plots – A,C,D
Control plots – B,E

Horizon 1: 0 – 1 cm.
2: 1 – 3 cm.
3: 3 – 5 cm.

TABLE 12b: Concentration of calcium in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer - Pine plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	2893 (1315-4471)	4451 (2802-6100)	3921 (2682-5160)	2309 (1003-3615)	2473 (1654-3291)	1963 (1113-2814)	1716 (598-2835)	1918 (1217-2619)	1608 (1072-2143)
G	2480 (1135-3826)	4031 (2568-5494)	3217 (1857-4576)	1769 (1049-2490)	1834 (1217-2452)	2043 (1190-2896)	1538 (639-2437)	1442 (1123-1760)	1660 (858-2462)
H	2112 (1021-3203)	3226 (2212-4239)	2647 (1445-3848)	1882 (1115-2648)	1982 (1372-2591)	1663 (908-2417)	1312 (576-2048)	1615 (890-2340)	1608 (886-2331)
I	2440 (1849-3030)	2775 (1951-3598)	2838 (1453-4224)	1563 (857-2269)	1570 (1111-2030)	1947 (1199-2695)	1160 (926-1395)	1557 (845-2269)	1385 (747-2022)
J	2039 (1107-2970)	1993 (1178-2807)	2053 (988-3117)	1744 (985-2503)	1847 (1465-2228)	1615 (854-2376)	1215 (693-1738)	1362 (964-1760)	1688 (1056-2319)

* Sampling one or two days after the burn

Note: Burnt plots - F,G,H
Control plots - I,J

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 13a: Concentration of magnesium in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer - Eucalypt plots. Sample means (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	1899 (1266-2532)	1996 (1640-2351)	1955 (1550-2360)	1367 (619-2115)	1254 (651-1857)	1400 (907-1893)	1343 (629-2057)	1761 (1167-2355)	1668 (1186-2151)
B	1556 (955-2157)	1288 (955-1620)	1662 (1146-2178)	1637 (549-2725)	1130 (698-1562)	1217 (768-1665)	2031 (1405-2658)	1366 (813-1918)	1905 (1482-2327)
C	1864 (1147-2580)	1737 (1417-2057)	1641 (918-2363)	1878 (1327-2429)	1364 (903-1825)	1522 (910-2134)	1846 (1460-2233)	1797 (1256-2338)	1706 (1420-1992)
D	2008 (1241-2776)	1572 (1382-1761)	1867 (1418-2317)	2179 (1919-2438)	1415 (753-2077)	1885 (1383-2387)	2044 (1719-2370)	2057 (1709-2404)	1884 (1260-2508)
E	1808 (1352-2265)	1659 (1445-1873)	1525 (1030-2020)	1886 (1389-2383)	1015 (819-1210)	1308 (692-1924)	1994 (1779-2208)	2055 (1697-2412)	1755 (1341-2170)

* Sampling one or two days after the burn

Note: Burnt plots - A,C,D
Control plots - B,E

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 13b: Concentration of magnesium in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer - Pine plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	1881 (935-2827)	2081 (1722-2441)	1927 (1002-2852)	1749 (935-2562)	1743 (1340-2146)	1688 (915-2461)	1394 (633-2154)	1692 (1226-2158)	1548 (699-2398)
G	1797 (1219-2374)	1941 (1525-2358)	2000 (1403-2598)	1719 (929-2510)	1554 (764-2345)	1456 (1026-1886)	1631 (1192-2070)	1482 (960-2003)	1961 (1581-2341)
H	1964 (958-2970)	1740 (955-2525)	1731 (966-2496)	1873 (916-2830)	2021 (1546-2495)	2014 (873-3154)	1775 (1116-2433)	1459 (846-2071)	1671 (1126-2648)
I	1782 (951-2612)	1858 (1211-2504)	1814 (1094-2534)	1887 (1067-2707)	1723 (1373-2073)	1927 (911-2943)	1712 (643-2780)	1731 (1186-2275)	1627 (1027-2228)
J	1772 (1327-2218)	1792 (1295-2290)	1693 (1048-2337)	1866 (1400-2332)	2133 (1688-2579)	1943 (1335-2552)	1834 (1298-2369)	1719 (1437-2002)	1682 (1250-2114)

* Sampling one or two days after burn

Note: Burnt plots - F,G,H
Control plots - I,J

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 14a: Concentration of iron in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer – Eucalypt plots. Mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	16800 (13728–18739)	17721 (15371–20070)	18541 (13143–23938)	17148 (12117–22179)	17816 (15989–19643)	17309 (12629–21988)	18811 (13404–24195)	20235 (16906–23563)	18434 (12398–24469)
B	17507 (13657–21357)	15431 (12127–18734)	17511 (12362–22659)	15925 (13798–18052)	14864 (8927–20801)	14951 (10750–19152)	17669 (12964–22374)	13457 (7274–19639)	16448 (11490–21306)
C	16741 (11476–21905)	16059 (9935–22183)	18503 (12676–24331)	16599 (12047–21150)	16690 (11598–21782)	15745 (12832–18658)	18891 (16496–21286)	17456 (13283–21629)	17505 (15715–19296)
D	17370 (13107–21632)	20669 (15348–25989)	17640 (14793–20487)	18527 (13692–23632)	16903 (14798–19007)	18347 (10571–26122)	21294 (18548–24041)	20894 (18476–23312)	19646 (16485–22806)
E	17528 (16321–18937)	16488 (12197–20778)	19155 (16362–21948)	18155 (16474–19835)	14070 (9769–18372)	16086 (12616–19555)	19809 (17239–22380)	19471 (16087–22855)	19362 (15999–22725)

*Sampling one or two days after the burn

Note: Burnt plots – A,C,D
Control plots – B,E

Horizon 1: 0 – 1 cm.
2: 1 – 3 cm.
3: 3 – 5 cm.

TABLE 14b: Concentration of iron in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer – Pine plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	30606 (13485–47726)	21055 (7242–34868)	22841 (13675–32008)	22506 (6982–38030)	18710 (8964–28455)	21409 (11528–31291)	20853 (7299–34406)	17672 (7409–27934)	19483 (11302–27664)
G	17724 (2218–33229)	17161 (5680–28643)	17979 (11937–24020)	26657 (12282–41031)	24224 (16810–31638)	19764 (11985–27543)	30055 (8089–52022)	24131 (16511–31751)	19701 (10422–28981)
H	12768 (8169–17637)	13263 (9269–17257)	15085 (11438–18733)	15396 (10129–20663)	15199 (10891–19507)	14799 (6882–22716)	13646 (8681–18611)	16660 (11402–21917)	16039 (9282–22795)
I	14964 (12347–17545)	16767 (11583–21950)	16912 (9207–24617)	13912 (9352–18471)	16084 (9566–24041)	14481 (11241–17720)	13065 (8775–17354)	15535 (12267–18804)	15896 (9695–22097)
J	13686 (11673–15698)	17034 (13447–20621)	18442 (13894–22990)	14483 (12164–16802)	18052 (11490–24514)	18232 (12462–24002)	14681 (11907–17455)	17175 (11142–23207)	14386 (11285–17487)

* Sampling one or two days after the burn

Note: Burnt plots – F,G,H
Control plots – I,J

Horizon 1: 0 – 1 cm.
2: 1 – 3 cm.
3: 3 – 5 cm.

