ALAN WALKER

Reconstructing the Fire History of the Jarrah Forest of south-western Australia

26

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"History is not only a valuable part of knowledge, but opens the door to many parts, and affords materials to most of the sciences." *David Hume, 1711-1776*

INDEX

Frontispiece: Typical grasstree after cleaning, showing cream and brown growth bands and dark bands where fires have occurred. From an illustration by Ian Dickinson.

Introduction

There are two approaches to understanding a complicated system. One is the analytic approach, where the system is broken into smaller fragments which may be easier to study. The other is the holistic approach, where the system is left intact, but studied from as many perspectives as possible. Due to their training, natural scientists tend to favour the former approach, but while analysis has merits, it also has drawbacks. The act of subdivision may destroy some essential properties of the system. A pile of petals is not a rose, nor is a pile of cogs a clock. In the old tale, three blind men concluded that an elephant was, from its leg, a tree: from its ears, a butterfly: and from its trunk a snake. Used in isolation, the narrow analytic approach of natural scientists can lead to false conclusions, due to false reasoning from the particular to the general.

The jarrah forest is a complicated system, involving humans for thousands of years. Anthropologists tell us of the importance of fire in Aboriginal culture, and there is historical evidence in the letters and journals of early European explorers of south-western Australia that fires occurred as frequently as every 2-4 years, at least in some parts. Some natural scientists tend to decry such evidence as "anecdotal", perhaps mistaking that word as a synonym for "apocryphal". Yet if we are to understand the jarrah forest as a connected system, rather than as a set of disconnected fragments, then the broader perspectives created by the humanities and social sciences are needed in order to link together the fragmentary knowledge created by natural scientists.

This study reconstructs fire history from marks on the stems of grasstrees (*Xanthorrhoea* spp). This information meshes with the broad perspectives of history and anthropology, giving a framework within which we can link the concerns of biologists, soil scientists, fire fighters, and managers. In turn, the framework can be used to create a map of consciously linked research questions, relevant to management of the jarrah forest[3].

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[3] David Ward (1992) Mapping Questions and Answers in Human Ecology, publicly defended Master's Thesis, Free University of Brussels.

Objectives

1. To develop a technique for reconstructing fire history from examination of dark stripes on grasstree (*Xanthorrhoea* spp.) stems; this development to include an investigation of the pigment which causes dark stripes where fires have occurred on grasstree stems.

2. Using this technique, to reconstruct the fire history of the jarrah forest, with attention to the effects on fire frequency of annual rainfall, landform, vegetation, and the differences between Aboriginal and European settler fire regimes.

3. To show the relevance of fire history to the ecology, and hence management, of the jarrah forest.

Methods

Grasstree (*Xanthorrhoea* spp) stems were cleaned with a grinder, so exposing cream and brown growth rings (Ward 1996), which match with internal growth bumps (Lamont & Downes 1979). The grinding also exposed some bands of dark pigment in the old leaf bases. These dark bands occurred consistently at points on the stems where fires were known from CALM records to have occurred; and where fires were likely to have occurred, since the grasstree had flowered at that point. Figure 1 shows part of a cleaned stem, with estimated dates, and dark bands. Diagonal faults in the stem can be seen. These are due to internal lateral expansion.

From CALM records, it is known that fires occurred at the site in spring 1984 and summer 1971/2. From their position in relation to fires, and to the internal growth bumps, the cream growth bands seem to be connected with winter/spring, and the brown with summer/autumn. The cream bands correspond to the growth surges described by Lamont & Downes (1979). More research into the physiology of grasstrees is proposed for next year.

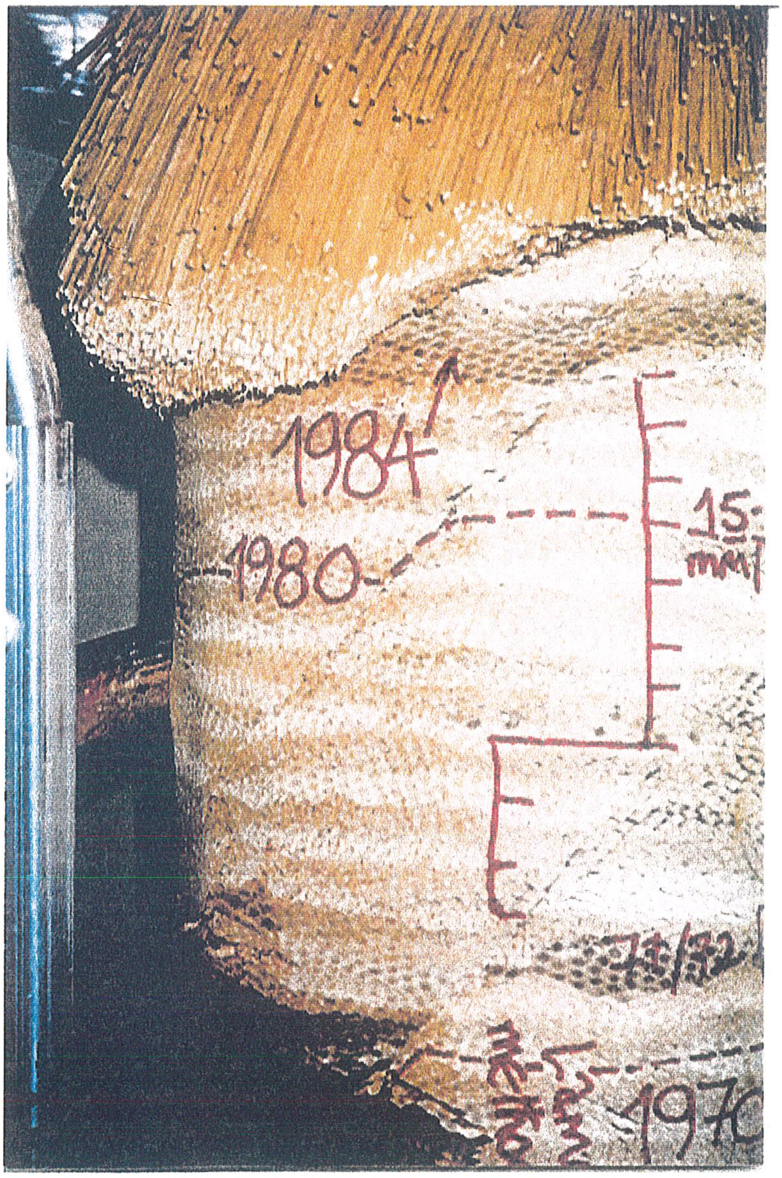

Figure 1: Section of cleaned grasstree stem with growth rings and dark bands

Some leafbases were carefully removed, washed in alcohol, and cut into 1 centimetre pieces measured from the proximal end. The length of leafbase can vary from tree to tree due to burning away by past fires (Drummond 1847). In this case each leafbase gave 5 pieces. Each year showed the twin band of cream and brown leafbases shown in Figure 1, and these were separated, giving a hundred samples for the decade. These samples were analysed by pyrolysis gas chromatography and mass spectrometry to identify the dark pigment (Challinor 1989, 1995). They were also analysed for zinc, calcium, magnesium, manganese and copper.

