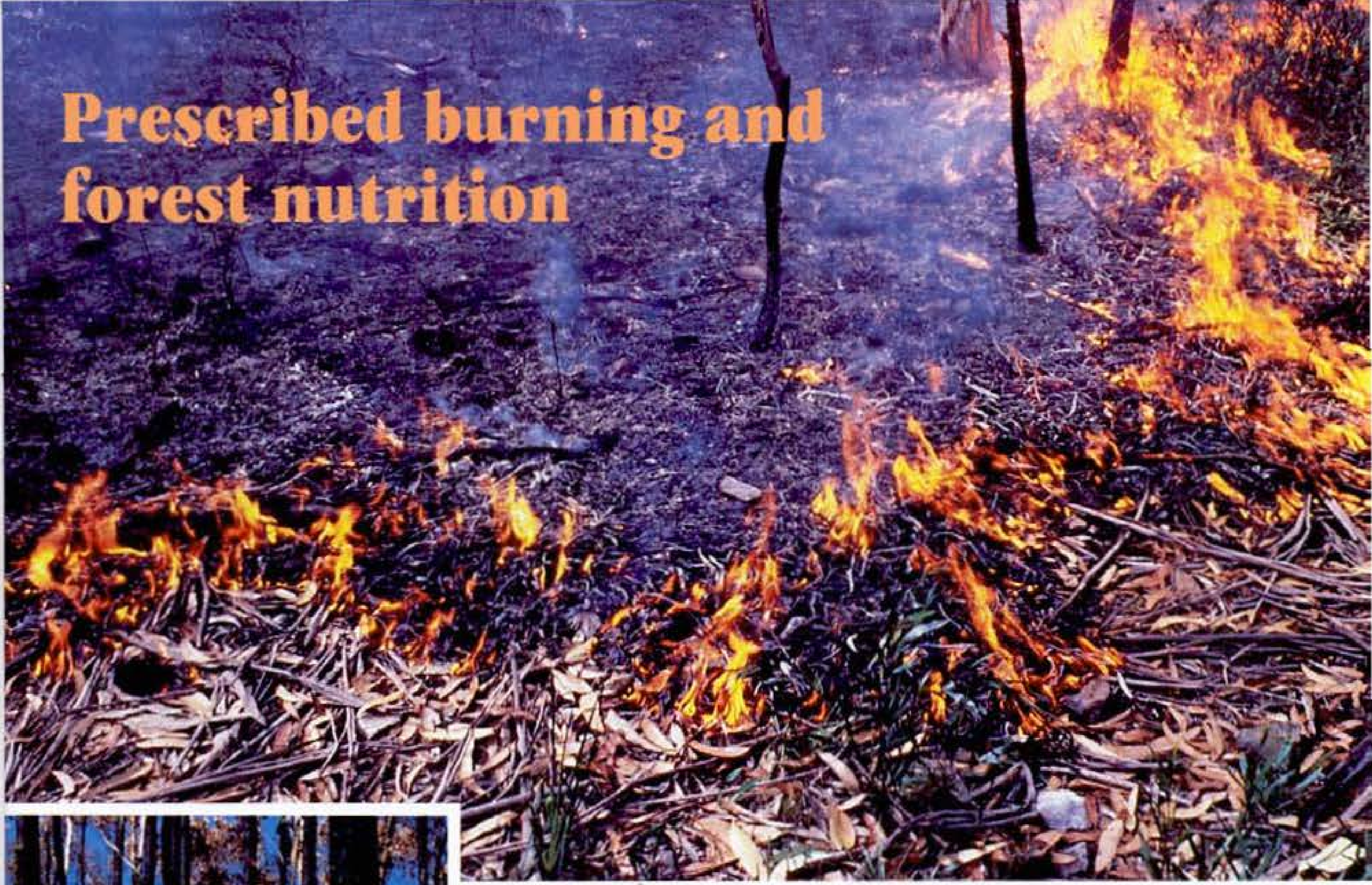
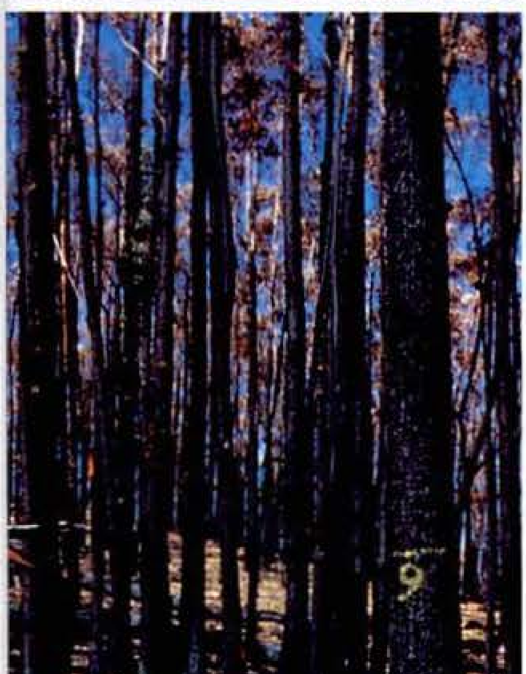
Prescribed burning and forest nutrition