TABLE 15a: Concentration of zinc in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer - Eucalypt plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	21 (10-32)	22 (11-33)	24 (11-36)	19 (10-27)	13 (8-18)	21 (9-32)	18 (11-26)	16 (11-21)	12 (5-19)
B	14 (10-18)	19 (16-21)	24 (12-35)	16 (11-22)	10 (5-14)	14 (8-19)	17 (12-22)	9 (4-13)	12 (5-22)
C	24 (17-30)	29 (19-38)	28 (11-44)	20 (11-30)	18 (9-26)	17 (7-27)	17 (12-21)	12 (6-18)	16 (7-25)
D	13 (9-17)	17 (15-20)	16 (7-26)	16 (11-22)	10 (5-15)	14 (9-19)	14 (9-20)	13 (6-19)	11 (2-20)
E	19 (15-23)	15 (8-21)	19 (6-32)	18 (13-22)	9 (4-15)	11 (6-16)	16 (10-22)	15 (9-20)	18 (12-23)

* Sampling one or two days after the burn

Note: Burnt plots - A,C,D
Control plots - B,E

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 15b: Concentration of zinc in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer - Pine plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	30 (18-42)	37 (20-53)	39 (26-52)	29 (23-35)	33 (19-46)	37 (20-54)	25 (16-34)	28 (16-41)	30 (16-43)
G	34 (30-39)	38 (28-47)	36 (25-48)	32 (21-42)	28 (19-37)	26 (13-39)	34 (22-46)	34 (22-47)	33 (22-44)
H	40 (21-60)	35 (22-47)	37 (17-57)	40 (25-54)	36 (29-43)	35 (23-47)	39 (25-53)	36 (25-47)	36 (27-45)
I	39 (34-45)	37 (21-52)	31 (18-44)	38 (30-45)	36 (22-49)	36 (24-47)	31 (18-43)	35 (17-54)	36 (20-52)
J	36 (27-45)	43 (29-58)	37 (24-50)	35 (22-48)	39 (25-52)	32 (24-40)	39 (29-48)	33 (21-46)	26 (15-36)

* Sampling one or two days after the burn

Note: Burnt plots - F,G,H
Control plots - I,J

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 16a: Concentration of manganese in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer - Eucalypt plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
A	142 (64-219)	127 (95-158)	130 (68-192)	62 (41-84)	51 (29-72)	44 (24-63)	48 (36-59)	57 (37-76)	48 (30-66)
B	77 (56- 99)	69 (59- 78)	67 (54- 80)	38 (20-56)	35 (15-55)	38 (14-61)	57 (32-81)	37 (16-58)	36 (18-54)
C	80 (54-105)	125 (80-169)	98 (69-127)	58 (45-71)	41 (24-57)	36 (17-54)	51 (35-67)	45 (21-68)	37 (20-53)
D	64 (40-88)	105 (64-146)	77 (39-114)	38 (26-49)	28 (14-42)	39 (22-56)	37 (26-48)	36 (19-53)	32 (20-44)
E	47 (34-59)	59 (38-80)	74 (51-97)	37 (26-47)	22 (15-28)	25 (11-38)	29 (16-42)	30 (16-43)	35 (19-51)

* Sampling one or two days after the burn

Note: Burnt plots - A,C,D
Control plots - B,E

Horizon 1: 0 - 1 cm.
2: 1 - 3 cm.
3: 3 - 5 cm.

TABLE 16b: Concentration of manganese in the upper soil horizons as determined by the Atomic Absorption Spectrophotometer – Pine plots. Sample mean values (p.p.m.) given, with corresponding 95 percent confidence limits in brackets

Plot No.	SOIL HORIZON 1			SOIL HORIZON 2			SOIL HORIZON 3		
	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn	Pre-burn	soon after burn*	12 months after burn
F	539 (61–1016)	757 (526–987)	720 (370–1070)	409 (250–568)	687 (392–982)	664 (217–1111)	389 (139–639)	704 (303–1104)	608 (257–959)
G	711 (488–934)	780 (283–1277)	771 (539–1003)	654 (111–1196)	739 (365–1112)	704 (429–978)	484 (197–770)	415 (237–592)	377 (183–571)
H	396 (92–699)	436 (262–610)	560 (94–1025)	470 (164–776)	481 (216–745)	549 (282–816)	330 (131–528)	349 (239–459)	387 (261–512)
I	863 (357–1369)	808 (352–1263)	753 (433–1072)	641 (374–909)	616 (241–990)	649 (316–982)	554 (358–749)	454 (284–625)	487 (389–584)
J	382 (268–495)	455 (188–722)	431 (296–566)	376 (225–527)	441 (206–676)	561 (259–864)	321 (213–429)	389 (273–505)	390 (233–548)

* Sampling one or two days after the burn

Note: Burnt plots – F,G,H
Control plots I,J

Horizon 1: 0 – 1 cm.
2: 1 – 3 cm.
3: 3 – 5 cm.

Examination of the initial concentrations of the mineral nutrients in the top 5cm. of the mineral soil at both study sites indicates that nitrogen, phosphorus and calcium tend to decline slowly down the profile while potassium, magnesium, iron, zinc and manganese are of relatively uniform distribution.

Chemical analyses indicated non-significant increases in potassium and calcium within the 0-1 cm soil horizon immediately after burning at both the eucalypt and the pine sites (Figs. 11a and 11b; 12a and 12b). These changes were followed by non-significant decreases in course of the first 12 months after the burn. For potassium, the non-significant increase was more apparent on the eucalypt plots. On the burnt pine plots, the post-burn decline in potassium was more rapid, particularly for plots F and G which showed contents at last sampling lower than pre-burn levels. The non-significant increase in calcium was more apparent on the burnt eucalypt plots (Tables 12a and 12b). Changes in the 2nd and 3rd soil horizons (1-3cm and 3-5cm) during the 12-month post-burn period were also non-significant; at the eucalypt site, potassium levels in horizon 2 appeared to be lower on plot A 12 months after the burn while levels appeared to be higher on plots C and D. In soil horizon 3 of plot A there was a non-significantly higher mean potassium content at last sampling while plots C and D had non-significantly lower contents. Levels were non-significantly higher in horizons 2 and 3 for all burnt eucalypt plots 12 months after the treatment. On the pine plots, potassium levels in horizons 2 and 3 showed non-significant increases

