Forest Research and Development Division
State Forests of NSW

LONG-TERM EFFECTS OF REPEATED PRESCRIBED BURNING ON FOREST INVERTEBRATES:
Management Implications for the Conservation of Biodiversity

Consultancy Report to the Department of
the Environment and Heritage

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Full credit must be given to Adrian van Loon who, in the 1950s, conceived and established a field trial which was sufficiently well designed and robust to not only be addressing questions still relevant 40 years later, but also sufficiently flexible to now facilitate questions probably not even conceived at that time. Similarly, much is owed to the Forestry Commission of New South Wales (State Forests) and its staff for the long-term maintenance of the trial, in particular Bill Buckler who methodically and reliably undertook routine measurements for over 20 years, and to Hugh Dowden, Bob Bridges and others who maintained and verified the enormous database.

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EXECUTIVE SUMMARY

BACKGROUND

Infrequent, periodic forest fires (bushfires) are an integral part of the modern physical environment of Australian sclerophyll forests. Low-intensity fires are extensively used in managed sclerophyll forests to stimulate regeneration, manipulate wildlife habitat and in particular, to reduce fuel levels with the intention of minimising the extent and severity of wildfires. In Australia, the use of deliberate fire to prevent high-intensity wildfires has become probably the most extensive use of fire in land management. The inherent variability in natural fire regimes generally results in a mosaic of habitats with vegetation at different stages of floristic and structural post-fire succession, each potentially supporting particular animal communities. Changes to the components of the fire regime (fire intensity, frequency and season of occurrence), as a consequence of forest management practices, have the potential to alter the composition and structure of natural communities. The research reported here deals with the impact of frequent low-intensity fire ("hazard-" or "fuel-reduction burning") on the abundance, richness, composition and structure of terrestrial invertebrate communities.

WHY INVERTEBRATES?

Invertebrates (insects, spiders, mites, worms, snails, centipedes etc.) are the most diverse and abundant animals in most natural systems, but their importance in sustaining those systems is commonly not appreciated. This multitude of organisms constitutes the bulk of the *biodiversity* within forests and plays an essential role in primary production, nutrient cycling and uptake, population & community level interactions and energy storage & transfer. Through their contribution to ecosystem function, these organisms also enable forest ecosystems to provide benefits to humanity. These benefits include amenity values in the form of aesthetics, recreation and education; heritage values as forests contribute to long-term security for catchment protection, air and water quality and nature conservation; and economic values including timber production, grazing and ecotourism. The maintenance of biodiversity is a fundamental principle underlying the ecologically sustainable management (ESM) of these environments.

THIS REPORT

Little is known about the effects of repeated hazard-reduction burning over long time scales. The research reported here was conducted as part of the Bulls Ground Frequent Burning Study (Experiment F8/2.9), located on the mid-north coast of New South Wales and established in 1969. The terrestrial invertebrate component of the project commenced in 1991 following 20 years of repeated low-intensity fire, and was undertaken with the following aims:

- to identify the effects of long-term repeated burning on terrestrial invertebrate biodiversity,
- to identify species and/or species groups most affected by this management practice and to devise strategies to ensure their continued conservation,
- to identify species which, due to the nature of their response, may be useful "indicators" of environmental disturbance and degradation.

The primary outcome was therefore to assess whether frequent hazard reduction burning is a sustainable long-term management practice with regard to the conservation of our forest biodiversity.

FREQUENT FIRE & HABITAT STRUCTURE

If frequent fire reduces the diversity of post-fire environments, then it has the potential to impact upon animal communities dependent upon this habitat mosaic. This research indicated that frequent burning resulted in a simplification of large-scale spatial patterning in the litter (fine-fuel) environment. The components (leaves, twigs, bark etc) that give the leaf litter its physical structure changed with regard to their relative abundance and spatial distribution. There were marked changes to the amount (cover) of vegetation in the understorey and its spatial patterning. While the quantity of vegetation closest to the ground (ground herbs & small shrubs) was not affected by frequent burning, there was a decrease in the spatial heterogeneity (patchiness) of these layers. Conversely, the cover of tall and very tall shrubs was substantially reduced and showed an increase in spatial heterogeneity. Top-soil moisture levels were, on average, 18% lower following 20 years of frequent burning, whereas the amount of light reaching ground level had increased (on average) by 125% and become more spatially homogeneous (less patchy). A number of habitat components (eg. top-soil hardness, the distribution of large sticks & logs) however showed no significant response to frequent burning.

TERRESTRIAL INVERTEBRATE COMMUNITIES

This study revealed a rich terrestrial invertebrate fauna with representatives from the Chelicerata (spiders, ticks & mites, pseudoscorpions, harvestmen), Crustacea (landhoppers, slaters), Chilopoda (centipedes), Diplopoda (millipedes), and a diverse array of Insect Orders and Families. Numerically, the most abundant groups overall were the springtails (33%), ticks & mites (24%) and ants (23%), with these three groups representing 80% of all individuals caught. For 10 broad taxonomic groups there were sufficient data to statistically test the effects of frequent burning. The results indicated a variety of responses with statistically significant decreases in abundance for ticks & mites (↓31%), insect larvae (↓35%), flies (↓58%) and beetles (↓31%). Many of these groups are associated with leaf litter and it is likely that their numbers have been influenced by the episodic removal of this resource. Three groups showed substantial increases in abundance following frequent burning; bugs (↑77%), ants (↑250%) and spiders (↑33%), probably as a response to both changes in habitat suitability and increased ease of capture in a simplified environment.

Biodiversity

Using ants, beetles, flies, spiders & bugs as representative groups and potential indicators of environmental degradation, this research demonstrated that although overall species richness at specific sites (α-diversity) did not change with frequent burning, all groups showed substantial changes in the composition of species assemblages. There was a loss of taxa dependent upon a substantial litter layer and stable moist conditions, and these species were frequently habitat or dietary specialists and often uncommon or "rare". The overall diversity of frequently burnt areas was maintained by the addition of species with broad tolerances, or adaptations, to drier and more open environments.