The aftermath of a wildfire in a dry sclerophyll forest near Eden, N.S.W.

In classical mythology, fire was given to man as a gift from the gods. In more recent history, however, uncontrolled fire has become a major problem to man — in Australia, the ravaging flames of bushfires have left wide trails of destruction and have burnt themselves into the nation's memory through outbreaks like the 1983 Ash Wednesday disaster.

Most of Australia's native vegetation has evolved in the presence of fire and much of the country is extremely fire-prone. Fire affects the distribution and growth of plants either directly or through its influence on soil properties and nutrient supplies. And it is essential for the survival of some Australian plant species. But its long-term effects on Australian plant communities are poorly understood — fire can either benefit or damage an ecosystem, depending on the length of time between burns, the intensity of the fire, the season when it occurs, soil characteristics, and so on.

Prescribed burning

Uncontrollable wildfires begin with a potent mixture of highly flammable eucalypt fuels, strong winds, and heat-wave conditions. To prevent excessive build-up of fire fuel — twigs, leaves, bark, and understorey vegetation — in Australia's eucalypt forests, foresters use hazard-reduction burning, or prescribed burning. This technique — initially researched by Mr Alan MacArthur of the Commonwealth Forest Research Institute and then by the CSIRO Division of Forest Research, in co-operation with State forest services — has been used in this country for 20 years to reduce the bushfire risk. Every 3–8 years, low-intensity fires are started by incendiary devices dropped from aircraft in a predetermined firing pattern during mild weather in autumn or spring. About a million hectares are subjected to this prescribed burning each year. The immediate effect is to reduce available fuel and assist fire control, but do these frequent fires have other effects on our forests?

Dr John Raison, Dr Partap Khanna, and Mr Paul Woods, of the Division of Forest Research, have been examining various aspects of this question since 1977. They are studying the nature and magnitude of the effects of low-intensity prescribed fire on fuel dynamics, pools of nutrient (nitrogen, phosphorus, potassium, sulfur, and calcium), and nutrient-cycling processes in three contrasting sub-alpine eucalypt forest communities situated in the Brindabella ranges near Canberra. The forests are dominated by snow gum, alpine ash, and mountain gum–peppermint eucalypts. These communities are typical of large tracts of mountain forest in south-eastern Australia.

Most Australian forests grow on nutrient-poor soils that receive only very low rates of nutrient input from weathering, rainfall, or nitrogen-fixing understorey shrubs. Such communities are likely to be sensitive to disturbance caused by regular burning. We know a little about how particular species of plants in various Australian forest communities respond to burning, but very few data exist on the effects of fire on the soil, particularly on biological processes related to nutrient cycling and soil fertility.

Fuel dynamics

The rate of litter decomposition (which includes both physical breakdown of leaves, twigs, etc. and mineralization processes) in forests affects the rate of build-up and total quantity of accumulated litter (fuel), the amount of organic matter in the soil, and the rate at which nutrients cycled in litterfall return to a form available for re-use by vegetation.