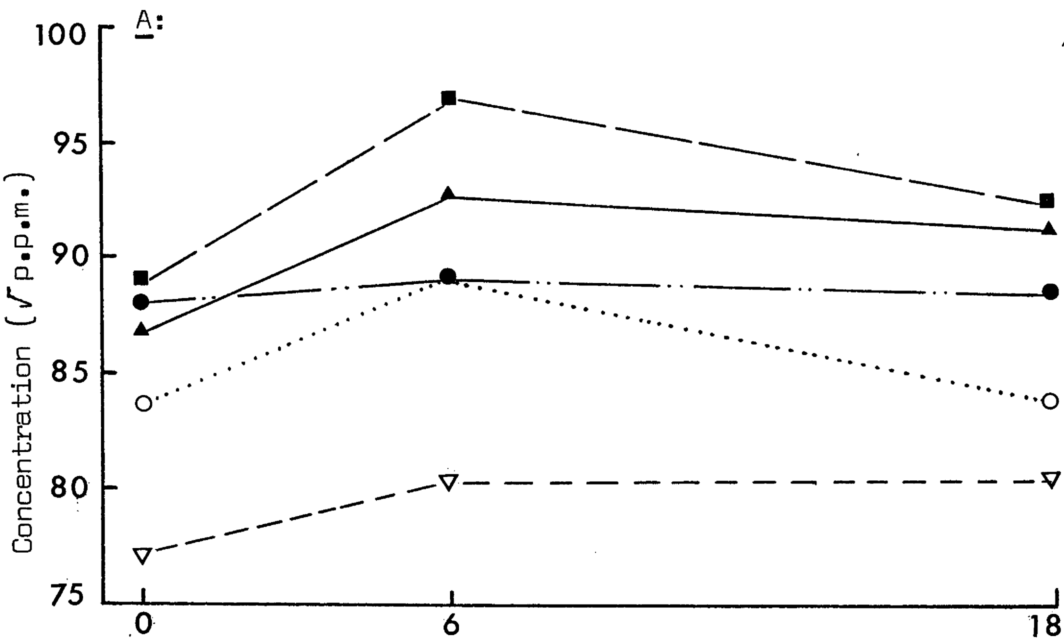
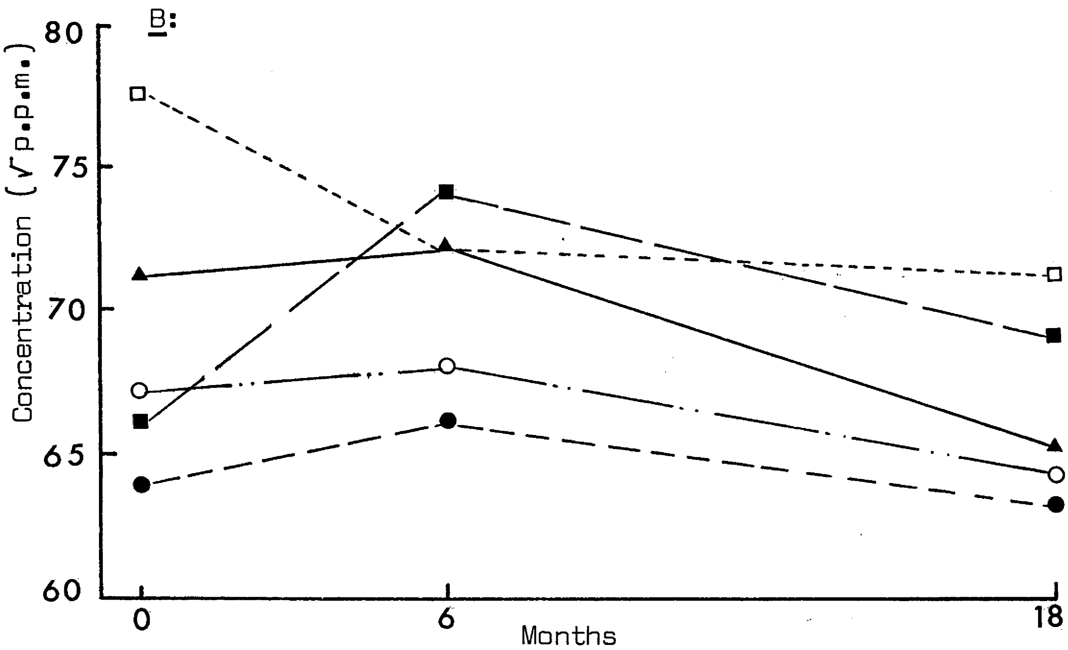


FIGURE 11: Potassium concentration curves for the top 0–1cm. of the mineral soil during the first 12 months after control burning*
(A) Eucalypt stand;
(B) Pine stand

▲——▲ Plot A
▽– – –▽ " B
■—— ——■ " C
●—·· —● " D
○·········○ " E



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H
Controls – B,E; I,J

▲——▲ Plot F
●– – –● " G
■—— ——■ " H
○—·· —○ " I
□- - - - -□ " J

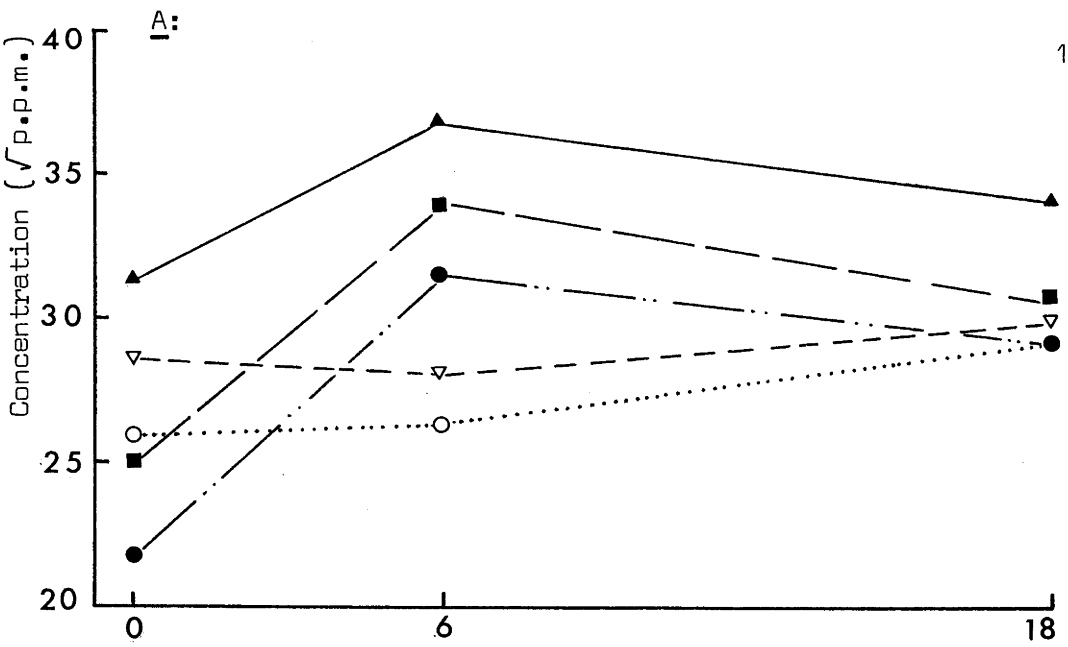
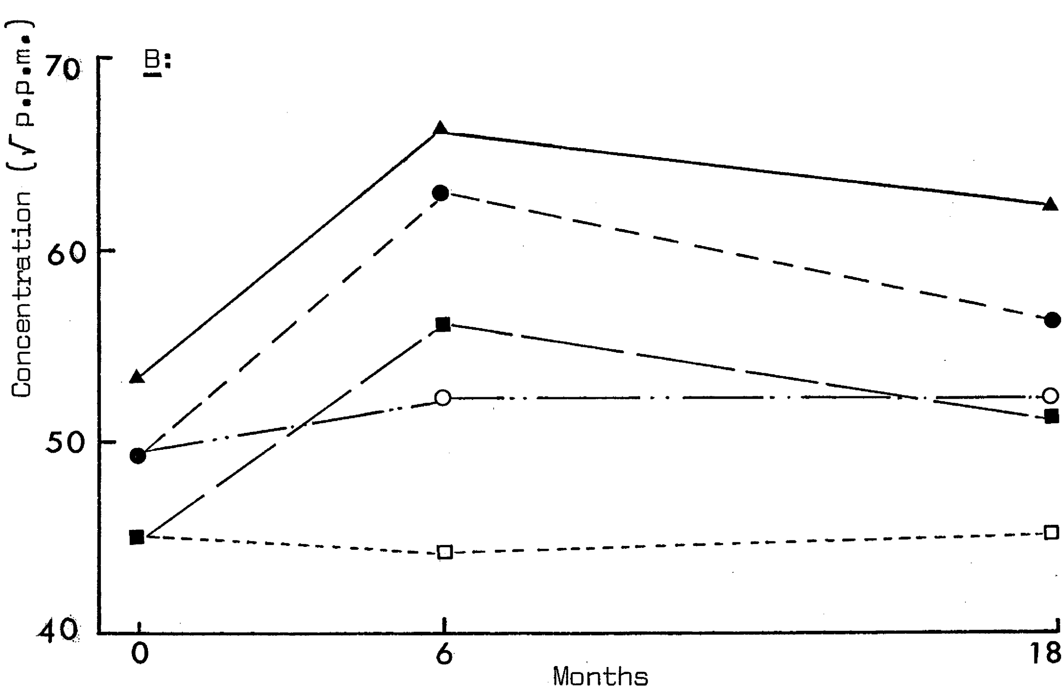


