FIRE ECOLOGY & MANAGEMENT

IN WESTERN AUSTRALIAN ECOSYSTEMS

Proceedings of May 1985 Symposium

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Organised by
WAIT ENVIRONMENTAL STUDIES GROUP
CONSERVATION COUNCIL OF WA

Edited by Julian Ford

FIRE ECOLOGY AND MANAGEMENT OF WESTERN AUSTRALIAN ECOSYSTEMS

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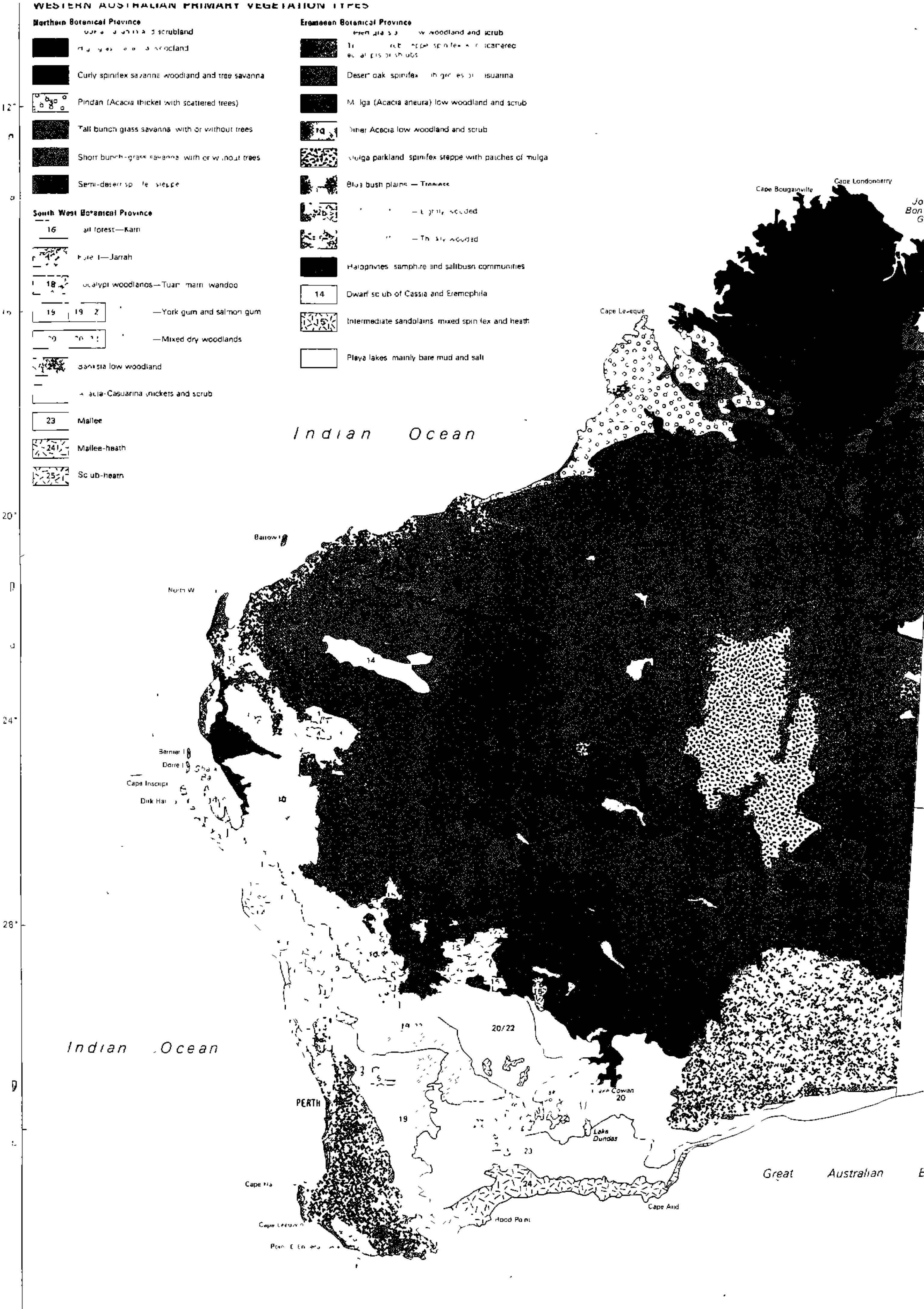
Major vegetation formations in Western Australia from south to north are wet sclerophyll forest, dry sclerophyll forest, semi-arid or sclerophyllous woodland, heath or kwongan, mallee, mulga, spinifex or hummock grassland, shrub steppe, savanna grassland, savanna woodland, gallery (riverine) forest, vine thickets, monsoonal rain-forest, and mangal.

WESTERN AUSTRALIAN PRIMARY VEGETATION TYPES



PREFACE

WAIT Environmental Studies Group

The WAIT Environmental Studies Group is a loosely affiliated group of WAIT staff from various disciplines who share a common interest in matters involving the environment. E.S.G. activities include the teaching of interdisciplinary courses on environmental topics, research and survey work, and public information exercises. E.S.G. welcomes approaches from private and government organisations for assistance and expertise on any problem pertaining to the environment.

In any given year E.S.G. may undertake several minor projects or concentrate its resources on a major topic. Recent examples of specific endeavours include the 1981 survey of Woodman Point's ecology and resources, and the 1983 symposium on the Darling Range escarpment. In 1985 E.S.G. devoted its entire resources to this symposium on the ecology and management of fire in Western Australian natural lands.

Conservation Council of W.A.

The Conservation Council of Western Australia is a non-government, largely voluntary organisation, formed in 1967 to focus public concern on environmental and conservation matters. Acting on behalf of its 44 member organisations, and with the assistance of individual supporter members, the Council works for the adoption of legislation and policies which provide for the sustainable use of renewable resources, the preservation of species of plants and animals, the protection of representative and outstanding examples of the natural environment, and the prevention of environmental pollution.

The Council is represented on bodies such as the Community Consultative Committee on Chemicals, the Northern Jarrah Advisory Committee, the Air Pollution and Noise Abatement Advisory Committee, the Reserves Review Committee, Greening Australia (W.A.) and the Roadside Vegetation Conservation Committee. Representatives of groups affiliated with the Conservation Council also hold positions on the National Parks and Nature Conservation Authority.

Positive contributors to the formulation of environmental policy by the Conservation Council have included the Jarrah Reserve Proposal, the publication of 'Karri at the Crossroads' and major submissions on the development of the North-West Shelf, environmental impact assessment, the Harding Dam proposal and the disposal of waste from Laporte's Titanium Dioxide Plant.

Major current concerns of the Conservation Council include the inadequacy of Western Australia's environmental impact assessment procedures, and the incompleteness of our system of National Parks and Nature Reserves.

Symposium of Fire Ecology and Management

The aims of this symposium were to synthesise existing information and to generate new concepts on fire ecology and management of natural ecosystems in Western Australia. Bush fires are accepted as part of the natural scene in Australia's sclerophyllous vegetation because a long history of natural and Aboriginal-controlled fires has promoted many intriguing ecological adaptive processes and phenomena in both the plants and animals.

