Fire Management
Department of Natural Resources and Environment
ISBN 0 7311 4239 X

# FUEL HAZARD LEVELS IN RELATION TO SITE CHARACTERISTICS AND FIRE HISTORY - CHILTERN REGIONAL PARK CASE STUDY

**Research Report No. 43**

Karen Chatto
CFTT - Creswick Research Station
October 1996

Production of this report was supported by Parks Victoria.

## SUMMARY:

Fire behaviour varies with changes in topography, weather and fuel. Of these three aspects, humans can only modify fuel. Fuel reduction burning aims to reduce the fire hazard by modifying fuel structure and quantity.

In recent years, the local Municipal Fire Prevention Committee, Friends of Chiltern Regional Park and the public have expressed concern about the high fuel quantities throughout Chiltern Regional Park.

Field sampling took place in mid-January 1995, assessing fine fuel depth, surface fine fuel quantity, bark hazard and elevated fuel hazard. Forest fuels were destructively sampled and the fine fuel component of the fuel was analysed. This component significantly affects fire behaviour. Bark hazard and elevated fuel hazard were assessed at each site as they also affect fire behaviour. Fuels were sampled across three overstorey vegetation classes, ten fire history classes and three site productivity classes. This study examined fine fuel accumulation rates across Chiltern Regional Park, determined fine fuel, bark and elevated fuel hazard levels, and mapped the Overall Fuel Hazard levels. This report summarises the findings of this assessment and recommends future management strategies.

A linear relationship was found between surface fine fuel load and litter depth, with depth explaining 89% of variation in fine fuel quantities of sites with Low to Moderate elevated fuel hazard. A negative exponential model was used to determine the relationship between each fuel component and time since fire. Within 3 years of fire, surface fine fuel loads had reached 95% of their predicted steady state levels, with only a Moderate surface fine fuel hazard being predicted as the steady state level for all productivity sites and forest types. Within 9 years of fire, elevated fuel loads had reached 95% of their predicted steady state levels. Despite taking three times as long as the surface fine fuel to re-accumulate, the elevated fuel has the potential to become a greater fuel hazard that the surface fine fuel. Bark hazard showed no relationship with time since fire, indicating that past prescribed fires have not had an effect on bark hazard. Bark hazard was related to forest types, being greatly influenced by the presence of stringybark. Areas of Very High bark hazard were of the Ironbark/Stringybark forest type, whilst those areas of Moderate hazard levels were of the Gum/Box forest type.

Across the three forest types studied, all three have reached their potential Overall Fuel Hazard at the time of this study. Of the three classes, only the Ironbark/Stringybark forest type exceeds the recommended level of High for areas classified as Fuel Management Zone 2. Future fuel reduction operations should be aimed at reducing bark hazard and elevated fuel hazard in these areas, whilst taking into consideration any ecological requirements.

## INTRODUCTION

Forests near urban developments can potentially provide some of the most fire hazardous areas in Australia, in terms of loss of lives and assets (Simmons and Adams 1986). Of the three factors that influence fire (topography, weather and fuel), fuel is the only factor that can be modified or manipulated by humans. Low intensity prescribed fires are regularly used in Victoria to reduce the quantity of surface fine fuel in forests. However in recent years, studies have shown that such fires may only reduce the surface fine fuel quantities for 2 to 4 years before reaching pre-fire levels (Tolhurst *et al.* 1992).

Fuel characteristics are incorporated into the majority of fire behaviour prediction models, with fuel quantity being the most emphasised parameter in Australia (McCaw 1988). Fuel quantity has been used to predict fire behaviour, in particular the intensity of the fire (Peet 1971, Luke and McArthur 1978, Raison *et al.* 1983, McCaw 1988) and forward rate of spread (Luke and McArthur 1978). Three components of available fuel were investigated in this study; surface fine fuel, bark fuel and elevated fuel. Fine fuels are those fuels that are consumed by the fire front, including dead litter less than 6 mm in thickness and live vegetation less than 2 mm in thickness. It is the fine fuels that will carry a fire. The accumulation of forest surface fine fuel is dependent on the species and the environment in which decay occurs (Walker 1981, Raison *et al.* 1983). Bark fuel is considered to be the component of bark held on trees which may contribute to spotting. This is dependent on the surface texture of the bark and the condition of the bark on the trees (Wilson 1992). Spotting causes new fires to ignite by sending airborne firebrands or embers ahead of the main fire (Luke and McArthur 1978). Elevated fuels include shrubs, heath, wiregrass and suspended dead litter (Wilson 1993). This component, in conjunction with surface fine fuel, influences the flame height, fire intensity (Raison *et al.* 1983), degree of crown scorch (Sneeuwjagt 1973) and scorch height (Raison *et al.* 1983, Buckley 1989).

Large, uncontrollable wildfires have not been a part of the recorded fire history in Chiltern Regional Park (NPS 1990), however the Box-Ironbark forest poses a fire threat to the township of Chiltern. Chiltern Regional Park surrounds the township of Chiltern to both the northwest and southeast. The Land Conservation Council (LCC 1984) classified the Park as Open Forest I and II of Red Ironbark (*Eucalyptus sideroxylon*) and Grey Box (*E. microcarpa*). Although fuel reduction burning operations have been carried out in the Park over the past 30 years, covering approximately 20% of the Park, the local Municipal Fire Prevention Committee and public are concerned that fuel levels in the forest are too high. The past record of fire suppression in the Park has been very good (NPS 1990) and this is said to be due to the sufficient fire lookouts resulting in early warnings of fires, easy access to all areas of the Park and a high public awareness of fire. However NPS (1990) states that fuel levels are increasing within the Park, because rabbits have been eliminated from the Park and therefore there is a greater amount of grass available.

Fuel reduction burning is used throughout the state to maintain surface fine fuel loads below critical levels. The Code of Practice for Fire Management on Public Land (DCNR 1995) has set up a strategic system for fuel management on public land. All public land is zoned according to the following points: the strategic importance of the area to fire protection, the appropriateness of burning as a means of fuel management and the alternatives, the natural and developed values of the area, other management objectives for the area, suppression methods most appropriate to the area and the principles of environmental care.

Fifteen per cent of Chiltern Regional Park is zoned for strategic fuel reduced barriers (Fuel Management Zone 2[1]), and the remaining 85% is zoned for specific flora and fauna management (Fuel Management Zone 4). Areas of strategic fuel reduced barriers can be found along the northwest and southeast boundaries of the Park neighbouring private property. Under the Code (DCNR 1995), Fuel Management Zone 2 will provide a substantial barrier to the spread of wildfire, and provide areas which will assist in making fire suppression safer and more effective. Fuel Management Zone 4 will provide for the use of prescribed burning for the active management of specific flora and fauna, and may provide fire protection benefits. Fuel Management Zone 2 areas require that surface fine fuel levels are maintained below 12 t/ha (Pook and Caddell 1990), or that the Overall Fuel Hazard is maintained at or below High (Wilson 1993).

In recent years, the importance of assessing the Overall Fuel Hazard rather than just the surface fine fuel has been emphasised (Tolhurst *et al.* 1992, Wilson 1993). Buckley (1989) states that stringybark fuels and heath vegetation are just as important as surface fine fuel levels when considering their effects on fire behaviour.

The aim of this study is to investigate the relationship between fuel depth and fuel quantity, the relationship between fuel hazard levels, site productivity, fire history and overstorey vegetation classes, and to assess the current surface fine fuel levels, surface fine fuel hazard, bark hazard and elevated fuel hazard. The current Overall Fuel Hazard will be determined and mapped, and the potential Overall Fuel Hazard will be predicted and also mapped.

[1] Fuel Management Zones have replaced the Protection Priority Zones that were formerly used by the Department of Conservation and Natural Resources. Fuel Management Zone 2 is equivalent to Protection Priority Zone 2.

## METHODS

Chiltern Regional Park is located in northeast Victoria (Figure 1), surrounding the township of Chiltern. It is approximately 4,250 hectares in area (Lloyd and Lau 1986, NPS 1994), bisected (almost equally) by both the township of Chiltern and the Hume Freeway. The Park is situated on "*gentle slopes rising from the Murray River flats to the north, and on the low divide between Black Dog and Indigo Creeks to the south*" (Lloyd and Lau 1986). Except for the Skeleton Hill range in the south, there are few areas of steep slopes. In the past, the Box-Ironbark forest has been cleared for both the mining of gold and the provision of valuable timber. Hence the forest that grows now is mainly regrowth. Timber is no longer commercially cut in the forest. Due to its early mining history and the Park being the "*most significant remnant in north-east Victoria of box-ironbark forest*" (NPS 1994), the Land Conservation Council of Victoria recommended the forest as a Regional Park in both 1977 and 1986 (LCC 1977, 1986). The Park consists mainly of Open Forest I and II of Red Ironbark and Grey Box (LCC 1984). The annual average rainfall for Chiltern is approximately 685 mm. The elevation of the Park ranges from 200 m to 400 m. The primary aim of the Park is to provide recreation for people in natural and semi-natural surroundings (LCC 1984).

Both the Open Forest I and II of Red Ironbark and Grey Box can be found on soils developed from Ordovician sediments (Lloyd and Lau 1986). The soils are generally shallow, with an abundance of quartz gravel on the surface. Red Stringybark (*E. macrorhyncha*) is generally associated with Red Ironbark. The Grey Box forest is usually found where there is a concentration of drainage channels, and subsequently is excessively wet during the winter period. The understorey for these forest types is generally grassy; with tussock grass (*Poa* spp.), wallaby grass (*Danthonia* spp.) and shell grass (*Briza major*) being the major species. However in some areas shrubs are quite dense.

### DATA COLLECTED IN 1991 AND 1992

Fuel sampling had previously been carried out in the Park, over a period of two years (1991-1992), by the Park Ranger. The five transects were located in areas zoned Fuel Management Zone 2 and areas proposed for fuel reduction burning. Each transect was selected to traverse a variety of topographical features (including ridges and gullies), be in areas with difficult control lines and to be in an area of potential difficult fire behaviour. The location of these transects are shown in Figure 1. Sample points were at approximately 80 m intervals, with the number of sample points per transect varying from 4 to 13.