At several sites the tops of recently burnt grasstrees were ground off, revealing dark bands of leafbases where green needles had burnt. Figure 2 shows a band of dark leafbases formed by the remains of green needles burnt a few weeks previously. The leaves immediately above the dark band were still live and green at the time of grinding. Leafbase samples were taken immediately above, on, and immediately below the dark band. These were submitted for analysis to identify the pigment.

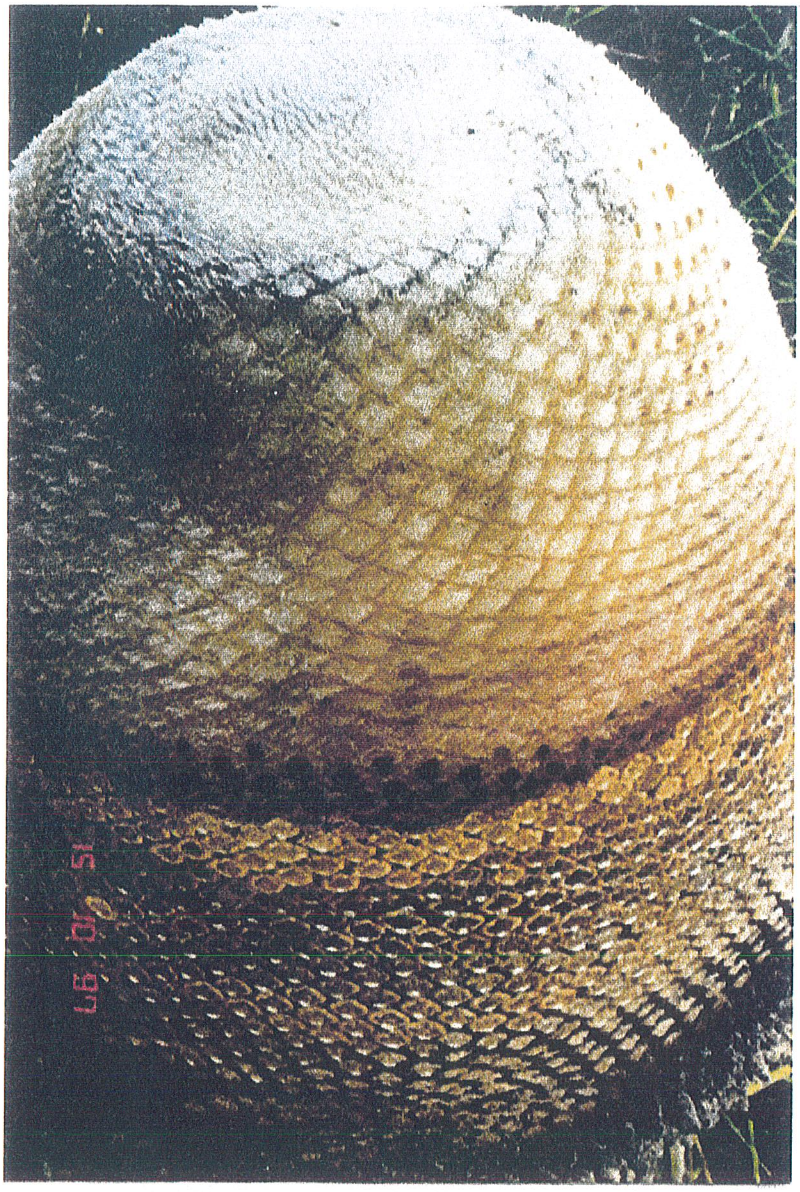

Figure 2: Dark band of leafbases formed by a fire a few weeks previously.

As a further check, the colour difference between the dark and light coloured leafbases was quantified using an industrial ColorTec–PCM colorimeter. This gives scores in the three spectra of the Hunter colour system (Wright 1969), namely black/white, red/green, and blue/yellow.

Results

Analysis by gas chromatography and mass spectrometry showed that for the samples taken immediately above, on, and immediately below the dark band in Figure 2, the compound lapachol[4] (2-hydroxy-3-(3-methyl-2-butenyl), 1, 4-naphthalenedione) was absent from the leafbase below, present in the dark leafbase, and present as a trace in the leafbase immediately above.

A randomly chosen section of stem, for the decade 1894-1903, was then sampled in detail. There were three external dark bands within the decade, implying three fires. Close examination suggested that the pigment was in the central vascular bundle of the leaf, so some samples were checked by excising the vascular bundle. When dark vascular bundle was removed from the sample, lapachol was absent, but when dark vascular bundle was present, lapachol was present. Lapachol was absent in light coloured vascular bundle.

Figure 3 shows the presence/absence of lapachol in the vascular bundles of the leafbases.

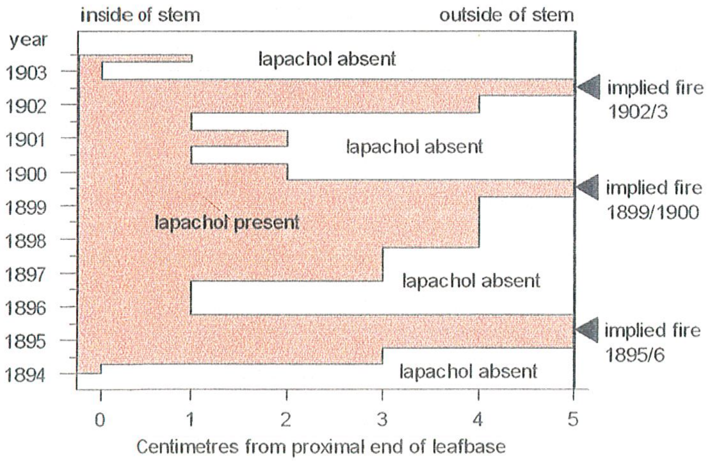

Figure 3: Presence/absence of lapachol in vascular bundles.

Figures 4, 5 & 6 show the colour differences between the leafbases with lapachol, and those without. Although not visibly green to the naked eye, the dark leafbases contain some green pigment. This suggests the presence of chlorophyll, which

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[4] The pigment may be a conjugate of lapachol. Unfortunately the chemist, John Challinor, has had a traffic accident and is on sick leave until after Christmas, so work is held up.

would confirm that lapachol is formed when fires kill green leaves. This colour and chemical analysis needs much more work than was possible in this short project, but these initial results support the validity of the technique.

