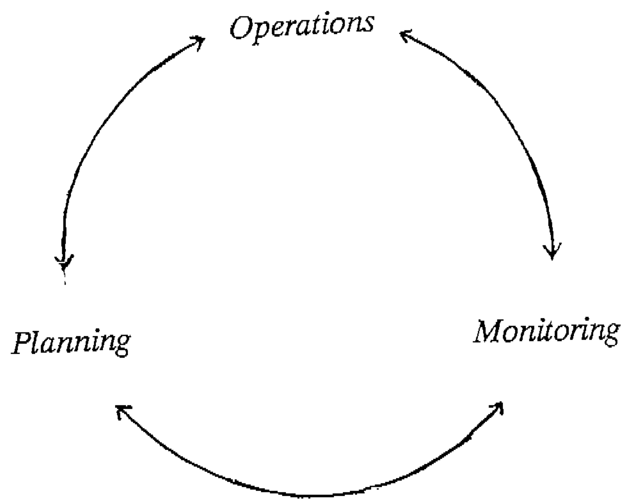
Fire Management Branch
Department of Conservation & Environment



MONITORING THE ECOLOGICAL EFFECTS OF FIRE

Proceedings of Fire Research Liaison Group Workshop

THE HERBARIUM, BIRDWOOD AVENUE, SOUTH YARRA

10 SEPTEMBER 1987

RESEARCH REPORT NO. 30
F. HAMILTON Ed.
SEPTEMBER 1987

This report was first published in 1987 under the auspices of the Fire Research Liaison Group, Department of Conservation, Forests and Lands.

INDEX

MONITORING THE ECOLOGICAL EFFECTS OF FIRE

INTRODUCTION

Fire is a powerful force in the dynamics of ecosystems, with great potential to induce change. If fire is to be used as a management tool its effects must be monitored in order to determine whether the aims of management are being achieved. Only by monitoring can changes induced by fire, whether wildfire or prescribed fire, be identified. Any monitoring program is based on getting out and observing these changes in the field.

This Workshop was intended to provide participants with monitoring techniques suitable for use in regional projects and with contacts who can provide further technical advice.

These proceedings are a brief record of the information presented at the Workshop and some of the questions raised by participants. They also include examples of recording forms which could be used in monitoring programs. The proceedings will serve as a manual for staff establishing monitoring programs. A contact list is included at the end of the manual. The relevant contacts should be consulted when a monitoring program is proposed, so that they can provide advice in the planning stages.

The Workshop was organised by the Department's Fire Research Liaison Group comprising representatives of all the head office divisions concerned with fire-related research and a representative of regional management. It followed requests from regional staff for assistance with monitoring projects. We hope that these proceedings will be of assistance to these and other staff in the future.

MONITORING - WHAT AND WHY

FIRE ECOLOGY,
SILVICULTURE AND FOREST MONITORING

PAPER PREPARED FOR WORKSHOP ON
"MONITORING THE ECOLOGICAL EFFECTS OF FIRE".
DEPARTMENT OF CONSERVATION, FORESTS AND LANDS,
10 SEPTEMBER 1987

ROB CAMPBELL
MOUNTAIN FOREST RESEARCH STATION
SHERBROOKE, VIC. 3789

FIRE ECOLOGY, SILVICULTURE AND FOREST MONITORING

1. FIRE ECOLOGY

Fire is one of the most important single events influencing the regeneration of native forest ecosystems in Victoria (Campbell et al. 1984). It can have major impact on the species composition, structure and evolution of the living organisms in the ecosystem and on the soils, water, and the atmospheric components of the physical environment. For example, the natural regeneration of mountain ash forests is almost totally dependant on wild-fires which destroy standing vegetation, prepare a seed-bed and induce a fall of seed from the canopy of standing trees. These wild-fires also influence the chemical and physical properties of soils, the quality and quantity of water yeilds and the particulate matter, gaseous composition, and radiation dynamics of the atmosphere.

Fire has been an important event in native forest ecosystems for at least 10 million years. During the past 50 000 years the Aboriginal population used fire for hunting, protection and vegetation management, and no doubt had a major impact on long standing fire patterns, and thus on flora and fauna of the native forest ecosystems that we inherited at the time of European settlement.

During the "split second" of the evolutionary time clock since European settlement (less than one half of the life cycle of a mature eucalypt!!) we have had a massive impact on the frequency, intensity and pattern of fires in native forest ecosystems. The need to understand the effects of this massive ecological change on the long standing natural processes of regeneration and evolution is both obvious and imperative. In depth understanding is a fundamental pre-requisite to the ongoing development of a silviculture that is capable of attaining the inter-dependant objectives of conservation, sustained productivity and social justice that constitute the corner stones of current State Government Strategies.

2. SILVICULTURE

Fire is one of the most powerful tools available for the silviculture of a forest ecosystem. It is potentially our most cost/effective and ecologically acceptable tool for activities such as fire protection, regeneration, and flora and fauna conservation. Chemical and mechanical alternatives are often exhorbitantly expensive or ecologically unacceptable. However, the successful use of fire as a silvicultural tool is totally dependant on scientific knowledge of the impact of both natural and man-initiated fires on ecosystem dynamics. Forest monitoring is the key to obtaining such knowledge.

3. FOREST MONITORING

Forest monitoring is concerned with awareness, observation, and understanding of key processes in a forest ecosystem (see e.g. Campbell, 1986). The most fundamental and important process in a forest are the life cycles of the individual organisms that come together to form the ecosystem as a whole. Forest monitoring must seek to understand these individual life cycles and the impact of altered fire regimes thereon. For example, the timing of fire in relation to seed maturation, germination patterns and the competitive position of individual organisms is critical to the success of regeneration. The effects of altered fire regimes must be evaluated against the natural processes of regeneration and evolution in the ecosystem if we are to understand the impact of altered regimes on life cycle processes. Knowledge of these natural processes must therefore be a primary aim of any monitoring program.