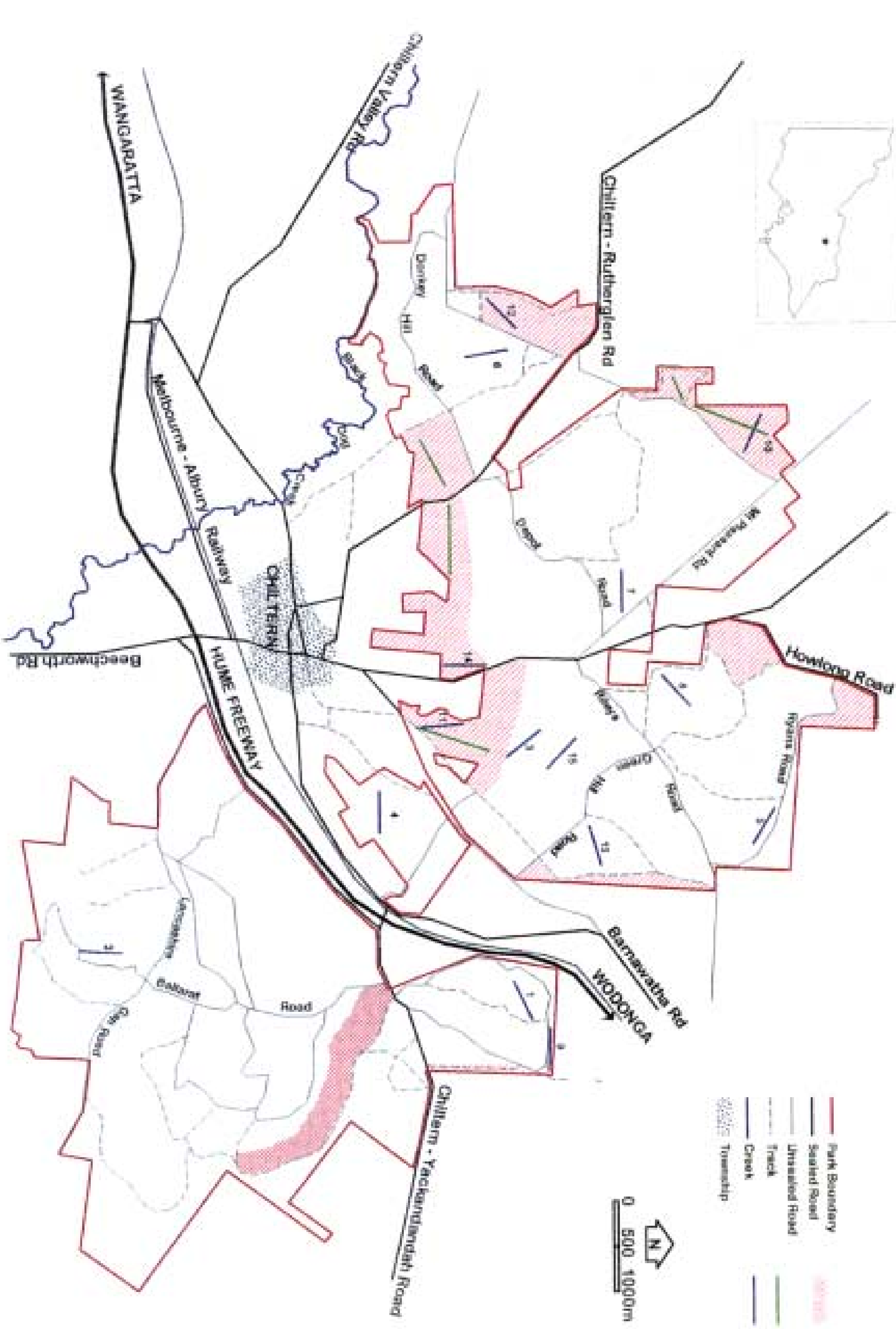



**Figure 1.** Location of transects, Fuel Management Zone 2 areas and Chiltern Regional Park.

At each sample point, surface fine fuel of less than 6 mm in thickness within a 0.1 $m^2$ sampling ring was collected, and weighed using a spring balance. The height and density of the understorey fuel, the height and percentage cover of grass and the bark hazard were also recorded for each sample point. The density of the understorey fuel was categorised as shown in Table 1.

**Table 1.** Hazard levels for understorey fuel, as used in data collection in 1991 and 1992. (These understorey fuels are equivalent to the elevated fuels measured in 1995.)

| Hazard level | Description |
|---|---|
| Discrete | sparsely situated |
| Touching | crowns of shrubs touching |
| Intermeshed | crowns of shrubs intertwined |

The percentage cover of grass was estimated visually. Bark hazard was categorised into four categories as follows: Low, Medium, High and Extreme. This assessment was a visual assessment, and carried out only on trees within a 30 m radius of the sample point and with a diameter at breast height over bark greater than 30 cm. Bark hazard also took into account the proximity to potential fire control lines, as well as the presence of bark. For each transect, fine fuel moisture content was measured using a *Speedy Moisture Meter*. Bark hazard and elevated fuel hazard were assessed differently from the assessment method used in 1995.

All five areas sampled had been burnt at least once since 1984. Four of the transects were in areas of Ironbark/Stringybark forest type, and the fifth in the Grey Box forest type.

Considering the amount of variation with the number of sample points for each transect, t-tests were conducted on these data series. It was found that generally not enough sample points had been taken, as the variation within each transect was often larger than the variation between transects. The required sampling intensity was calculated from 95% confidence intervals being within 20% of the average (for each transect). The result being that at least 15 sample points would be required for each transect. Consequently these data were neither included with the data collected in 1995, nor were they analysed further.

## DATA COLLECTED IN 1995

To determine where the transects would be located, a composite map of the Park was constructed showing forest type, fire history and stand height across Chiltern Regional Park. Both vegetation stratification and stand height had previously been mapped. The fire history map was constructed from prescribed burning records and the Interim Plan of Management (NPS 1990) for the Park. From these records, the fire history of the Park consisted of mainly fuel reduction burning, with only a couple of small wildfires (less than 5 ha) which were never mapped. Fire records show that the earliest prescribed fire was conducted in 1967, and then fuel reduction burning was not used again as a management tool until the early 1980's. The fuel reduction burning operations have been confined to areas adjacent to private property, and were carried out in 1967, 1982, 1984, 1985, 1986, 1988, 1990, 1991 and 1993. Stand height varied throughout the Park from 10 m to 30 m. This range was split into three "productivity" classes as follows: 10.0 - 17.9 m, 18.0 - 23.9 m and 24.0 - 30.0 m. The Park consists of six major forest types (Lloyd and Lau 1986), based on the overstorey vegetation. These include Red Ironbark-Red Stringybark, Grey Box, Red Box-Red Stringybark, ridge type, gully type and Long Leaf Box-Red Stringybark. (Refer to Table 2 for a list of species within each forest type.) Of these, only three forest types were studied: Red Ironbark-Red Stringybark, Grey Box and ridge types, as the areas of the other three forest types were not large enough to sample and represented less than 13% of the total area. (Refer to Appendix A and B for a fire history map and vegetation map of Chiltern Regional Park.)

**Table 2.** Showing the six major forest types (based on the overstorey vegetation) of Chiltern Regional Park.

| Forest type | Major species | Associated species | Site | Area (ha) |
|---|---|---|---|---|
| Red Ironbark - Red Stringybark | *E. sideroxylon*<br>*E. macrorhyncha* | *E. polyanthemos*<br>*E. blakelyi* | Lower slopes | 2200 |
| Grey Box | *E. microcarpa*<br>*E. albens* | *E. sideroxylon* | Moist flats | 720 |
| Ridge | *E. albens*<br>*E. blakelyi* | *E. macrorhyncha*<br>*E. sideroxylon* | Rocky ridges | 770 |
| Gully * | *E. polyanthemos*<br>*E. albens*<br>*E. blakelyi* | *E. macrorhyncha*<br>*E. sideroxylon* | Gullies & moist flats | 280 |
| Long Leaf Box - Red Stringybark * | *E. goniocalyx*<br>*E. macrorhyncha* | | Southern slopes | 40 |
| Red Box - Red Stringybark * | *E. polyanthemos*<br>*E. macrorhyncha* | *E. sideroxylon*<br>*E. goniocalyx*<br>*E. blakelyi* | Southern slopes & gullies | 240 |

* Denotes the forest types that were too small in area to sample.

Fuels were sampled in each of the eight classes of fuel age, three classes of forest types and three classes of site productivity. The locations of the transects were determined by stratified random sampling. Transects were placed in each of the fire history classes, forest types and site productivity classes. (Refer to Figure 1 for the location of each transect.) Each transect was 450 m long, with 15 sample points at 30 m intervals.

At each sampling point fuel depth was measured, using a fuel depth gauge. The fuel depth gauge consists of a plastic ruler and a cardboard slide measuring 5 x 15 cm (Figure 2). The cardboard slide was held down on top of the fuel with gentle hand pressure, as described in Tolhurst *et al.* (1992) and a reading of fuel depth taken. Sampling was done in mid-January (mid-summer) where there was maximum leaf curl.

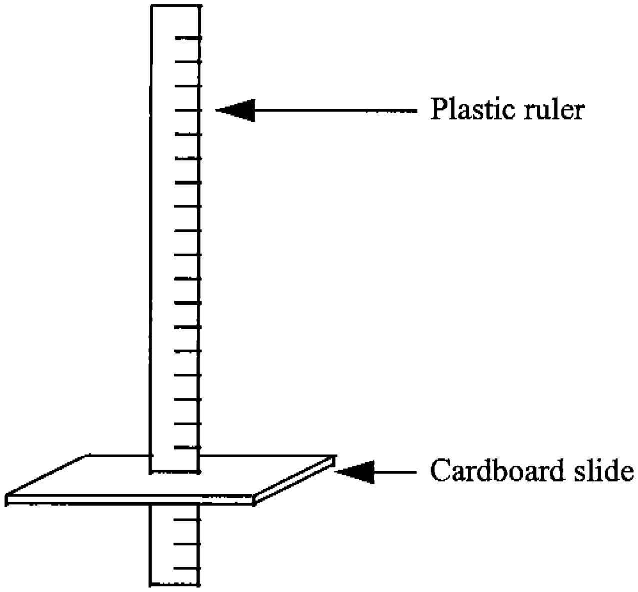



**Figure 2.** Diagram showing the fuel depth gauge.

Surface fine fuel within a 0.0973 $m^2$ fuel ring was collected. All dead plant material less than 6 mm in thickness and living plant material less than 2 mm in thickness was collected. The fuel samples were taken back to the laboratory for oven-drying and weighing. Stand height for each transect was measured, taking the average height of the three tallest trees along the length of the transect and within 20 m either side of it. A bark hazard and an elevated fuel hazard classification were determined for each transect using the Eucalypt Bark Hazard Guide (Wilson 1992) and the Elevated Fuel Guide (Wilson 1993) respectively. The bark fuel hazard guide is a visual estimation of the amount of loose bark on the trees. All trees in the area of the transect were assessed for an average bark hazard rating. The elevated fuel hazard guide is a visual estimation of the vertical and horizontal distribution of the fuel and an assessment of the amount of dead suspended fuel. Using the Elevated Fuel Guide (Wilson 1993), an Overall Fuel Hazard rating for each transect was determined. This rating is the sum of the bark hazard, elevated fuel hazard and surface fine fuel hazard. Each transect took two to three hours to complete.

All fuel samples were oven-dried at 105°C for at least 24 hours or until no further weight loss occurred. Fuels were then weighed for a total weight and subsequently sieved through both a 5 mm and a 2 mm sieve, and each size class weighed. Fuels were put through a 2 mm sieve to eliminate any soil in the sample. (On collection of the samples, it was noticed that a lot of soil was being picked up due to both the fuel and soil being very dry.)

### Data Analysis

As mentioned previously, the data collected from 1991 and 1992 were not analysed any further.

Total fuel load was originally plotted to form a frequency plot. This graph showed a normal distribution. Averages for the surface fine fuel load, stand height and fuel depth were calculated for each transect. Each variable (time since fire, forest type, stand height, maximum tree height and fuel depth) was plotted against surface fine fuel load. This allowed an examination of the distribution, to determine whether or not transformations would provide a more fitting relationship (i.e. a linear relationship rather than a non-linear relationship). Multiple stepwise linear regression techniques were used to determine the parameters which most influenced the surface fine fuel load. Plots of residuals were inspected for randomness.