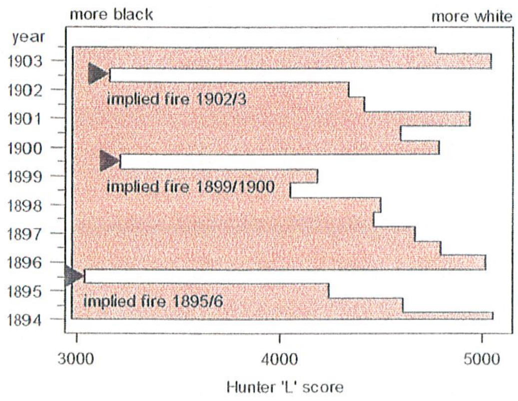


Figure 4: Hunter "L" score (black/white) for outer centimetre of grasstree leafbase

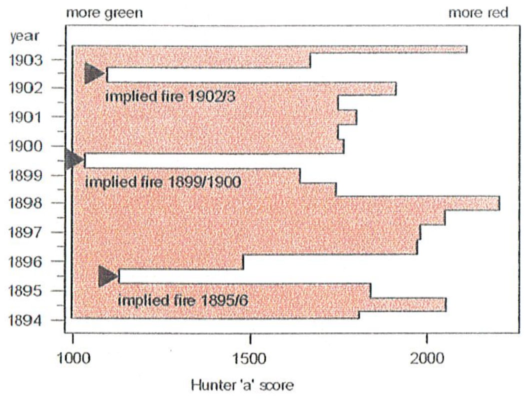


Figure 5: Hunter "a" score (green/red) for outer centimetre of grasstree leafbase

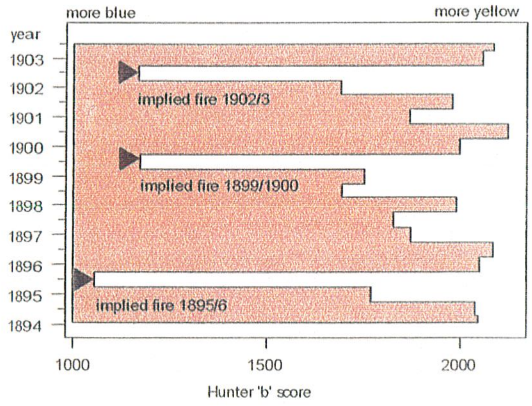


Figure 6: Hunter "b" score (blue/yellow) for outer centimetre of grasstree leafbase.

Some chemical analysis has been completed on leafbases, but not all the results are yet available. There will be a large amount of data, but early analysis shows changes in the levels of nutrients and trace elements which match with implied fire events. Analysis of the stem shown in Figures 3, 4, 5 & 6 shows, in Figure 7, implied fire events and subsequent elevated zinc levels.

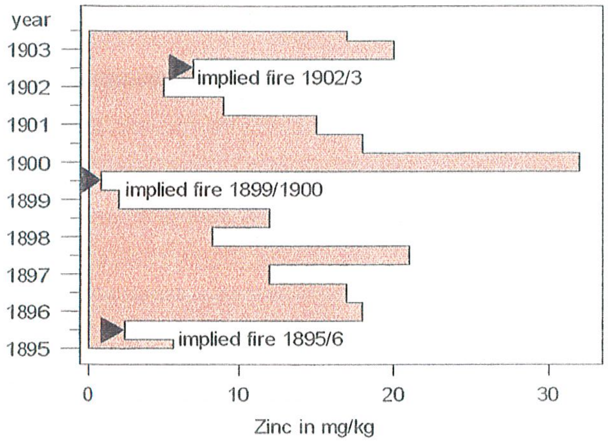


Figure 7: Zinc at 4 cm from proximal end of grasstree leafbase

Calcium levels show an association with implied fire events in Figure 8. The calcium in wood ash has a well known effect in raising the pH of forest soils (Fowells & Stephenson 1933, Fuller *et al* 1955, Braathe 1973).

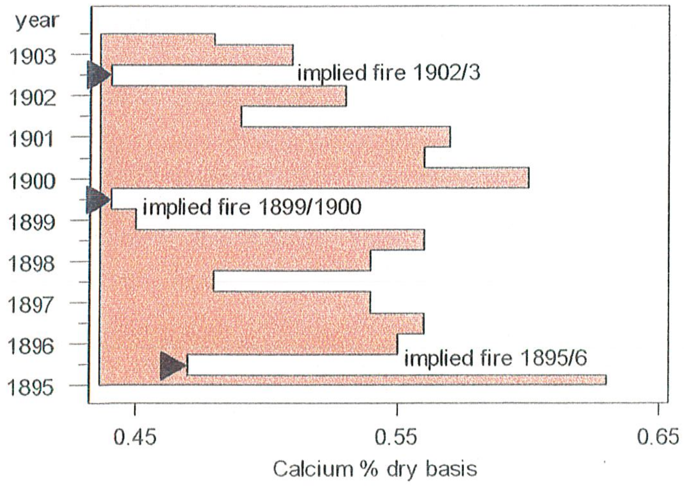


Figure 8: Calcium at 1 cm from proximal end of grasstree leafbase

Magnesium also showed a pattern in relation to implied fire events. Magnesium is an essential structural element in chlorophyll (Salisbury & Ross 1969), and is generally more available as soil becomes more alkaline.

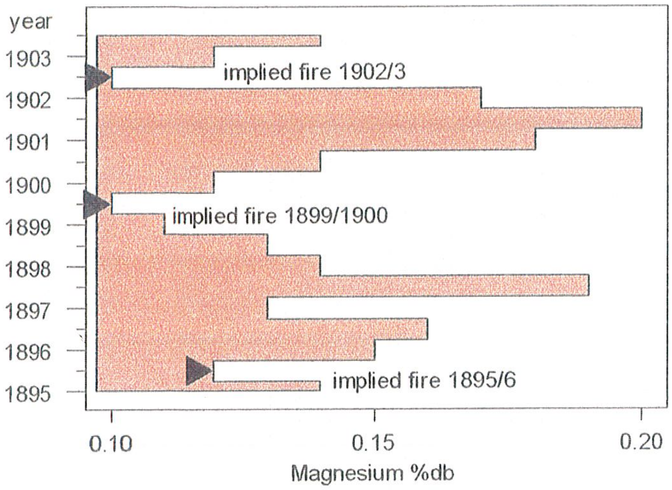


Figure 9: Magnesium at 4 cm from proximal end of grasstree leafbase

Manganese showed a different pattern in that it was highest in the dark pigmented leaf bases. It, too, is believed to have a role in chlorophyll formation (Salisbury & Ross 1969), but becomes less available as soil becomes more alkaline.