The scientists studied the litter decomposition in both unburnt and burnt sub-

A systematic pattern of smoke plumes left by aerial ignition of a hazard-reduction fire.

alpine forests and found that the major release of organically bound nutrients does not occur until litter has undergone several years of decay, when decomposition rates increase as leaves become fragmented and incorporated into lower moister litter layers. After prescribed burning, the amount of solar radiation absorbed by the forest floor increases; this in turn hastens the rate of drying of the remaining and newly fallen litter after rain, reducing litter decomposition rates.

These studies provide information for answering two important questions: how does repeated fire change nutrient balance and cycling processes, and how quickly do fuels build up after a fire? Knowing patterns of fuel accumulation in different types of forests is essential for formulating scientifically based fire management plans.

To answer the second question, the scientists compiled information from two sources — the published results of previous studies and their own measurements in the Brindabella mountains. They found that, for dry sclerophyll forests after fires, litter accumulates to dangerous levels in 3–6 years, severely limiting the period during which prescribed burning provides protection from wildfire. The rapid build-up of nutrients in litter also means that they are highly susceptible to loss in smoke during subsequent fires.

After a low-intensity fire, litter accumulates very rapidly at first, mainly because the total amount of it decomposing on the forest floor decreases markedly while rates

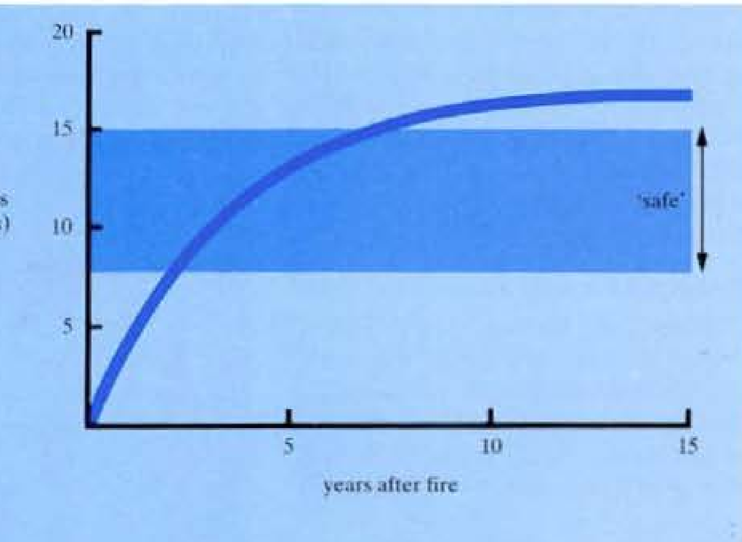
In dry sclerophyll forests after fires, litter accumulates to dangerous levels in 3–6 years.

of litter input remain as high as before. The litter build-up can be readily predicted from simple equations and always approaches a 'steady-state' value — indicating that fire risk does not continue to increase with time but rather reaches a constant level.

In the Brindabella study, litter weights of up to 12 tonnes per hectare, sufficient to create control problems under high to very high fire-danger conditions, accumulated within 4 years of a fuel-reduction burn. Earlier studies by other researchers have shown that maximum fuel weights consistent with hazard-reduction requirements range from about 10 to 15 tonnes per hectare. Similar rates of fuel accumulation occur in many other Australian eucalypt forests.

Not only litter, but undergrowth as well, contributes to fuel; apart from adding to the

How fuel accumulates in a dry eucalypt forest



Once the 'safe' fuel mass level, reached a few years after fire goes through, is exceeded, fuel weight tends to level off. Because of this, lengthening the fire rotation may not produce a continuing increase in fire risk. However, the risk will continue for more years. Longer fire rotations lower the average rates of nutrient loss.

total weight of fuels, its presence may affect fire spread by passing on flame above the litter layer and by influencing wind fields. Some shrubs, such as *Daviesia* species, are highly combustible. Combustion of elevated fuels (shrubs or eucalypt litter suspended by ground vegetation) usually results in increased fire intensities and greater 'scorch' heights.