However, scientists, conservationists, land managers and the general community have been expressing renewed concern on the frequency of man-caused fires, the dangers posed by uncontrolled fires, the use of fire in management programmes and the ecological consequences of various fire regimes.

The two-day Symposium, held on 10-11 May 1985, on the WAIT campus, brought together researchers in fire ecology, representatives and organisations with an interest in the management of fire on particular types of lands, and the planners who must synthesise conflicting land management objectives and often conflicting research data to produce a practical plan for the use of fire on natural lands.

The Symposium had its genesis in 1984 when I commenced a two-year term as Chairman of E.S.G. My initial aim was to cover the various major vegetation formations south of the tropical part of Western Australia. Subsequently, it was learnt that the Conservation Council was vitally interested in our proposal and had been contemplating a parallel programme. Consequently, E.S.G. invited Mr Michael McGrath, Director of the Council, to a meeting in 1984 and a cooperative plan was conceived. These Proceedings are the result of our joint venture.

Acknowledgements

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John Burling	- Treasurer
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Rob Rippingale	- Catering
Julian Ford	- Day one
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Jacob John	- Labels
Cheryl Cartlidge	- Publicity

E.S.G. is especially indebted to the Department of Conservation and Environment and the Department of Conservation and Land Management for a grant towards the printing costs of these proceedings. The Hon. Minister for Lands and Surveys, Mr Ken McIver, opened the Symposium.

Julian. R. Ford
1985 Chairman of E.S.G.

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INTRODUCTION: SUMMARY OF ABORIGINAL USE OF FIRE AND CURRENT IMPACT OF FIRE ON MAJOR VEGETATION FORMATIONS

Julian Ford

Aboriginal use of fire and its impact on plants and animals is variously discussed by Hallam, Lewis, Burbidge and Smith. Hallam examines archaeological and geomorphic aspects over the last 50,000 years and argues for an initial early penetration of Aboriginal colonists and firing through the savanna woodland zones inland of the coastal forests, followed only later (about 40,000 BP) by penetration and opening up of forest zones, including the heavily vegetated, south-west coastal plains. Recent criticism of this interpretation of archaeological (and ethno-historical) data ignores the manner, skill, control, frequency, extent and effects of Aboriginal burning. Hallam concludes that burning was of extreme importance both to Aboriginal communities and to the Australian vegetation, fauna and landscape. Long before the arrival of Europeans to Australia, Aborigines had established a harmonious fire equilibrium though presumably their initial impact would have induced a major perturbation on the environment as happened elsewhere on the arrival of man, his commensals and the fire-stick to a virgin land-mass.

Strong support for Hallam's view is provided by the excellent work of Lewis in tropical northern Australia where fire is currently manipulated in two distinctly different ways by Aborigines and cattlemen. Despite the much more impressive array of tools and techniques used by cattlemen, the technological methodology used by Aboriginal hunters and gatherers involves a much more sophisticated understanding of the reticulate networks of environmental cause and effect. The differences in complexity relate directly to different resource strategies: for stockmen the ultimate resource is cattle; for the hunter-gatherers, a very broad spectrum of natural resources is exploited.

In the tropics the Aborigines were especially careful to prevent fire penetrating and so destroying vine thickets and monsoonal forests, because these were fire sensitive and an important source of fruits, but the indiscriminate burning by cattlemen has caused unwitting destruction of these relatively scarce habitats in the Kimberley and Northern Territory. Aborigines also practiced fire exclusion in the Mitchell Grass plains for they were well aware of the deleterious effect of fire on this habitat. It should be pointed out that, although Lewis worked mainly in the tropical half of the Northern Territory, his findings are absolutely applicable to the Kimberley because vegetation assemlages and land forms of the two regions are very similar.

The significance of traditional Aboriginal burning programmes in creating and maintaining a serial array (successive stages) of habitats, and a concomitant diversity in especially the vertebrate fauna has only recently been understood (Latz & Griffin 1978; Kitchener et al. 1980). Burbidge correlates the demise of the intermediate-sized mammal species (wallabies, bandicoots, large rodents) in the spinifex lands with the Aboriginal exodus to mission stations. In the south-west various causes have been suggested for the disappearance of native mammals, including predation by the feral cat and the fox, introduction of exotic diseases, competition from rabbits, habitat destruction by browsing and grazing stock, land-clearing and wildfires. The survival of native mammals on off-shore islands and in certain protected or remote areas suggests that the critical factor is possibly the retention of adequate shelter from predators. Land clearing, overstocking and wildfires destroy shelters consisting of particular vegetation structures whereas exclusion and patchy fire regimes maintain and regenerate shelter belts. It is difficult to attribute the presumed extinction of the Stick-Nest Rat (**Leporillus conditor**), an inland breakaway inhabitant, to some aspect of fire. In the case of the Boodie Bettong (**Bettongia lesueur**) and Rabbit-eared Bandicoot or Dalgite (**Macrotis lagotis**), old-timers related how these burrowing marsupials were usurped from their burrows by swarms of rabbits in the 1930s soon after the rabbit invasion (cf. Jenkins 1974), and viral disease has been suggested for the decline in some arboreal marsupials. Much more research is required before there is an understanding of all the factors that caused the disappearance of the intermediate-sized native mammals but certainly changes in the fire regime contributed.

Post-Aboriginal changes in fire regimes have certainly had a disasterous impact on several sedentary bird-species, especially the Noisy Scrub-bird, Western Bristle-bird, Western Whip-bird, Rufous Bristle-bird and Ground (Swamp) Parrot which require mature heath-scrub and/or understorey formations. Smith has monitored populations of the first three species in the Two Peoples Bay Nature Reserve and recorded a progressive increase in abundance and concomitant expansion into new territories since fires were excluded and controlled from the 1960s. The endemic subspecies of the Rufous Bristle-bird (**Dasyornis broadbenti litoralis**) has become extinct in the south-west probably as a direct result of uncontrolled fires lit by stockmen (Carter 1924) and the Ground Parrot has suffered a severe diminution in range, only surviving in south-coastal areas where fires are infrequent. Besides the south-western form of the Rufous Bristle-bird, one other distinct avian population in Australia has been completely eliminated by fire: the endemic Roper River population of the Northern Scrub-Robin (**Drymodes superciliaris colcloughi**) (Bennett 1983). This inhabited monsoonal gallery forest but succumbed to the fires produced by cattlemen in the Northern Territory. Vagile birds have been more able to cope with recent burning practices (Bamford).

Fire in various major vegetation associations is discussed by Bell, Hingston, Christensen and Annels, Hopkins and Fox. Kwongan (Beard 1976) and Jarrah forest understorey generally recover fairly quickly following fire mainly because a large proportion of plant-species are resprouters and may achieve pre-fire biomass within ten years. Satellite-based technology is now being used to assess general biomass accumulation and floral recuperation in heathlands (Bell). Diversity in time depends on fire frequency, intensity and patchiness, for frequent, extensive burning can produce a progressive loss of species, the most vulnerable being those that regenerate from seeds rather than by resprouting. The majority of understorey plant-species in Karri forest regenerate from seeds suggesting that fires have always been less frequent in Karri than in Jarrah (Christensen & Annels). Present burning practices in the Jarrah appear to have no adverse effect on nutrient cycles (Hingston), but possibly are harmful to the invertebrate fauna (Majer).