Non-linear regression techniques were used to analyse the data on the basis of the negative exponential model outlined by Olsen (1963) used to describe litter accumulation and decay in forests. Olsen's model is based on the theory that the fine fuel load increases rapidly in the period immediately after the fire (Fox *et al.* 1979, Raison *et al.* 1983, Buckley 1989, Tolhurst *et al.* 1992), until it reaches a relatively stable level (Luke and McArthur 1978, Fogarty 1993). The rapid rate of litter re-accumulation is due to the decrease in the amount of litter decomposing (Raison *et al.* 1983). As previous studies have shown (Fox *et al.* 1979, Raison *et al.* 1983, Hutson and Veitch 1985, Buckley 1989, Burrows and McCaw 1990), the negative exponential model best describes fuel accumulation with a continuous steady fine fuel fall (Walker 1981). The following equation was the basis for the negative exponential models determined by this set of data to predict fine fuel accumulation.

$$X_t = X_{ss}\,(1 - e^{-kt}) \qquad (1)$$

where $X_t$ = weight of the fine fuel per unit area (t/ha) $t$ years after fire
$X_{ss}$ = weight of the fine fuel accumulated under steady state conditions (t/ha)
k = decomposition rate constant ($yr^{-1}$)
$t$ = time since fire (years)

The decomposition rate constant, k, should take a value between 0 and 1.0 $yr^{-1}$. The lower this value, the slower the rate of decomposition and hence the quicker $X_t$ approaches $X_{ss}$.

## RESULTS

DATA COLLECTED IN 1991 AND 1992

A description of forest type and fine fuel quantity for each transect measured in 1991 and 1992 is shown in Table 3. The mean fine fuel quantity for each transect varies from 5.6 t/ha to 10.6 t/ha. The variation within these transects is quite high.

**Table 3.** Description of each transect measured in 1991 and 1992, including forest type, mean fine fuel quantity, standard deviation and 95% confidence intervals for each transect.

| Transect number | Forest type * | Mean fine fuel quantity (t/ha) | Standard deviation (t/ha) | 95% C.I. (t/ha) | Number of samples (n) |
|---|---|---|---|---|---|
| 1 | I/S | 5.9 | ± 3.5 | 2.57 | 7 |
| 2 | B | 9.2 | ± 3.7 | 2.11 | 12 |
| 2b | I/S | 10.6 | ± 6.1 | 5.96 | 4 |
| 3 | I/S | 6.8 | ± 1.7 | 0.95 | 12 |
| 4 | I/S | 5.6 | ± 2.4 | 1.27 | 13 |

* where I/S = Ironbark/Stringybark and B = Box

According to the Elevated Fuel Guide (Wilson 1993), the fine fuel hazard for the five transects varies from Moderate (4 - 8 t/ha) to High (8 - 12 t/ha). Bark hazard varied from Low to Moderate, and elevated fuel hazard varied from Sparse to Touching, with Transect 2 having no understorey. As mentioned previously, both the bark hazard and the elevated fuel hazard were assessed using different criteria, so an Overall Fuel Hazard based on Wilson's guide (1993) could not be determined.

DATA COLLECTED IN 1995

Table 4 gives a site description for each transect measured in 1995, including fuel depth, surface fine fuel quantity, surface fine fuel hazard, bark hazard, elevated fuel hazard and the Overall Fuel Hazard rating.

**Table 4.** Descriptions of each transect measured in 1995, including time since fire, forest type, site productivity, fuel depth, surface fine fuel quantity, surface fine fuel hazard, bark hazard, elevated fuel hazard and overall fuel hazard.

| Transect number | Time since fire (yrs) | Forest type | Site productivity | Fuel depth (mm) | Surface fine fuel quantity (t/ha) | Surface fine fuel hazard | Bark hazard | Elevated fuel hazard | Overall fuel hazard |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 50 | G/B | L | 10.7 | 5.38 | M | M | H | M |
| 2 | 50 | G/B | L | 28.0 | 6.08 | M | M | H | M |
| 3 | 50 | I/S | M | 26.3 | 7.95 | M | VH | M | VH |
| 4 | 50 | I/S | M | 24.5 | 7.17 | M | VH | H | VH |
| 5 | 50 | B | H | 21.9 | 6.45 | M | M | H | M |
| 6 | 50 | B | H | 25.2 | 7.51 | M | M | H | M |
| 7 | 50 | B | H | 30.7 | 9.69 | H | M | M | H |
| 8 | 28 | I/S | M | 29.4 | 6.47 | M | VH | H | VH |
| 9 | 5 | B | M | 25.5 | 8.08 | H | M | M | H |
| 10 | 4 | B | M | 24.1 | 6.63 | M | H | L | M |
| 11 | 2 | I/S | M | 23.7 | 6.01 | M | H | M | M |
| 12 | 11 | B | H | 27.7 | 8.15 | H | M | M | H |
| 13 | 10 | B | M | 23.9 | 6.36 | M | H | VH | VH |
| 14 | 9 | I/S | M | 21.1 | 6.83 | M | VH | VH | VH |
| 15 | 50 | I/S | L | 28.5 | 8.01 | H | VH | H | VH |

Species class categories :- G/B = Gum/Box I/S = Ironbark/Stringybark B = Box
Site productivity :- L = Low (10-17.9 m) M = Moderate (18-23.9 m) H = High (24-30 m)
Hazard categories :- L = Low M = Moderate H = High VH = Very High

**Surface Fine Fuel Depth**

The relationship between surface fine fuel quantity and fuel depth was investigated to determine if fuel depth could be used to provide an accurate, but indirect, estimation of surface fine fuel quantity. Fuel depth varied from 10.7 mm (5.38 t/ha fine fuel) to 30.7 mm (9.69 t/ha fine fuel). With all data, transformations of depth were examined, and it was found that $(\text{depth})^3$ accounted for the most variation in surface fine fuel quantities. The $(\text{depth})^3$ explained almost half of the variation in the surface fine fuel samples (Table 5).

**Table 5.** Those parameters that explain the most variation of litter fuel load, using all data.

| Parameter | % Variation |
|---|---|
| $(\text{Depth})^3$ | 44 |
| 1/(Species class) | 14 |
| $(\text{Time since fire})^3$ | 10 |
| $(\text{Time since fire})^2$ | 6 |
| $(\text{Depth})^{1/2}$ | 8 |

However the micro-elevation of fine fuel material (i.e. near surface fuels) can interfere with fuel depth (McCarthy in prep.), and subsequently surface fine fuel hazard assessment. Therefore an analysis was carried out on the data from those transects on sites with an elevated fuel hazard of Low to Moderate, that is, with little or no micro-elevated fine fuel. In this analysis it was found that depth accounted for 89% of the variation of the surface fine fuel quantity. Depth was the only parameter that explained any variation in the surface fine fuel quantity when analysed by using multiple stepwise linear regression. Fine fuel quantity was found to have a linear relationship with fuel depth and is defined in Equation 2.

$$Q_f = 0.47148(d) - 4.6639 \quad (2)$$

$[n = 6 \quad r^2 = 0.89 \quad p < 0.005]$

where $Q_f$ = surface fine fuel quantity (t/ha)
$d$ = fuel depth (mm)

Figure 3 shows the linear relationship between surface fine fuel quantity and fuel depth for those transects with Low to Moderate elevated fuel hazard levels. An outlier can be seen in Figure 3. Transect 1 shows an unusually high surface fine fuel quantity for a relatively small fuel depth. This transect was located in an area long unburnt, of Gum/Box forest type and on a low productivity site, resulting in a large amount of humus (i.e. greater than 40% of the total fuel weight).

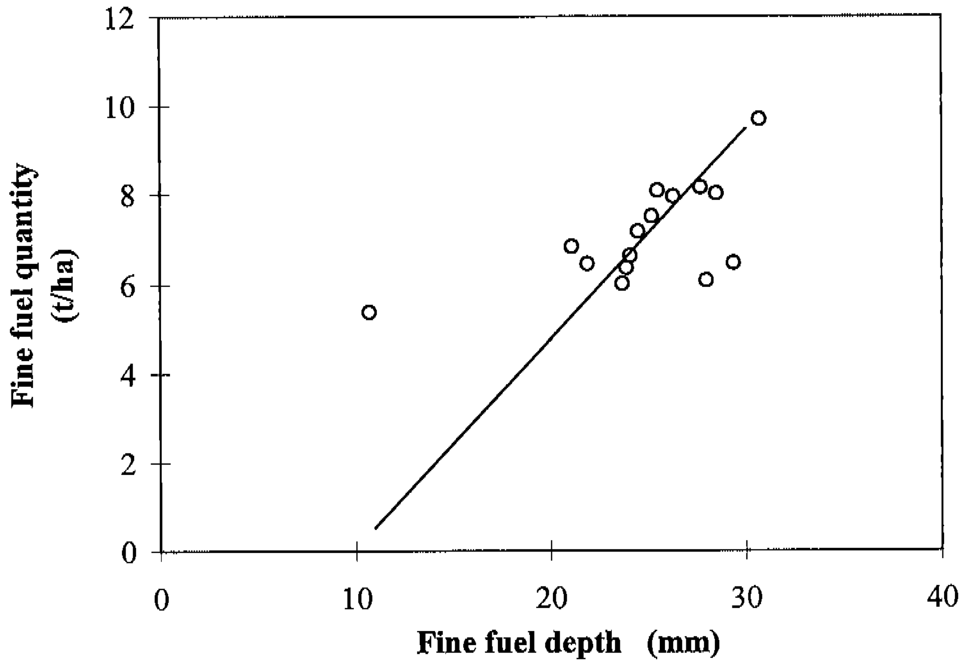



**Figure 3.** Fine fuel quantity and fine fuel depth relationship. The observed points are marked individually (O) and the predicted model (Equation 2) is shown as a solid line (—).

**Surface Fine Fuel Accumulation**

Litter, humus, twig and bark components of the surface fine fuel were measured at each plot. However only the non-humus components were included in the surface fine fuel estimates of the Overall Fuel Hazard on the basis that humus does not contribute to the forward rate of spread of the fire. The average surface fine fuel quantity across the Park was 7.1 t/ha ±1.1 t/ha, ranging from 5.38 t/ha to 9.69 t/ha across the sites sampled (which is similar to the range measured in 1991/92).

Plotting surface fine fuel quantity against time since fire showed a single outlier, as can be seen in Figure 4. Transect 9 (refer to Table 4 for the site description) shows an unusually high surface fine fuel quantity. This transect was run within 100 m of a fenceline, in an east-west direction, in the southern part of the Park (Figure 1). This site was chosen to be sampled so as to sample an area burnt by fire in 1990. Sneeuwjagt (1973) comments that fuel quantities measured at the edges of forests will often be quite different from internal areas. The fenceline borders grazing paddocks to the south, subsequently the site is very open to north-northwesterly winds. Due to the openness of the site, the site would most likely be drier than other sites sampled. If this is the case, then it is highly likely that the decomposition rate constant for this site would be less, therefore allowing for greater fuel accumulation than anywhere else in the Park. It is also possible that the site is higher in productivity, due to both water and soil being more available due to less competition. By taking this set of data out, only 14 sets of data are left.

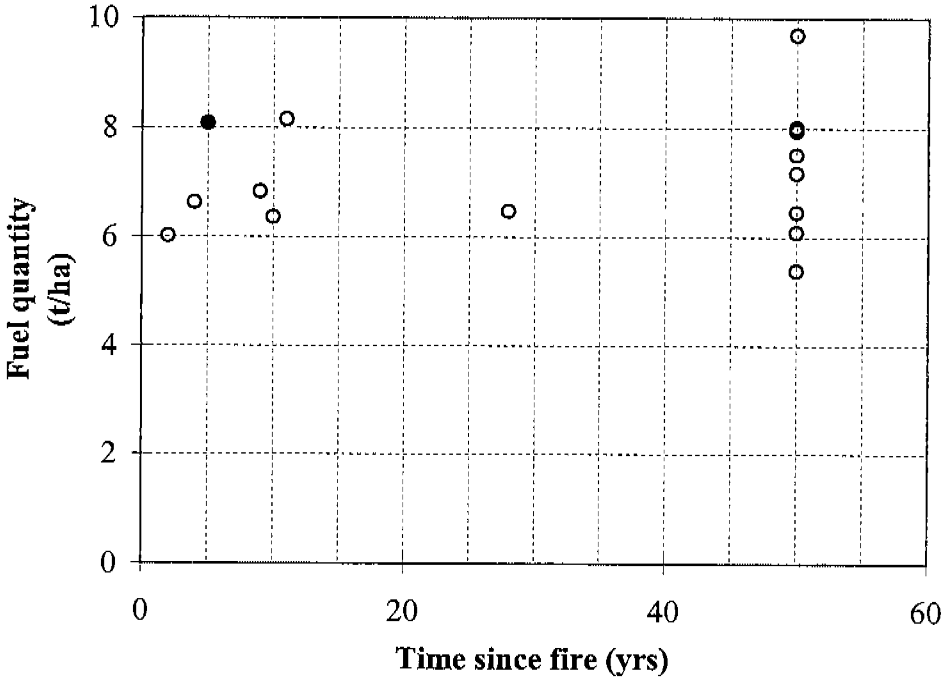



**Figure 4.** Fine fuel quantity for all transects plotted against time since fire. Observed values are marked individually (○). An outlier is observed at time since fire = 5 years (fuel quantity = 8.08 t/ha), marked (●).