These shifts in community composition were substantial and suggested that the extensive and frequent application of fuel-reduction burning could result in a reduction in terrestrial invertebrate biodiversity at a regional scale, with this decrease potentially as high as 50%. Current fuel management strategies which limit the extent of frequent burning will ameliorate these impacts, however there remains a need to establish secure refuges for species with specialist requirements and limited dispersal abilities, and provide links (ie corridors) between habitat patches to facilitate recolonisation. The effectiveness of similar strategies developed to conserve vascular plants and vertebrates remains untested however for the groups which actually constitute the bulk of our forest biodiversity. Realistically, the conservation of biodiversity cannot be achieved without consideration of the important role that invertebrates play, both through their involvement in ecological processes, and as a significant component of the overall richness of biotic communities.

Community Structure & Ecosystem Function

The biological structure of a community involves species composition (diversity and relative abundance) and the relationships between species - their *ecological role*. It was demonstrated here that considerable additional detail concerning, and insight into, the nature of invertebrate community changes could be provided by the inclusion of fairly general information concerning habitat and dietary preferences. It was apparent that frequent burning leads to a change in the structure of the invertebrate community. Within species assemblages there were shifts based on feeding strategy and habitat preference. While the impact of these changes on ecosystem function was beyond the scope of this study, substantial measured changes in the structure of invertebrate assemblages and the loss of species associated with the decomposer cycle implies frequent burning may be impacting upon nutrient cycling and transfer within these forests. If this is the case, it would have serious implications with regard to the maintenance of ecological sustainability.

Biodiversity Indicators

Indices used to gauge the success of ecologically sustainable management practices need to be interpretable, significant and cost efficient. They also need to account for variability in space and time, and be appropriate for the scale of management. The research reported here identified the limited usefulness of data obtained using coarse-scale taxonomic classification (eg. Family or Order), with the cost-effectiveness of abundance data alone shown to be low. This research also identified substantial limitations with regard to the use of a single index, species richness, as a measure of change and/or environmental impact. Species richness (α-diversity) is frequently used to describe and compare communities, however in this case it was found to provide a deceptive summary of community characteristics and severely restrict the level of interpretation that could be derived for impact assessment purposes. The application of Rapid Biodiversity Assessment (RBA) methodology here demonstrated that the study of the composition and structure of communities is likely to prove more rewarding in this regard. The identification of individuals to distinct "morphospecies" facilitated the incorporation of broad-level ecological information into the assessment, and interpretation, of environmental impact. This in turn enabled the development of management recommendations consistent with the conservation of biological diversity.

Note:

Following the preparation of this report, there have been some taxonomic revisions and associated morphospecies corrections of the ant data. These have been independently published, however they were of a minor nature and do not alter the outcomes of the analyses or the conculusion drawn in this report.

1. INTRODUCTION

The concept of Ecologically Sustainable Development (ESD) was defined by the United Nations in 1987 as "… *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" ("Bruntland Report" - WCED 1987). This concept has been developed and refined regularly since that time, most recently at the "Earth Summit", the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. ESD forms part of the World Conservation Strategy (IUCN 1980) and is the basis for the National Conservation Strategy for Australia (Commonwealth of Australia 1983).

The conservation of biological diversity is a foundation of ESD and is one of the three core objectives of the Australian National Strategy for Ecologically Sustainable Development. Biological diversity refers to the variety of all life forms - the different plants, animals and micro-organisms, the genes they contain and the ecosystems of which they form part. Australia has ratified the Convention on Biological Diversity arising from the Earth Summit, and is now developing strategies to assess and protect its biodiversity. The conservation of biological diversity is a major objective of the National Forest Policy Statement (NFPS 1992), to be achieved through the protection of ecosystems (reserve strategies) and complementary off-reserve management (Ecologically Sustainable Management — ESM). In New South Wales, State Forests has put forward ESM as a major objective in its 1992–5 Corporate Plan (Forestry Commission of NSW 1992). This concept has been widely adopted by other land management agencies throughout Australia and forms part of the National Strategy for the Conservation of Australia's Biological Diversity.

Low-intensity fires are extensively used in managed sclerophyll forests to stimulate regeneration, manipulate wildlife habitat and in particular, to reduce fuel levels with the intention of minimising the extent and severity of wildfires. In Australia, the use of deliberate fire to prevent high-intensity wildfires has become probably the most extensive use of fire in land management (Whelan 1995). While infrequent, periodic fires (bushfires) are an integral part of the modern environment of Australian sclerophyll forests, there is growing concern that repeated low-intensity burning, as a management prescription, may have a negative influence on plant and animal communities. Frequent firing may remove vegetation species that rely on seed production for their persistence (Gill 1981; Bradstock and Myerscough 1981; Benson 1985; Fox and Fox 1986), often leading to dominance by herbaceous fire-tolerant species (Cary and Morrison 1995). Fire frequency becomes a significant factor for plant species requiring a long period of time (relative to the interval between fires) to reach reproductive maturity (Zedler et al. 1983; Nieuwenhuis 1987). Changes in habitat structure as a consequence of frequent burning are likely to disadvantage many native mammal and bird species (Catling 1991; Whelan 1995).

While sclerophyll forests, woodlands and heaths are dominated by plant species with adaptive responses to fire that enable them to survive exposure to periodic burning (see for example Gill 1981; Noble and Slatyer 1981), the impact of such fires on terrestrial invertebrates is poorly understood. The consumption of some or all of the leaf litter by flame, short-lived but substantial rises in soil temperature during fire, and post-fire changes in the surface radiation budget, mean that soil and litter fauna are substantially affected by fire in the short-term (Bornemisszа 1969; Springett 1979; Moulton 1982; Coy 1996). Recovery from a single fire may take up to 3-5 years (Metz and Farrier 1973; Seastedt 1984; Neumann and Tolhurst 1991), however the timing and intensity of burning is important, as is the mobility and recolonising ability of particular species (Morris 1975). Given the patchy nature of low-intensity fuel-reduction burns, and the protection afforded by small habitat refuges and within the soil, it has been suggested that periodic fires used for fuel management purposes have few long-term effects on most soil and litter invertebrates (Majer 1980; Campbell and Tanton 1981; Abbott et al. 1984).