FIGURE 12: Concentration of calcium in the top 0–1cm. of the mineral soil during the first 12 months after a prescribed burn* – (A) Eucalypt stand; (B) Pine stand

Plot A
" B
" C
" D
" E



* Time of burning – month 6
Burnt plots – A,C,D; F,G,H

Plot F
" G
" H
" I
" J

during the first 12 months after the burn but decreased slightly on plot H (Table 11b). On plot F the mean value for horizon 2 was slightly lower at last sampling, while horizon 3 had a slightly higher value. Calcium levels were slightly higher in horizons 2 and 3 on plots G and H during the first 12 months after burning while plot F showed lower levels.

Fluctuations in magnesium in all horizons did not follow definite trends (Tables 13a and 13b). At the eucalypt site, there was a slight increase in the first horizon (0–1cm.) on plot A immediately after the burn while decreases were noted in the same horizon on plots C and D. At the pine site, levels increased slightly on plots F and G as against a reduced level on plot H.

The other cations iron, zinc and manganese showed slight apparent changes over the period of the experiment. These changes were insignificant compared to those on the control plots. The changes also failed to indicate definite patterns (Tables 14a and 14b – 16a and 16b).

Nitrogen varied very little from original values in the 0–1cm. horizon at both sites immediately after the burning treatment (Tables 9a and 9b). Slightly lower levels were noted for eucalypt plot A and pine plot F immediately after burning while eucalypt plots C and D as well as pine plots G and H indicated slightly higher levels. Changes in horizons 2 and 3 were similarly slight. A noticeable change at the eucalypt site was apparently higher levels of nitrogen in horizons 2 and 3 at last sampling. This was, however, not clearly evident on the pine plots.

In all the three horizons studied at the two sites, phosphorus fluctuated slightly over the period of the experiment (Tables 10a and 10b). No definite trends were established to indicate apparent treatment effects.

CHAPTER 5

DISCUSSION

With the exception of plot A at the eucalypt site, all burnt plots received burning treatments that could be considered "mild" enough for a large scale prescribed operation. Examination of the results presented in this study shows that the light burning treatment had little apparent effect on the health of mature trees at both the eucalypt and the pine sites. The uninterrupted diameter growth trends observed for these trees agree with conclusions by Woodridge and Weaver (1965). Charring of the outermost portion of the stem is the most common damage associated with fires of relatively light intensity, as noted on the burnt plots in the present study. This damage is probably of little or no harm to the mature tree except in a situation where living bark is also charred (Cremer, 1962). Two trees were burnt down on eucalypt plots A and C and one on eucalypt plot D. This may not necessarily suggest apparent degrade to trees since deep fire scars were common on most butts prior to the burning. However, insofar as fires affect the distribution and availability of nutrients, they may be expected to influence the growth rate of vegetation, and periodic fires are likely to depress plant growth on sites marginally deficient in major soil nutrients.

The majority of the understorey species at the eucalypt site showed resistance to the burning, and appear to be especially suited to an environment in which fire is an important factor. With the exception of two species (Leucopogon microphyllus and Dillwynia retorta) post-fire sprouting was remarkable for all species within the first year after burning, although ground cover was not restored during this period. The ability of an undergrowth to survive burning is of fundamental importance to erosion control and ecosystem nutrient cycling. In the present study, the post-fire recovering ability of the ground species may emphasize the potential threat of fire use in the control of undergrowth in some situations. At the same time, this ability of post-fire re-establishment may suggest the possible application of fire in managing vegetation for the benefit of wildlife. Most of the ground species appear to bear underground vegetative organs of reproduction. This ensures rapid post-fire recovery since there is a fully developed root system containing food reserves readily available to the young developing shoots. A relationship appears to exist between the intensity of burning and the rate of post-fire re-establishment of the ground species (Figs. 6b - 6h). For example, this rate was greatest on eucalypt plot A, which received the hottest fire, compared with eucalypt plots C and D. There was no clear evidence to suggest that the burning stimulated growth from seed at the eucalypt site. This appeared surprising since seed dispersal was possible from the adjoining stands onto the burnt ground. Similarly, it has been noted in foothill eucalypt forests in west-central Victoria that, although most plant species that are burnt by light spring fires produce new shoots in the first month after burning, successful seed germination is often delayed until the subsequent winter and spring (Heislers and Hodgson, 1970). The recovery rate of ground species at the pine site was more rapid compared with that at the eucalypt site. This, however, appears to be of no permanent importance as long as the canopy cover of the pine trees remains closed. Regrowth of annual herbs and pine seedlings was from seed and the rapid post-fire recovery might reflect improved seedbed conditions in contrast to the previous condition, where fallen or dispersed seed could not contact mineral soil.

The data reported in the present study indicate only slight changes in the soil physical properties considered. Lack of substantial difference in soil moisture regimes between burnt and unburnt eucalypt plots six months after the burning indicated that there was no remarkable difference between soil moisture loss by evapotranspiration and that by direct evaporation from the bare ground despite the open canopy situation. This does not seem consistent with the finding by Zahner (1958) that hardwood understorey species can contribute significantly to soil moisture loss. At the pine site, however, while burnt plots F,G and H showed apparent declines in soil moisture six months after the burn, control plots I and J increased slightly in moisture content over the period. This suggests the possibility of greater soil moisture losses from the burnt plots presumably due to the part removal of the original litter mat by the fire - a situation likely to enhance evaporation in the top soil.

Soil bulk density showed non-significant changes throughout the period of the experiment, although it is reported in other studies that this soil property may be significantly reduced after light fires (Tarrant, 1956b). Similar to soil bulk density, soil total porosity was not influenced by burning at the two sites. The work of Scott and Burgy (1956) illustrates that changes in soil porosity occur mostly after prolonged soil heating. It has also been remarked that total removal of the forest floor is an important factor contributing to post-burn changes in soil porosity (Tarrant, 1956b).

Results of soil pH analysis indicated non-significant increases on all burnt plots immediately after burning. There was a tendency for the pH levels to decline during the first six months after burning. The unusually high levels of pH noted for all plots 12 months after burning at both sites appeared to have been caused by physical site factors. For example, soil moisture regimes were higher at the two sites compared with previous sampling levels. Considering the heat intensity values for the burnt pine plots F, G and H and those for the burnt eucalypt plots C and D (Appendix 7), it may be observed that the apparent pH rise was related to increasing heat intensity as suggested by Humphreys (1966). However, the data for burnt eucalypt plot A renders this inconclusive, with the most intense fire on this plot corresponding with a relatively low pH rise.