Using Equation 1 as the basis for a prediction model, the following relationship was found to be the best fit for the data analysed.

$$X_t = 7.1543*(1\text{-}e^{(-0.8699*t)}) \qquad (3)$$

where $X_t$ = surface fine fuel quantity (t/ha) $t$ years after fire
$t$ = time since fire (years)

Figure 5 shows the negative exponential relationship between surface fine fuel quantity and time since fire. The data do not show 0 t/ha at 0 years after fire because generally there is residual fuel after a low intensity fire, however there were no areas that had been burnt within one year of sampling, so no such data were able to be collected.

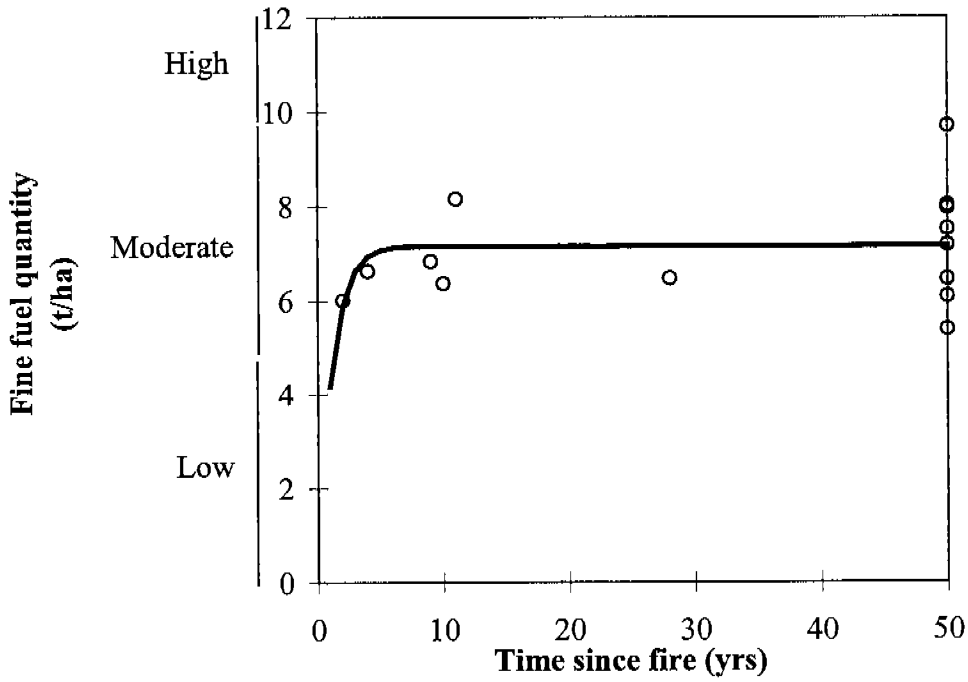



**Figure 5.** The relationship between fine fuel quantity and hazard class, and time since fire, using only 14 sets of data. The observed points are marked individually (O) and the predicted model (Equation 3) is shown as a solid line (–).

This relationship shows a rapid increase in surface fine fuel quantity immediately after a fire, for approximately 3 years, and then the fine fuel accumulation decreases, reaching a steady state within 5 years after the fire at 7.2 t/ha. The decomposition rate constant, k, is quite high at 0.87 $yr^{-1}$. Within 3.5 years since a fire, 95% of the steady state level is reached (assuming that all fuel was burnt in the fire).

This relationship does not take into account the variation in surface fine fuel quantity that is due to site productivity. By analysing the data from each site productivity class separately, the data sets become quite small (Table 6).

**Table 6.** Summary of parameters describing patterns of litter accumulation following fire using the negative exponential model (Equation 1) on data separated into site productivity classes.

| Site productivity class | No. of data sets | * | Estimate | 95% confidence intervals | | 95% of $X_{ss}$ reached |
|---|---|---|---|---|---|---|
| | | | | lower | upper | |
| Moderate (18.0 - 23.9 m) | 7 | $X_{ss}$ | 6.9320 | 6.2975 | 7.5664 | 6.59 t/ha |
| | | K | 0.9832 | 0.1681 | 1.7985 | 3.06 yrs |
| High (24.0 - 30.0 m) | 4 | $X_{ss}$ | 7.9572 | 5.7376 | 10.1769 | 7.56 t/ha |
| | | K | 0.4532 | -0.4657 | 1.3721 | 6.61 yrs |

* where $X_{ss}$ is the weight of the surface fine fuel accumulated under steady state conditions (t/ha), and k is the decomposition rate constant ($yr^{-1}$)

There were only three sample points available from low productivity sites, and these three sites were from areas long unburnt. Data analysis was carried out on these three data points, however the decomposition rate, k, was almost zero, so the value of $X_{ss}$ was not meaningful. For this reason, the low productivity site $X_{ss}$ and k values are not shown in Table 6, and the curve is not shown in Figure 6.

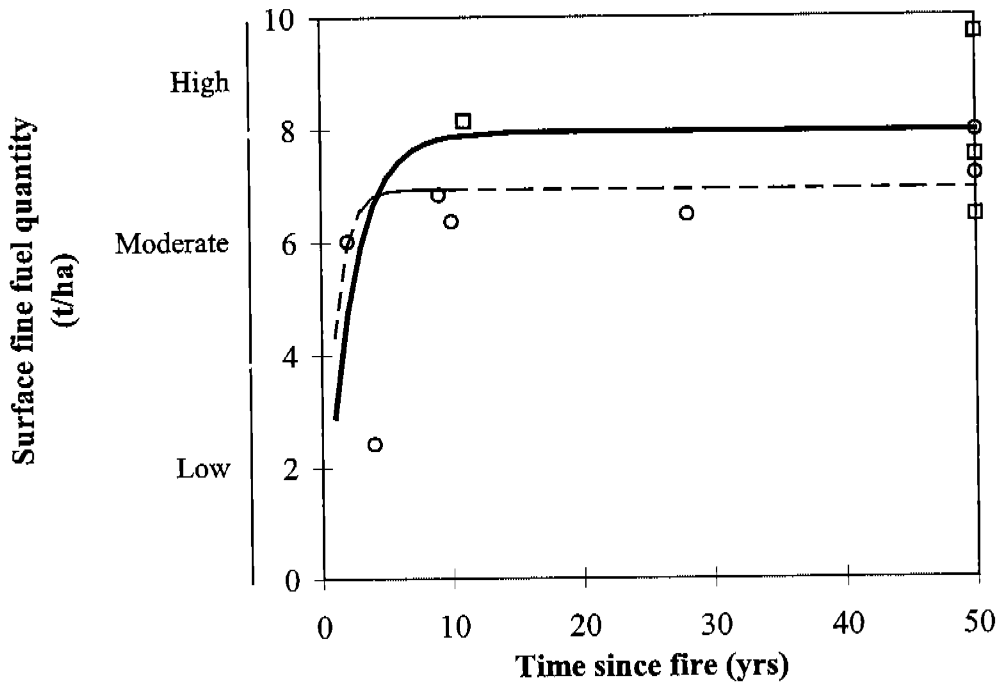



**Figure 6.** The relationship between time since fire and surface fine fuel quantity and hazard class for both moderate and high productivity sites. The observed points are marked individually, O for moderate productivity sites and □ for high productivity sites. The predicted models are shown by a thin broken line (--) for moderate productivity sites and a thick solid line (–) for high productivity sites.

For both the moderate and high productivity sites, a Moderate fine fuel hazard is predicted as the steady state level. However the decomposition rate constant for the high productivity sites is only half that of the moderate productivity sites, therefore it will take twice as long for the high productivity sites to reach their predicted steady state level as it does for the moderate productivity sites. This means that the high productivity sites will not have to be burnt as often (assuming that all other fuel component hazards are equal).

### Surface Fine Fuel Hazard

According to the Elevated Fuel Hazard Guide (Wilson 1993), surface fine fuel level hazards can be related to surface fine fuel quantities as shown in Table 7.

**Table 7.** The relationship between surface fine fuel quantity and surface fine fuel hazard.

| Hazard class | Low | Moderate | High | Very High | Extreme |
|---|---|---|---|---|---|
| Quantity (t/ha) | 0 - 4 | 4 - 8 | 8 - 12 | 12 - 18 | 18 + |

Surface fine fuel hazards ranged from Moderate to High across the Park. There were four sites that recorded a High surface fine fuel hazard, one of which was the outlier mentioned previously (Transect 9). Two of the other three sites, plus the outlier, were in the Box forest type. These sites all had very little understorey, with the elevated fuel hazard rating only Moderate. The fourth site was only just classified as High (8.01 t/ha) and was found in the Ironbark/Stringybark forest type. It is interesting to note that only one of the four sites that recorded a High hazard level was in a Fuel Management Zone 2, and that was Transect 12, located on the western boundary of the Park.

**Bark Hazard**

Table 8 shows bark fuel hazard ranging from Moderate (found in the Gum/Box and Box forest types) to Very High (found in the Ironbark/Stringybark forest type). The Very High hazard level was found only on sites that where Red Stringybark were co-dominant. The bark of the Red Stringybark was generally unburnt and becoming quite loosely held throughout the Park. The Gum/Box forest type, Blakely's Gum (*E. blakelyi*) and White Box (*E. albens*), had box bark generally tightly held and the gum bark did not have any long ribbons. The Box forest type, consisting mainly of Grey Box, had bark that was tightly held, however in some areas Red Stringybark was also present thus increasing the bark hazard level on these sites.

**Table 8.** The bark hazard range for each species type.

| Species type | Hazard level range |
|---|---|
| Gum/Box | Moderate |
| Ironbark/Stringybark | High - Very High |
| Box | Moderate - High |

Bark hazard and time since fire data were also analysed using the negative exponential model as shown in Equation 1. Figure 7 shows that there is no negative exponential relationship between bark hazard and time since fire. Instead when plotted against time, bark hazard showed a straight horizontal line at just below the High hazard level, indicating that the current bark hazard levels across the Park have no relationship with time since fire at all. This indicates that the bark hazard was not significantly reduced in the prescribed fires that have been carried out in the past. Considering the threat of firebrand spotting in the Park, it will be important to direct future prescribed fires at reducing bark hazard levels where required.