Successful forest monitoring requires a clear understanding of needs and objectives, cost effective monitoring methods, and motivated people who are willing to place priority on the forest rather than the paper warfare of the bureaucracy (see e.g. Campbell and Bray 1987). Key needs include an improved understanding and further development of slash fire for regeneration following harvesting, fuel reduction burning for forest protection and the use of fire to eliminate unwanted alien species or to promote the regeneration and growth of indigenous species, especially those that may be on the endangered list. Effective methods must inovlve a personal presence on site in the forest on a continuing basis and for sufficient time to develop an intuitive awareness of the processes which the monitoring seeks to understand. Quantitiative data is important, but in no way a subsitute for the understanding that comes from a regular and one-pointed presence in the forest. This presence is difficult to achieve in the face of the increasing pressure of people and paper, and the reducing resources available to the public sector of the economy.

The development of effective forest monitoring practices throughout the Regional Systems that are responsible for management on the ground in the ecosystem could be fostered by the formation of a core group of motivated and experienced people, and the development of a register of ecological information on each major forest type (e.g. as suggested in the State Conservation Strategy). The basic building block in this register should be details of the life cycle of individual organisms in the ecosystem and their interaction with the physical environment in which they exist. The core groups, and the register, should then be used as a catalyst and a guide to the development of the forest monitoring methods and the network of positive people that are esential to the understanding and improvement of our use of fire as a tool for the protection and silviculture of native forest ecosystems.

REFERENCES AND FURTHER READING

Campbell, R G *et al.* 1984 Silvicultural and environmental aspects of harvesting some commercial eucalypt forests in Victoria. A review. Research Report, Dept. Conservaiton, Forests & Lands, Vic. 129 p.

Campbell, R G 1986 Forest monitoring to improve efficiency in regeneration silviculture for mountain forest ecosystems. Paper presented to the Workshop on "Assessment and Monitoring and Forest Regeneration for Hardwood Production", West Sale, Victoria, 22-23 April 1986. Dept. Conservation, Forests and Lands, Vic. 16 p.

Campbell, R G and Bray, P L 1987 Field germination, survival and seedling growth of mountain ash following clear-felling of a regrowth stand at Xylophone Bridge in the Central Highlands of Victoria. Research Report 327, Public Lands and Forests Division, Dept. Conservation, Forests and Lands, Vic. 50 p.

A DEVELOPMENT ACTION NOTE:

Campbell, R G 1988 Germination surveys. A simple technique for predicting and improving the success of eucalypt regeneration. Research and Development Note, Lands and Forests Division, Dept. Conservation, Forests and Lands, Vic 4 p.

MONITORING - WHAT AND WHY?

Arnis Heislers

HABITAT

- taken to be the physical environment for plants and animals
- in relation to fire it includes the flamable material (living and dead)

To monitor is to "observe critically", which implies reporting on the condition of habitat over some time span, i.e., changes with time (long or short or both).

Why Monitor?

- to assess the effect of fire and consequences for achievement of goals and determine any warranted management action.

What might be monitored?

- The condition of the habitat as a result of fire and the critical aspects affecting recovery of habitat.

  a) Terrestrial Habitat i.e., - soil, litter, logs and vegetation (in profile)
     - nature of the fire:
       - season
       - intensity & extent: amount material consumed
         : scorched
         : patchiness
       - frequency
     - Weather conditions after fire affecting recovery (e.g. temp. & moisture)

     - detail of record depends on the habitat of interest; may be species specific (e.g. of a rare species) or may be of a community (e.g., Vegetation type).
     - key parameter is vegetation - its condition most directly affects flora and fauna.

  b) Aquatic Habitat i.e. water quality and quantity and substrate
     - consider sedimentation, chemical leachates, stream flows, water temperatures.

Monitoring the Ecological Effects of Fire : Fuel Reduction burning and Wildfire

John Nankervis
Regional Fire Protection Officer
Department of Conservation, Forests
and Lands

Introduction

With respect to fuel reduction burning and wildfire suppression, the overriding consideration for monitoring by the land manager concerned with fire protection should be of fuel factors. The direct relationship between available fuel and fire parameters such as intensity and rate of spread is well documented. The most important fuels in determining fire behaviour are fine fuels, comprising dead twigs, leaves and bark less than 6 mm in diameter. Living foliage of small plants up to 6 mm in diameter or thickness may also make a significant contribution to fire behaviour.

What to Monitor and Why

(a) Total fine fuel load must be known to predict fire intensity during planned burning operations, and hence allow safe conditions to be prescribed; it must be known to predict wildfire behaviour under given conditions, and hence the suppression effort required and safety considerations; it must be known to plan protection activities in a timely and orderly fashion.

(b) Fuel distribution and arrangement must be monitored to give the manager data to predict flame heights and spread rates under given conditions.

(c) Fuel accumulation rates must be monitored to allow long range planning of fuel modification programs.

(d) Fuel moisture content must be monitored in the short term to determine available fine fuel levels.

(e) Fuel composition must be monitored to provide data on such things as plant succession leading to altering fuel flammabilities, and the contribution to the fuel load of living scrub and undergrowth.

What Is and Is Not Done

Given the importance of fuel factors in prescribing or predicting fire behaviour, grossly insufficient monitoring of any of the factors is presently carried out.

Pre fuel reduction burning monitoring is usually restricted to a very few samples of fine fuel load (if sampled at all) and fuel moisture content. Planned burning often fails (at both ends of the intensity scale) because limited or ocular fuel load monitoring has failed to reveal important fuel gradations on a site.

Post wildfire and fuel reduction burning monitoring of fine fuels is rarely undertaken. Too often there is an assumption that any burning has been as effective as it could have been, and that accumulation of new fine fuels is commencing from some minimum base. Fuel arrangement is insufficiently monitored prior to planned burning operations, where it could be an important factor, and also often lends to a planned burn being too intense.

What Is and Is Not Known

The relationships of fuel and other parameters to fire behaviour are generally well known. Techniques for measuring fuel quantities and moisture contents are also generally developed. However these techniques are cumbersome and time consuming, and deter more extensive monitoring.

The contribution of living shrub material to fire behaviour is not as well known, and techniques for quantitatively describing this fuel component need to be developed for Victorian plant communities.

Plant community changes following regular burning are still not widely understood and further work is required, particularly regarding possible 'invading flammables'. Simple sample plots could be established in regional programs.

Finally much more data is required to be developed on fuel accumulation rates for different forest types in different parts of Victoria.