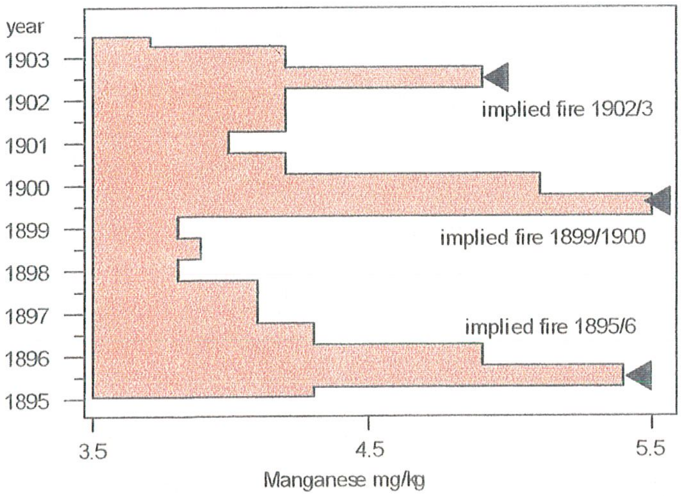


Figure 10: Manganese at 1cm from proximal end of grasstree leafbase

Like manganese, copper was highest in the dark leafbases. The pattern in Figure 11 suggests a fall in available copper over the few years after a fire, followed by a rise. It is known that a rise in soil alkalinity can cause copper to become unavailable to plants. Without reaching too hasty a conclusion, the relationship of fire to copper availability certainly merits further investigation (Gartrell 1969).

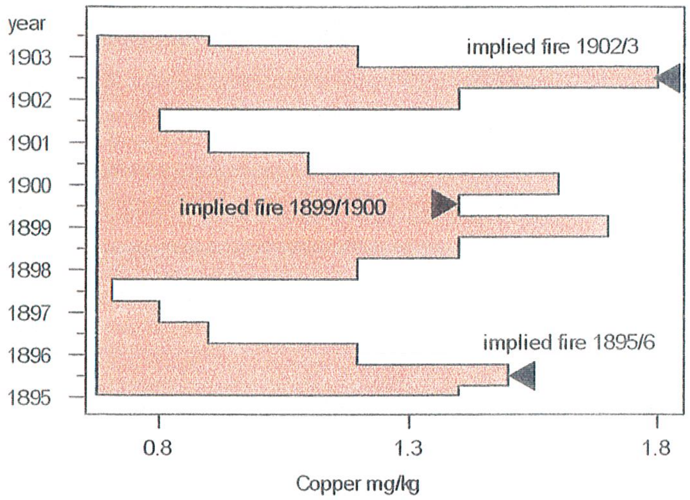


Figure 11: Copper at 5 cm from proximal end of grasstree leafbase

Given that the dark bands are quantitatively different both in colour and chemically from the rest of the stem, and given that they can be produced by deliberately burning green needles on grasstrees, then it seems reasonable to use them as bio-indicators of past fires.

A total of 159 grasstrees was examined at 50 sites distributed throughout the jarrah forest. Each tree yielded information on at least two decades, some giving a record of over twenty decades. The final data matrix consisted of 1548 records, each record containing fields for the number of fires in that decade, the annual rainfall at that site, site latitude and longitude, vegetation type, distance from creek, etc. A deliberate attempt was made to sample both tall and short trees at each site, to check whether tall trees were underestimating recent fire frequency due to fires passing underneath without igniting the thatch.

The sites were deliberately spread across the rainfall isohyets, so giving good representation of different rain zones. With regard to vegetation and landform, grasstrees generally prefer moist, open sites, low in the landscape. This means that ridges are under represented in the data. This matter will be discussed later. Figures 12, 13, & 14 show the sample sites in relation to the RFA region, annual rainfall and the jarrah forest blocks respectively.