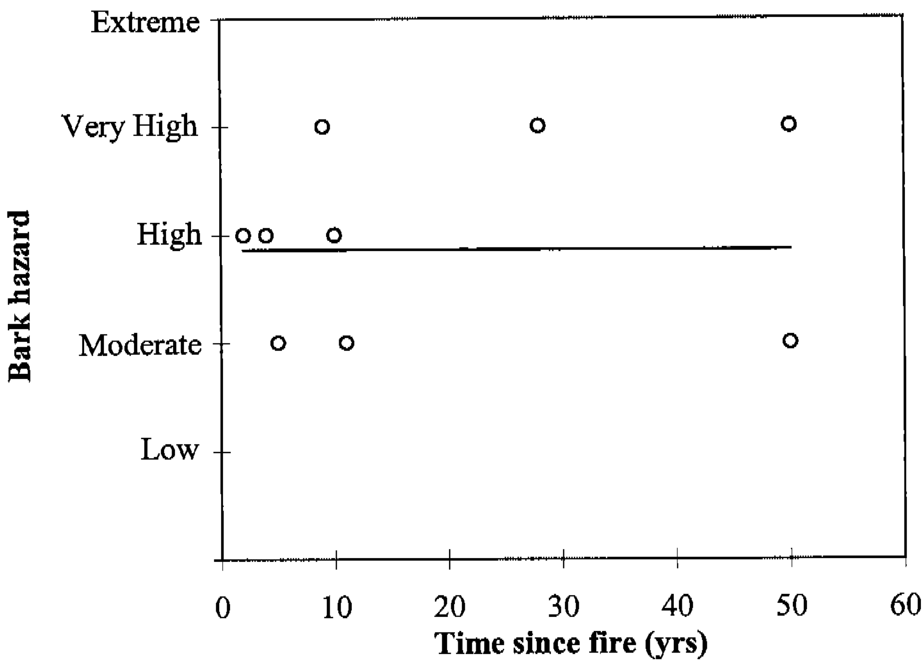



**Figure 7.** Bark hazard plotted against time since fire. The observed points are marked individually (O) and the predicted model is shown as a solid line (–).

**Elevated Fuel Hazard**

The elevated fuel hazard varied from Low (consisting of virtually no understorey) to Very High (consisting of a dense shrubby understorey). On the sites of Very High elevated fuel hazard, fire behaviour would be significantly affected; as the fuel itself was quite dense and generally over 1 m in height. Only one of the two sites that recorded a Very High hazard level was in a Fuel Management Zone 2. All other sites that were located in a Fuel Management Zone 2 had an elevated fuel hazard level of Low or Moderate. As with surface fine fuel and bark hazard, elevated fuel and time since fire data were analysed using the negative exponential model (Equation 1). Elevated fuel hazard shows a negative exponential relationship with time since fire (Figure 8). Within 9.2 years since fire, 95% of the steady state level of elevated fuel will have reaccumulated. The accumulation of the elevated fuel hazard is almost three times as slow as the accumulation of fine fuel, however the fuel hazard is greater for elevated fuel than for fine fuel.

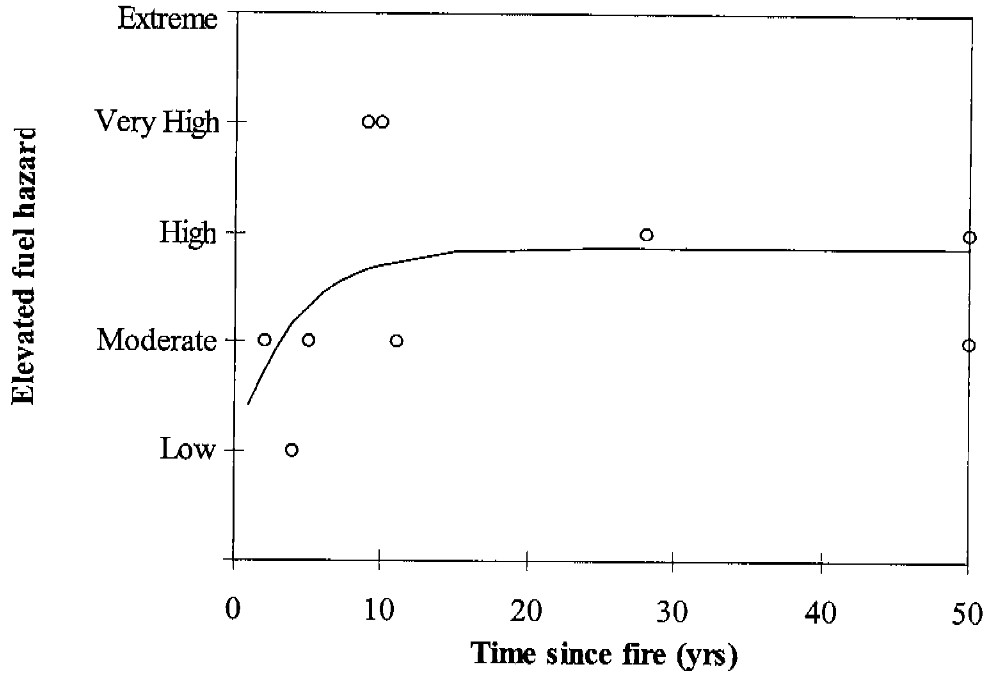



**Figure 8.** The negative exponential relationship between elevated fuel hazard and time since fire. The observed values are marked individually (O) and the predicted model is shown as a solid line (–).

Figure 8 shows a peak in the elevated fuel hazard occurring within 10 years since a fire. Unfortunately, insufficient data were collected to show whether the shrubs actually die back after 10 years or if this is just an irregularity that was picked up due to the limited sampling.

## Overall Fuel Hazard Rating

The Overall Fuel Hazard rating is a combination of the surface fine fuel hazard, the bark hazard and the elevated fuel hazard of a site. The Overall Fuel Hazard rating ranged from Moderate to Very High across the Park (Table 4). In the majority of sample sites within Chiltern Regional Park, the bark fuel or the elevated fuel hazard have shown to have a greater influence on fire behaviour than the surface fine fuel hazard.

The current average Overall Fuel Hazard for each species class was mapped (Figure 9). This map shows the average current fuel hazard according to the forest type. The Gum/Box forest type had a current Overall Fuel Hazard of Moderate, whilst the Ironbark/Stringybark forest type had a current Overall Fuel Hazard of Very High. This Very High classification was mainly due to the Very High bark hazard classification, although one of the six sites also had a Very High elevated fuel hazard. The Box forest type had an Overall Fuel Hazard of High.

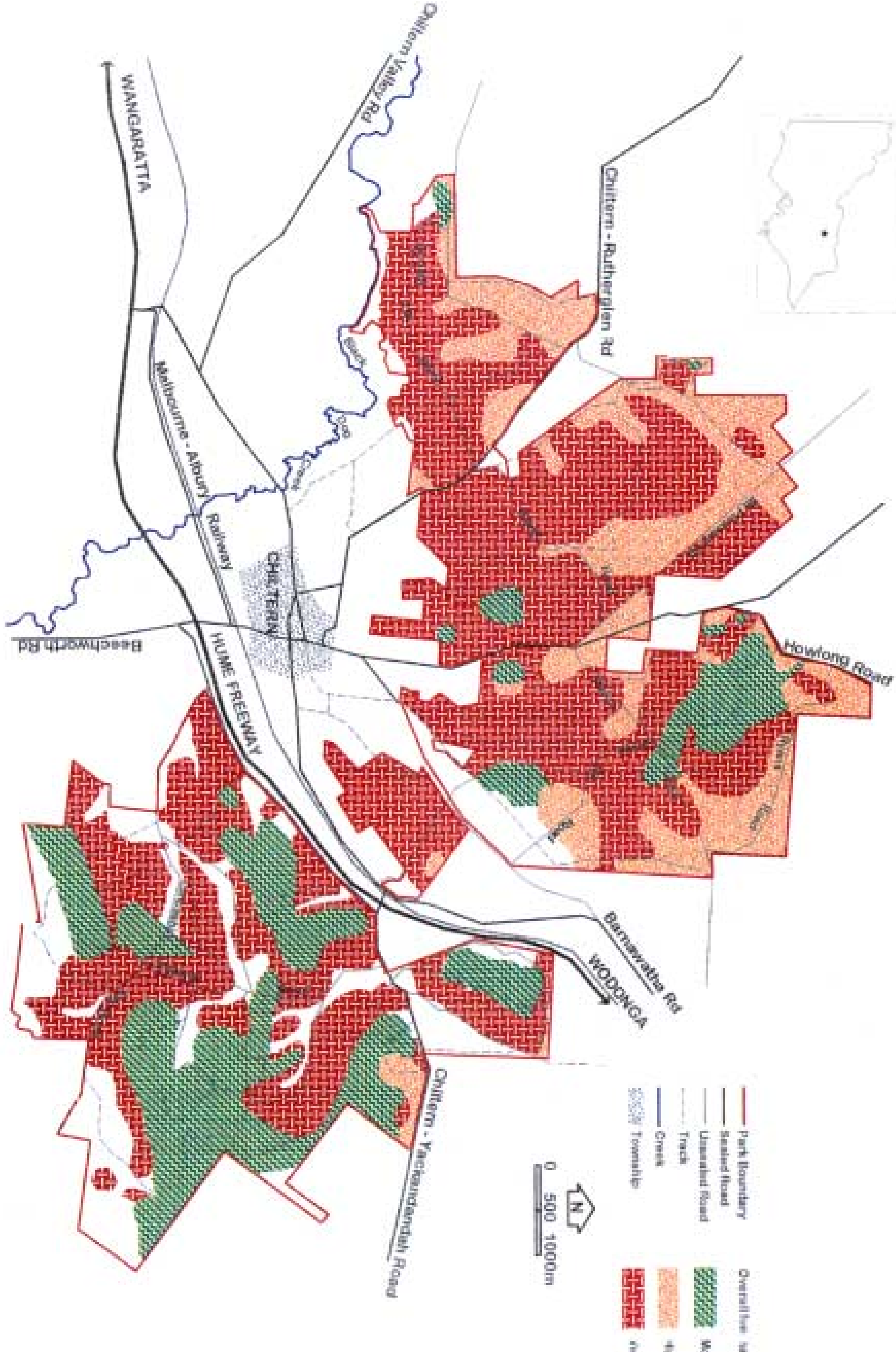



Figure 9. Current overall fuel hazard for Chiltern Regional Park.

The potential average Overall Fuel Hazard for each forest type was estimated, assuming that there is no fire for at least 50 years (i.e. steady state has been achieved in all fuel components). The Gum/Box forest type had a potential Overall Fuel Hazard of Moderate, the Ironbark/Stringybark forest type had a potential Overall Fuel Hazard of Very High and the Box forest type had a potential Overall Fuel Hazard of High. Although the bark hazard in the Ironbark/Stringybark forest type may increase to Extreme, this seems unlikely, as Very High bark hazard levels were only found on sites that had not been burnt for at least 50 years. Therefore all forest types have already reached their potential Overall Fuel Hazard, and the potential Overall Fuel Hazard map is the same as the current Overall Fuel Hazard map (Figure 9).

Wilson (1993) states that a Fuel Management Zone 2 should have an Overall Fuel Hazard maintained at or below High. Of the 15 transects, only six transects had an Overall Fuel Hazard rating of Very High, and of these one transect was in an area classified as a Fuel Management Zone 2.

## DISCUSSION

### Surface Fine Fuel Depth

Fuel depth is a measurement of fuel quantity and fuel structure, and several authors (Sneeuwjagt 1973, Schneider and Bell 1985, Burrows and McCaw 1990) have suggested that fuel structure may influence forward rate of spread and flame height more than fuel quantity. Figure 3 indicates that the fuel depth model (Equation 2) provides a good fit to the data. Schneider and Bell (1985) found that 53% of the variation in fine fuel quantities in shrub fuels was explained by fine fuel depth. Whereas in this study 44% of the variation in the surface fine fuel quantity with all data included and 89% of the variation when using only those sites with a Low or Moderate elevated fuel hazard was found.