The influence of burning on soil nitrogen content is of particular importance because this mineral contributes significantly to soil fertility. On all burnt plots, changes in total nitrogen content over the period of the experiment were non-significant; at both sites, while some plots showed lower contents of nitrogen in the top 0-1 cm horizon immediately after the burning, others showed apparently high levels. This inconsistency may partly be explained by natural site variability both between and within plots. For burnt eucalypt plots A and C as well as burnt pine plot H, chemical analysis indicated peak nitrogen levels in the topmost 0-1 cm soil horizon 12 months after burning (Tables 9a and 9b). Peak nitrogen levels were also apparent in the lower horizons, 1-3 cm and 3-5 cm, for all burnt eucalypt plots 12 months after burning although this was not true for the burnt pine plots. Since these changes were statistically non-significant, they do not suggest stimulation of the activities of soil micro-organisms as evident in other studies (e.g. Miller <u>et</u>. <u>al</u>., 1955).

Throughout the period of the experiment contents of phosphorus showed non-significant changes, indicating no response to the burning treatment. Other workers have reported similar results, for example Humphreys (1969) who concluded that soil total phosphorus is not affected by heating within the temperature range of 100^{o}C and 600^{o}C. Even organic phosphorus is not completely volatilized by burning until a temperature of about 400^{o}C is exceeded.

The non significant gains in contents of potassium and calcium in the top 0-1 cm horizon after burning failed to support the work of Scotter (1963). Potassium accumulation in the lower horizons due to the burning was not significant at both sites to reflect probable gains from the topmost horizon.

Post-burn release of calcium was considered more probable at the eucalypt site where the burnt undergrowth was likely to contribute to this (Appendix 8). However, post-burn increases were non-significant at the two sites.

Of all the cations considered in the present study, iron had the highest concentration in soil samples from the two sites. Throughout the experimental period, fluctuations in iron content were non-significant and did not follow definite patterns. Similar changes were noted for zinc and manganese with no evidence of treatment effect.

It seems clear from the present study that field experiments on the effects of prescribed fires on forest ecosystems are difficult to conduct due mainly to natural inherent variability between, as well as within, plots. The combined effect of a particular burn may be non-significant. Coupled with this, local site factors may exert considerable influence on potential fire effects to make general predictions very unreliable. However, if area fuel modification burning is to achieve its objectives, reliable predictions of fire effects are necessary. Following are some observations that have become apparent from the present study:

(1) Losses of mineral nutrients at each burning time in a prescribed burning programme may be non-significant but these losses are likely to accumulate to significant proportions after several fires. This appears particularly true for volatile elements such as nitrogen and sulphur. Although in the case of nitrogen most of these losses may be compensated for by increased activity of soil microbes after burning, stability of this nutrient supply to vegetation is likely to be disrupted, at least temporarily, after each burn.

Losses in mineral cations from the ecological system under the influence of windblow, water run-off or leaching may also reach remarkable levels after several periodic fires.

(2) The non-significant changes in the soil physical properties of bulk density, porosity and moisture relations may develop to significant levels after several years of prescribed burning treatment. These physical properties are largely influenced by the extent of organic matter removal at each burn. Hence there appears to be the need to ensure retention of residual forest floor material during each burning.

(3) There is the possibility of erosion as a result of periodic exposure of the forest floor to direct impact of raindrops. Although detailed hydrological aspects were not investigated in the present study, visual observation of the burnt plots revealed evidence of dispersion of the accumulated ash during the first 6 months after burning. This was particularly notable at the eucalypt site where open canopy conditions allowed rain to fall directly onto the forest floor. This observation may suggest the possibility of more serious consequences on steeper slopes and the likelihood of soil loss from the mineral top soil.

(4) The problem of interrupting the life cycles of micro- and macro-litter-dwelling insects has been mentioned by several critics of prescribed burning. Destruction of these organisms by fire, although of a temporary nature, can

upset organic matter accumulation and decay rates markedly, hence affecting the supply of nutrients to vegetation. However, at both the eucalypt and the pine sites, the experimental fires failed to induce violent fluctuations in the stability of litter fauna (Campbell,* 1973).

(5) In any large scale prescribed burning treatment, there could be delays in restoring food and habitat for some large forest animals and some litter-dwelling animals. These organisms exist and operate in the forest as important components of the ecosystem. In order to ensure continuing survival of these fauna, there appears to be the need to select burning seasons which have climatic conditions favouring rapid regrowth of vegetation after each prescribed burning. In this regard, the spring season appears most desirable for wildlife habitat-improvement burns.

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* Campbell, A.J. (1973). The effects of prescribed burning on surface active invertebrate fauna in pine and eucalypt forest within the Australian Capital Territory.
B.Sc.(For.) Hons. Thesis, Australian National University, Canberra.

SUMMARY AND CONCLUSIONS

1. An investigation was carried out into the effects of prescribed burning on two distinct forest ecosystems; namely, a dry-sclerophyll eucalypt forest and a plantation of radiata pine.

2. Pre-burn conditions at the two study sites were evaluated within five 0.25 hectare sample plots.

3. Prescribed burning was carried out experimentally on three plots at each site, while the unburnt plots served as controls. Except for one eucalypt plot that received a late spring fire, all burnings were comparable to "normal" mild prescribed treatments. At the eucalypt site, the heat intensity range of 83 to 107 KJ/sec/m (24 to 31 B.T.U./sec/ft) for plots C and D was within the optimum limits set by McArthur (1962) for acceptable damage standards in commercial eucalypt forests. The late spring burn of eucalypt plot A showed an intensity of 678 KJ/sec/m (196 B.T.U./sec/ft) which exceeded McArthur's upper intensity limits for acceptable damage standards. At the pine site, heat intensities ranged between 114 and 156 KJ/sec/m (33 to 45 B.T.U./sec/ft) for all burnt plots. Forest fuel was significantly reduced under all stands as a result of the burning.

4. The prescribed burning treatment had marked temporary effects on undergrowth species but caused no significant degrade to mature trees at the two sites.

5. At the eucalypt site, failure of the major shrub species to reach their pre-burn levels of ground cover during the first one year after burning suggested possible adverse effects from the point of view of wildlife.

6. Post-burn changes in the soil physical properties of moisture, bulk density and total porosity at the two sites were non-significant.

7. Soil pH showed a non-significant increase on all burnt plots immediately after burning, followed by a non-significant decline.

8. Soil total nitrogen was not significantly altered by the burning treatment.

9. Small amounts of potassium and calcium were released into the ash by burning. The top 0-1 cm of the mineral soil appeared to be the zone of maximum accumulation of the released nutrients during the entire 12 months after the burn. Sample means of contents of magnesium, iron, zinc and manganese over the period of the experiment indicated non-significant differences at the two sites.

10. The relevance of the present study to some aspects of prescribed burning was briefly discussed.

11. The findings reported in the present study are based on sample plots and are likely to have some limitations. However, these findings may serve to illustrate probable effects of large-scale prescribed burning treatments on the ecosystem factors considered.