There is little information on the effects of fire frequency on forest invertebrates, but Abbott et al. (1984) suggest that periodic low intensity fires have few permanent effects on most of the invertebrate taxa present in the litter and soil of the Jarrah forest. Long-term studies of spiders

(Huhta 1971; Merrett 1976) and ants (York 1994, 1996) suggest that, in the years following fire, there is a replacement series of groups of species related to their particular habitat requirements being met as the habitat changes in structure over time. A number of species persist throughout this period, but show changes in relative dominance within the community. York (1996) suggested that, for ants, the use of regular widespread fires for fuel reduction was likely to result in a truncation of these successional patterns and an associated loss of regional biodiversity.

Periodic low-intensity fire (hazard-reduction burning) is a conspicuous management strategy in virtually all of Australia's dry forest communities. While it is primarily used to reduce fuel levels, little is known about the effects of its repeated use on natural ecosystems over long time-scales. On the east coast of NSW, extensive wildfires in January 1994 have led to calls for increased use of hazard-reduction burning, however the impacts of the resulting increase in fire frequency are poorly understood in the very forest environments this management strategy seeks to protect. The paucity of information available on the effects of increased fire frequency on forest invertebrates is of considerable concern. Invertebrates constitute 95% of known species of fauna in Australia, thereby making a substantial contribution to our National biodiversity (New 1984; CONCOM 1989). Realistically, the conservation of biodiversity cannot be achieved without consideration of the important role that invertebrates play, both through their involvement in ecological processes, and as a significant component of the overall richness of biotic communities.

The research reported here was therefore undertaken with the following aims:

- to identify the effects of long-term repeated burning on terrestrial invertebrate biodiversity,
- to identify species and/or species groups most affected by this management practice and to devise strategies to ensure their continued conservation,
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The primary outcome is therefore to assess whether frequent hazard reduction burning is a sustainable long-term management practice with regard to the conservation of our forest biodiversity.

2. METHODOLOGY

2.1 STUDY AREA

As part of the F8 series of “fire effects” studies, State Forests has an ongoing experimental project which is particularly suitable for addressing questions relating to repeated disturbance and biodiversity conservation. The F8/2.9 Frequent Burning Study is located in even-aged coastal blackbutt *Eucalyptus pilularis* regeneration in Compartment 70, Bulls Ground State Forest, Kendall Management Area on the mid-north coast of New South Wales (31°33'S, 152°38'E, 240m ASL.). The stand was logged and silviculturally treated in 1958–9, with seed trees retained singly and in groups, and unmerchantable trees culled in line with Timber Stand Improvement (T.S.I.) techniques. The area has experienced no further management treatment (except experimental fuel-reduction burning) since that time.

In 1969 twenty-one 0.225 acre (0.1 ha.) temporary plots were established in openings created by the logging treatment which carried a good stocking of young blackbutt regrowth (11 years old). These areas were found to support a mean number of 339 stems per hectare (Van Loon 1970), consisting mainly of blackbutt (48%) and bloodwood *E. gummifera* (31%). The remainder (21%) consisted most commonly of turpentine *Syncarpia glomolifera*, red mahogany *E. resinifera*, white mahogany *E. acmeniodes* and grey gum *E. punctata*. Following an assessment of stand parameters, a number of these plots were selected on the basis of their similarity for a long-term fire study (F8/2.9), which was formally initiated in March 1970.

Fourteen 0.1 ha. permanent research plots were established, 7 randomly allocated as burning treatments (**burnt**), the remaining 7 as control (**unburnt**) plots from which fire was excluded (7×2 randomised block design). These study plots were located within similarly treated forest blocks of approximately 1 ha. and separated by cleared buffer areas to protect them from wildfire (see Figure 2.1). For the remainder of this report the term “plot” refers to the 1 ha. treated forest areas, while “research plot” refers to the 0.1ha study plots defined in 1970 (see Figure 2.2). Fuel reduction burning was implemented in Autumn whenever fuel build-up permitted, generally every 3 years (1970, 1973, 1977, 1980, 1983, 1986, 1989, 1992). This burning regime is ongoing.

A program was instituted to monitor aspects of the response of this forest to repeated low-intensity fire. A number of parameters were regularly measured on each research plot: tree growth, major and minor understorey vegetation, litterfall, and fine and heavy fuel. These measurements were made systematically between 1970 and 1987, when the project was reviewed; and then less frequently until 1992.

2.2 EXPERIMENTAL DESIGN

From an inspection (by the author) of the area in 1990 it was apparent that twenty years of repeated burning had resulted in substantial changes in macro- and micro-habitat parameters. It was hypothesised that these changes would have had a significant effect on terrestrial invertebrate communities. In 1991, two years after the last fire, a project was initiated to assess the impact of long-term fuel reduction burning on terrestrial invertebrates, and to investigate the possibility of using this faunal group as monitoring agents in the assessment of ecologically sustainable management. The overall approach was to view this single sample period as a “snapshot” of the effects of 20 years of prescribed burning by comparing burnt and unburnt replicates. While this does not enable a description of changes over time, it does provide a unique opportunity to assess the long-term impact of this management practice.

Twelve of the fourteen plots were selected as suitable, six within each treatment (**unburnt** & **burnt**). Plots 7A and 7B were excluded as they contained rocky outcrops and were subjectively assessed to be different to other plots. Randomised assignment of treatments to experimental units ensured “true” replication of treatment effects (see Hurlbert 1984). In order to increase the sensitivity of the experiment by increasing the “precision” with which properties of each experimental unit (plot) and hence each treatment were estimated, it was necessary to take multiple samples from each plot. Four 20m transects were therefore established within each