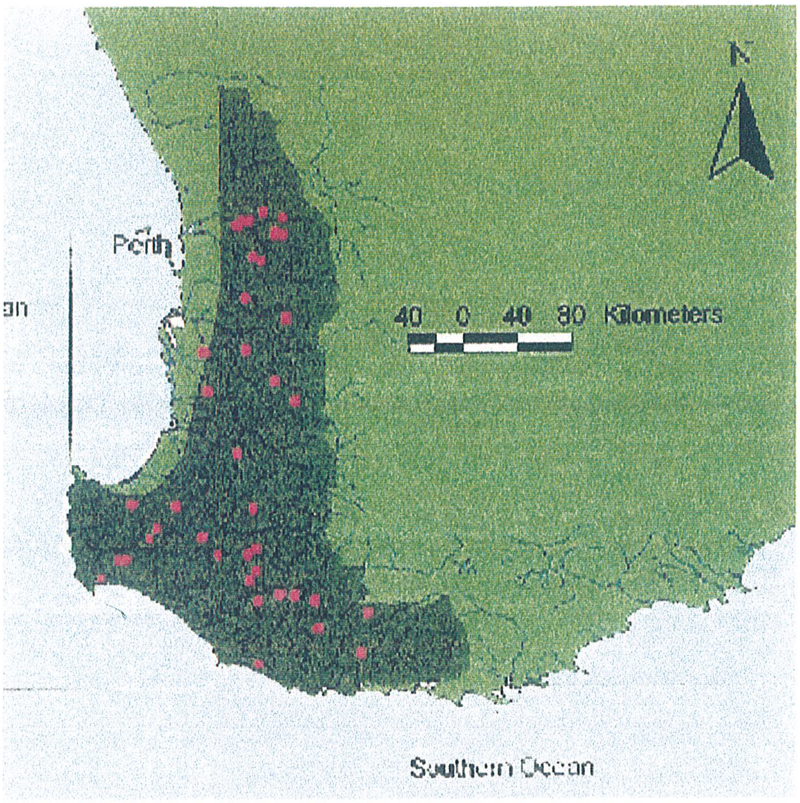


Figure 12: Sample sites in RFA region

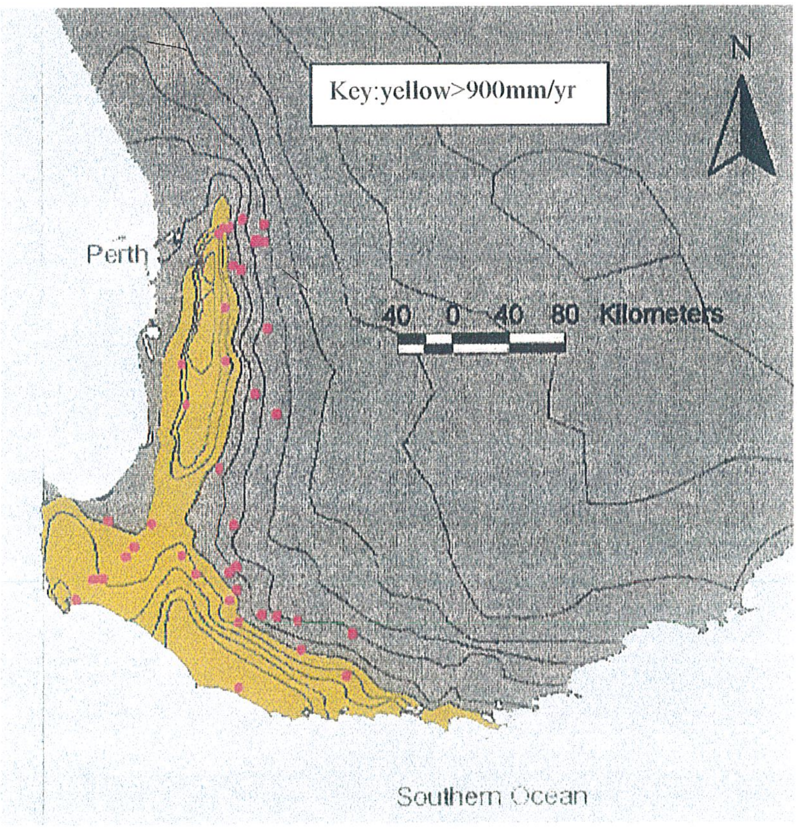


Figure 13: Sample sites with rainfall

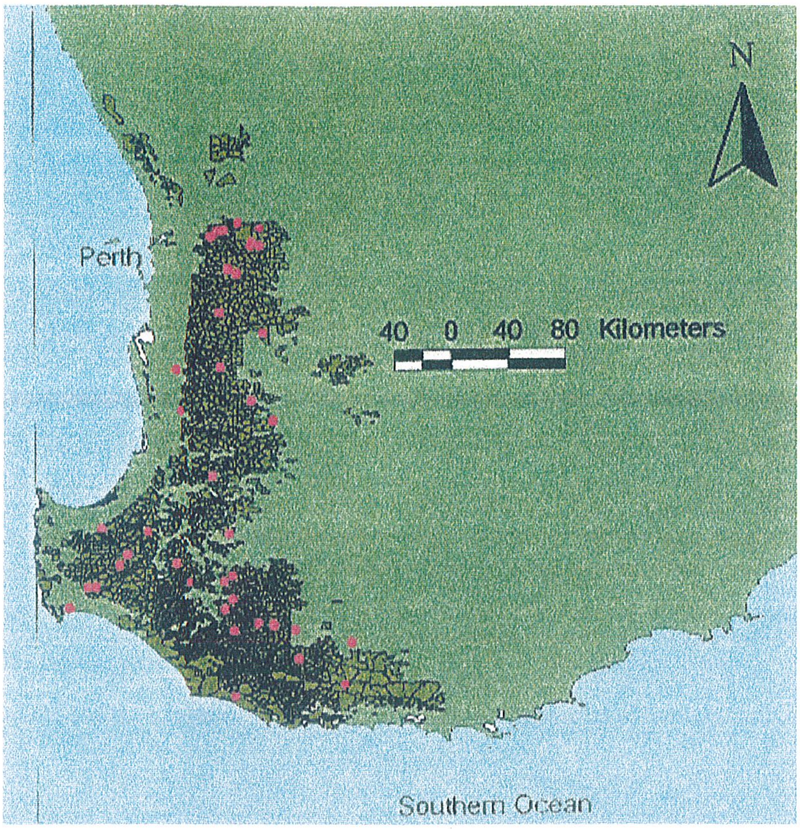


Figure 14: Sample sites in jarrah forest blocks

A multiple linear regression was used as a crude preliminary test of the hypotheses that:

1. Fire frequency has changed over the past two centuries

2. Pre-European fire frequency at a site related to its annual rainfall

3. Tall trees tend to give a pessimistic estimate of fire frequency

This regression shows significant covariance between fire frequency and annual rainfall, decade (i.e. 1800,1810 etc.), and tree height (at the time of the fire). The number of fires in the 1990s has been adjusted slightly upward to compensate for the fact that only eight years of the present decade have elapsed.

$$\textbf{Fires/decade} = 23.8 - .0014*\text{rainfall(mm)} - .0103*\text{decade} - .685*\text{height(m)}$$

$$n = 1548, \quad F = 398, \quad p < .001, \quad \text{R-squared} = 43.5\%$$

The reconstructed fire history of the jarrah forest is summarised in Figure 15. The large standard errors in the earliest decades are caused by the small size of the samples, such old trees being relatively rare. The pronounced drop in fire frequency between 1860 and 1870 coincides with a severe measles epidemic which ravaged the Nyoongar population in the early 1860s (Richards 1978, Cliff *et al* 1993). On many stems the change in fire frequency is quite abrupt for that period.

At some sites the abrupt drop in fire frequency occurs in the 1880s, when a second severe measles epidemic occurred (Hammond 1933, Hasluck 1942). The abrupt drop in fire frequency in the 1940s is probably due to the absence of young men on military service and also due to an official policy of banning burning on the grounds that fires might provide guidance to Japanese night bombers. The decline in fire frequency in recent decades is due to stricter management plans, public opposition to burning, and lack of opportunity and resources to carry it out.

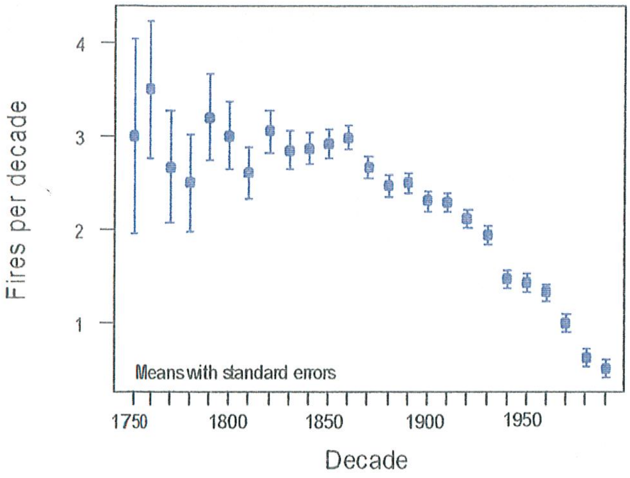


Figure 15: Reconstructed jarrah forest fire history by decade

In Figure 16 the same data are grouped into eight eras:

1. 1750-1829 – pre-European era, lightning and Nyoongar burning
2. 1830-1859 – early settlement era with traditional Nyoongar burning still common
3. 1860-1889 – disease epidemic era, with great decline in Nyoongar population
4. 1890-1919 – uncontrolled logging era, severe wildfires
5. 1920-1939 – attempted fire exclusion by Forests Department, but severe wildfires
6. 1940-1959 – men absent at World War II, heavy fuel buildup, severe wildfires
7. 1960-1979 – introduction of controlled burning after Dwellingup fire
8. 1980-1997 – strict management plans, public complaints, declining resources etc.