APPENDIX 1: Mean monthly temperatures and rainfall readings taken at the Lee's Creek Nursery site between 1967 and 1972. (Data provided by the Forest Research Institute, Watershed Research Section)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Average
RAINFALL													
1967	300	37	263	0	104	99	102	503	293	209	164	9	20.83 ins.
1968	229	0	112	338	1041	324	194	784	155	501	227	496	44.01 "
1969	164	599	429	663	402	262	333	360	306	524	327	158	45.27 "
1970	443	310	277	418	214	231	157	754	871	174	729	538	51.16 "
1971	431	911	135	254	430	71	156	522	237	254	390	665	44.56 "
1972	610	190	203	206	199	207	153	497	135	329	272	25	30.26 "
MEAN MAXIMUM TEMPERATURE													
1967	24.8	25.7	21.6	19.5	15.2	11.5	10.7	10.4	15.2	19.6	22.6	24.7	18.5^{o}C.
1968	27.5	29.9	25.4	19.8	10.8	9.6	6.2	9.6	13.7	17.6	20.1	22.7	17.7 "
1969	28.1	24.4	22.0	17.8	12.7	10.5	10.7	12.7	11.7	17.8	19.0	22.9	17.5 "
1970	22.9	25.8	21.2	18.2	10.0	11.4	9.8	9.7	11.3	18.1	19.3	24.2	16.8 "
1971	25.2	23.4	22.2	18.2	12.3	10.0	9.5	9.1	13.6	16.8	18.8	23.7	16.9 "
1972	21.7	22.7	21.9	18.4	15.0	12.0	9.8	11.7	17.8	18.8	21.7	29.1	18.4 "
MEAN MINIMUM TEMPERATURE													
1967	11.9	11.6	8.9	6.7	2.4	3.4	0.2	1.8	1.9	6.6	7.8	9.3	6.0^{o}C.
1968	12.9	13.4	11.5	7.3	4.9	1.5	− 0.3	1.0	0.7	5.1	9.7	9.2	6.4 "
1969	11.0	12.8	11.4	6.7	4.0	1.0	1.3	2.7	2.0	6.8	7.9	8.5	6.3 "
1970	11.3	12.8	7.8	6.7	2.4	2.4	0.5	1.2	1.9	5.2	6.8	9.7	5.7 "
1971	11.8	13.0	12.2	6.4	2.7	−0.3	− 1.4	0.7	2.1	3.0	6.8	10.6	5.6 "
1972	10.9	10.3	8.0	3.8	1.3	−1.5	0.8	1.6	2.1	5.3	6.9	10.7	5.0 "

APPENDIX 2: Condition of the eucalypt stand prior to burning – the growing stock

Plot Number	Species	Mean d.b.h. (cm.)	Rel. density (%)	Rel. frequency (%)	Rel. dominance (%)	Species importance value	No. of stems/ ha (all spp
A	E. d E. m E. ma	30.1 51.8 0.0	87.5 12.5 0.0	100.0 18.8 0.0	70.3 29.7 0.0	258 61 0	319
B	E. d E. m E. ma	33.9 39.2 0.0	82.8 17.2 0.0	87.5 31.3 0.0	78.2 21.8 0.0	249 70 0	195
C	E. d E. m E. ma	31.0 0.0 0.0	100.0 0.0 0.0	100.0 0.0 0.0	100.0 0.0 0.0	300 0 0	240
D	E. d E. m E. ma	32.6 42.8 0.0	93.8 6.3 0.0	100.0 18.8	89.7 10.3 0.0	283 35 0	328
E	E. d E. m E. ma	32.9 47.1 23.4	87.5 7.8 4.7	100.0 25.0 12.5	82.6 15.2 2.2	270 48 19	363

E. d – *Eucalyptus dives* Schau.

E. m – *Eucalyptus mannifera* Mudie sub sp. *maculosa* (R.T. Bak) L. Johnson.

E. ma – *Eucalyptus macrorhyncha* F. Muell ex Benth.

APPENDIX 3.1: Condition of the undergrowth prior to burning - relative frequencies of species

Species	Relative frequency (%)				
EUCALYPT PLOTS:	Plot A	Plot B	Plot C	Plot D	Plot D
Leucopogon microphyllus	60	40	32	12	32
Monotoca scoparia	24	24	8	24	48
Dillwynia retorta	36	32	84	4	16
Daviesia mimosoides	44	8	4	36	36
Daviesia uliciformis	0	20	4	40	20
Acacia buxifolia	0	12	0	48	72
Acacia vomeriformis	0	0	4	0	0
Brachyloma daphnoides	32	36	0	44	16
Hibbertia calycina	0	16	88	68	36
Hibbertia obtusifolia	0	48	28	56	44
Hovea heterophylla	0	4	4	8	0
Hardenbergia sp.	4	8	0	0	4
Tetratheca ericifolia	68	80	56	48	56
Lomandra longifolia	12	8	0	24	32
Stylidium graminifolium	16	64	12	12	12
Poa caespitosa	36	20	4	28	8
Eucalyptus seedlings	48	36	52	40	32
PINE PLOTS:	Plot F	Plot G	Plot H	Plot I	Plot J
Cryptostemma sp.	17	10	7	20	13
Hydrocotyle sp..	30	27	43	33	17
Hardenbergia sp.	0	3	0	0	3
Lomandra longifolia	7	0	0	0	7
Poa caespitosa	17	13	17	20	20
Pine seedlings	7	7	3	3	7

APPENDIX 3.2: Condition of the undergrowth prior to burning - relative densities of species

Species	Relative density (%)				
EUCALYPT PLOTS:	Plot A	Plot B	Plot C	Plot D	Plot E
Leucopogon microphyllus	11.1	7.1	4.4	1.4	2.5
Monotoca scoparia	6.6	1.7	0.6	3.3	4.6
Dillwynia retorta	9.7	5.0	14.5	0.3	1.2
Daviesia mimosoides	5.7	0.5	0.3	3.7	2.6
Daviesia uliciformis	0.0	2.1	0.3	11.1	4.1
Acacia buxifolia	0.0	0.7	0.0	7.1	10.1
Acacia vomeriformis	0.0	0.0	0.3	0.0	0.0
Brachyloma daphnoides	3.3	4.1	0.0	4.3	1.9
Hibbertia calycina	0.0	3.8	28.7	11.6	5.1
Hibbertia obtusifolia	0.0	5.2	3.3	6.2	3.6
Hovea heterophylla	0.0	0.2	0.3	0.3	0.0
Hardenbergia sp.	0.4	0.9	0.0	0.0	0.6
Tetratheca ericifolia	50.9	59.3	44.4	42.8	59.9
Lomandra longifolia	1.8	0.7	0.0	2.8	2.2
Stylidium graminifolium	4.5	8.0	2.7	1.7	1.2
Poa caespitosa	6.3	1.7	0.3	3.4	1.2
Eucalyptus seedlings	6.0	6.3	4.2	7.1	4.0
PINE PLOTS:	Plot F	Plot G	Plot H	Plot I	Plot J
Cryptostemma sp.	8.9	10.2	21.2	4.3	2.9
Hydrocotyle sp.	58.6	74.2	60.2	73.4	48.7
Hardenbergia sp.	0.0	0.4	0.0	0.0	0.9
Lomandra longifolia	1.0	0.0	0.0	0.0	0.9
Poa caespitosa	7.2	2.3	13.4	3.9	11.6
Pine seedlings	17.5	32.5	16.6	30.1	27.3

APPENDIX 3.3: Condition of the undergrowth prior to burning - above ground biomass of species

Species	Biomass (to nearest 5 g.)				
EUCALYPT PLOTS:	Plot A	Plot B	Plot C	Plot D	Plot E
Leucopogon microphyllus	590	230	190	235	240
Monotoca scoparia	160	190	10	330	460
Dillwynia retorta	75	230	495	0	50
Daviesia mimosoides	75	45	0	710	380
Daviesia uliciformis	0	95	0	745	185
Acacia buxifolia	0	30	5	105	65
Acacia vomeriformis	0	0	35	0	0
Brachyloma daphnoides	170	200	0	160	75
Hibbertia calycina	0	540	3,000	1,245	340
Hibbertia obtusifolia	100	175	35	10	50
Hovea heterophylla	20	10	15	5	10
Hardenbergia sp.	10	0	0	20	20
Tetratheca ericifolia	130	100	165	35	55
Lomandra longifolia	130	10	10	25	40
Stylidium graminifolium	40	20	10	5	10
Poa caespitosa	65	50	5	165	40
Eucalyptus seedlings	115	90	130	95	100
Total Wt.	1,680	2,015	4,105	3,890	2,120
Wt. per hectare (Kg.)	1,120	1,343	2,736	2,593	1,413
PINE PLOTS:	Plot F	Plot G	Plot H	Plot I	Plot J
Cryptostemma sp.	0	10	0	15	10
Hydrocotyle sp.	10	15	5	10	5
Hardenbergia sp.	0	0	0	0	5
Lomandra longifolia	0	0	0	0	15
Poa caespitosa	25	10	15	15	35
Pine seedlings	15	5	10	10	15
Total Wt.	50	40	30	50	85
Wt. per hectare (Kg.)	33	27	20	33	57