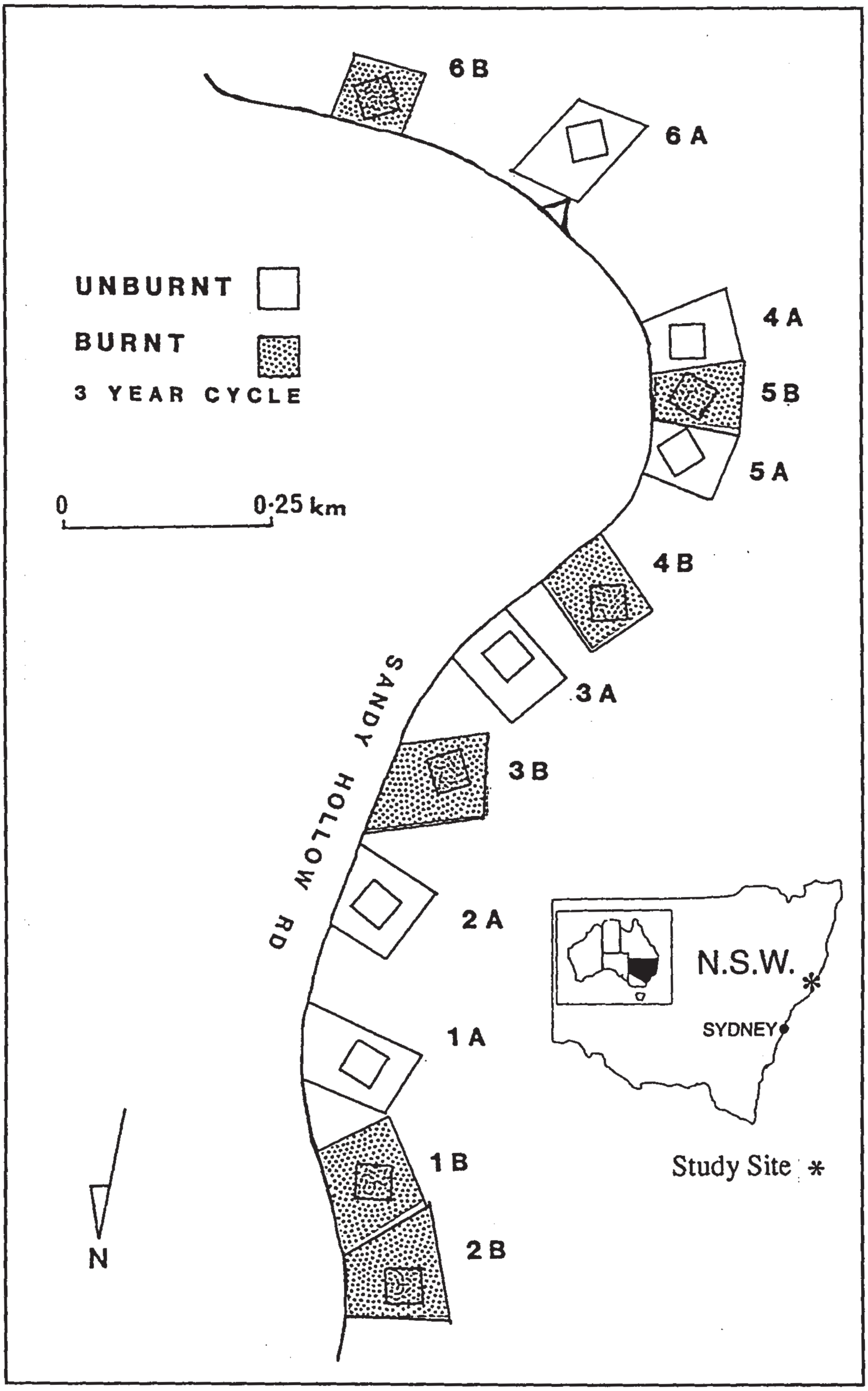

Figure 2.1 F8/2.Frequent Burning Study, Bulls Ground State Forest. Location of study plots. (Plots 7A and 7B not shown).

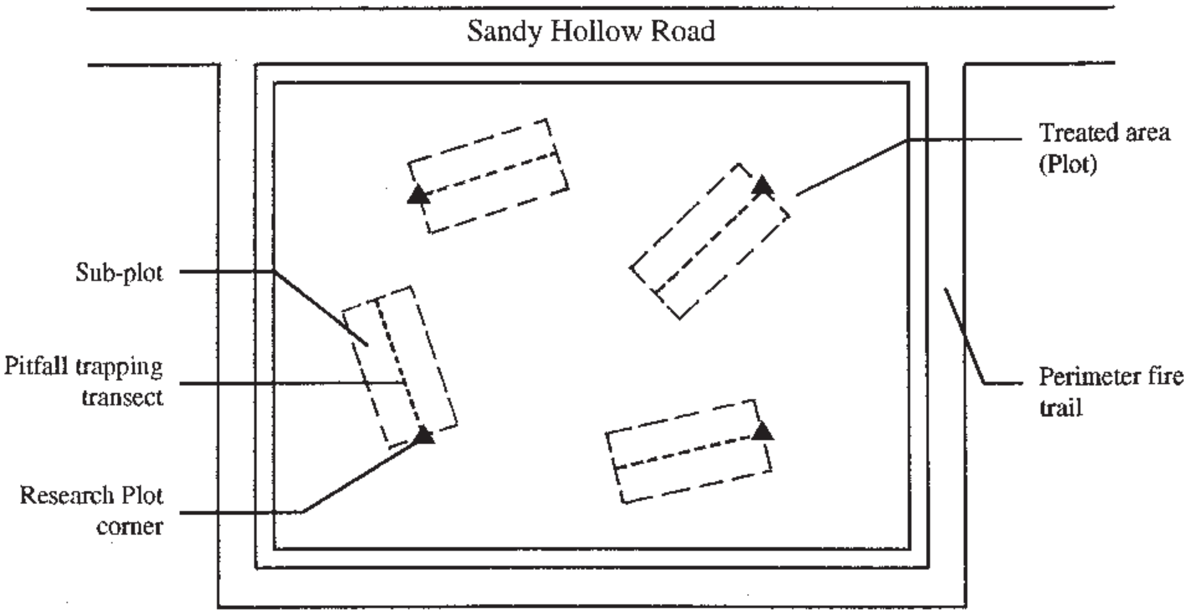

Figure 2.2 Schematic layout of study "plot"

plot (a "nested" design), each on a randomly-oriented compass bearing starting from each corner of the established "research plot". A 20m×10m sub-plot was then centred on this transect (see Figure 2.2) in order to assess the small-scale variability of measured parameters.