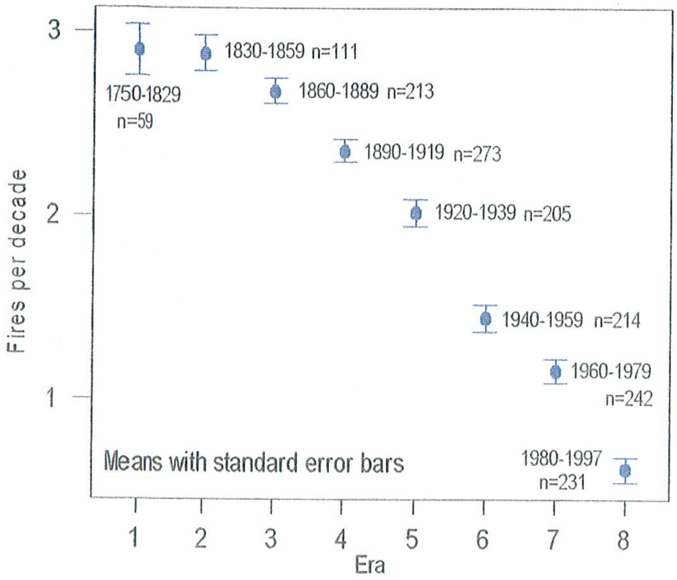


Figure 16: Reconstructed jarrah forest fire history by era

For a better understanding of the distribution of the fire frequency variable about the mean, Figure 17 gives eight histograms. It will be seen that the pre-European era shows a leptokurtic, symmetric distribution. As time passes, the distribution of fire frequency becomes more platykurtic and skewed. These data lend strong support to the validity of the method, since it is difficult to think of any forest phenomenon, other than fire, which could cause this statistical pattern, which matches so well with known human events and activities over the past 170 years.