Dr Raison, Dr Khanna, and Mr Woods stress that, currently, inadequate knowledge of the relations between fuel weight and fire behaviour under high to very high fire-danger conditions makes it impossible to define with any certainty a safe maximum mass for fuel, and thus to determine the number of years for which prescribed burning will effectively reduce fire hazard.

They suggest that, where studies of fuel dynamics indicate that prescribed burning gives only a short period of effective hazard reduction, forest managers need to consider alternatives to short-rotation, broad-scale burning. They stress the need for integrated fire management and have proposed the use of strategically located buffer zones, which are frequently burnt, and the lengthening of fire rotations for areas between these. More effective fire detection and monitoring, and greater suppression capability, are also needed.

The researchers emphasize the importance of assessing the long-term ecological impacts of repeated burning and using these assessments as a basis for selection of appropriate management strategies.

Barely visible under the litter is an aluminium tray for measuring nutrient changes.

A tray holding burnt residue, made up of different kinds of nutrient-rich ash.

Regaining lost nutrients

	loss (kg per ha)	replacement time (years)	replacement mechanism
nitrogen	109	11	legumes, rain
phosphorus	3·0	20	rain

The scientists derived these figures — for nutrient losses in smoke during a prescribed burn and for their natural replacement times. The figures are for a snow gum forest. A burning frequency of about 5 years is needed to keep fuels at 'safe' levels in this type of forest.

Studies by Dr Sid Shea of the Western Australian Forests Department and other researchers indicate that frequent burning with low-intensity fire can alter the understorey species composition. In parts of Western Australian jarrah forest, non-leguminous understorey species have replaced important nitrogen-fixing legumes after low-intensity burns.

Another significant question in relation to prescribed burning concerns its impact on ground cover and soil erosion. Erosion depletes soil and can adversely affect the quality of water, the vital product of forest catchments. The few data available suggest that, on impermeable soils, erosion rates increase after burning; this is an area requiring further research.

Nutrient cycling

How does prescribed burning alter nutrient balance and cycling processes? In the short term, fire mobilizes nutrients by incinerating organic material to create ash and by heating the soil. Balanced against this improved availability of nutrients is loss of organic matter and nutrient transfer into the atmosphere, and an increased potential for losses due to leaching, run-off, or erosion by wind or water. In any assessment of how fire affects the nutrient budget of plant communities, many regulatory and compensating ecological processes complicate the picture. For example, rates of nitrogen fixation or weathering rates may increase after fire.

Nutrients transported into the atmosphere during fire either go up in smoke particles or are directly vaporized. How much of an element is lost in gaseous or particulate form during burning depends largely on its vaporization temperature and on fire intensity. Carbon, nitrogen, and sulfur are vaporized at low temperatures. The vaporization temperatures for inorganic forms of other elements range from relatively low for phosphorus and potassium (774°C) to relatively high for calcium (1484°C) and manganese (1962°C). The temperatures required to volatilize elements bound in organic compounds in plants or litter may be significantly lower than those required for inorganic forms. In biological materials, elements occur in many forms and have a wide range of volatilities, depending on combustion conditions.

Temperatures in forest fires vary widely — glowing combustion occurs at about 650°C, while woody fuels produce flame temperatures of about 1100°C. In high-intensity fires, most of the fuel will be surrounded by flaming combustion, and understorey vegetation may be subjected to high temperatures even in low-intensity fires.

Studies elsewhere have established that a high proportion of the nitrogen and sulfur in vegetation fuels is volatilized during combustion. Researchers have assumed that only small quantities of other elements are lost in smoke so they are mostly deposited in ash on the soil surface.

Dr Raison, Dr Khanna, and Mr Woods measured the transfer of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, and boron to the atmosphere during low-intensity prescribed burns in the three sub-alpine forests, each of which has an understorey dominated by the leguminous shrub *Daviesia*. The forest had been unburnt for 7 years. They placed small aluminium trays in the forest for an accurate measure of the ash residue left by the fire — essential for accurate budgeting for elements other than nitrogen.