The general physical characteristics of each sub-plot were summarised by measurements of ground slope and aspect. The average slope of the site in degrees below the horizontal was determined with a hand-held clinometer, while the aspect was determined by use of a compass. The sub-plots had low slope angles (0–9) and predominantly north-west to south-west aspects (see Table 2.1). On average, burnt sites had slightly steeper slopes, primarily plots 4, 5 & 6. The differences in slope however were slight and reflect the ridge-top nature of the study area. The range of aspects was similar for both treatments.

Table 2.1 Slope and aspect of study plots

		Unburnt		*Burnt*	
Plot	*Sub-plot*	*Slope°*	*Aspect°*	*Slope°*	*Aspect°*
1	1	1	290	1	220
	2	1	300	1	220
	3	0	325	2	245
	4	1	330	3	210
2	1	1	250	2	320
	2	3	240	5	300
	3	3	260	2	340
	4	0	360	3	310
3	1	2	290	2	310
	2	4	330	2	315
	3	1	290	1	290
	4	0	280	4	310
4	1	1	210	2	250
	2	3	240	9	285
	3	3	195	5	265
	4	1	200	5	270
5	1	1	225	2	275
	2	2	280	4	270
	3	0	270	2	255
	4	2	275	6	270
6	1	0	360	7	225
	2	1	230	7	200
	3	1	210	2	200
	4	1	220	3	220
Range		0–4	195–360	1–9	200–340
Mean±s.e.		1.4±0.2	269±10	3.4±0.4	26±69

2.3 MEASUREMENT OF ENVIRONMENTAL PARAMETERS

The environmental framework within which terrestrial invertebrate communities function primarily involves elements of the vegetation understorey, the top-soil and litter components. A number of parameters were quantitatively assessed to evaluate their possible influence on species richness and community structure.

The distribution of data for most variables suggested that the sample mean was the best estimate of average conditions at each sub-plot. Because individual samples were randomly drawn from within replicates, a measure of variability about the mean also provided information about the spatial variability ("patchiness") of the variables concerned. The coefficient of variation (CV = standard deviation/mean × 100%) was selected as the most appropriate measure here due to the large fluctuations in mean values and the observed dependence of the standard deviation on the mean. In order to satisfy the assumptions underlying particular statistical procedures, variables were appropriately transformed as required.

2.3.1 Understorey Vegetation Structure

The physical structure of the vegetation understorey in this forest environment consists primarily of a shrub stratum and a herb stratum whose heights and spatial distribution are a function of fire history. A structural classification of the vegetation was chosen because it allowed a relatively quick and consistent assessment of the sites (48 sub-plots in total) to be made in an environment which is floristically diverse (Doug Binns *pers. comm.*). Vegetation structure is of direct significance in ecological studies of soil and soil-surface invertebrates because the amount and distribution of vegetation determines both the physical framework within which activity takes place, and the food availability and hence carrying capacity of the environment (Greenslade and Thompson 1981).

Vegetation structure was quantitatively assessed using the "cover-board" technique (see MacArthur & MacArthur 1961; Fox 1979). Percentage cover was measured at 20 points systematically located along each transect for five structural components of the understorey (see Table 2.2). The mean of the 20 measurements was used as an estimate of percentage cover for each vegetation layer at each sub-plot, and the coefficient of variation (CV) as an estimate of spatial variability.

Table 2.2 Structual vegetation components

Height class	Structural component
0–20 cm	Ground herbs
20–50 cm	Small shrubs
50–100 cm	Mid-sized shrubs
100–150 cm	Tall shrubs
150–200 cm	Very tall shrubs

2.3.2 The Litter Environment

Ground-dwelling invertebrates have been shown to be sensitive to levels of forest litter, particularly during post-fire recovery (Bornemisszza 1969; Springett 1976; Seastedt 1984). Five randomly placed samples (0.1 m^2) of litter (including sticks up to 2.5cm diameter) were collected from each sub-plot, sieved with 1mm soil sieves to dislodge soil material, and then dried in an oven at 105° for 72 hours. Material was then sorted into 5 components and weighed: twigs 0–5mm & twigs 6–25mm diameter, bark, leaves, and very fine fuel (miscellaneous decomposing matter). This approach was consistent with that used to estimate the "fine fuel" fraction over the previous 20 years.

2.3.3 Sticks and Logs

The incidence and diameter of all sticks & logs ("heavy fuel", >2.5cm) was recorded along 2 orthogonal 20m transects centred on each sub-plot. Following an examination of the frequency distribution of values, data were grouped for subsequent analyses into the following five diameter categories: 2.5–9.9, 10–24.9, 25–49.9, 50–74.9, 75+cm.

2.3.4 Insolation

Levels of insolation have been shown to be critical factors determining the abundance and distribution of certain terrestrial invertebrates. The amount of light reaching the forest floor was used as an index of insolation levels, and measured using a *Lunasix 3* Gossen exposure meter, fitted with incident light cone. Twenty measurements were taken systematically within each sub-plot and expressed as a percentage of available light as measured outside the forest at that time of day.

2.3.5 The Soil Environment

The underlying geology of the site consists primarily of conglomerate, sandstones and shales. These have weathered to form shallow soils (yellow earths & brown podzolics) which are relatively low in nutrients. Two aspects of the soil physical environment were assessed: top-soil moisture and top-soil hardness.

2.3.5.1 Top-soil Moisture

Five samples (10cm diameter 3cm deep) per sub-plot were collected and kept in sealed containers. Samples for each sub-plot were pooled in the laboratory, weighed and dried in an oven at 105° for 72 hours. An estimate of "field moisture content" for each sub-plot was calculated in the following manner (see Lambert 1982):

$$\% \text{ Moisture Content} = \frac{\text{air-dried weight - oven dried weight}}{\text{air-dried weight}} \times 100$$

2.3.5.2 Top-soil Hardness

An index of top-soil hardness (0–5cm) was obtained using a *Geonor* inspection vane, which measures soil shear strength. Twenty measurements were taken within each sub-plot, the mean value representing the average shear strength and the coefficient of variation (CV) an indication of spatial variability.