MONITORING

THE ECOLOGICAL EFFECTS OF FIRE

WORKSHOP

10 September 1987

3. FIRE BEHAVIOUR, FIRE EFFECTS AND FIRE HISTORIES

Prepared by: Peter Billing

Fire Behaviour, Fire Effects and Fire Histories

Fire Behaviour, Fire Effects and Fire Histories

1. INTRODUCTION

Fire and drought are the most obvious factors to have shaped the character of flora and fauna in south-eastern Australia since the last ice age to what we have today. Our recent experience of severe fires and drought in 1982 and 1983 has rekindled interest in monitoring their effects. These notes are a guide to describing fires for fire effects and fire history purposes.

1.1 What is fire behaviour

Fire behaviour of a free-burning surface fire is the development of an ignition source subject to the interactions of weather, fuels and topography. In some situations multiple ignitions enhance fire development, so fire managers are able to manipulate fire behaviour to some extent. Apart from selecting the general conditions and ignition pattern, fires behave according to factors largely beyond our control.

1.2 Variability

As fires develop, their behaviour and effects change. These changes are further compounded by changes in weather, fuels or topography, so even small fires can have quite variable effects which require careful sampling. Fire behaviour during weather changes, or in clumpy fuels and broken topography is extremely difficult to describe.

1.3 Purpose of the study

Description of a fire and the conditions which precede and succeed it are dictated by the purpose of the study. i.e. if we are interested in fire effects on seed capsules, part of the study should be to record temperatures in the canopy of the particular shrub or tree (Ashton 1986, Bradstock et al 1981, Gill 1976), whereas for fire scar formation on trees we would be interested in temperature changes and the duration of combustion in the region of basal bark (Gill 1974, Vines 1968).

1.4 Main factors

The main effects of fire relate to the heat generated, the frequency of fire events, and conditions before and after each event. Heat output and its duration creates a range of opportunities. Frequency and the ambient conditions tend to be selective factors which reduce the range of opportunities.

The key factors to be evaluated in fire effects studies should include:-

(a) Climatic conditions before, during and after each fire event.

(b) Fire characteristics

(c) Fuel properties

(d) History, frequency and season of fire.

(e) Site factors such as soils, vegetation, aspect and slope.

(f) Description of vegetation, animals, soils etc.

2. Weather description

Monitoring weather is an essential part of studying fire behaviour and fire effects.

Long term weather impact on a site can be measured simply by monitoring rainfall prior to and after the fire.

For short term measurements such as are necessary during the fire it is best to set up a Stevenson screen and rain gauge on site, using a Meteorological Observers Handbook as a guide. However since we are studying a modified environment, especially in tall forests, instruments should be sited under canopy if applicable. Instruments required include wet and dry bulb themometers, a maxi-min thermometer, a sensitive anemometer and compass, and a rain gauge. A thermohygrograph recorder is useful but not essential. The cost of these instruments, plus a Stevenson screen would be roughly $1000 (1987).

Another method for short-term measurements is to use an aspirated or whirling psychrometer for temperature determination.

Whatever the method, during a fire, weather measurements would be noted regularly, such as on the hour, but wind speed and direction may be noted at closer intervals or whenever a change occurs. Relative humidity is calculated from wet and dry bulb temperatures.

Weather forecasts are a key part of prescribed burning and wildfire behaviour assessment and play an important role in fire management planning.

3. Fuel Description

Fuel characteristics important to fire behaviour and fire effects are fuel quantity, fuel size and continuity, fuel type and moisture content.

Techniques to determine these characteristics are well described by Norman (1986) and Sneeuwjagt (1973) as well as in fire behaviour texts, so they will not be discussed here.

Fuel measurements are made prior to the fire at known points and then remeasured after the fire if appropriate. Fuel quantity is usually the most important descriptor to measure, as the quantity of fuel burnt is directly related to the heat output, fire intensity, scorch and surface heating. Destructive sampling is the most practical method to gauge quantity, and there are a variety of sample plot sizes and techniques to suit a particular site and purpose. Fuel is sorted into size classes (see below) and the weight is corrected for moisture content by oven drying (105^{o}C) or by moisture content sampling. Combustion of damp fuel is often incomplete and slow. Moisture content of some fuel components (such as fine fuels) can change rapidly, thus having a profound effect on combustion rates and the quantity of fuel burnt.

Fuel particle size and arrangement also influence the combustion rate since fine fuels (defined as less than 6mm diameter) burn more rapidly than coarse fuels (which are larger than 6mm diameter). Well aerated fuels burn faster than fuels in a compact layer. Continuity or distribution of fuel influences fire spread at low to moderate fire intensities but has no relevance to static fires. Fuel type is mainly responsible for spotting characteristics and flame spread up trees (bark type) but species can influence flammability. For example, in stringy-bark forests the quantity of bark plays a dominant role in fire behaviour and flame spread, and scorch may bear little resemblance to fuel quantity in the litter layer burnt by a fire on the ground surface.

4. Topography

It is normal to describe slope, aspect and elevation in the methodology of a study or in descriptions of vegetation and these should be sufficient. Localised variations in slope and aspect which influence fire behaviour can be noted during the fire and used to explain fire effects.

5. Description of Fire Behaviour

Fire behaviour must be expressed quantitatively to explain fire effects. Fire intensity and heat per unit area are two descriptors of fire behaviour which are convenient to relate to fire effects. These and other descriptors can be determined from observations of flame dimensions and fire behaviour as described below and in the appendix.

5.1 Chemical reaction

Fire is a chemical reaction; every tonne of dry organic matter burnt requires at least 7 tonnes of air (6000 m^3) for complete combustion. The end products are 1/2 a tonne of water vapour, 1 1/2 tonnes of carbon dioxide and 20,000 M J of heat. In the field this reaction is less efficient due to moisture in the fuel, living fuel and poor air supply. These factors not only reduce the heat yield but contribute to smoke emissions. The temperature range is from 300°C to 1200°C with the flame zone.

5.2 Sampling

Since the behaviour of fires is subject to change, predicting the effects of fires must account for this variability by sampling the range of observed behaviour. For very small, low intensity fires, one or two measurements may be adequate but for fires of more than 1/2 hectare or more intense fires, the variation between headfire and backfire at any point in time would mean several measurements are necessary.