APPENDIX 3.4: Condition of the undergrowth prior to burning - ground cover

Species	Mean cover (%)				
EUCALYPT PLOTS:	Plot A	Plot B	Plot C	Plot D	Plot E
Leucopogon microphyllus	13.4	6.2	6.4	2.4	4.4
Monotoca scoparia	6.6	4.6	2.0	7.4	9.2
Dillwynia retorta	5.4	4.8	11.4	0.2	0.6
Daviesia mimosoides	2.4	1.4	0.2	1.8	4.2
Daviesia uliciformis	0.4	1.8	0.0	10.2	8.8
Acacia buxifolia	0.0	1.6	0.4	3.2	2.6
Acacia vomeriformis	0.0	0.2	0.2	1.0	0.2
Brachyloma daphnoides	0.6	0.2	0.4	3.8	4.8
Hibbertia calycina	0.0	13.8	43.0	19.4	7.2
Hibbertia obtusifolia	2.4	2.0	0.6	1.2	3.6
Hovea heterophylla	0.6	0.2	0.4	0.2	1.2
Hardenbergia sp.	0.4	0.0	0.0	0.0	0.6
Tetratheca ericifolia	2.6	4.6	3.2	2.4	6.2
Lomandra longifolia	2.4	1.0	0.0	1.8	2.6
Stylidium graminifolium	3.0	2.6	0.4	1.2	1.6
Poa caespitosa	1.8	0.2	0.2	1.0	1.4
Eucalyptus seedlings	2.4	2.8	3.4	2.6	2.2
Total ground cover	44.4	48.0	72.2	59.8	61.4
PINE PLOTS:	Plot F	Plot G	Plot H	Plot I	Plot J
Cryptostemma sp.	0.3	0.0	0.8	0.7	1.0
Hydrocotyle sp.	0.5	0.3	1.0	0.8	0.7
Hardenbergia sp.	0.2	0.0	0.0	0.2	0.0
Lomandra longifolia	0.5	0.3	0.2	0.7	0.5
Poa caespitosa	1.2	2.5	0.8	2.7	1.7
Pine seedlings	0.3	0.5	0.5	0.7	1.5
Total ground cover	3.0	3.6	3.3	5.8	5.4

APPENDIX 4a: Fuel components and weights prior to the burn – Eucalypt and pine plots. Weights given in Kilograms per hectare

Plot No.	Miscellaneous litter	Ground vegetation	Total fuel
A	17,450	1,120	18,750
B	16,738	1,343	18,081
C	13,484	2,736	16,220
D	15,977	2,593	18,570
E	13,618	1,413	15,031
F	8,915	33	8,948
G	9,369	27	9,396
H	9,448	20	9,468
I	8,928	33	8,961
J	12,243	57	12,300

APPENDIX 4b: Fuel components and weights after the burn, and amounts and percentages of fuel consumed by the fire. Eucalypt and pine plots. All weights given in Kg/ha.

Plot No.	Miscellaneous litter	Ground vegetation	Total fuel	Total fuel consumed*	Percentage fuel consumption
A	1,421	301	1,722	16,848	90.8
B	13,907	1,517	15,424		
C	5,848	985	6,833	9,387	57.9
D	2,773	1,387	4,160	14,410	77.6
E	13,561	1,498	15,059		
F	1,748	0	1,748	7,200	80.5
G	2,526	0	2,526	6,870	73.1
H	2,769	0	2,769	6,699	70.8
I	11,410	27	11,437		
J	9,061	43	9,104		

APPENDIX 5: Soil profile description

SOIL PROPERTY	EUCALYPT PLOTS	PINE PLOTS
Colour	Horizon B: 5YR 5/8 to 2.5 YR 5/4	Horizon A_2: 5YR 7/1 to 5 YR 8/1 Horizon B: 5 YR 7/3 to 5 YR 4/6
Consistence	Friable to firm	Very friable
Texture	Sandy loam to clay loam	Silt loam to clay loam
Structure	Coarse granular to medium crumb	Coarse granular to fine granular
Stoniness	Gravelly	With few gravels
Mottles	Few to many	Few to many
Horizon differentiation	Diffuse to slightly distinct	Distinct
Depth of humified layer	0.5 cm. to 5.0 cm.	2.0 cm. to 6.0 cm.
Depth to hardpan	20 cm. to 90 cm.	15 cm. to 110 cm.
Field pH (colorimetric)	4.0 to 5.0	5.0 to 5.5

APPENDIX 6: Laboratory determination of soil particle density and calculation of soil porosity

Weigh a long glass vial empty as (Wt.A). Add 10g. of fine earth and weigh (Wt. B). Add water to the soil, with stirring to exclude air bubbles, and make up to mark in the vial (Wt. C). Wash away the vial contents, fill to mark with water and weigh (Wt. D). Calculate the particle density (Dp) from the equation :

$$Dp = \frac{B - A}{(D-A) - (C-B)}$$

Total porosity of soil was calculated from bulk density and particle density values as follows:

(a) The percentage of the soil solid fraction of the total soil volume is given by $\left\{\frac{Db}{Dp} \times 100\right\}$

where Db = bulk density.

(2) The above percentage taken from the total volume of soil (i.e. 100 percent) gives the percentage of pore space. Hence :

$$\% \text{ total pore space} = 100 - \left\{\frac{Db}{Dp} \times 100\right\}$$

APPENDIX 7: Meteorological data, fuel moisture contents and fire characteristics

Plot No.	Average temp. (°F.)	Rel. humidity (%)	Wind velocity (Km/h.)	Fuel moisture (%) Surface	Total	Rate of spread: headfire[1] (m/min.)	Range of flame heights (m)	Average flame height (m)	Average resistance time (min.)	Soil surface temp. (°F.)	Heat intensity (KJ/sec/m)
A	59.0	25	0.5–2.6	6.7	8.2	1.2	0.6–1.5	1.0	1.3	573.8	678
C	54.3	58	2.4–3.4	12.6	16.9	0.3	0.2–0.9	0.6	0.7	425.3	105
D	54.3	57	1.5–3.2	13.2	16.6	0.2	0.2–0.3	0.2	0.7	440.6	83
G	57.0	57	1.3–1.9	15.8	18.0	0.5	0.2–0.3	0.3	0.3	368.6	116
H	57.0	57	1.3–1.9	15.8	18.0	0.7	0.3–0.5	0.3	0.6	309.9	155
F	Measurements assumed to be in the range of data for plots G and H.										

[1] Rate of spread figures were derived from experimental fires on the plots and values are greater than the average for the burn.

APPENDIX 8: Concentrations of mineral elements - potassium, sodium, calcium, magnesium, iron, zinc, manganese, nitrogen and phosphorus - in undergrowth species (eucalypt site) determined by foliar analysis.