2.4 TERRESTRIAL INVERTEBRATE COMMUNITIES

Epigaeic (surface active) invertebrate communities were assessed by a single summer pitfall trapping program in February 1991. Nine points were established and marked along the 20m transect within each sub-plot. At each point a 6.5cm diameter 9cm deep plastic cup was sunk flush with the ground surface and half-filled with a non-attractive preservative solution. Pitfall traps were left open for a period of 7 days (5–12th February 1991), reducing the effect of temporal changes in abundance and activity on estimates of species richness and community composition (York 1989). Weather during this period was typical for that time of year; temperatures ranged from 17–35°C and 27mm of rain fell between the 7th and 8th.

Samples were returned to the laboratory and examined with a binocular microscope where material was sorted to the taxonomic level of Order. A number of groups were chosen for more detailed investigation based on the criteria of sufficient numbers for statistical analysis, the ability to recognise and define species, and the likely appropriateness of the sampling methodology. Ants (Hymenoptera: Formicidae), beetles (Coleoptera), spiders (Araneae), bugs (Hemiptera) and flies (Diptera) were subsequently sorted to "morphospecies" using the protocols described in Oliver & Beattie (1993), with final taxonomic verifications being performed by Mike Gray (spiders), Gerry Cassis (bugs) and Dan Bickel (flies) of the Australian Museum, John Lawrence (beetles) and Robert Taylor (ants) of the CSIRO.

Oliver and Beattie (1996a) have shown that morphospecies can provide a robust estimate of species richness across a variety of habitats. This study provides a substantial test of the hypothesis that the lack of knowledge concerning so many Australian invertebrates, the so called "taxonomic impediment" (Taylor 1983), no longer prevents the inclusion of invertebrates in biodiversity assessment and studies of management impacts.

2.5 ANALYTICAL PROCEDURES

All initial analytical procedures were performed using the SPSS statistical package on a 486PC at SFNSW's Research Division. Data distributions were examined using exploratory data analysis techniques (*EXAMINE*) and transformed (as required) for subsequent analyses (*MANOVA* and *REGRESSION*). Canonical Correspondence Analyses (*CCA* - Ter Braak 1986) were performed using programs written in *Splus* on a Sun Workstation.

2.5.1 Treatment, Exposure and Position Effects

Plots had been allocated to one of two *treatments*: **burnt** (1B-6B) or **unburnt** (1A-6A). Aspect values were coded from 1-6 to reflect the relative "exposure" of sub-plots to solar radiation; with 300–330° = 1 (highest), 270–300° = 2, 330–360° = 3, 240–270° = 4, 210–240° = 5, and 180–210° = 6 (lowest). Sites intermediate between categories were allocated an average (mean) code.

To evaluate any large-scale spatial trend in habitat variables (and species' responses) a new variable (*position*) was generated to reflected the north-south location of plots along Sandy Hollow Road (see Figure 2.1). The value of *aspect* and *position* for each plot ranged from 1-6 (see Table 2.3).

Table 2.3 Values of *exposure* and *position* for each sub-plot. Aspect was coded from 1-6 to reflect the relative exposure of sub-plots to solar radiation (see text). Position was coded from 1 (north) to 6 (south) to reflect location along Sandy Hollow Road (see Figure 2.1) so as to detect possible spatial patterns.

			Exposure (sub-plots)			
Treatment	*Plot*	*Position*	*1*	*2*	*3*	*4*
Unburnt	1A	1	2	1.5	1	2
	2A	2	4	4.5	4	3
	3A	3	2	2	2	2
	4A	5	5.5	4.5	6	6
	5A	4	5	2	3	2
	6A	6	3	5	5.5	5
Burnt	1B	2	5	5	4	5.5
	2B	1	1	1.5	3	1
	3B	3	1	1	2	1
	4B	4	4	2	4	3
	5B	5	2	3	4	3
	6B	6	5	6	6	5

Patterns in environmental parameters at plots differing in *treatment* and *position* were examined graphically, and using Analysis of Variance (ANOVA) procedures. For frequency data, the degree of association between variables was examined using contingency tables (crosstabulation), with significant associations tested using the χ^2 statistic.

2.5.2 Inter-relationships Between Environmental Variables

The environmental (habitat) variables were subsequently analysed using an ordination procedure (Principal Components Analysis - PCA) in order to untangle linear relationships between variables, and reflect inherent structural patterns. In this analysis, each pattern appears as a component delineating a distinct cluster of interrelated data. Components are rotated orthogonally (*VARIMAX* procedure) to clarify the definition of these clusters by maximising or minimising correlations between variables and components. The projection (the loadings) of each variable on the component axes defines the clusters of variables. Kaiser's criterion (only the components with eigenvalues greater than one) was used to determine the number of components to be extracted. Eigenvalues measure the amount of variation accounted for by a pattern, while the loadings measure the degree to which variables are involved in the component pattern. The first component delineates the largest pattern of relationships in the data (defines the greatest amount of variation in the data); the second delineates the next largest pattern and so on.

2.5.3 Terrestrial Invertebrate Communities

Samples were sorted to Order using morphological characteristics and general taxonomic keys. Relative abundance of individuals within these groups at plots differing in *treatment* and *position* were examined using Analysis of Variance (ANOVA) procedures.

2.5.3.1 Biodiversity

Selected taxa (see 2.4) were described in terms of the relative abundance of individuals within constituent groups (families, sub-families, genera etc. as appropriate), and their species richness (as defined by morphospecies). Patterns in these community descriptors at plots differing in *treatment* and *position* were examined graphically, and using Analysis of Variance (ANOVA) procedures.

2.5.3.2 Community Composition

Patterns of species' responses to treatments are illustrated in tables of relative abundance. This enabled broad "assemblages" of species, with similar responses to disturbance, to be identified.

2.5.3.3 Environmental Determinants of Community Composition

The relative importance or ability of the measured habitat variables to explain the composition of invertebrate assemblages was assessed using Canonical Correspondence Analysis (CCA, Ter Braak 1986, 1991). This method arranges species along environmental gradients by constructing linear combinations of environmental factors which result in maximal separation of species' distributions in ordination species-space. These analyses were performed to determine whether any differences in turnover or spatial similarity of assemblages among taxa might be explained by the different taxa responding to environmental gradients. Ter Braak (1986) fully describes the underlying assumptions and strengths of this method. The main assumption is that individual species response models are all similar and of unimodal, Gaussian form. Although it is doubtful whether this assumption is reasonable for all species, CCA has been shown to be robust to moderate violations of assumptions (Palmer 1993) and offers the potentially most powerful method available in revealing patterns of community composition in relation to environmental factors. It also has the advantage that the results are unaffected by correlations among environmental variables.