Mulga, sclerophyllous woodlands and island assemblages are especially fire sensitive. In pre-European times, fire was an uncommon episodic phenomenon in these formations and typically produced a succession sequence. Now mulga is mainly under threat from fire at the northern margins where it co-occurs with highly inflammable spinifex (**Triodia**) but devastating fires periodically occur in southern areas following high-rainfall years when the herbage layer becomes dense, and fire-prone on becoming dry (Fox). In the semi-arid region of south-western Australia, the successional stage from mallee-heath to tall woodland of monopodial eucalypts may take at least a century of years. Fire reinforces the former structure (Hopkins), but the entire absence of fire probably allows a persistent balance of structures as old formations senesce and are replaced by earlier stages (Muir). Uninhabited islands off the coast provide ideal laboratories for long-term responses to a single fire. An important finding is that long-term exclusion does not radically alter floristic composition. Fire-free regions provide important baselines for the future (Weston).

The ideal method of predicting the responses of plant community richness and diversity to fires would require detailed information on a wide range of variables on each species. Such data may perhaps never be accrued for efficiently predictive ecosystem management programmes. Lamont describes how some of the essential variables were obtained for several species of **Banksia**: pre-fire population size, area of distribution, seeds per follicle, follicles per cone, cones per tree, age of flowering (seed setting), seed viability with age, seed storage, seed predation, recruitment mode (i.e. resprouter or seeder), etc. The rate of propagule (seed) elimination between generations is strongly correlated with the fire regime. For rare and endangered plants, it is imperative that such data be obtained with haste.

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THE HISTORY OF ABORIGINAL FIRING

S. J. Hallam

1. Introduction

The effects of European communities on Australian landscapes have been assumed to be far greater than those brought about by their Aboriginal predecessors. "Fire was probably the only major tool of Aboriginal culture which shaped the vegetation across the continent. Europeans have a far more complex toolkit, which of course includes fire, and their impact is greater in proportion to greater complexity of the technology" (Adamson & Fox 1982). European vegetation clearance allowed wind erosion, water erosion, increased salinity. Urban and industrial development, mining, ploughing, irrigation, introduced plant and animal species, monoculture - all altered vegetation cover; bird, insect and mammal populations; soils; run-off; depositional regimes; flooding; even climate. Surely, even with firesticks, Aboriginal groups had no such dramatic effects?

But the first human colonisation of the continent was itself an unprecedented change perhaps unmatched by any later impact. Aboriginal spread into a range of new environmental zones brought successive disturbances to a variety of previously stable ecological systems. How far can archaeology and other disciplines trace this interaction?

2. Chronological Synthesis

2.1 The Last Interstadial Onwards

Radiocarbon dating methods as so far applied to Australian sites do not allow exact dates to be obtained earlier than the practical limits of ordinary methods, that is about 40,000 BP (years ago). By that time Aboriginal groups had already spread right across the continent, taking up and adapting their resource management patterns to most Australian vegetational zones, from the tropical forest of New Guinea (Huon Peninsula 45,000 BP (Groube 1984; Flood 1983)) to the cool damp forests of the southwest of the continent (Devil's Lair before 35,000 BP (Dortch 1983)) and the semi-arid scrubland of the south-east interior (on the shores of Mungo, one of the now-dry lakes then fed by the Willandra Creek, a distributary of the Lachlan, by dates nudging 40,000 BP (Bowler & Jones 1979; Shawcross 1975; Shawcross & Kaye 1980)). We must not assume that these first dates chronicle the first entry of people to the continent, and their first impact upon it. Nonetheless, between 50,000 and 30,000 BP a relatively salubrious climatic phase within the generally arid and windy timespan of the last glacial period may have allowed an easier spread by Aboriginal groups, particularly through areas now semi-arid, than could have occurred later, at the maximum aridity around 20,000 BP. Further penetration, into more heavily vegetated areas, involved the use of fire as a clearance tool.

The years around 40,000 BP provide some of the earliest dated and definite evidence not only of Aboriginal presence in Australia, but also of the occurrence and impact of Aboriginal firing. There is also some probably earlier evidence whose interpretation and chronology is debatable. The backdrop of vegetational zones was very different from the present, and constantly changing through the climatic fluctuations of the last third of the Pleistocene. We must look first at this changing backdrop.

During the last two thirds of a million years, great continental ice sheets spread slowly and intermittently (during at least nine major glacial episodes and their warmer interstadials), and alternately contracted rapidly in relatively brief interglacials like the present. During the glaciations water was tied up in great ice-masses, most extensive over the high latitude land areas of the northern hemisphere, but temperatures fell worldwide. Sea levels dropped, reaching for instance, approximately 150 m below their present levels at the maximum of the last glaciation around 20,000 BP. Sea levels had also been very low at the maximum of the previous glaciation, about 150,000 BP. As the ice sheets melted, seas rose to maximum levels slightly above the present, for instance about 125,000 BP, during the last interglacial, and about 6000 BP, during the present interglacial.

At times of low sea level, e.g. during the whole span of the last glaciation from about 110,000 to 10,000 BP, the continental shelves around Australia were exposed, and the Greater Australian land mass extended from the equator to 45°S, including the now separate islands of New Guinea and Tasmania, plus Torres Strait and Bass Strait, as well as the Gulf of Carpentaria, the Timor Sea, and wider coastal plains, particularly on the west and south (Chappell & Thom 1977). With less marine influence, rain-bearing winds did not penetrate so far towards the centre, and the great concertina of concentric climatic zones expanded outwards giving cold, arid, windy conditions at the maxima of glaciation (e.g. 150,000 BP and 20,000 BP), with a great swirl of dry winds whipping up longitudinal dunes about the heart of the continent (Fig. 1 - Glacial maximum).

On the other hand, during some intermediate phases of glaciation, the so-called "interstadials", conditions seem to have been rather more salubrious. In Jim Bowler's words "Australia was a land of lakes" (Bowler & Jones 1979). During the 50,000 to 30,000 BP interstadial, temperatures were lower than at present, and evaporation consequently much less. Streams like the Willandra Creek (a distributary of the Lachlan), which now lose all their water by evaporation, then flowed on to supply chains of lakes. Bowler deduces, from the dates for lake-full phases in the Willandra Lake and other southeastern lakes, and from the distribution of now-dry lakes, that around 40,000 BP the present semi-arid (mulga) zone about the arid centre was characterised by precipitation/evaporation ratios more like those of the present mallee and