If fire behaviour and weather conditions are steady-state, sampling intensity can be diluted, but when fire behaviour is changing rapidly useful information can only be gathered by intensifying sampling.

The outcome of a detailed study of a fire would be a map of the area burnt showing fire descriptor measurements at sample points, so that these could be related to other descriptors of the ecosystem at these sites. The selection of useful fire behaviour descriptors is important.

5.3 Flame dimensions

The most obvious impacts of flames are damage to vegetation, the amount of fuel burnt and difficulty of fire control. Flame height, flame angle, flame depth and flame length are the usual flame descriptors measured. Temperatures are useful for specific studies. Except for quite small low intensity fires, observations of these descriptors are quite difficult mainly due to heat, smoke and short term variation in the flame shape.

Flames should be observed for periods of up to one minute. Scaling aids such as steel posts or height poles (multicoloured) are essential for any degree of accuracy. Strategic photographs assist in describing flames. Details of flame measurements are stylised in Figure 1 for a wind driven fire.

5.3 Flame dimensions (continued)

Flame height is the vertical distance from flame tip to the fuel bed surface, (in forests this is the surface of the litter bed; in heaths the ground surface) or the base of the fire. Maximum as well as average values can be recorded.

Flame angle is the angle between the line of projection of the flame tip and the surface of unburnt fuel bed measured from the direction of fire spread or unburnt fuel.

Flame depth is the distance from the flame front perimeter to the rear of this flame front i.e. the depth at flame measured parallel to the direction of spread. It involves the zone of active flaming of fine fuels but does not consider flaming of scattered heavy fuels such as branches, logs or stumps. In areas containing large quantities of heavy fuels flame depth is very difficult to measure compared to areas containing predominantly fine fuels.

Flame length together with flame angle are important descriptors of head fires and flank fires. In the head fire zone of wind-driven fires, flame length is almost impossible to measure from direct observations. It is usually calculated from flame height and flame angle observations and from phtographs. (Johnson 1982)

Thermal measures of flames generally use either card pyrometers or thermo-electrical devices. Card pyrometers are cheap , easy to make from mica sheets and thermo-crayons, easy to use and give useful information (Whittaker 1961). Thermo-electrical devices such as thermocouples and thermistors are more accurate and give useful information on heat yield and temperature fluctuations. Simple billy calorimeters can be used to quantify surface heating by low intensity fires (Beaufait 1966). Location and exposure of any of these instruments has a significant effect on their results.

5.4 Fire spread descriptors.

Fires which develop from a single ignition point initially spread uniformly in all directions like a wave, and may form a ring. The influence of wind, fuels and slope gradually changes this spread pattern to an ellipse. Wind tends to dominate fire spread so that stronger winds elongate the fire spread axis. A measure of fire shape, the length to width ratio, can be as high as 6 to 1 for wind driven fires.

Since there is a gradual change in fire behaviour around the perimeter of a fire, for descriptive purposes the perimeter is divided into 3 zones. In each zone it is usual to measure the progress or spread of the fire edge, flame height, flame angle and flame depth. The most active zone of fire behaviour is known as the head fire zone, the least active edge is the back fire zone and the remaining portion between these is called the flank fire zone. (Figure 2).

In the head fire zone where the fire is being driven by wind or slope, flames lean forward over unburnt fuel. Stronger winds or steeper slopes cause flames to tilt further (flame angle decreases), increasing flame length and rate of spread, refered to as the forward rate of spread (F.R.O.S.). Maximum values of rate of spread, flame height and flame depth are always observed in the head fire zone. Minimum values are observed for flame angle and residence time (except if there is no backfire).

In the flank fire zone, flame heights, flame depths and rates of spread are somewhat less than near the head fire and more variable since the fire edge moves slightly across the wind direction or slope. For descriptive purposes these observations are made along a line at an angle of 60° to the direction of head fire spread. Most of the area burnt from point ignition fires is burnt by flank fire activity, an important consideration for fire effects studies.

In the back fire zone, fire behaviour is least active and most uniform. Flames lean over the burnt fuel towards the headfire. Flame height and fire spread are relatively constant and low in value. Under moderate conditions back fires may fail to spread.

Growth in fire area in the absence of spotting is closely related to the forward rate of spread. In simple mathematical terms fire area can be approximated to a double ellipse (Fons 1946) or a simple ellipse (Van Wagner 1969) if spread is under constant conditions. Van Wagner's ellipse formula shows that fire area increases quadratically with time:

$$A_t = /_2 \, \frac{(V + W)\, ut^2}{10,000}$$

where A_t is fire area (ha) at time t.

V is headfire rate of spread (m/h)
u is flank fire rate of spread (m/h)
W is back fire rate of spread (m/h)
t is time since ignition (h)

(see Figure 2)

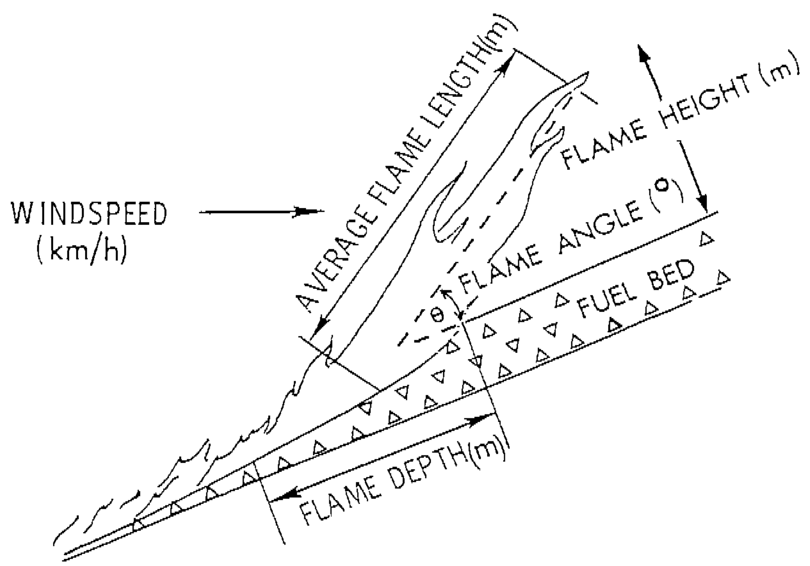


Figure 1.—Flame dimensions shown for a wind-driven fire on a slope.