UNDERGROWTH SPECIES	CONCENTRATION (p.p.m.)								
	K	Na	Ca	Mg	Fe	Zn	Mn	N	P
Leucopogon microphyllus	1694	273	2986	660	244	2	828	457	123
Monotoca scoparia	2507	174	3361	940	307	1	871	619	105
Brachyloma daphnoides	2200	67	4582	876	162	2	1135	576	114
Dillwynia retorta	3350	104	5135	732	314	7	382	823	127
Daviesia mimosoides	5616	45	2899	1889	88	23	540	881	149
Daviesia ulicifromis	2539	111	2166	704	153	11	266	895	123
Hibbertia calycina	2781	80	4498	2666	816	13	418	516	114
Hibbertia obtusifolia	2638	126	3329	1845	724	26	427	472	144
Acacia buxifolia	2348	49	3170	960	329	7	100	1038	140
Acacia vomeriformis	4440	79	2341	1333	117	14	153	823	136
Tetratheca ericifolia	3946	156	4091	2026	347	9	509	472	141
Hovea heterophylla	3042	28	2970	3541	297	4	206	1067	166
Lomandra longifolia	9710	43	1302	1177	805	16	364	604	170
Stylidium graminifolium	10450	107	4487	2293	593	4	193	619	183
Poa caespitosa	7127	73	4044	1201	1142	16	188	531	241
Eucalyptus dives seedlings	2754	29	2915	2487	110	1	459	765	196

APPENDIX 9: Mean values of d.b.h. (cm.) for *Eucalyptus dives* and *Pinus radiata*. 95 percent confidence limits of the means are given in brackets

Plot Number	Pre-burn	Immediately after burn*	6 months after burn	12 months after burn
EUCALYPTUS DIVES:				
A	30.1 (24.7 – 35.5)	30.6 (25.3 – 35.8)	30.8 (25.5 – 36.2)	31.1 (25.8 – 36.4)
B	33.8 (30.3 – 37.4)	34.4 (30.8 – 38.0)	34.9 (31.2 – 38.6)	35.1 (31.4 – 38.7)
C	30.9 (26.5 – 35.4)	31.4 (26.9 – 35.8)	31.7 (27.2 – 36.2)	31.9 (27.3 – 36.4)
D	32.6 (27.7 – 37.5)	32.8 (27.9 – 37.7)	33.1 (28.2 – 38.1)	33.3 (28.4 – 38.2)
E	32.9 (27.1 – 38.6)	33.1 (27.4 – 38.8)	33.3 (27.6 – 39.0)	33.6 (27.8 – 39.4)
PINUS RADIATA:				
F	22.6 (21.7 – 23.6)	23.0 (21.9 – 24.2)	23.4 (22.2 – 24.5)	23.6 (22.5 – 24.7)
G	22.2 (20.7 – 23.7)	22.4 (21.0 – 23.9)	22.6 (21.0 – 24.1)	22.7 (21.2 – 24.2)
H	21.0 (20.0 – 21.9)	21.1 (20.2 – 22.1)	21.3 (20.2 – 22.3)	21.4 (20.4 – 22.4)
I	21.8 (21.0 – 22.7)	22.0 (21.2 – 22.8)	22.3 (21.5 – 23.1)	22.5 (21.6 – 23.4)
J	21.4 (20.5 – 22.3)	21.6 (20.8 – 22.5)	22.0 (21.1 – 22.9)	22.2 (21.3 – 23.1)

* Measurements about one week after the burn

Note: Burnt plots – A,C,D (eucalypt); F,G,H (pine)
Control plots – B,E (eucalypt); I,J (pine)

APPENDIX 10: Mean percentage canopy cover of eucalypt and pine plots. Eucalypt plots – A to E; Pine plots – F to J. 95 percent confidence limits of the means given in brackets

Plot Number	Pre-burn	Immediately after burn*	6 months after burn	12 months after burn
A	52.8 (44.6 – 60.9)	52.0 (39.3 – 64.7)	53.6 (38.5 – 68.7)	53.6 (47.9 – 59.3)
B	48.0 (35.3 – 60.7)	49.6 (43.9 – 55.2)	49.6 (35.3 – 63.9)	53.6 (41.6 – 65.6)
C	44.8 (38.3 – 51.3)	46.4 (42.0 – 50.8)	48.8 (38.0 – 59.6)	45.6 (39.9 – 51.3)
D	49.6 (43.9 – 55.3)	52.0 (47.0 – 57.0)	50.4 (44.7 – 56.1)	49.6 (42.1 – 57.1)
E	50.4 (44.7 – 56.1)	54.5 (48.7 – 60.1)	54.4 (48.7 – 60.1)	53.6 (41.6 – 65.5)
F	86.4 (80.7 – 92.1)	87.2 (81.7 – 92.6)	85.6 (78.1 – 93.1)	85.6 (79.9 – 91.3)
G	84.0 (77.9 – 90.1)	85.6 (78.9 – 92.3)	87.2 (83.0 – 91.4)	87.2 (83.0 – 91.4)
H	81.6 (75.9 – 87.3)	84.0 (79.0 – 89.0)	81.6 (75.9 – 87.2)	82.4 (79.7 – 85.1)
I	86.4 (83.6 – 89.1)	88.0 (84.5 – 91.5)	86.6 (80.2 – 92.0)	87.2 (83.0 – 91.4)
J	85.6 (81.2 – 90.0)	87.2 (83.0 – 91.4)	84.8 (74.6 – 93.0)	82.4 (70.7 – 85.1)

* Sampling one or two days after the burn

Note: Burnt plots – A,C,D (eucalypt); F,G,H (pine)
Control plots – B,E (eucalypt); I,J (pine)

APPENDIX 11: Mean percentage ground cover of eucalypt and pine plots. Eucalypt plots – A to E; Pine plots – F to J. 95 percent confidence limits of the means given in brackets

Plot Number	Pre-burn	Immediately after burn*	6 months after burn	12 months after burn
A	44.2 (34.9 – 53.5)	6.0 (3.0 – 9.0)	22.2 (19.0 – 25.4)	28.0 (22.5 – 33.5)
B	48.0 (39.4 – 56.6)	56.0 (41.4 – 70.6)	46.6 (34.9 – 58.8)	43.8 (33.0 – 54.6)
C	72.2 (65.4 – 78.9)	15.2 (11.1 – 19.2)	16.8 (15.2 – 18.4)	27.2 (21.0 – 33.4)
D	59.8 (55.2 – 64.4)	19.4 (15.1 – 23.7)	24.6 (20.5 – 28.7)	35.2 (16.5 – 53.9)
E	61.4 (55.2 – 67.6)	62.0 (57.4 – 66.6)	54.8 (41.9 – 67.7)	57.6 (33.9 – 81.2)
F	3.5 (1.9 – 5.1)	0.0 (0.0 – 0.0)	3.0 (2.1 – 3.9)	3.7 (1.7 – 5.6)
G	3.3 (0.8 – 5.9)	0.0 (0.0 – 0.0)	2.3 (1.2 – 3.4)	3.5 (1.3 – 5.7)
H	3.3 (1.8 – 4.9)	0.0 (0.0 – 0.0)	2.8 (0.7 – 5.0)	2.8 (1.0 – 4.6)
I	5.6 (3.6 – 7.7)	1.8 (0.8 – 2.9)	3.8 (2.3 – 5.4)	4.7 (1.1 – 8.3)
J	4.8 (1.8 – 7.8)	2.5 (1.1 – 3.9)	3.2 (1.6 – 4.7)	3.7 (2.0 – 5.4)

* Sampling one or two days after the burn

Note: Burnt plots – A,C,D (eucalypt); F,G,H (pine)
Control plots – B,E (eucalypt); I,J (pine)

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