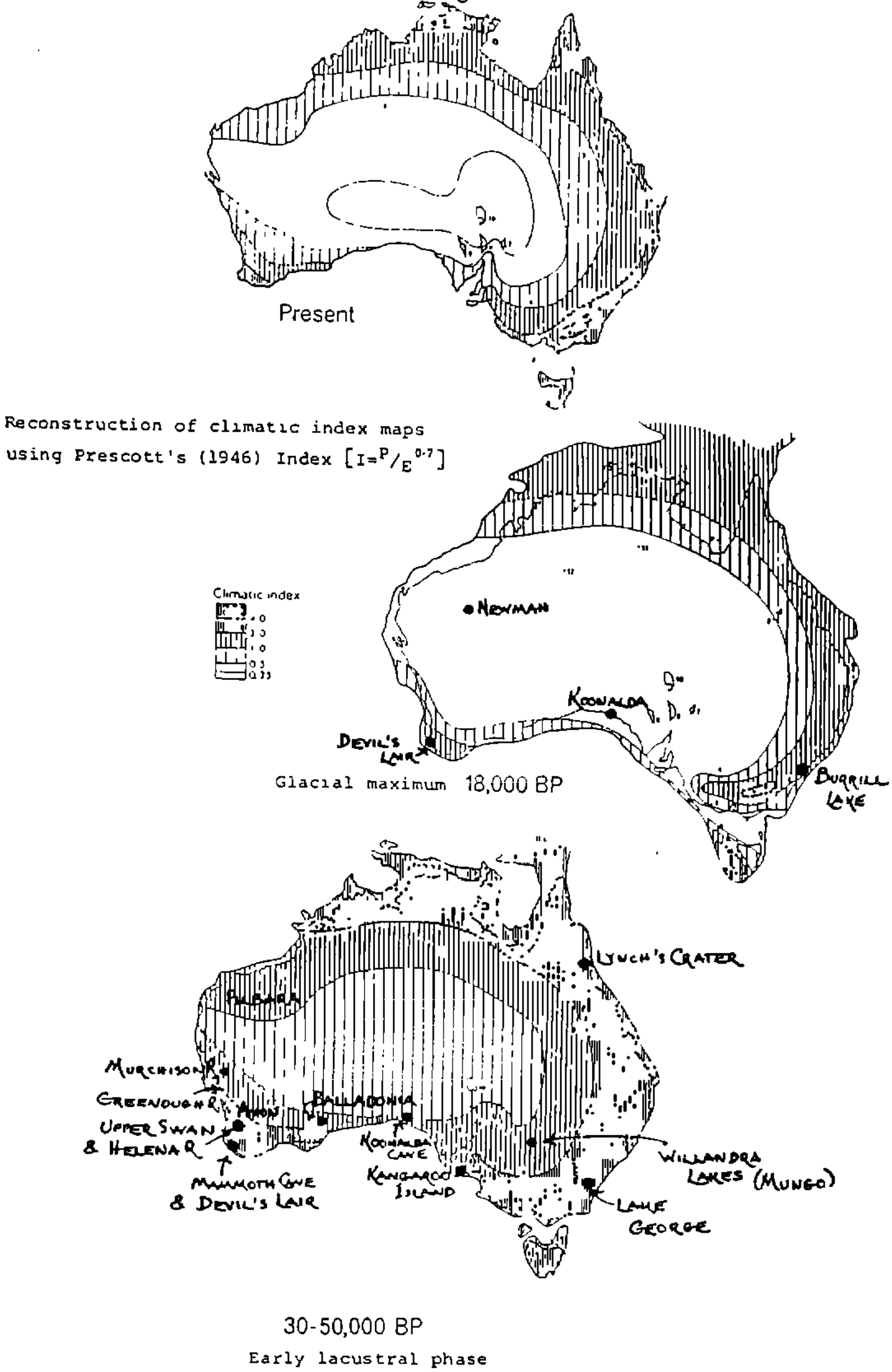

Figure 1. Bowler's reconstructions of Australian climatic zones at 18,000 BP (Glacial maximum) and 30-50,000 BP (Early lacustral phase) compared with the present, on the basis of precipitation/evaporation ratios. (Based on Jones & Bowler 1980: figure 6).

The location of places mentioned in text is shown on the appropriate maps; the Early lacustral map shows sites which contain material which has been dated to that period (Upper Swan, Helena River, Koonalda, Devil's Lair, Willandra Lakes, and pollen events at Lynch's Crater) and others which may be contemporary or earlier (Pilbara, Murchison River, Greenough River, Avon, Balladonia, Kangaroo Island, and Lake George).

wheat-belt, and this zone of moderately well-watered woodland savannah, supporting plant and game resources, would have given relatively easy access to people moving around the continent between the forested margins and the arid centre (Jones & Bowler 1980; Horton 1982b); see Figure 1 - Early lacustral phase.

At the same time however, the continental margins would be more extensive (stretching further inland, and also outward across a wider coastal plain). It is just at this time, around 40,000 BP, that there is the first firm evidence for the use of fire to open up heavily vegetated zones, and provide access to the plant resources within tropical forest; or to the rich fish, fowl, mammal and plant resources of the estuaries, lakes and swamps of the southwestern coastal plains. The best evidence is from Queensland. A pollen sequence for the last 140,000 years from Lynch's Crater at the inland margin of the rain forest (Fig. 2), shows rainforest during interglacials (at about 130,000 BP and over the last 10,000 years) alternating with a partial takeover by sclerophyll forest during cold arid glacial maxima, e.g. briefly about 75,000 BP and again from 27,000 to 12,000 BP (Kershaw in Singh, Kershaw & Clark 1982: 34-39). Small quantities of charcoal indicated fires, probably mainly natural, intermittently throughout the timespan, with most charcoal during cooler sclerophyll phases. Just after 40,000 BP, however, there was a sudden more than tenfold increase in quantities of charcoal, followed by a steep decline in fire-sensitive rain-forest elements in the pollen count and a concomitant increase in the fire-resistant eucalypt component, and this is seen as due to Aboriginal firing. After the initial catastrophic impact firing continued, but giving a lower level of charcoal density (but none the less higher than before 40,000 BP), peaking again just after the arid 20,000 BP glacial maximum, as rainforest threatened to take over in the warmer wetter conditions about 10,000 BP. In the long run (as in Tasmania) even firing could not hold back the post-glacial tide of trees, which overwhelmed the area about 8,000 BP.

Around 40,000 BP the west coastal plain may also have been penetrated by Aboriginal burning, though the evidence is less conclusive and its interpretation more debatable. In Devil's Lair in the extreme south-west the basal charcoal-rich levels containing human artefacts and burnt bones washed into the cave between 40,000 and 30,000 BP (Dortch 1983), and may chronicle penetration and even partial devegetation of parts of the forest during the intermediate temperatures and humidity of the interstadial.

Alongside the Swan River, just where it emerges from the Darling Scarp, Pearce excavated Aboriginal flaked quartz tools and grinding material from within an overbank deposit topping the 20m terrace. Associated charcoal gave dates from almost 40,000 to 35,000 BP (Pearce & Barbetti 1981). The entire thin late Pleistocene deposit is rich in charcoal, and lies directly on Tertiary Guildford clay. What brought about charcoal-rich overbank deposition for the first time within the Pleistocene? One possibility is devegetation due to aboriginal firing along the Darling Scarp and the wide valleys of the Swan tributaries, e.g. the Wooroloo Brook, forming corridors for Aboriginal movement between the open woodlands of the Avon valley and the heavily vegetated coastal plain.