In McArthur's (1962) guide to control burning in eucalypt forest types, fuel depth is used to estimate fuel quantity if the time since last fire is not known. Sneeuwjagt (1973) established a close relationship between litter quantity and depth for a number of forest types (both hardwood and softwood). Tolhurst *et al.* (1992) measured fine fuel depth so as to determine the fine fuel quantity in Messmate/Gum forests in Victoria. However it was found that the ratio between litter depth and litter weight, a packing ratio, best explained variations in forward rate of spread and flame height. Sneeuwjagt and Peet (1985) used litter depth to estimate litter quantity when determining fire behaviour in various forest types in Western Australia. Fogarty (1993) found a non-linear relationship between surface fuel load and litter bed depth in East Gippsland (Victoria), using the negative exponential model (Equation 1), replacing time since fire with litter depth.

Schneider and Bell (1985) noted that the fuel depth gauge they used was found to be inaccurate if the fuel was compact or if used in sandy surface soil horizons. Compactness of fuel can be reduced by taking fuel depth measurements when the fuel is dry and maximum leaf curl is achieved. McCaw (1988) also notes that the horizontal uniformity will influence the accuracy of the predictions made. The horizontal uniformity of the litter bed will be influenced by the understorey vegetation. The measurement of fine fuel depth is a rapid and reliable method for estimating fine fuel load (Sneeuwjagt 1973), although McCaw (1988) comments that this is dependent on the bulk density of the fuel being relatively constant. However if sampling is extensive enough - any local irregularities in fuel arrangement will average out.

Being able to measure fuel depth and accurately estimate the surface fine fuel hazard enables field staff to accurately determine fuel hazard throughout the Park, without having to take time-consuming fuel samples.

### Surface Fine Fuel Accumulation

The negative exponential model provides a simple but useful way of predicting the re-accumulation of fine fuels after a fire (Raison *et al.* 1983). Although this model has a strong theoretical basis (Fogarty 1993), it is based on a number of assumptions, which must be considered when using this equation. The assumptions of this model include: a steady state relationship between litterfall and litter quantity, the rate of decomposition is constant, litterfall is constant, fuel is uniform and that all fuel is burnt in a fire. These assumptions are discussed in detail.

It is assumed that a steady state relationship is achieved between litterfall and litter quantity, and the rate of decomposition is constant (Fox *et al.* 1979). Van Loon (1977) found that the litter layer in the Blue Mountains, NSW, did not show any tendency to level off. In this study, it is assumed that a steady state is achieved within 50 years since last fire.

Litterfall is also assumed to be constant both seasonally and annually. It has been found by Ashton (1975), Rogers and Westman (1977), Simmons and Adams (1986), O'Connell (1987) and Tolhurst *et al.* (1992) that litterfall does vary throughout the year in Australian forests. These fluctuations depend on climate, fire history, disease, rainfall, site characteristics and largely, species. However Australian situations tend to have continuous litterfall rather than discrete litterfall (Fox *et al.* 1979, Simmons and Adams 1986, Tolhurst *et al.* 1992). Lee and Correll (1978) found seasonal fluctuations in litterfall, with the maximum fall in summer (Ashton 1975, Rogers and Westman 1977, Simmons and Adams 1986 and Tolhurst *et al.* 1992) and the minimum fall in winter. If this pattern is assumed to be the case for the Ironbark/Box forest of Chiltern Regional Park, then sampling in 1995 took place when litterfall was near maximum. Simmons and Adams (1986) also found that litterfall varies annually. This is especially the case following a period of drought, when litterfall can be expected to be higher than usual (Simmons and Adams 1986).

Fuel accumulation curves assume that the vegetation sampled is relatively uniform (Burrows and McCaw 1990), which may not always be the case. The inherent variability of fuels in any natural ecosystem will impose limitations to any model (McCaw 1988), therefore when sampling fuel quantities, it is important to collect sufficient samples to account for any irregularities. Consequently 15 samples were collected per transect for the 1995 set of data.

The negative exponential model also assumes that all fuel is burnt in a fire. This can be the case after a wildfire or a high intensity prescribed fire, however it is generally not the case after a low intensity prescribed fire. A low intensity prescribed fire rarely burns all the fuel available, often leaving patches of unburnt fuel. Kessell *et al.* (1982) modified Equation 1 so as the amount of fuel remaining after a fire could be included (Equation 4). Equation 4 assumes that the residual fuel will decompose at the same rate that the litter that falls after the fire.

$$Q_t = X_t + X_r e^{-kt} \qquad (4)$$

where $Q_t$ = total fine fuel quantity (t/ha)
$X_t$ = weight of fine fuel per unit area (t/ha), $t$ years after fire
$X_r e^{-kt}$ = amount of residual fire fuel (t/ha) remaining at time $t$ (years)
$X_r$ = amount of residual fire fuel immediately after a fire

Raison *et al.* (1983) states that Equation 1 is adequate to describe fuel accumulation after a prescribed burn because "most of the post-burn residues appear to either decompose or become highly fragmented and incorporated into the soil within two years". However Tolhurst *et al.* (1992) found that up to 40% of the pre-fire litter load was not burnt, and subsequently contributed to the rapid accumulation of litter after fire. Such information was not available for this study. Due to the fact that little bark has been removed from tree trunks due to fire, it is assumed that fireline intensity has not been high, therefore residual fine fuel remaining immediately after a fire could play an important role in fuel accumulation rates and the recovery of the litter bed after a fire.

Fogarty (1993) comments that the above-mentioned assumptions have been violated within a number of studies on Australian eucalypt forests. However even with these violations, the negative exponential model is still considered by Fogarty (1993) to be the most appropriate model when determining fuel accumulation. As Fogarty (1993) comments, such models provide an excellent tool for scheduling prescribed fires, however they do not provide enough information for the actual conduct of the fire or to predict fuel in any one year. However O'Connell (1987) showed that the use of a single exponential decay model (Equation 1) generally overestimates the rate of decomposition and underestimates the forest floor accumulation. Whereas the double exponential decay model provides a better fit as the litter fraction is divided into soluble and resistant compounds (O'Connell 1987).

Hutson and Veitch (1985) found quite high accumulation rates, correlating with rainfall, for Blackbutt (*E. pilularis*), with a decomposition rate constant value of 0.68 $yr^{-1}$. The accumulation rate determined in Equation 3 is also quite high, with a decomposition rate constant of 0.87 $yr^{-1}$, compared to those published by Hatch (1955), Van Loon (1977), Lee and Correll (1978), Fox *et al.* (1979) and Raison *et al.* (1983) who all found decomposition rate constants for a variety of eucalypt forests less than 0.50 $yr^{-1}$. Thus the high accumulation rate that was found in this study was unexpected, as Chiltern does not experience a high annual rainfall. Walker (1981) comments that a high decomposition rate constant yields maximum fuel accumulation after a few years, which is clearly the case in this study. Steady state levels are achieved within 10 years of a fire, compared to at least 15 years found in other studies.

Raison *et al.* (1983) found that fine fuel levels accumulated quite quickly, in some instances with 12 t/ha being reached in less then 4 years, however steady state levels were at least 15 t/ha and k values 0.31 $yr^{-1}$ or less. No sites in Chiltern Regional Park had fine fuel levels over 12 t/ha (Fuel Management Zone 2 "trigger" level). As Chiltern Regional Park only has Fuel Management Zones 2 and 4, then the whole Park comes in below the "trigger" level of Fuel Management Zone 2 of 12 t/ha. However we know that bark and elevated fuels also need to be considered when contemplating the need to reduce fuel levels (Wilson 1992, 1993).

## Surface Fine Fuel Hazard

The Elevated Fuel Guide (Wilson 1993) states that Fuel Management Zone 2 can have a maximum of 12 t/ha or a High fine fuel hazard. Throughout the Park, the average surface fine fuel quantity was 7.1 t/ha, with the maximum being 9.7 t/ha. Of all the transects, only four had a surface fine fuel hazard of High, of which, only one was located in a Fuel Management Zone 2. This indicates that fuel reduction burning does not need to be carried out solely for the purpose of reducing surface fine fuel quantities.

## Bark Hazard

Bark hazard is determined by taking into account the flammability of the bark and the looseness of the bark. Flammability of bark is determined by the bark moisture content and the amount of protective, dead fibrous material held on the bole of the tree (Vines 1968). The level of bark hazard will determine the likelihood of a fire reaching the tree crowns and the amount of spotting that is likely to occur. Due to the nature of stringybark bark, the distance that these firebrands or embers is only short compared to the distance that the ribbons from gum bark will travel. Tolhurst *et al.* (1992) comments that the reduction of bark in Messmate/Gum forests of Victoria provides good protection from short distance spotting for at least 10 years. The amount of bark on trees is important when considering fire under very dry and windy conditions. If bark is available, then short distance spotting will most likely occur, and subsequently influence the forward rate of spread of the fire and suppression operations.

The time taken for the bark on the trees to recover to pre-burn conditions is dependent on the growth rate of the bark. In the Messmate/Gum forests in central Victoria - Kellas (1992) found that bark thickness increased by 1.3 mm/yr and Tolhurst *et al.* (1992) predicted that it would subsequently take 15 - 25 years for the bark to recover to pre-burn conditions. Gill *et al.* (1986) found that charred bark was less combustible than uncharred bark from a stringybark. This indicating that as long as there is some charring still present on a tree trunk, then bark hazard level is lower than if there was no charring.

Low intensity prescribed fires generally have an average flame height of about 50 cm, which means that depending on the bark accumulation at the bottom 50 cm of a tree trunk and the continuity of surface fine fuel (Tolhurst *et al.* 1992), bark may not carry flame further up the trunk. This can result in either very patchy bark losses, or no bark loss above average flame height of the prescribed fire. This seems to be what has happened throughout Chiltern Regional Park. Kellas (1992) found that bark loss at 50 cm above ground level in Messmate/Gum forests was related to the Soil Dryness Index. As the Soil Dryness Index increased, so did bark loss. However Kellas (1992) also found that a subsequent fire (within 2 - 3 years of the first) had less of an impact on bark losses than in the initial fire because the bark had already been removed.

## Elevated Fuel Hazard

Within 9.2 years since fire, 95% of the steady state level of elevated fuel will have re-accumulated. Fox *et al.* (1979) and Tolhurst *et al.* (1992) both found that it was at least 10 years before the elevated fuel in the areas studied recovered. Whereas Van Loon (1977) found that it took at least 25 years for the elevated fuel to recover in the Blue Mountains. This is two and a half times that found in Chiltern. Fox *et al.* (1979) indicated that the rainfall and more equable temperature range of the coastal study site could explain the rapid growth rate. However both the sites studied by Tolhurst *et al.* (1992) and Chiltern Regional Park do not receive as much rainfall as the site studied by Fox *et al.* (1979), so it may be the length of the growing season that has an effect on the reaccumulation of elevated fuel.

**Overall Fuel Hazard Rating**

According to Wilson (1993), a Fuel Management Zone 2 should have a hazard level maintained at or below High. For an Overall Fuel Hazard rating of High or below, the litter hazard must be High or below, the bark hazard must be High or below (unless there is less then 4 t/ha of litter) and the elevated fuel hazard must be High or below.

If only fine fuel quantities were to be considered when determining a burning rotation, then Chiltern Regional Park would not need burning to maintain fine fuel quantities below the "trigger" level of 12 t/ha. However, when considering all three fuel components, the recommended Overall Fuel Hazard rating of High is exceeded in the Ironbark/Stringybark forest type. Considering that the areas that are currently zoned Fuel Management Zone 2 are either Ironbark/Stringybark or Box forest type, then future fuel reduction operations will need to be aimed at these forest types, and at the bark hazard in particular. At the same time, any ecological requirements also need to be considered, and taken into account when determining frequency and intensity of future prescribed fires.