Results of the CCA ordination were displayed as "bi-plots" which show the configuration of the variables, the scatter of sub-plots, and the relationship between the two. This gives an overview of how community composition varies with the environment (Ter Braak 1986). The interpretation of the results of the bi-plots was simplified by using a sub-set of the environmental variables in the analyses. This sub-set was composed of representative variables from each of the eight independent patterns identified by the Principle Components Analysis (see 2.5.2), with the additional inclusion of two largely independent variables: aspect and insolation.

2.5.3.4 Community Structure

Analyses of species' "assemblages" often fails to adequately account for rare species, which are frequently represented by too few records to allow any meaningful patterns to be determined (see York 1994). One common means to overcoming this problem, at least to some extent, is to group species according to some ecological characteristic, so that the collective behaviour of the group can be assessed. At the species level there is insufficient ecological information for most groups to do this with confidence, however broad grouping may be identified at higher taxonomic levels, such as sub-family or family. Broad groups of this kind (functional groups) were identified in this analysis by reference to the literature (eg. see Andersen 1990) and following discussions with relevant taxonomists. The numbers of morphospecies within these groups was graphically presented and examined in order to detect those which may be sensitive to microhabitat features associated with structural characteristics of the environment.

Additionally, the relative abundance of species recorded in one treatment only was displayed in tabular form and discussed in relation to their likely ecological roles.

2.5.3.5 Biodiversity Indicators

Decisions regarding conservation evaluation often are based upon the diversity (species richness) of the area under concern (see Margules et al. 1988). Similarly, species richness is a common "performance indicator" used for monitoring disturbance impacts (see Kremen 1992). In order to simplify these processes, it is often hypothesised that one taxonomic or functional group may reflect the response of other taxa, and hence function as "indicator" or "umbrella" species.

To test whether the richness of particular invertebrate taxa could be useful in predicting overall invertebrate biodiversity, the relationship between species richness of selected taxa was investigated using correlation analyses (Pearson's Product-Moment and Spearman's Rank).

Forest area one day after a low-intensity fuel-reduction burn. The small areas of leaf litter and unburnt understorey vegetation remaining indicate the patchy nature of such burns. These represent potential refuges for terrestrial invertebrates; refuges that are reduced in number and extent by frequent fire. /Alan York

Dry eucalypt forest that has remained unburnt for over 25 years. These forests are characterised by deep leaf litter and low light levels. /Alan York

Dry eucalypt forest that has been frequently burnt for the past 25 years. These forests are very open and characterised by low leaf litter levels and high light levels. /Alan York

A spider from the Family Zodariidae. These spiders typically live under stones, logs and in leaf litter. There were four times as many species from this Family on frequently burnt plots, suggesting that they prefer these more open habitats in which to hunt. /Alan York

A spider from the Family Salticidae. These "jumping spiders" hunt for their food on understorey vegetation, trees and logs. The two species from this Family were only found on unburnt plots, suggesting that they prefer habitats with more structurally complex vegetation in which to hunt. /Alan York

A spider from the Family Lycosidae. These "wolf spiders" are ground hunters. All three species from this Family were only found on frequently burnt plots, suggesting that they prefer these more open habitats in which to hunt. /Alan York

This is a species of ant known as *Rhytidoponera metallica* which is an "opportunist" commonly found in disturbed habitats. In this study it was 500 time more abundant on frequently burnt sites, potentially indicating that frequent burning is having a negative impact on the environment. /Alan York

An ant from the genus *Probolomyrmex*. It is a rare "cryptic" species that was only found in leaf litter samples collected from one site. Little is known about its habitat preferences, although it is not thought to be disadvantaged by frequent burning at this stage. /Alan York

An ant from the genus *Orectognathus*. These ants are specialist predators who use their long mandibles to catch soft-bodied insects such as Springtails (Collembola). Because of their specialist habitat requirements, they were not caught in pitfall traps but only in leaf litter samples collected from near large logs on unburnt sites. They were not found on frequently burnt sites. In these forests they could be considered an uncommon species with high conservation status. /Alan York

3. RESULTS

The results for the various components of the project are reported separately, and then discussed in terms of their relevance to the existing experimental fire regime.

3.1 ENVIRONMENTAL PARAMETERS

The following sections summarise the results of an investigation into the effects of frequent burning on environmental variables as they relate to components of terrestrial invertebrate habitat. Where differences are described as "significant", this refers to statistical significance at a probability level of 0.05. Where results were not considered to be statistically significant, the general nature of any observed patterns is described. "Box and Whisker" plots are utilised to graphically represent variation in environmental variables. The box represents the interquartile range (25th–75th percentile) with the median shown. The whiskers indicate the range of values which lie within 1.5 box lengths of the upper and lower quartile (75th and 25th percentile respectively).

3.1.1 Understorey Vegetation Structure

3.1.1.1 Ground Herb Layer

The cover of Ground Herbs (0–20cm) on sub-plots showed considerable variation overall (means ranged from 29–98%) with average (mean±s.e.) values for **unburnt** and **burnt** plots 72.5±1.5 and 80.1±1.3 respectively. Cover of Ground Herbs was less variable ("patchy") on **burnt** plots.

Mean values of Ground Herb cover were not significantly different between **burnt** and **unburnt** plots, however there were significant spatial trends, with patterns quite variable and independent of *treatment* and spatial location (*position*) within the study area (see Figure 3.1A).

3.1.1.2 Small Shrub Layer

The cover of Small Shrubs (20–50cm) on sub-plots showed considerable variation overall (means ranged from 12–91%) with average (mean±s.e.) values for **unburnt** and **burnt** plots 49.5±1.7 and 57.7±1.6 respectively. Cover of Small Shrubs was less variable ("patchy") on **burnt** plots.