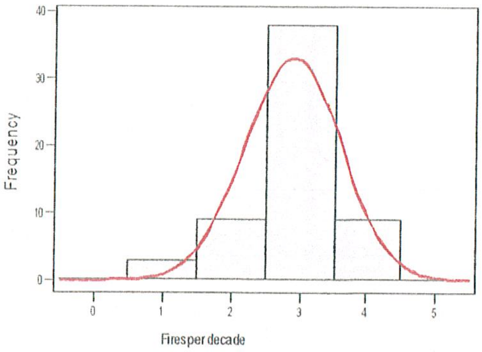


Figure 17(a): Era 1750-1829

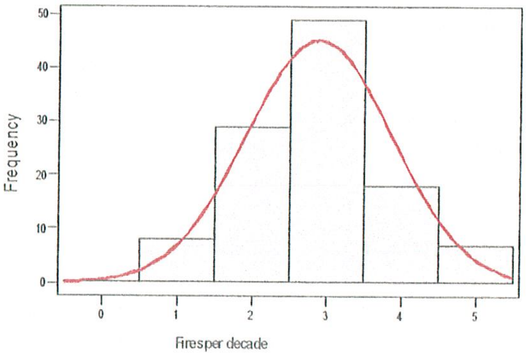


Figure 17(b): Era 1830-1859

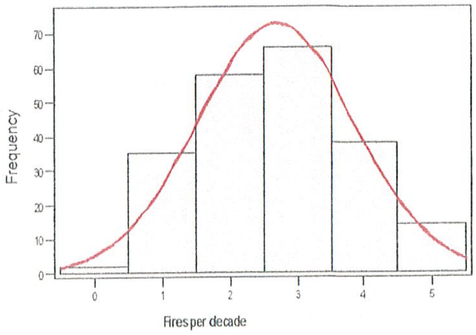


Figure 17(c): Era 1860-1889

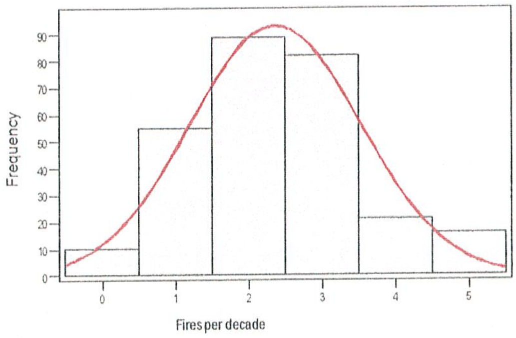


Figure 17(d): Era 1890-1919

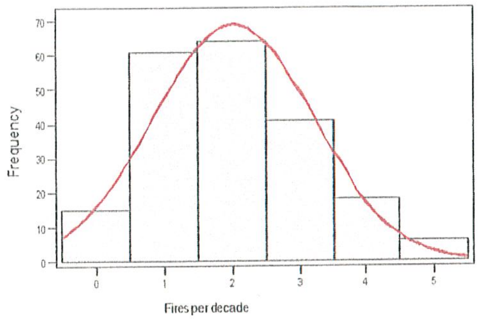


Figure 17(e): Era 1920-1939

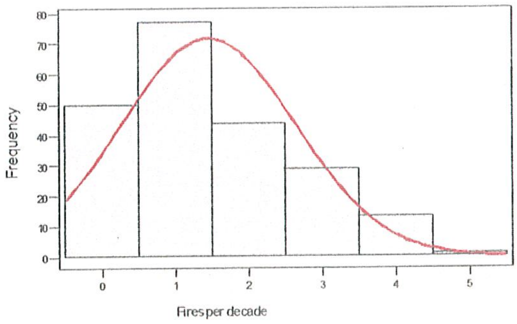


Figure 17(f): Era 1940-1959

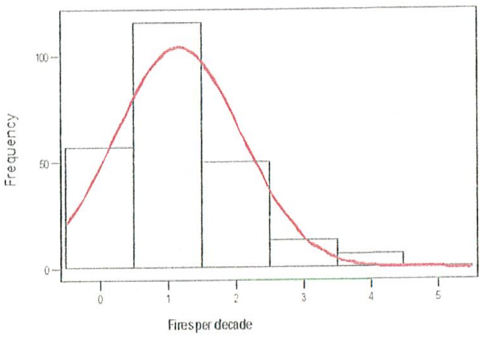


Figure 17(g): Era 1960-1979

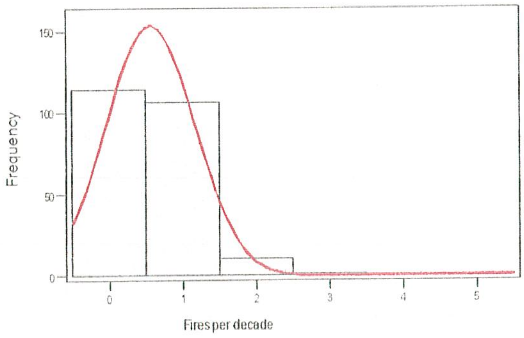
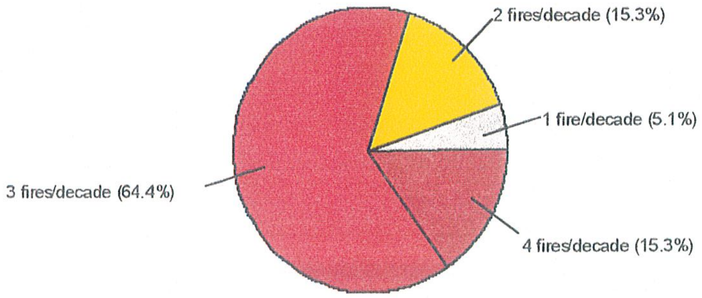
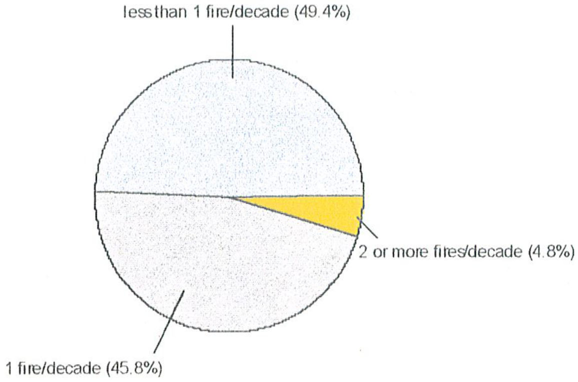


Figure 17(h): Era 1980-1997

The data can also be presented as piecharts, and some readers may find this helpful. For example Figure 18 compares the reconstructed fire frequency in the pre-European and modern eras.



Jarrah forest fire regime 1750-1829



Jarrah forest fire regime 1980-1997

Figure 18: Comparison of reconstructed Aboriginal and recent fire regimes

No relationship of fire frequency was found with the crude vegetation types used in the study, but work will continue on a more sophisticated approach (see discussion later).

Although most grasstrees occur close to water, analysis of the data so far shows no relationship between proximity to a water body and fire frequency. However, an analysis of the drainage and landform of the jarrah forest shows that the forest has such a rich network of creeks that it is difficult to find anywhere that is more than a kilometre from a drainage line. A sample of over 1000 random map points within the jarrah forest yielded the probability chart shown in Figure 19.

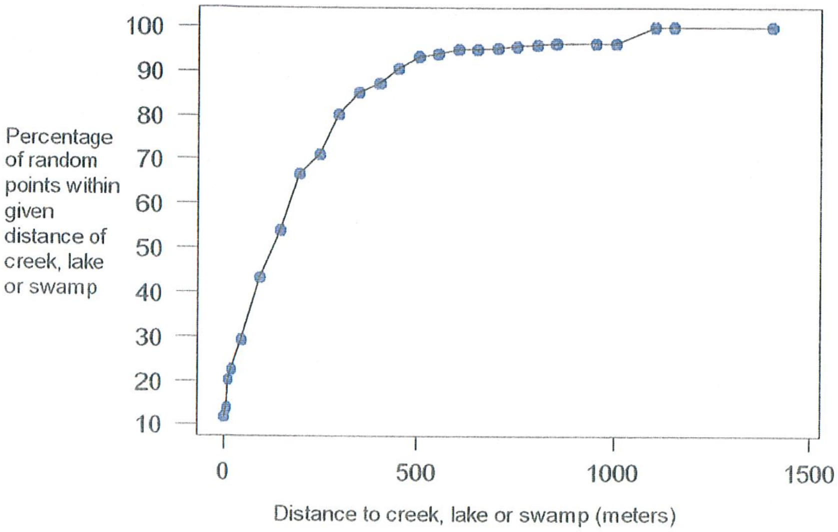


Figure 19: Jarrah forest landform

Discussion

Placing the above reconstructed fire history in its social and historical context, we may note that smoke in urban areas has become a political issue in recent years, and has been used as an argument against frequent fire. It should be clearly understood that it is the urban areas and their inhabitants which are new, not the smoke, which is a very old feature of summer in south-west Australia. The newly arrived British migrants of Perth in the 1830s complained of dense smoke from Aboriginal fires, and at Jerramungup in the 1880s Ethel Hassell described the annual *man carl* (bushfire) dance by Nyoongars before they dispersed to light widespread fires. She also mentioned the dense smoke which enveloped the station in the bushfire season (Hassell 1975). Other writers have described the smoke from Nyoongar fires. The Reverend John Wollaston in 1842, described how their fires near Bunbury "filled the sky with smoke". He was reminded of the scene Abraham witnessed on looking toward Sodom and Gomorrah after their overthrow; "for I beheld and lo the smoke of the country went up as the smoke of a furnace…". He also wrote "the fires occur every summer and for the time, destroy hundreds of acres of vegetation…" (Wollaston 1975).

The central importance of fire in Nyoongar culture is clear not only from present day Nyoongar elders (Mr. Jo Walley, personal communication), but also from early European observers. For example, Henry Revett Bland wrote to the Governor of the Swan Colony (Colonial Secretary's Records, 1846), saying that "it has always been the custom of the Natives to fire the country during the summer season for a variety of purposes". He was supported by Richard Meares, who said "they burn for their food", and Charles Symmons, who was "extremely sceptical as to the success of any remedial plan for checking one of their most ancient and cherished privileges". Lt-Colonel John Molloy confessed his "utter inability to offer an opinion as to any effective means of controlling the incendiary propensities of the Natives." Francis Corbet Singleton described how half the sandy coastal plain to the west of the Darling Range was burnt every year, so that any one place burnt biennially. The fires were "kindled by the Natives for the purpose of more effectually securing their game; which is captured in extraordinary numbers where a strong wind impels the fires."

Given this interaction between fire, plants and animals, there is clearly a management issue concerning the welfare of native plants and animals. Much useful research has been done on the fire ecology of the native plants and animals of the jarrah forest, yet to investigate the needs of every species before deciding on an appropriate fire regime is obviously impractical. If Nyoongar people were burning the forest on a frequent basis immediately before European settlement, then it is likely that such a fire regime had been in place for many thousands of years. Any plants or animals which could not tolerate it would have either disappeared, or been driven back into refuges in moist or rocky places.

There is historical and anthropological evidence that Nyoongar people tended to light fires close to creeks, swamps, or other water bodies. They travelled mainly along creeks for the obvious reason of access to water, and because these were the most productive areas for food (Hallam 1975). To keep the creeks open they fired the vegetation. It has been suggested, therefore, that only areas close to creeks or other water bodies would have been burnt frequently, and that ridges would have been burnt much less often.