The Swan is not alone in showing charcoal-rich alluvial deposits in the late Pleistocene. On the next river south Schwede (1983a, b, c) excavated artefacts and charcoal with dates of 29,000 to 28,000 BP at depths of 1 to 2 m within the middle terrace of the Helena, so deposition of charcoal-rich alluvium washed down from the Darling plateau continued after 30,000 years ago.

Again, from the Greenough northward, Wyrwoll has investigated a dissected deposit many metres thick of charcoal-rich "Red Alluvium", giving a date of more than 37,000 years in its upper levels (Wyrwoll 1984; Wyrwoll & Dortch 1978). Does this massive deposition on the Greenough and associated minor streams correlate with initial human presence and firing in and around their alluvial terraces and floodplains, supporting rich plant resources, e.g. yams and reed rhizomes (Hallam 1984)? Did colonists move down the west coastal plain, encountering plant resources similar to those already familiar in lower latitudes (Golson 1971) and firing to open up access to more heavily vegetated areas as they penetrated southward to the Swan, the Helena, the extreme south-west, and even along the southern coastal plain to penetrate the Nullarbor, where dates of 30,000 to 20,000 BP came from bonfires within flood deposits washed into the deep cave of Koonalda, a quarry and ritual site (Wright 1971).

On the east of the continent Aboriginal people had moved onto lake-margins of the Darling & Lachlan drainage before 40,000 BP (Shawcross 1975; Shawcross & Kaye 1980), but the penetration of the heavily forested continental margin was later. In Burrill Lake shelter, then 16 km from the coast (south of Sydney), rapid clay deposition, with pieces of charred wood scattered throughout, at the time of earliest human occupation about 21,000 BP, may relate to destabilisation of the slopes above the shelter by fire (Lampert 1971). Aborigines occupied the Tasmanian uplands when they were open periglacial tundra around 20,000 BP (Kiernan, Jones & Ransom 1983), and attempted with partial success to hold back the advance of temperate rainforest in the warm wetter climate around 15,000 BP (McPhail & Colhoun 1985). For most of the humid south-east (as for the south-west - see below) the real impact of Aboriginal usage was not felt until 7000 BP and later, when rising populations opened up areas previously little used, bringing about destabilisation of vegetation, hillslope movement and stream aggradation (Hughes & Sullivan 1981; Williams 1978) in many ways similar to the geomorphic effects of farming clearance in Mediterranean Europe (Vita-Finzi 1978).

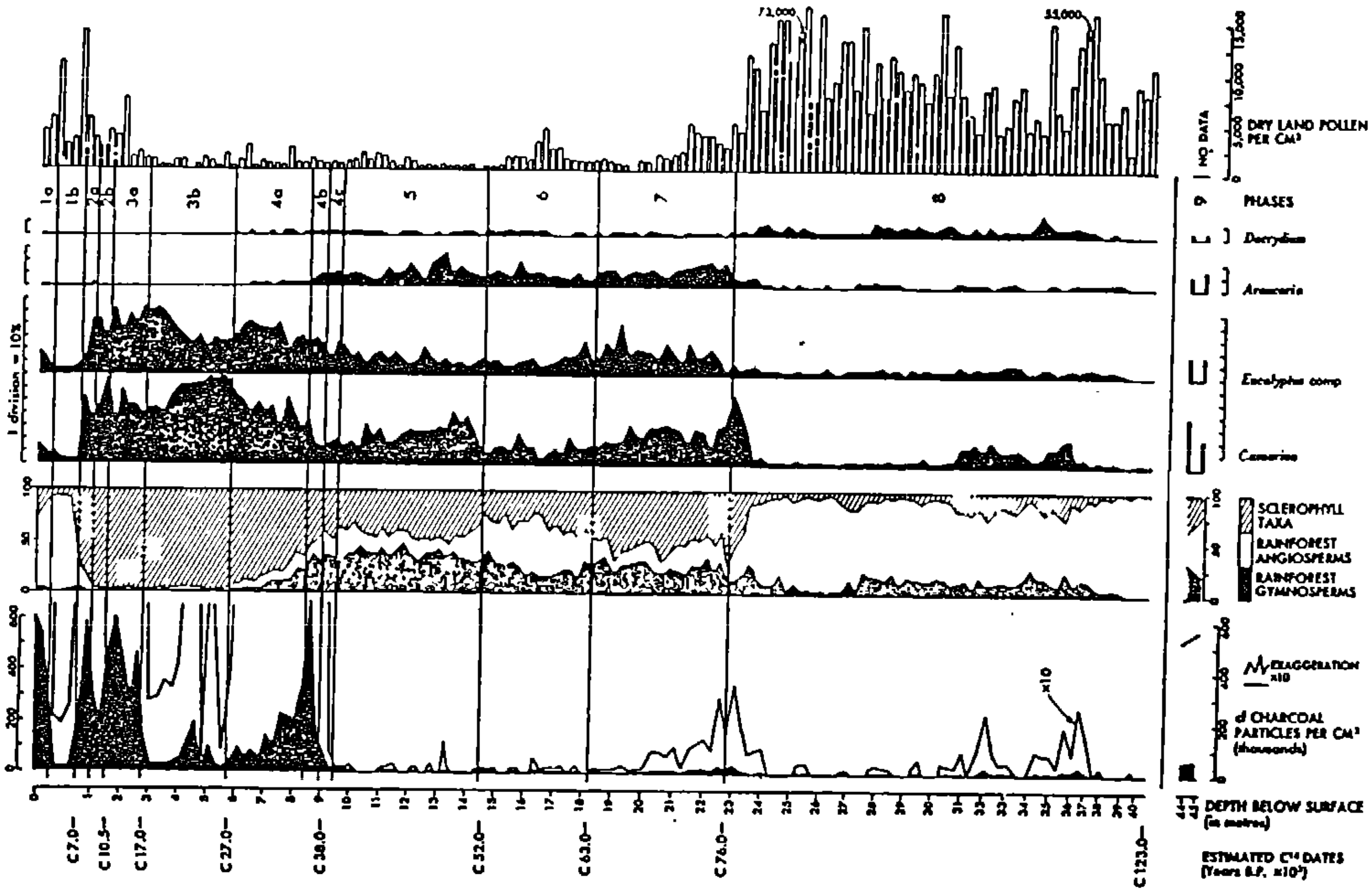

Figure 2. Summary pollen diagram from Lynch's Crater. Pollen values are expressed as percentages of total pollen of dry land plants. Charcoal estimates are shown as absolute numbers of particles per unit volume of sediment. (Based on Singh, Kershaw & Clark: figure 5).