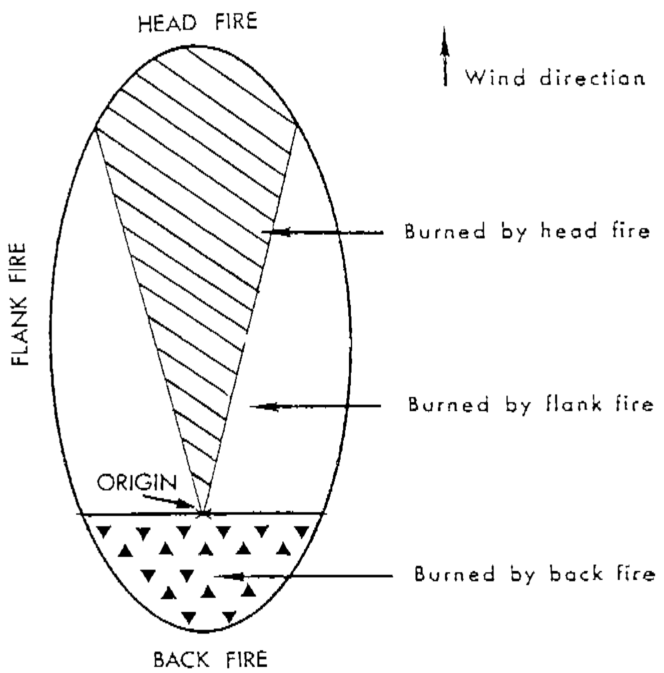


FIGURE 2 DIAGRAM OF SIMPLE FIRE GROWTH MODEL

5.4 Fire spread descriptors (continued)

More accurate models use wind speed, fuel type and rate of spread to calculate length to width ratios. (Anderson 1983)

Measurement of fuel growth for small fires is carried out by placing numbered metal tags or markers around the perimeter at regular time intervals (Peet 1967). Wire 'arrows' and steel pegs at regular spacings are useful. Surveying the location of these tags is very simple with a plane table-tape measure technique for small fires, or by chain and compass for larger fires.

A number of other techniques rely on a present grid of markers such as steel posts, wire arrows and coloured ribbons or strings. They can be quite elaborate but are seldom as practical and flexible to changes in fire spread, so these methods are more suited to very small intensively monitored fires or for demonstration purposes.

Other mapping techniques, such as aerial observation and infra-red techniques, require specialist input and are well described in recent publications. They are more applicable to larger fires.

From a plot of fire growth or isopleths it is possible to accurately determine fire spread rates and area spread.

5.5 Description of heat from a fire.

5.5.1 Scorch height

The height of vegetation scorch is probably the most obvious and easiest to measure descriptor of the heat output of a low to moderate intensity fire. Most plant tissues such as leaves are severely damaged or scorched if heated to around 60°C (Byran 1958). After a fire, scorch height can be measured at predetermined points where flame characteristics and fire spread are known. Scorch height as usually compared to flame height or flame length or fire intensity (Van Wagner 1972).

5.5.2 Fire Intensity

This was devised by Byram (1959) as a measure of fire behaviour. It has been widely used for fire effets studies, fire control and damage potential purposes. Fire intensity is easy to calculate although it is limited to describing moving fires in fuels largely consisting of fine particles (less than 6 mm diameter).

Fire intensity is the rate of energy release per unit length of fire front:

$$I = H.W.R.$$

where - I is fire intensity (KW/m)
- H is heat yield of fuel (usually 18,000 to 23,000 KJ/kg)
- W is the dry weight of fuel burnt (fine fuel kg/m^2)
- r is the forward rate of spread (m/sec)

5.5.2 Fire Intensity (cntinued)

A useful approximation of this formula in forest fuels is:

$$I = .5\ WR$$

Note that W is expressed as tonnes/ha and R in m/hr, units commonly used in the field.

Fires described as low intensity are generally less than 350 KW/m, moderate intensity up to 1200 KW/m and high intensity over 5000 KW/m. Severe forest fires can have intensities above 20,000 KW/m, even as high as 60,000 KW/m.

For any given fire, fire intensity is greatest in the zone of maximum spread and highest fuel consumption, usually the head fire zone.

Fire intensity is also related to flame length as described by Byram (1959):-

$$I = 258F_L^{2.17}$$

where I is fire intensity (KW/m)
F_L flame length (m).

Because rate of spread and fuel quantity are easier to measure than flame length, this formula is seldom used to calculate fire intensity.

While fire intensity is an extremely versatile descriptor for fire effects studies, it is best suited to studies close to or within the flame zone above the fuel bed (Van Wagner 1972).

Apart from being inapplicable to static fires and fires in coarse fuels, the fundamental problem with fire intensity for other studies is that it quantifies energy released from a combustion wave or zone, but expresses this as energy released from a unit length of fire front. So we have an imaginary line, parallel with the flame front, somewhere within the flame zone, radiating energy in what direction? (Tangren 1976)

Finally, since fire intensity varies around the fire perimeter there is considerable difficulty in quantifying this unless detailed fuel sampling and fire spread measurements are carried out. (Catchpole et al 1982).

5.5.3 Heat per unit area

This fire behaviour descriptor is most useful for fire effects studies of soils or vegetation near the soil surface since it is a direct measure of heat released from a unit area of burnt fuel.

5.5.3 Heat per unit area (continued)

$$H_A = HW$$

where

H_A is heat per unit area (KJ/m^2)

W is dry weight of fuel burnt (Kg/m^2)
H is heat yield of fuel
(18000 - 23000 KJ/kg)

Since heat per unit area is dependant on the total quantity of fuel burnt, measurements of fuel quantity before and after a fire are quite adequate. In uniform fuel types this descriptor gives useful information on spatial variation in fire heat output, while it is perhaps the best descriptor for stationary fires or fires in heavy quantities of coarse fuel.

5.5.4 Reaction Intensity

Reaction intensity is a measure of the energy release rate per unit area of fire front.

$$Ir = HW\ Ra$$

where

Ir a reaction intensity (KW/m^2)
H is heat yield of fuel
(18000 - 23000 KJ/kg)
W is dry weight of fuel burnt (kg/m^2)
Ra is area rate of spread of fire front
(m^2/sec)

Reaction intensity is easier to rationalise than fire intensity but it is inconvenient to calculate, and like fire intensity it varies around the fire perimeter with changes in fire spread.