## CONCLUSIONS

In some areas of Fuel Management Zone 2, the Overall Fuel Hazard already exceeds the recommended levels set out by Wilson (1993). Park managers need to aim future efforts at reducing bark hazard and elevated fuel hazard. Fine fuel hazard does not currently exceed the recommended level of 12 t/ha.

Surface fine fuel hazard is only reduced for a period of up to 3 years, however the potential surface fine fuel hazard does not exceed 12 t/ha (High). Therefore it is not necessary to aim fuel reduction operations at reducing the surface fine fuel hazard. A Moderate surface fine fuel hazard is predicted as the steady state level for all productivity sites.

The main fuel hazard across Chiltern Regional Park is bark hazard, and to a lesser extent elevated fuel hazard and surface fine fuel hazard respectively. Bark hazard showed no change with time since fire, due to insignificant amounts being burnt in the low intensity fuel reduction burns. Bark hazard levels reached Very High in areas of Ironbark/Stringybark, but only High in areas of Box and Moderate in areas of Gum/Box. The presence of Stringybark greatly influenced the bark hazard level.

The elevated fuel hazard is reduced for a period of up to 9 years after fire. Areas of Very High elevated fuel hazard were found at sites that had been burnt 9 - 10 years previously. However, areas burnt less recently (i.e. 12+ years) were found to have elevated fuel hazards less than Very High, indicating that the shrubs may die back naturally after 9 - 10 years. Although the re-accumulation of elevated fuel is three times slower than the re-accumulation of the surface fine fuel, the fuel hazard is greater (reaching Very High hazard levels) for the elevated fuel than for the surface fine fuel.

Future fuel reduction operations need to be aimed at reducing the bark hazard, especially in areas containing Red Stringybark, and the elevated fuel hazard.

## RECOMMENDATIONS

1. Prescribed fires should be of sufficient intensity or carried out under such conditions that ensure that the bark on the stringybark trees will be burnt, but control of the fire is still possible.

2. Areas of high bark hazard should be burnt at least once every ten years, and monitored to see if this is sufficient time to maintain a Low or Moderate bark hazard level across the Park.

3. Elevated fuel levels should be monitored to see if a peak hazard level is reached after 9 or 10 years since fire, and then if natural reduction occurs.

4. Each fuel hazard component should be assessed after each prescribed fire to monitor the effectiveness of the prescribed fire.

**ACKNOWLEDGMENTS**

I wish to thank Kevin Tolhurst at the Centre for Forest Tree Technology (Creswick Research Station) for providing assistance with the data analysis and for constructive criticisms. Greg McCarthy (CFTT – Orbost Research Station) reviewed all drafts, providing very constructive criticisms. Jenny Craigen (2nd Year of Natural Systems and Wildlife Management, Gatton University, Queensland) assisted in the collection of the fuel samples and fuel hazard assessments. John McDonald (Park Ranger, Chiltern Regional Park) assisted in collating the fire history, stand height and overstorey vegetation composition maps. John also assisted in the field and provided the results of the data collected prior to 1995.

## REFERENCES

Ashton, D.H. (1975) Studies in Litter in *Eucalyptus regnans* Forests. *Australian Journal of Botany* **23**: 413-33.

Buckley, A. (1989) Fine Fuel Accumulation, Moondarra State Park. Fire Protection Branch. Dept Conservation and Environment, Victoria. 18pp. (unpubl.)

Burrows, N.D. and McCaw, W.L. (1990) Fuel Characteristics and Bushfire Control in Banksia Low Woodlands in Western Australia. *Journal of Environmental Management* **31**: 229-236.

DCNR (1995) Code of Practice for Fire Management on Public Land. Dept of Conservation and Natural Resources, Victoria. 38pp.

Fogarty, L.G. (1993) The Accumulation and Structural Development of the Wiregrass (*Tetrarrhena juncea*) Fuel Type in East Gippsland. Research Report No. 37. Fire Management Branch. Dept of Conservation and Natural Resources, Victoria. 29pp.

Fox, B.J., Fox, M.D., and McKay, G.M. (1979) Litter Accumulation After Fire in a Eucalypt Forest. *Australian Journal of Botany* **27**: 157-65.

Gill, A.M., Cheney, N.P., Walker, J. and Tunstall, B.R. (1986) Bark Losses from Two Eucalypt Species Following Fires of Different Intensities. *Australian Forest Research* **16**: 1-7.

Hatch, A.B. (1955) The Influence of Plant Litter on the Jarrah Forest Soils on the Dwellingup Region - Western Australia. Forestry Timber Bureau, Australia. Leaflet No. 70. 18pp.

Hutson, B.R. and Veitch, L.G. (1985) Relationships Between Litterfall Rate, Litter Mass and Decomposition Rate in *Eucalyptus* Forest in South-eastern Australia. *Australian Journal of Ecology* **10**: 443-450.

Kellas, J.D. (1992) Effects of Low Intensity Fire on Tree Growth and Bark Thickness in Mixed Species Eucalypt Forest - Wombat State Forest. In Tolhurst, K.G. and Flinn, D.W. (Eds) Ecological Impacts of Fuel Reduction Burning in Dry Sclerophyll Forest : First Progress Report. Research Branch Report No. 349. Dept Conservation and Environment, Victoria. Chapter 12.

Kessell, S.R., Good, R.B. and Potter, M.W. (1982) Computer Modelling in Natural Area Management. Australian National Parks and Wildlife Service. Special Publication No. 9. 43pp.

LCC (1977) Final Recommendations - North-eastern Study Area Districts 3, 4 and 5. Land Conservation Council. Melbourne.

LCC (1984) Report on North-eastern Area (Benalla - Upper Murray) Review. Land Conservation Council. Melbourne. 228pp.

LCC (1986) Final Recommendations - North-eastern Area (Benalla - Upper Murray) Review. Land Conservation Council. Melbourne. 223pp.

Lee, K.E. and Correll, R.L. (1978) Litterfall and Its Relationship to Nutrient Cycling in a South Australian Dry Sclerophyll Forest. *Australian Journal of Ecology* **3**: 243-252.

Lloyd, P.G. and Lau, J.A. (1986) Timber, Vegetation and Habitat Resources of the Chiltern Regional Park Resource Assessment Report 86/4. Public Land Management and Forests Division. Dept Conservation, Forests and Lands, Victoria.

Luke, R.H. and McArthur, A.G. (1978) Bushfires in Australia. Australian Government Publishing Service. Canberra. 359pp.

McArthur, A.G. (1962) Control Burning in Eucalypt Forests. Forestry and Timber Bureau, Australia. Leaflet No. 80. 31pp.

McCarthy, G.J. (in preparation) Fuel Hazard Rating for Forest Fuels - Surface Fine Fuel Hazard. Research Report No. 44. Fire Management Branch. Dept Natural Resources and Environment, Victoria.

McCaw, L. (1988) Measurement of Fuel Quantity and Structure for Bushfire Research and Management. In Cheney, N.P. and Gill, A.M (Eds) Proc. Conference on Bushfire Modelling and Fire Danger Rating Systems. CSIRO Australia. Canberra. pp.147-155.

NPS (1990) Chiltern State Park - Interim Plan of Management. National Parks Service. Dept Conservation and Environment, Victoria.

NPS (1994) Chiltern Regional Park. National Parks Service. Dept Conservation and Natural Resources, Victoria. 2pp.

O'Connell, A.M. (1987) Litter Dynamics in Karri (*Eucalyptus diversicolor*) Forests of South-western Australia. *Journal of Ecology* **75**: 781-796.

Olsen, J.H. (1963) Energy Storage and the Balance of Producers and Decomposers in Ecological Systems. *Ecology* **44**: 322-31.

Peet, G.B. (1971) Litter Accumulation in Jarrah and Karri Forests. *Australian Forestry* **35**: 258-262.

Pook, A.A. and Caddell, R.T. (1990) North East Region - Regional Fire Protection Plan. Dept Conservation, Forests and Lands, Victoria. pp9-10.

Raison, R.J., Woods, P.V. and Khana, P.K. (1983) Fuel Dynamics in Recurrently Burnt Eucalypt Forests. In Institute of Foresters of Australia 10th Triennial Conference Proc. pp59-64.

Rogers, R.W. and Westman, W.E. (1977) Seasonal Nutrient Dynamics of Litter in a Subtropical Eucalypt Forest, North Stradbroke Island. *Australian Journal of Botany* **25**: 47-58.

Schneider, B.H. and Bell, D.T. (1985) A Simple, Effective Technique for Rapid Measurement of Fuels in Low Shrub Communities. *Australian Forest Research* **15**: 79-84.

Simmons, D. and Adams, R. (1986) Fuel Dynamics in an Urban Fringe Dry Sclerophyll Forest in Victoria. *Australian Forestry* **49**: 149-154.

Sneeuwjagt, R.J. (1973) Measuring Forest Fuels. W.A. Forest Department Research Paper No. 9. 6pp.

Sneeuwjagt, R.J. and Peet, G.B. (1985) Forest Fire Behaviour Tables for Western Australia. 3rd Edition. Dept Conservation and Land Management, Western Australia.

Tolhurst, K.G, Kellas, J.D. and Wilson, A.A.G. (1992) Low Intensity Fire Behaviour and Fuel Dynamics in Dry Sclerophyll Forest, Wombat State Forest. In Tolhurst, K.G. and Flinn, D.W. (Eds) Ecological Impacts of Fuel Reduction Burning in Dry Sclerophyll Forest: First Progress Report. Research Branch Report No. 349. Dept Conservation and Environment, Victoria. Chapter 2.