2.2 Possibly Earlier Colonists and Firing

In the upstream portions of the drainage basins of the Greenough and the Murchison, yet earlier artefact-bearing deposits, highly weathered and silicified, lie beneath the pre-37000 "Red Alluvium" (Wyrwoll & Dortch 1978; Bordes **et al.** 1983; Jones 1979). It has been argued (Lofgen & Clark in an unpublished paper to the W.A. Anthropology Society, 1977) that the first onset of Pleistocene deposition may relate to occasional flash floods across an arid landscape at the onset of the last glacial episode, about 110,000 BP. Again it is possible to suggest that initial human presence, firing and destabilisation of vegetation triggered a new cycle of deposition (Hallam 1983). If so, movement through the open zones inland from the forested margin of the continent may have taken place during the last interglacial, about 130,000 to 120,000 BP, earlier than penetration of the heavily forested continental margins (cf. Horton 1982a). However a date of about 150,000 BP, at the maximum of the previous glaciation, has been suggested for man and megfauna under arid conditions in Mammoth Cave in the south-west (Archer, Crawford & Merrilees 1980).

From the other side of the continent comes evidence which more definitely suggests an unprecedented change brought about by human presence and humanly initiated firing in comparatively lightly wooded zones as early as the last interglacial, around 130,000 to 120,000 BP (Singh in Singh et al. 1981: 26-33; Singh 1982, 1984). From Lake George, in the Southern Tablelands of New South Wales around Canberra, Singh has investigated a pollen sequence which extends back many times further than the Lynch's Crater deposits (Fig. 3) - continuously back to before 350,000 BP (spanning four major glacial-interglacial alternations) and intermittently back to 700,000 BP. Here pollen counts showed open grassland vegetation during cold dry glacial conditions before 350,000 BP, and, at 300,000 BP, 200,000 BP and 75,000 BP; with open Casuarina woodland during the warmer damper interglacials (at about 350,000 BP and 250,000 BP). There was little trace of fire during the treeless glaciations, but moderate amounts of charcoal indicated some wildfires in interglacial woodlands. During the last interglacial however, from around 130,000 BP, the repeating pattern changed. Charcoal quantities were many times greater, indicating something like four-fold firing activity; and simultaneously fire-sensitive Casuarina woodland yielded place to eucalypts with a heavy component of grasses and chenopods. Open eucalypt woodland continued to dominate later interstadials, and the present interglacial. Fire activity continued virtually unabated through the interstadial around 40,000 BP, and on into the present interglacial. Overall charcoal quantities rise, but fluctuate wildly, perhaps indicating intermittent but relatively frequent fires, giving greater total charcoal than prehuman interglacials.

Thus Aborigines with firesticks, moving through the savannah belt between the forested margin and the arid centre, appear to have reached the open grasslands of the Murchison and Greenough on one side of the continent, and the cold Southern Tablelands on the other before the end of the last interglacial (around 120,000 BP). Abundant and heavily weathered engravings in the Pilbara, scattering of large stone artefacts in the northern wheatbelt, along the Avon valley, at Balladonia and in South Australia, including Kangaroo Island, may document an initial (but in the main undated) spread through open country (Hallam 1983). Penetration of the more difficult forested margins of the continent was much slower, and may not have become effective until some 80,000 years later. The open grasslands offered mainly seed resources and game, both improved and probably extended by burning to remove old dry clumps and allow new young growth. Forest resources, on the other hand, included plants with underground storage organs and aboveground vines, which have to be protected from fire. The ethnographic record shows that certainly recent Aborigines took care to preserve vine-thickets unburnt (e.g. Jones 1975; Hallam 1975; Hallam 1984); but by opening-up the surrounding areas they made possible movement and access to these important fixed "patch" resources, and also to the food sources of river, lake and swamp.

3. Criticisms and Discussion

3.1 Humans = High Charcoal or Humans = Low Charcoal?

There have been challenges (Nicholson 1981; Horton 1982a; Clark 1983) both to the interpretation of bio-geomorphic data as evidence for Aboriginal firing activity; and also to syntheses (e.g. Jones 1969 or Hallam 1975) based on ethnographic and historical evidence for the manner and role of firing at the time of European contact.

Robin Clark (1983) and David Horton (1982a) doubt the interpretation given to charcoal abundance at Lynch's Crater and Lake George. Clark obtained a pollen sequence from Kangaroo Island in which increased and fluctuating charcoal levels appeared to imply human absence rather than human presence (Clark in Singh, Kershaw & Clark 1981: 39-43; Clark 1983; Horton 1982a: 240). The inconsistency with Lynch's Crater and Lake George is only apparent. Both in Queensland (Lynch's Crater) and on the Tableland (Lake George) large quantities of charcoal correspond to initial human impact on vegetational communities adapted to a regime which did not include human firing, and at a time of climatic change which allowed more plentiful fuel (warmer and damper interglacial conditions allowing tree growth in the Southern Uplands; and moderate interglacial warmth, becoming drier, in Queensland). On Kangaroo Island there was also a change in a previous equilibrium, the eventual cessation of human