Given that over 90% of the jarrah forest is within 500 meters of a potential Nyoongar ignition point (see Figure 19), then it is likely that fire frequency varied little over the landscape. A fire lit in summer along a creek would easily spread to the top of a nearby ridge by nightfall, provided there was enough fuel to carry fire. Obviously rocky or steep ridges would act as fire breaks, so sheltering rare (i.e. fire sensitive) plant species. The idea that the distribution of south-western flora has been influenced by frequent Aboriginal fire is, of course, not new (Gardner 1957). It is emphasized that the above reasons for uniformity of fire frequency apply to the jarrah forest, where litter accumulates rapidly after a fire. They are not true, for example, in wandoo woodland at Dryandra, where the evidence from grasstrees plainly suggests that fires were much more frequent along the (then grassy?) drainage lines (every 2-3 years) than on the bare, rocky ridges (every 10-20 years) where fuel accumulates slowly.

Concern has been expressed about the effect of frequent burning on refugial vegetation along creeks. Under the current fire regime, CALM burns from the ridge top down, so creeks rarely burn until late summer or autumn, when the riparian soil, vegetation and litter are dry. This results in complete burn out of the creek bed. Nyoongars probably lit close to the creek in early to mid-summer, so the fire travelled uphill. If the riparian soil and vegetation were still moist, thickets of intact vegetation would have been left along the creek bed and immediate banks.

Unburnt thickets were the subject of a special hunting technique in spring, in which vegetation was broken down around the perimeter to entangle the animals when they were driven out (Green 1979), and there is a record of Nyoongars deliberately guiding fires away from some places (Stokes 1846, in Hallam 1975).

If Nyoongar people burnt as frequently as the evidence presented suggests, then it would be more rational to switch the research spotlight away from the effects of frequent burning, and toward the effects of not burning for long periods. Some interesting work has been done in Tasmania on this (Ellis 1994), but there are many interesting leads to be followed in the jarrah forest.

While cats and foxes are efficient predators, so were the Nyoongar people. It would be useful to estimate the likely annual harvest of native animals by Nyoongar predation, and compare it with that by introduced predators. Based on a Nyoongar population of 1,000 to 1,200 people (Richards 1978), a ration of one small mammal for each Nyoongar each week would suggest a total harvest of at least 50,000 small mammals each year. To this should be added predation by dingoes, which were present in the jarrah forest (Abbott 1988). Is the current harvest by cats and foxes greater or lesser? If less, then has the fecundity of native mammals declined, as fire frequency has declined?

We need to investigate the effect of fire regime on recycling of nutrients and trace elements, and their significance in animal fecundity. In Scotland, studies on burnt moors have shown that there are major increases in the nutrient content of heather shoots after fire, with the effect lasting for four years (Miller & Watson 1973). In the same country it has been observed that a grouse population increased by more than 50% in the three years following a fire, remained at that level for three more years, then declined again. No change in numbers was recorded on a nearby unburnt control area (Miller & Watson 1973). In the Netherlands a five fold increase in a grouse population within a few years of fire has been claimed (Van der Ven 1973).

In Scotland before the First World War, Lord Lovat noted a decline in both internal and external parasites of grouse after heather fires (Lovat 1911). It is generally accepted in Africa that both internal and external parasites are greatly reduced in number by frequent grassfires (Brynyard 1971). Ticks and other parasites exist in the jarrah forest. In particular, ticks are abundant in the thatch of some long unburnt grasstrees (Ward, personal observation). Might frequent fire have had a role in controlling such parasites, and so enhancing the health and fecundity of their hosts, human or otherwise?

The significance of the calcium result is that calcium is present in wood ash and, with other cations, is known to have an effect on soil pH and hence on soil bacteria and microfungi (Fowells & Stephenson 1933, Ahlgren & Ahlgren 1965). Some soil bacteria play an important role in nitrogen fixation, nitrification and denitrification, so affecting availability of nitrogen to plants, and ultimately to animals. Soil pH can also affect the availability to plants of other nutrients

(Ahlgren & Ahlgren 1960), and increased acidity can mobilise some elements, such as manganese and aluminium, to levels toxic to plants. Increased soil alkalinity can decrease potentially toxic levels of copper.

The full analysis of nutrient and trace element levels at different positions in the leaf bases, their relationship to soil nutrients, trace elements, and potential toxins, will need several years work. Initial investigation suggests that annual rainfall may have a joint influence with fire on the availability of calcium in the soil. There is need for intricate modelling of this potential interaction. This is well outside the scope of this project, which had a time frame of only a few months. Professor Byron Lamont at Curtin University is currently supervising an Honours student, Ms Chantal Burrows, who is investigating nutrient levels in grasstree stems, and a Ph.D. project is proposed for 1998.

This study has given a broad picture of the fire history of the jarrah forest, but there is a need now for more detailed studies at specific sites. More detailed study may yet reveal a relationship between landform, vegetation and past fire regime. Vegetation data (Mattiske, personal communication) have been entered into the data base, and work continues. The vegetation types in use are defined by a combination of landform, soil, climate and plant species, so analysis is complicated. There is a need for a multivariate exercise to cluster the many types into a few, but again, that is beyond the scope of this project.

Once achieved, such a classification would give CALM the option of including in its fire management smaller, more precise burns, as a supplement, or alternative, to the broader techniques used at present. The smoke from such small burns might be easier to manage for minimum public nuisance. They could also address the specific needs of local plant and animal communities, in much the way that Nyoongar people seem to have done in the past, and Aboriginal people still do in the northern part of Australia (Jones 1994).

The terms "precautionary principle" and "nature conservation" are widely used, yet this study throws a spotlight on their fuzzy definition. As a piece of logic, the "precautionary principle" is a two-edged sword. CALM is legally responsible for the welfare of native plants, and will soon be legally responsible for the welfare of native animals. Some may argue that CALM should not burn the forest until we can be sure that relatively frequent fire is not harming native plants and animals. Taking an historical perspective, it is equally logical to argue that we should not reduce the frequency of burning until we are absolutely sure that such a reduction in fire frequency will not adversely affect soil chemistry, and hence soil bacteria and nutrient cycling. This is quite separate from the issue of protecting human life and property from devastating fires in heavy fuel.

We should also consider the term "nature conservation". Is the jarrah forest remnant we have now "natural", or has it been shaped by forestry practices? Was the pre-European jarrah forest "natural", or was it the result of millennia of human disturbance by fire? Do we wish to conserve what we have now - or do we wish to restore and conserve the immediate pre-European condition? A third possibility is to try to restore the (presumably natural) pre-Aboriginal state, if we can determine what it was. In the case of fire regime it was possibly one of occasional, extremely fierce fires caused by lightning. Would that be compatible with our present agricultural, residential, and industrial land uses?

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