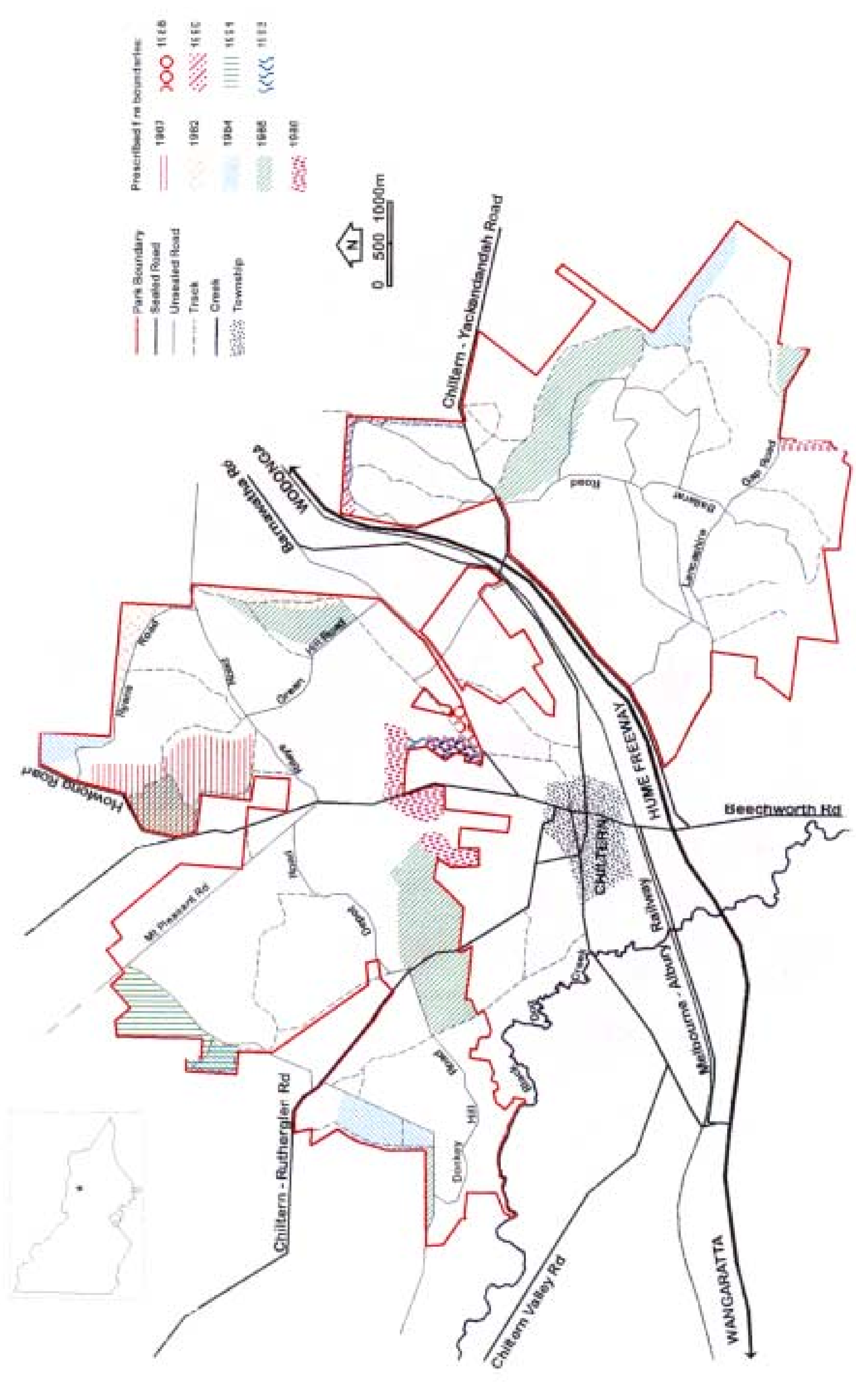
Van Loon, A.P. (1977) Bushland Fuel Quantities in the Blue Mountains - Litter and Understorey. Forest Commission New South Wales. Research Note 33. 23pp.

Vines, R.G. (1968) Heat Transfer through Bark and the Resistance of Trees to Fire. *Australian Journal of Botany* **16**: 499-514

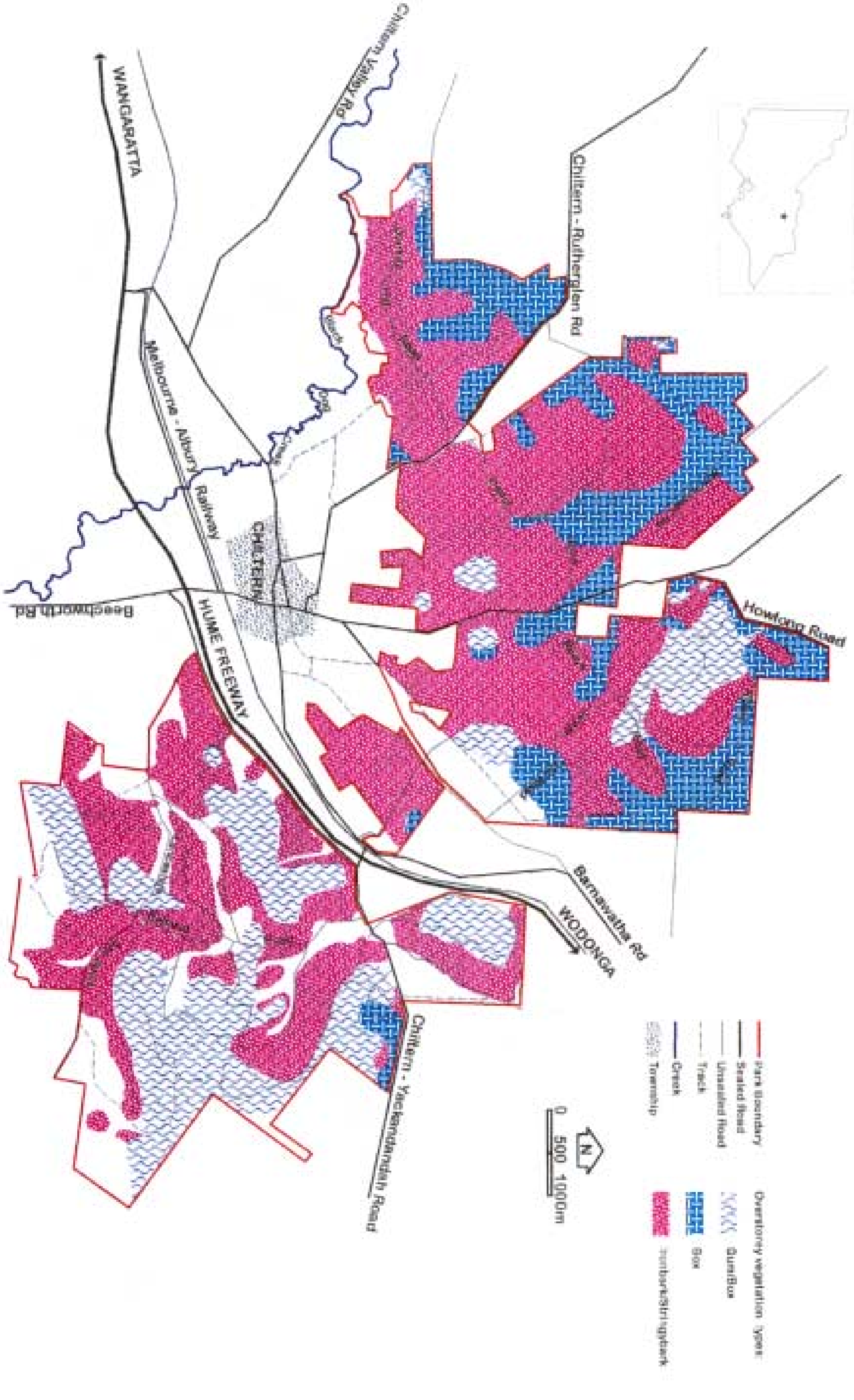
Walker, A. (1981) Fuel Dynamics in Australian Vegetation. In Gill, A.M., Groves, R.H. and Noble, I.R. (Eds) Fire and the Australian Biota. Australian Academy of Science. Canberra. Chapter 5.

Wilson, A.A.G. (1992) Eucalypt Bark Hazard Guide. Research Report No. 32. Fire Management Branch. Dept Conservation and Environment, Victoria. 16pp.

Wilson, A.A.G. (1993) Elevated Fuel Guide. Research Report No. 35. Fire Management Branch. Dept Conservation and Environment, Victoria. 22pp.




**Appendix A.** Fire history of Chiltern Regional Park.




**Appendix B.** Overstorey vegetation classification of Chiltern Regional Park.

Other Reports in this Series include:

1. A Study of the Distribution of Aerially Applied Fire Retardant in Softwood Plantations. R. Rawson 1977.
2. Low Intensity Prescribed Burning in Three *Pinus radiata* Stand Types. D.S. Thomson 1978.
3. Fuel Properties Before and After Thinning in Young Radiata Pine Plantations. D.F. Williams 1978.
4. Using Fire to Reduce Fuel Accumulations After First Thinning in Radiata Pine Plantations. P.R. Billing 1979.
5. Some Effects of Low Intensity Burning on Radiata Pine. P.R. Billing 1979.
6. A Low Intensity Prescribed Burning Operation in a Thinned Radiata Pine Plantation. P.R. Billing 1980.
7. Some Aspects of the Behaviour of the Caroline Fire of February 1979. P.R. Billing 1980.
8. Changes in Understorey Vegetation in Sherbrooke Forest Following Burning or Slashing. R. Rawson and B. Rees 1981.
9. Hazard Reduction Burning in the Big Desert. P. Billing 1981.
10. The Effectiveness of Fuel-Reduction Burning: Five Case Histories. P.R. Billing 1980.
11. A Fire Tornado in the Sunset Country January 1981. P. Billing and R. Rawson 1982.
12. A Summary of Forest Fire Statistics, 1972-73 to 1980-81. R. Rawson and B. Rees 1982.
13. Fuel Moisture Changes Under Radiata Pine. M. Woodman 1982.
14. Fuel Reduction Burning in Radiata Pine Plantations. M. Woodman and R. Rawson 1982.
15. Project MAFFS/HERCULES the Modular Airborne Fire Fighting System in Victoria. R. Rawson, B. Rees, E. Stuckey, D. Turner, C. Wood and M. Woodman 1982.
16. Using Fire to Reduce Aerial Fuels in First Thinned Radiata Pine. P.R. Billing and J.V. Bywater 1982.
17. Fuel Properties Before and After Second Thinning in Radiata Pine. M. Woodman 1982.
18. Retardant Distributions From Six Agricultural Aircraft. B. Rees 1983.
19. The Bright Plantation Fire: November, 1982. N. Watson, G. Morgan and D. Rolland 1983.
20. Otways Fire No. 22 - 1982/83: Aspects of Fire Behaviour. P. Billing 1983.
21. Otways Fire No. 22 - 1982/83: A Case Study of Plantation Protection. P. Billing 1983.
22. Forest Fire Statistics 1974-75 to 1983-84. B. Rees 1984.
23. The Avoca Fire 14 January 1985. P. Billing 1985.
24. Fuel Management in Radiata Pine Following Heavy First Thinning. P. Norman 1985.
25. Effectiveness of Fuel-Reduction Burning. R. Rawson, P. Billing and B. Rees 1985.
26. Operational Aspects of the Infra-Red Line Scanner. P. Billing 1986.
27. Heathcote Fire: Bendigo Fire No. 38 - 1986-87. P. Billing 1987.
28. Fire Behaviour and Fuel Reduction Burning - Bemm River Wildfire, October 1988. A. Buckley 1990.
29. Fire Hazard and Prescribed Burning of Thinning Slash in Eucalypt Regrowth Forest. A.J. Buckley and N.J. Corkish 1991.
30. Monitoring the Ecological Effects of Fire. Proceeding of Fire Research Liaison Group Workshop, The Herbarium, South Yarra, 10 September 1987. F. Hamilton (Ed.) 1987.
31. Assessing Fire Hazard on Public Land in Victoria : Fire Management Needs, and Practical Research Objectives. A.A.G. Wilson 1992.
32. Eucalypt Bark Hazard Guide. A.A.G. Wilson 1992.
33. Fuel Reducing a Stand of Eucalypt Regrowth in East Gippsland: A Case Study. A.J. Buckley 1992.
34. Monitoring Vegetation for Fire Effects. M.A. Wouters 1992.

35. Elevated Fuel Guide. A.A.G. Wilson 1993.
36. Wildfire Behaviour in Heath and Other Elevated Fuels: A Case Study of the 1991 Heywood Fire. M.A. Wouters 1993.
37. The Accumulation and Structural Development of the Wiregrass (*Tetrarrhena juncea*) Fuel Type in East Gippsland. L.G. Fogarty 1993.
38. A Case Study of Wildfire Management in the Byadbo and Tingaringy Wilderness Areas. A.G. Bartlett 1993.
39. Developing Fire Management Planning in Victoria: A Case Study from the Grampians. M.A. Wouters 1993.
40. Fuel Reducing Regrowth Forests with a Wiregrass Fuel Type: Fire Behaviour Guide and Prescriptions. A.J. Buckley 1993.
41. The Effect of Fuel Reduction Burning on the Suppression of Four Wildfires in Western Victoria. S.R. Grant and M.A. Wouters 1993.
42. Fire Behaviour and Fire Suppression in an Elevated Fuel Type in East Gippsland: Patrol Track Wildfire, February 1991. A.J. Buckley 1994.