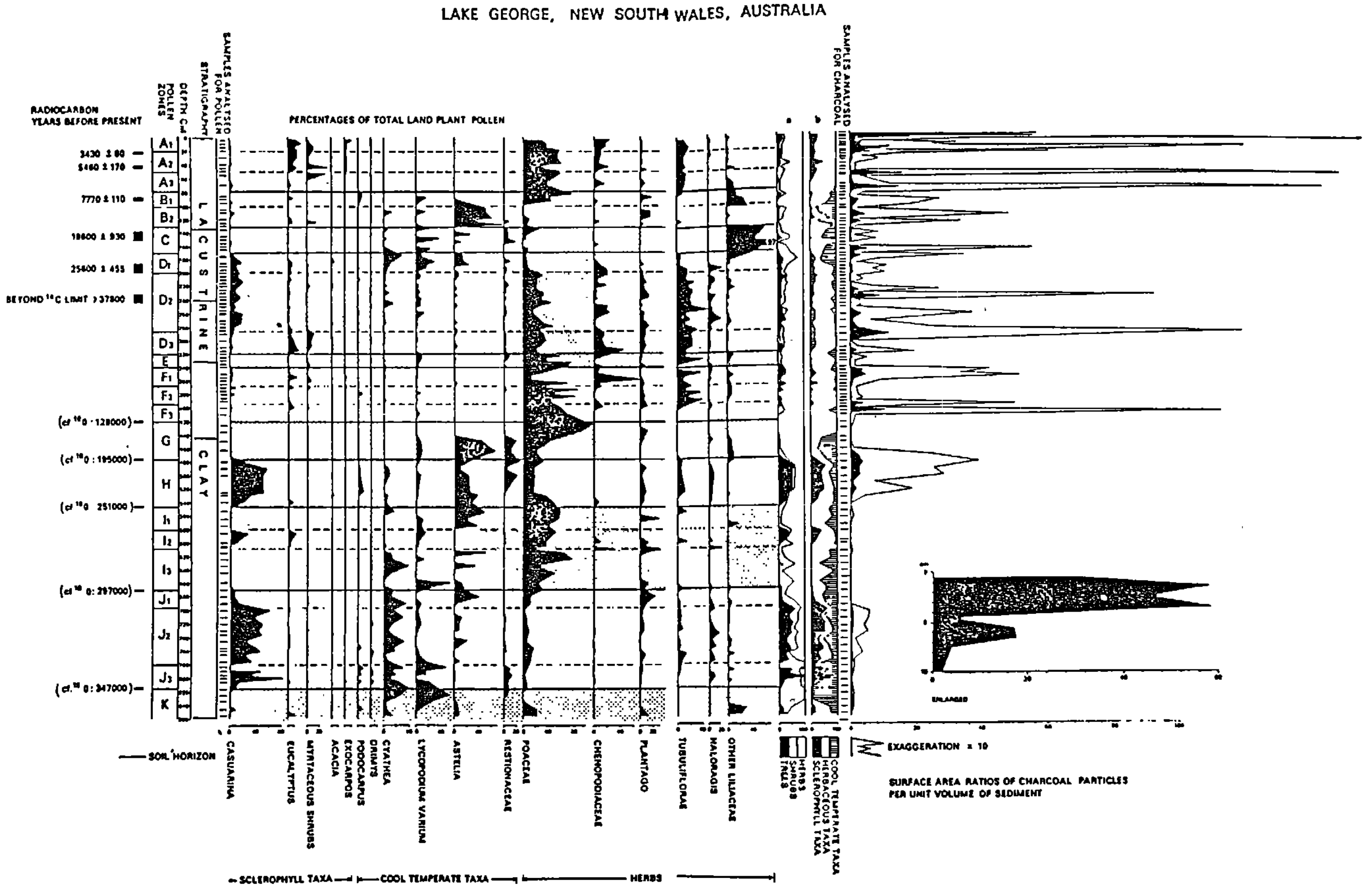

Figure 3. Summary pollen diagram from Lake George. Pollen and spore values are expressed as percentages of total pollen and spores of dry land plants. Charcoal values are expressed as surface area ratios of all visible charcoal particles per unit of sediment. The cf. ^{18}O dates beyond ^{14}C dating limit in the pollen diagram have been based on the ocean palaeotemperature sequence of Shackleton and Opdyke (1973). The stippled zones represent cool-cold periods. Some fossil pollen of Chenopod-

occupation on the island, now cut off from the mainland, allowing unchecked scrub development and fuel buildup. Infrequent fierce natural fires, replacing the frequent mild grassland fires characteristic of Aboriginal management, would give greater charcoal concentrations.

Similarly in the south-west of Western Australia, Churchill's (1968) swamp pollen records showed intense burning mainly early in the sequence (at Weld Swamp from about 7000 BP, with a devastating fire at 3500 BP; at Scott River Swamp approximately 4000 BP) as Aboriginal groups first penetrated the forest from the coast, which now lay near. Similarly devastating burning affected Karri forest near the coast at Denmark before it was engulfed in advancing sanddunes around 7000 BP (Bermingham etc. 1971). Later sustained burning gave lighter charcoal densities, indicating low intensity fires rather than devastating inflagrations. It was initial human impact, not continued presence, which produced high charcoal.

Horton is worried because he expects a simple formula applicable to all ecological zones at all stages in their development. Either the formula must be "high charcoal = human presence" or it must be "low charcoal = human presence" (Horton 1982: 241). He feels uncomfortable because pollen analysts do not and will not tie themselves to any such simple blanket proposition. The trouble is that real situations are much more complex, as Lewis has shown brilliantly both in Canada and in the Northern Territory (Lewis 1980, 1982, n.d. in press). It may be true that "initial human advent in a fuel rich situation = high charcoal". But continued human impact may reduce the scrub component, litter buildup, and therefore charcoal levels; or intermittent further impact may continue to yield high charcoal. The nature of the vegetation (rainforest, sclerophyll, grassland), climatic fluctuation, frequency of visitation, frequency and seasonality of firing all affect the outcome in measurable charcoal. Diversity of patterns of firing and fire reaction, through space and time are demonstrable ethnographically and must be expected in the pollen record.

3.2 Critics and Advocates of Aboriginal Firing

The importance of Aboriginal burning to Australian ecosystems has been played down by Nicholson (1981) and by Horton (1982a). Horton puts this rejection in its most extreme form - "Aboriginal use of fire had little impact on the environment ... "fire-stick farming" would have been counter-productive ... because of the adverse effects ... upon small species of animals".

Horton sees Jones' (1969) notion of "fire-stick farming" as concerned with "short-term management of rate of production and long-term increases in the area of production" - ignoring the overall effects stressed by Hallam and by Lewis - production of a mosaic of resources; and opening-up of once heavily vegetated areas to penetration and access to resource zones (Hallam 1975: 46-48, 64-65; 1984; Lewis 1980, 1982 n.d. in press). To a certain extent Horton's criticisms are a sort of "shadow-boxing" - demolition of ideas and concepts not actually put forward by the writers he cites, a synthetic "Tindale - Jones - Hallam hypothesis" which neither Tindale nor Jones nor Hallam has ever advocated.

Tindale's 1959 propositions contained the germ of the ideas later expounded simultaneously and independently in 1968 by the archaeologist Jones on the one hand and the palaeontologist Merrilees on the other (Jones 1968; Merrilees 1968). Jones' (1968) accounts of firing were secondary to his general theme - the process of colonisation. For Merrilees also exposition of the effects of fire was incidental to his main thesis - the depletion of faunal diversity in the late Pleistocene, which he argued resulted from human impact. The mechanisms he envisaged were not so much direct, through predation, as indirect, through firing. Merrilees sees firing as causing environmental degradation, rather than amelioration, in the long term. It was Jones (1969) who stressed the positive effects of firing, both immediately and overall. Similarly Hallam focussed on the complex way in which firing tied into total patterns of Aboriginal landholding, subsistence, scheduling, social and symbolic life, rather than on its narrowly ecological effects; she did not set out to explore firing in isolation.

3.3 Nineteenth Century Observation of the Effects of Firing

The topic had, however, been discussed long before Merrilees, Jones, Hallam or even Tindale.

Tindale drew on knowledge common among ecologically-oriented field scientists, farmers, pastoralists and observers of Aboriginal life throughout the nineteenth century. Howitt had in 1890 commented percipiently on "wide-spread ... reforesting ... since the time when the white man appeared in Gippsland, and dispossessed the Aboriginal occupiers, to whom we owe more than is generally surmised for having unintentionally prepared it, by their annual burnings, for our occupation" (Howitt 1890, III). "These annual bush fires" he deduced "tended to keep the forests open and to prevent the open country from being overgrown" (ibid. 109).

Neither Jones nor Hallam has originated the idea that Europeans took up lands initially cleared by Aborigines. Though they reached this conclusion independently each owed much to nineteenth century European colonists who specifically stated that land clearance would have been virtually impossible if it had not already been undertaken by the Aborigines (e.g. Byrne 1848, II: 321; Bunbury 1930: 105; Bussell 1833a, 1833b; quoted Hallam 1975: 47, 76). Bunbury, for instance, said that "by these [Aboriginal] fires the country is kept comparatively free from underwood and other obstructions, having the character of an open forest through most parts of which one can ride freely; otherwise ... it would soon become impenetrably thick" (ibid. 105).