5.5.5 Total fire intensity

This term is only used to describe stationary fires, usually in heavy fuels.

$$I_T = Ir\ A.$$

where

I_T is total fire intensity (KW)
Ir is reaction intensity (KW/m^2)
A is total fire area (m^2)

5.5.6 Fire duration

Residence time and burn-out time are two measures of the time span that a site is subject to heating from a fire. They are important in fire effects studies of soils and vegetation.

5.5.6 Fire duration (continued)

Firstly residence time is a measure of duration of flaming or the time for a fire front to pass a given point. It is dependent on wind speed and rate of spread but is also influenced by fuel properties such as the size distribution of fuel particles, the quantity in these size classes, their arrangement, moisture content and combustion rate. Typical combustion rates for some fine fuels are around 2000 KW/m^2 for grass and from 340 to 450 KW/m^2 for eucalypt litter.

In uniform fuel beds largely composed of fine fuel, residence time for the fire front can be estimated as follows.

$$Tr = D/R$$

where

Tr is residence time (min)
D is flame depth (m)
R is rate of spread (m/min)

In fuel beds with a significant component of coarse fuel there may be two heat pulses, the first from the rapid combustion of fine fuel (i.e. residence time) and the second pulse from an often much hotter slow burn-out of larger fuels. Burning of coarse fuels is termed the burn-out time and is applicable to stationary fires where as residence time describes a moving fire.

Burn-out time for piles of logs may be in the order of 20 hours. Rough estimates can be obtained from observations of active charing but thermo-electric measurements are more precise. Calculations involving mass flow rates and fuel loadings can also be used but are quite complex as mass flow rates change during the combustion process.

6. Fire History

Fire histories describe the recent fire events on a given site. They indicate fire frequency as well as the type of fire.

In most instances records of fires within the last 30 years are sufficient. In many areas of Victoria quite detailed fire history maps exist and there are often earlier records, although usually less accurate. This information is quite adequate to establish the fire history of a study site.

On site inspections can also provide clues to past fires. In stringybark forests, bark chars during a fire and this is slowly eroded by weather, so that after 60 to 70 years there is no visible sign of past fires on surface bark. This gives a general idea of age since the last fire.

In more open forest, such a red gum and box-ironbark, mild fires leave distinct fire scars which can be dated by core samples and simple dendrochronology or ring counts.

6. Fire History (continued)

In dense mountain forests which burn infrequently but with high intensities, and also in foothills forests, the lower tree or shrub stratum or even the dominant trees could have originated from a single very high intensity fire. Ring counts are still useful. Low intensity fires, unless quite recent, are difficult to age in these forests.

Stringybark forests which are more resilient to fire tend to have very complex fire histories i.e. Grampians.

Heathlands are quite difficult to determine fire histories for if there are more than two or three recent fires, so we rely more on fire history maps for these areas.

Although beyond the scope of this discussion quite detailed fire histories for 100 to 200 years can be pieced together using methods described by Dieterich (1982).

References:

General

- Fire Control Notes. Vic. Dept. Conservation Forests and Lands 1986.

- Rothermel, R.C. and Deeming, J.E. (1980). Measuring and interpreting Fire behaviour for correlation with Fire effects. U.S.D.A. F.S. Gen. Tech. Rep. INT-93.

- Forest Fire Control and Use (1959). McCraw - Hill. New York.

- Luke, R.H. and McArthur, A.G. (1978). Bushfires in Australia. Aust. Gov. Canberra.

- McArthur, A.G. and Cheney, N.P. (1966). The characterization of fires in relation to ecological studies. Aust. For. Res. 2, 36-45.

Text

Anderson, H.E. (1983). Predicting wind-driven wildland fire size and shape. U.S.D.A. F.S. Int. For. Ra. Exp.Sta. INT-305

Ashton, D.H. (1986). Viability of seeds of Eucalyptus obliqua and Leptospermum juniperinum from capsules subject to crown fire. Aust. For. 49 (1). 28-35

Beaufait, W.R. (1966). An Integrating device for evaluating prescribed fires. For. Sci. 12 (1). 27-29

Bradstock, R.A. and Myerscough, P.J. (1987). Fire effects on seed release and the emergence and establishment of seedlings in Banksia ericifolia L.F. Aust. J. Bot. 29, 521-31

Byram, G.M. (1958). Some basic thermal processes controlling the effects of fire on living vegetation. U.S. For. Serv. S.F. For. Exp. Stn. Res. Note 114

Byram, G.M. (1959). Combustion of forest fuels. In K.P. Davis, Forest Fire Control and Use. McGraw-Hill. New York.

Catchpole, E.A. de Mestre, N.J. and Gill, A.M. (1982). Intensity of Fire at its Perimeter. Aust. For. Res. 12, 47-54

Dieterich, J.H. (1982). Fire history of south western mixed conifer - A case study. For Ecol. & Man. 6. 13-31

Fons, W.T. (1946). Analysis of fire spread in light forest fuels. J. Agric. Res. 72 (3):93-121

Text (continued)

Gill, A.M. (1974). Toward an understanding of fire-scar formation: field observation and laboratory simulation.
For. Sci. 20. (3):198-205

Gill, A.M. (1976). Fire and the opening of Banksia ornata F. Muell. follicles.
Aust. J. Bot. 24:329-335

Johnson, V.J. (1982). The dilemma of Flame length and Intensity.
Fire Man. Notes 43.(4): 3-7

McArthur, A.G. (1973). Forest Fire danger meter.
For. & Timber Bur. Canberra.

Norman, P. (1986). Fuel Appraisal. In Fire Management Techniques Notes. V.C. F. & L.

Peet, G.B. (1967). The shape of mild fires in Jarrah Forest.
Aust. For. 31: 121-127

Sneeuwjagt, R.J. (1973). Measuring forest fuels.
For. Dept. W.A. Res Pap. 9.