Frequent burning with low-intensity fire can alter the understorey species composition.

The scientists calculated for each element the proportion of the mass initially present in the fuel (litter and shrubs) that was transferred to the atmosphere: 54–75% for nitrogen, 37–50% for phosphorus, 43–66% for potassium, 31–34% for calcium, 25–49% for magnesium, 25–43% for manganese, and 35–54% for boron. Clearly, substantial amounts of the major nutrients, nitrogen and phosphorus, are lost to the atmosphere during hazard-reduction fires. For nitrogen, the losses correlated with the amount of fuel burnt. *Daviesia* spp. shrubs held considerable amounts of potassium, nitrogen, and phosphorus in the fuel before burning, so they contributed significantly to redistribution of these elements.

Fire concentrates most elements in the ash residues; in comparison with unburnt litter, concentrations in the ash left after the Brindabella fires were 10–50 fold higher for calcium, 10–35 fold higher for magnesium, and 10 times higher for phosphorus. This means that even a small removal of fine ash from a site either during or after a fire may result in the relocation of considerable amounts of these nutrients.

As well as their field studies, Dr Raison, Dr Khanna, and Mr Woods have used data from studies elsewhere and from laboratory

A snow gum forest on an 8-year rotation cycle prior to burning ...

... and after.

The small white-capped containers are used to measure nitrogen mineralization after a burn.

combustion experiments to determine the relative contributions of volatile and particulate (ash) mechanisms to nutrient transfer in fires. They discovered that, because calcium is not volatilized even at the temperatures generated in most bushfires, higher ratios of calcium to other elements in the burnt residue of specific fuel components (for example, leaves, bark, and wood) point to some gaseous transfer of nitrogen, phosphorus, potassium, boron, magnesium, and manganese — for the first four the contribution of particulate movement to losses is quite small.

Nutrients in smoke particles may be blown to adjacent regions, but vaporized elements are either lost (nitrogen in particular) or transported very large distances, often to the ocean off eastern Australia. Such transfers of phosphorus, which is largely vaporized, are ecologically significant for the phosphorus-deficient Australian landscape. Nitrogen lost in smoke may be replaced via rainfall and via nitrogen fixation by native plants such as acacias, which often proliferate after burning.

For the forests studied, the CSIRO researchers conclude that about 10–12 years are needed between prescribed burns to permit natural inputs of nitrogen to approximately replace the amounts transferred to the atmosphere in a single fire. The natural rates of phosphorus replacement are usually very slow. Slow release of phosphorus from organic reserves held in the soil may compensate for some losses. For replacement of phosphorus by rainfall only, the scientists estimate the required length of burning rotation to be about 20 years. Nutrient losses in individual wildfires will exceed those in prescribed burns, but the frequency of wildfires is lower and should be further reduced with fuel-reduction burning.

Minimizing nutrient losses

Moisture can moderate the effects of burning. By burning after rain, when the lower litter layers and surface soil are moist, forest managers can prevent heating of these nutrient-rich zones above 200°C and thus prevent volatilization of carbon and nitrogen.

Additionally, Dr Raison has observed that a thin cover of residual litter (4–6 tonnes per hectare) can be retained by burning when the lower litter layer is moist. If the fire doesn't burn the litter completely, less nutrient is lost to the atmosphere, direct losses of organic matter and nitrogen (from surface soil) are avoided, and the potential for erosion is reduced by the residual 'mulch' covering the mineral soil. The residual burnt litter eventually breaks up and does not contribute to any subsequent fuel build-up.

The CSIRO team is continuing to explore various aspects of the impacts of repeated burning. In their present studies, they are attempting to quantify the effect of fires on soil chemical properties and nitrogen-supplying capacity, as well as looking at the chemistry of water in the soil to provide further information on nutrient leaching. The scientists believe that further detailed studies are needed before they can predict more accurately the long-term effects of prescribed burning and so provide information required to improve fire management systems.

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More about the topic

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