Mean values of Small Shrub cover were not significantly different between **burnt** and **unburnt** plots, however there were significant spatial trends, with patterns quite variable and independent of *treatment* and but not spatial location (*position*) within the study area (see Figure 3.1B).

3.1.1.3 Mid-sized Shrub Layer

The cover of Mid-sized Shrubs (50–100cm) on sub-plots showed considerable variation overall (means ranged from 2–47%) with average (mean±s.e.) values for **unburnt** and **burnt** plots 14.3±0.8 and 14.5±0.8 respectively. Cover of Mid-sized Shrubs was similarly variable ("patchy") on **burnt** and **unburnt** plots.

Mean values of Mid-sized Shrub cover were not significantly different between **burnt** and **unburnt** plots, however there were significant spatial trends, with patterns quite variable and independent of *treatment* and but not spatial location (*position*) within the study area (see Figure 3.1C).

3.1.1.4 Tall Shrub Layer

The cover of Tall Shrubs (100–150cm) on sub-plots showed moderate variation overall (means ranged from 2–12%) with average (mean±s.e.) values for **unburnt** and **burnt** plots 5.5±0.4 and 1.9±0.2 respectively. Cover of Tall Shrubs was less variable ("patchy") on **unburnt** plots.

Mean values of Tall Shrub cover were significantly different between **burnt** and **unburnt** plots, with substantially lower cover on frequently burnt plots. There were however significant spatial trends, with patterns quite variable and independent of *treatment* and but not spatial location (*position*) within the study area (see Figure 3.1D).

3.1.1.5 Very Tall Shrub Layer

The cover of Very Tall Shrubs (150–200cm) on sub-plots showed moderate variation overall (means ranged from 0–10%) with average (mean±s.e.) values for **unburnt** and **burnt** plots 2.8±0.3 and 0.2±0.6 respectively. Cover of Very Tall Shrubs was less variable ("patchy") on **unburnt** plots.

Mean values of Very Tall Shrub cover were significantly different between **burnt** and **unburnt** plots, with substantially lower cover on frequently burnt plots. There were however significant spatial trends, with patterns quite variable and independent of *treatment* and spatial location (*position*) within the study area (see Figure 3.1E).

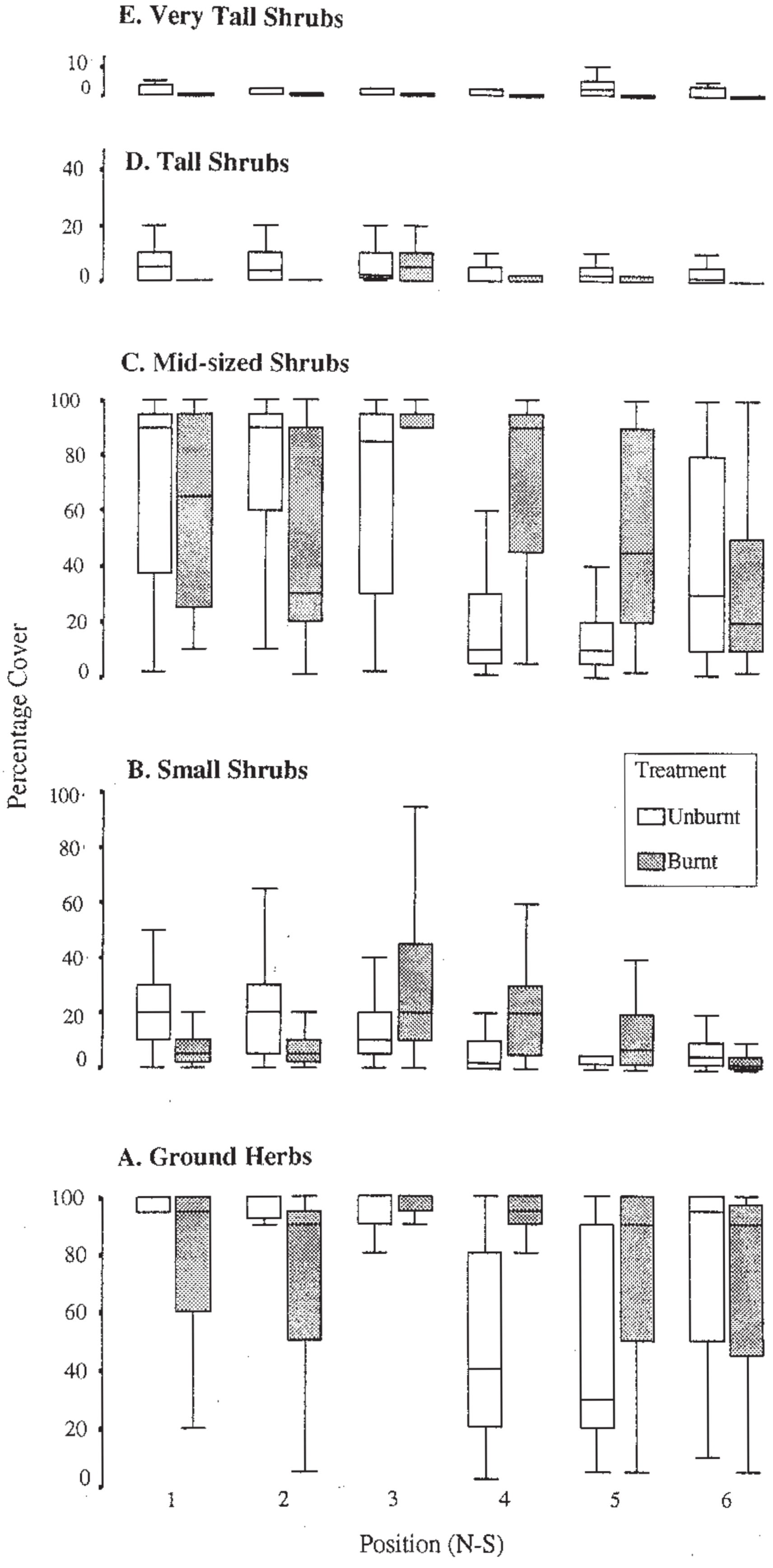

Figure 3.1 Understorey Vegetation Structure