Tangren, C.D. (1976). The trouble with fire intensity.
Fire Tech. 12(4):261-265

Van Wagner, C.E. (1969). A simple fire growth model.
For. Chron. 45.(2):103-104

Van Wagner, C.E. (1972). Height of Crown Scorch in Forest Fires.
Car J. For. Res. 3: 373-378

Vines, R.G. (1968). Heat transfer through bark and the resistance of trees to fires.
Aust. J. Bot. 16:499-514

Whittaker, E. (1961). Temperatures in heath fires.
J. Ecol. 49 : 709-715

Appendix

Metric units for describing Forest Fires.

The following lists of metric units includes the most commonly used descriptors in fire research in Australia, these generally conform to the International System of Units (SI).

TABLE 1. Symbols of S.I. units for Forest Fires.

^{o}	- degree Celsius
mm	- millimetre
cm	- centimetre
m	- metre
km	- kilometre
s	- second
min	- minute
h	- hour
g	- gram
kg	- kilogram
t	- tonne
ha	- hectare
J	- Joule
KJ	- Kilojoule
W	- Watt
KW	- Kilowatt
Pa	- Pascal
mPa	- millipascal
hPa	- hectopascal
Kpa	- kilopascal
l	- litre

TABLE 2. S.I. Units and Composite units for describing Forest Fires.

1.	Weather			
	Temperature		^{o}C	Screen degrees Celsius.
	Dew point		^{o}C	degrees Celsius
	Relative Humidity		%	percentage
	Wind velocity		km/hr	measured at 10m. kilometre/hour
	Wind velocity		km/hr	points as specified
	Wind direction		^{o}	degrees from True North
	Rain		mm	millimetre
	Evaporation		mm	millimetre
	Air pressure		h.Pa	hectopascal
	Lapse rates		^{o}C/km	degrees celsius/kilometre
2.	Topography			
	Distance	-	m	metres
		-	km	kilometre
	Altitude	-	m	metres above sea level
	Slope	-	^{o}	degrees
	Aspect	-	^{o}	or compass points, degrees.

3. Fuel

size classes	fine	- less than 6mm diameter	
	course	- greater 6mm diameter	
		- mm diameter	millimetre
		- cm diameter	centimetre
depth		- cm	centimetres
surface area/volume		- cm -1 (cm^2/cm^3)	centimetres
quantity		- kg/m^2	kilogram/squre metre
		- t/ha	tonne/hectare
bulk density		- kg/m^3	kilogram/cubic metre
moisture content		- %	percentage oven dry weight

4. Fire

Fire Danger	- McArthur's Forest Fire Danger Meter MKV.	
rate of spread	- m/min	metres/minute
	- m/h	metres/hour
	- km/h	kilometre/hour
flame height	- m	metres
flame depth	- m	metres
flame angle	- ^{o}	degrees
flame length	- m	metres
fire area	- ha	hectares
area spread rate	- ha/hr	hectares/hour
perimeter	- m	metres
	- km	kilometres
heat quantity	- J	joules
heat of combustion	- KJ/kg	kilojoules/kilogram
combustion rate	- KW/m^2	kilowatt/square metre
heat per unit area	- KJ/m^2	kilojoule/square metre
fire intensity	- KW/m^2	kilowatt/square metre
total fire intensity	- W	Watt
heat transfer rate	- KW/m^2	kilowatt/square metre
heat flow	- W	Watt
residence time	- S	seconds
	- min	minutes
burn-out time	- min	minutes
	- hr	hours
mass flow	- $kg/m^2.s.$	kilogram/sqm sec

5. Fire Control

Fire line construction rate	- m/hr	metre/hour
	- km/hr	kilometre/hour
pump rate	- l/min	litre/minute
viscosity	- mPas	megapascals
retardant surface concentration	- l/m^2	litres/square metre
retardart viscosity	- m.f.s.	Marsh funnel seconds

3. FIRE BEHAVIOUR, FIRE EFFECTS AND FIRE HISTORIES

DISCUSSION

What can one person do to monitor a fire ?

- Even one person alone can collect useful information on fire behaviour and the factors which affect it. For example, information on fuels can be collected even during a wildfire. Small quadrats can be marked out in the path of the fire, the number of individuals of different species and heights for each stratum recorded and the litter fuel weighed and then replaced. The fire behaviour can then be observed as the plot burns.

Can we develop models to predict the percentage of an area likely to be burnt by a fire ?

- The area covered by a prescribed fire will depend on the fuels, topography and weather but also on the ignition system used and the pattern of ignitions. It would not be easy to develop models for this.

FIRE WEATHER AND FUEL

FESA : . . . . OBSERVER : . . . .

LOCATION : . . . . DATE : . . . .

FIRE TYPE : . . . .

TIME : . . . .

WEATHER

Drought Index : . . . . Station : . . . .

Soil Dryness Index : . . . . Station : . . . .

Last Rain : . . . . Station : . . . .

Days since Last Rain : . . . . Station : . . . .

Fire Danger Index – In Forest : . . . .

– In Open : . . . . Station : . . . .

Temperature – In Forest : . . . .

– In Open : . . . . Station : . . . .

Relative Humidity – In Forest : . . . .

– In Open : . . . . Station : . . . .

Wind Speed – In Forest : . . . .

– In Open : . . . . Station : . . . .

FUEL

	Humus (5mm sieve)	Litter (<6mm)	Twigs (6–25mm)	Trunks and Branches (>25mm)
Pre Burn (t/ha)				
Post Burn (t/ha)				
Available Fuel (t/ha)				

Fine Fuel Moisture Content (Surface) : . . . .

Area Last Burnt : . . . .

Fuel / Vegetation Description : . . . .

Percentage of Fine Fuel Burnt : . . . .

Example of Recording form: K. Tolhurst

FIRE BEHAVIOUR

FESA : .... OBSERVER : ....

LOCATION : .... DATE : ....

PARAMETER	MEAN	MAXIMUM	MINIMUM
Flame Height (m)			
Flame Length (m)			
Flame Angle (°)			
FROS (km/hr)			
Scorch Height (m)			
Fireline Intensity (kw/m)			
Heat / Unit Area (kJ/m^2)			
Temp. at Soil Surface (°C)			
% Area Burnt			
Fine Fuel Burnt (t/ha)			
% Fine Fuel Burnt			
Billy Calorimeter : Heating Time at >1.2°C/min (min)			
Increase in Temperature (°C)			

Example of Recording Form: K. Tolhurst

MONITORING THE EFFECTS OF FIRE

- SOILS AND HYDROLOGY

P. F. Clinnick. September, 1987

INTRODUCTION

The purpose of this paper is to place the role of monitoring in the perspective of the overall planning and management process and to briefly outline some factors important in monitoring the effects of fire on different soil and water parameters.

1. POLICY DEVELOPMENT

The subject in this series of papers deals with one aspect of fire research, that is, monitoring the ecological effects of fire. The Report by the Standing Committee on Environment and Conservation (1984) recognised the importance of obtaining more information on the ecological effects of fire so that land managers and fire controllers are able to meet the need to develop environmentally safe and realistic natural resource management policies.

Without reliable information on changes in populations of animals, vegetation, soils and hydrology following fire, it is not possible to develop policies which the community will accept is responsible and give them confidence in us as capable land managers.

Before embarking on a monitoring program, it is important to gain an appreciation of where monitoring activities are located in the planning process (Fig. 1).

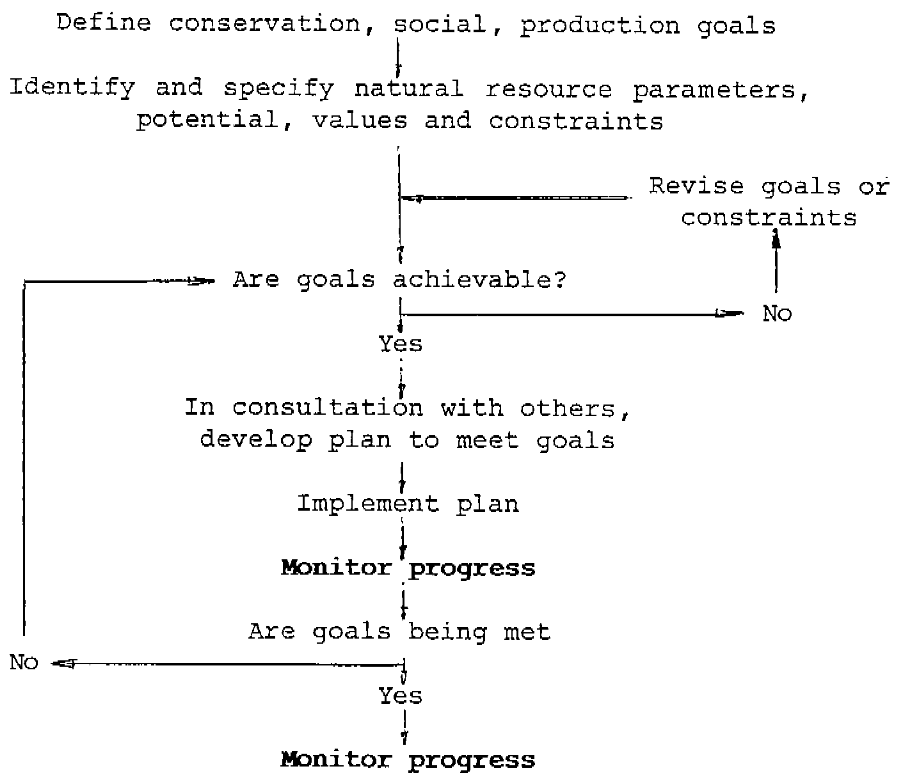


Figure 1. Mainframe Planning Process

2. PLANNING

It is essential before embarking on any monitoring or research program that:

- Projects are well researched (i.e. the work has not been done already),
- Officer time is available to complete the project, including reporting,
- Funding will be available,
- Communication links are established with co-ordinating bodies

  (Refer Australian Bushfire Research Directory),
- The project is statistically well based and run on sound scientific principles,
- The information that is to be recorded is in a standardised format for the particular discipline concerned (Refer to the D Base III site cards included at the end of this paper.).

3. MONITORING

3.1 Soil Monitoring

Various soil parameters can be monitored to improve our understanding of the effects of fire. Important physical parameters include temperature, structure and stability, water retentivity and infiltration and organic matter content. Some chemical parameters include pH and soluble salts, macronutrients including nitrogen, phosphorus, sulphur and micronutrients including Mo, Zn, Cu, Fe, Al.

Often overlooked but most essential to forest ecology is the biological aspect, including micro-organisms and soil fauna.

Research studies can be constructed so as to include other features in conjunction with any of the above. Soil loss is one such parameter since a measure of soil loss can provided important information on other soil attributes.

3.2 Measuring Soil Loss

Three basic methods are available for estimating soil loss, these are:

1. Direct comparative sampling
2. Transects or grids
   a) direct measurement
   b) remote sensing
3. Plot trials
   a) closed plots
   b) open plots

A brief explanation of each method follows:

3.2.1 Direct comparative sampling

Using $caesium_{137}$ isotope analysis the extent of loss of soil from specific locations can be determined. Samples are taken from undisturbed and the treatment sites and a comparison is made on the basis of Cs_{137} content of various levels in the soil profile.

This method is useful in studying the detachment, transport, and deposition process at specific sites. Collection of samples requires specialised techniques and analyses of samples is somewhat time consuming. A reliable statistical base is therefore expensive to acquire.

3.2.2 Transects or grids

a) Direct Measurement

Transects or grids can be established using erosion pins (galvanised iron nails) or some other means of recording changes in the soil surface level. Some researchers have used the method satisfactorily but some problems with the method do arise. These are:

- nails lost during erosion or displaced by animals,
- catchment generally difficult to define precisely,
- time to resurvey is considerable,
- reliability is low in some cases because of shrink/swell characteristics of some soils.

b) Remote Sensing

A recent innovation by CSIRO Environmental Mechanics and Applied Physics Divisions involves use of a high resolution low power laser source and image detector.

This system has several advantages:

- cheap to build ($400),
- accurate (0.4mm horizontal and 0.1mm vertical resolution),
- does not interfere with the treatment,
- versatile in the scale that can be assessed,
- results can be datalogged directly at the site.

3.2.3 Plot Trials

a) Closed Plots

Closed plot trials can be easily established to measure soil loss. The most satisfactory method for use in fire research has