3.4 Mosaic Firing

Another of Horton's worries is the variety of animal responses to firing. Once the mosaic nature of patch-fired vegetation belts is understood, this is no problem. One of the effects of firing, whether in boreal, Mediterranean or tropical latitudes, (Lewis, in press) has been to attract game to restricted fired areas, often along streams, lakesides or around swamps or soaks (Hallam 1975, 75) effectively "yarding" large game for their hunter-herdsman (cf. Mellars 1976). Horton himself cites one striking instance of the effects of high protein plant regrowth after fire on kangaroo condition, breeding and hence numbers (Horton 1982a: 241). While recently burnt areas within forest offer larger macropods in numbers, other patches burnt more or less recently and more or less frequently (more frequently where more frequented - Hallam 1975: 46) will offer a mosaic of different conditions to other flora and fauna. Horton's notion of massive destruction of small species is based on an image generated by post-European fires - fierce, extensive and destructive, and very different from any of the varied patterns of controlled fires, all smaller and less intense, practised by their Aboriginal predecessors. Horton's listing of shelter requirements simply underlines the point that, as with quokkas on Rottnest (Hallam 1975: 49; Pen & Green 1983) most species will thrive best where a close mosaic of open and dense patches offers both suitable shelter and suitable forage on closely adjacent patches (see also Burbidge, this symposium). Horton's own data (1982a: 241-3) underline the point that patchy burning, providing a mosaic of shelter and forage, is advantageous to most species, not disadvantageous as he seems to imagine.*

4. The Ethnographic Evidence

4.1 Controlled Firing

No student of Aboriginal firing has ever maintained that it was applied simultaneously and non-selectively over wide areas. Always certain nodes and zones would be kept regularly burned, while to other areas fire penetrated only infrequently. This is the distinction which the south-west Aborigines made between "Mundak - the bush; the wild country, the woods" and "Nappal - burned ground; ground over which fire has passed. Over this ground the natives prefer walking; it is free from all scrub and grass and their progress is not therefore obstructed ..." This could go through various stages from "Kundyl - young grass springing after the country has been burned ..." to "Narrik - unburned ground, but ready for burning. Land of which the vegetation is abundant and dry, fit to be set on fire ..." (Moore 1884b, quoted in Hallam 1975: 37, 38, 40). And even within the burnt areas, certain patches would remain unburnt, partly as an inevitable result of low-intensity firing, partly kept deliberately to preserve certain plant and animal resources, for instance thickets containing "warran holes" (diggings for yams) on the alluvial terraces of the Swan (Hallam 1975: 50; 1984) or vine-thickets in Arnhem Land (Jones 1975).

Deliberate control of areas burnt is characteristic of forager-hunter burning worldwide, as Lewis has demonstrated (Lewis 1980, 1982). It might be achieved in various ways - by choosing stage of the season for burning, so that, for example, only the drier portions of a swamp-margin would burn (Nind spoke of "burning in consecutive portions" - Nind 1831); choosing stage of vegetational succession, so that fuel was not too heavy; choosing wind-direction in relation to natural firebreaks or already burnt areas; choosing time of day, weather, etc., and even actually beating out a fire if necessary. In 1840, just north of Albany, Stokes and a party from the Beagle "met a party of natives engaged in burning the bush, which they do in sections every year... Those armed with large green boughs, with which if it moves in a wrong direction, they beat it out untrue that "late succession species could not survive a regular programme of control burning" (Horton 1982, 243) - if it were indeed control burning.

Horton assumes that great numbers of Aboriginal fires as compared with lightning fires would necessarly mean that any and every patch of ground was burnt over thousands of times as often as under a pre-human regime. Jones cites an increase in frequency of fire within a band territory by a factor of tens of thousands (Jones 1975: 76; Horton 1982: 243) - but such fires might cover only a small fraction of the area of an uncontrolled fire. To calculate even an average figure for frequency at any one spot we would need data on extent of prehuman and human fires, as well as numbers. And where each firing is closely tailored to specific circumstances averages are meaningless.

4.2 Marginal Times and Places

Horton also argues that climatic zones affect burning patterns. This is quite obviously so, and is either implicit or explicit in all accounts of burning. No-one has ever argued for homogenous Aboriginal burning regimes right across the continent.

Even within the land of one group diversity of burning patterns is the theme, tuned to soil, resources, circumstance, individual property rights (e.g. Hallam 1975: 42), and even social roles (see for instance Hallam 1975: 33, on men's burning and women's burning, in scrub and grassland, on a large scale or a small, harvesting big game or small fry).

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* e.g. Horton cites Christensen & Kimber's (1975) work which showed high numbers of Setonix in the first few years after fire in a south-west forest, but says they were "only feeding and not resident". But after 10 years vegetation was too dense! Clearly patchy firing at intervals of less than 10 years would maintain maximum numbers. Similarly Lagorchestes in spinifex needs both old clumps for shelter and new clumps for forage - a combination firing will provide.

Of course, as Horton states, there are limits to what burning can achieve. But that does not imply no burning. Aboriginal groups thrived on the game resources of the open upland tundra of western Tasmania when glaciers still topped Frenchman's Peak and Cradle Mountain (Kiernan etc. 1983). And even firing could not hold back the tide of trees which eventually submerged western Tasmanian rainforest as warmer conditions prevailed in the final Pleistocene and post-Pleistocene. But this does not mean that there were no attempts to do just that. Rainforest began to move in from the south coast about 17,000 BP, but this was a temporary development and by about 15,000 BP fire-sensitive rainforest had given place to fire-resistant sedgeland with Gramineae, Compositae and chenopods. Ooze Lake in south-west Tasmania showed this change in the pollen record in levels which also gave very high charcoal values indicating frequent and intense fires (McPhail & Colhoun 1985). However, as the climate became not only warmer but wetter after 13,000 BP fire proved in the long run ineffective in preventing the spread of temperate rainforest and wet sclerophyll, although "corridors" of sedgeland were maintained through the forest (if also the north-west (Jones 1975; Lourandos 1983)).

Fire, then, could be most effective in marginal places - near the margin of the tropical rainforest (as at Lynch's Crater); or the eastern margin of the jarrah forest*, as in Western Australian ethnohistorical sources (Hallam 1975: 63-4); in creating sclerophyll woodland in north-west Tasmania (Jones 1968). Firing could not and did not bring about major change in the core of the Queensland rainforest, the heart of the karri, the depths of the wet Tasmanian south-west as they were at contact. It could and did create "clear patches" on the Bunya Mountains; grassland corridor along valleys through the jarrah (e.g. the Chittering Valley or the Wooroloo Brook); or maintain sedgeland corridors from the Cradle Mountain uplands to the coast in Tasmania (Jones 1975; Lourandos 1983). Fire was also most effective at marginal times - in maintaining open country over south-west Tasmania during that initial four thousand years while cold and arid gave place to warm and less arid and then to warm and wet climatic conditions; or in the southern uplands (Lake George) at the onset of the last and present interglacial, as trees began to move across open uplands; and also during the intermediate conditions of the interstadials, rather than the treeless phase at the glacial maximum; during interstadial conditions in the Queensland rainforest - neither as cold as at glacial maxima nor as warm as in the present interglacial.

4.3 Aboriginal Firing or Natural Burning

But it is also true that Aboriginal firing was pursued not only in areas which most easily carried natural fires, but also in those which did not. Certainly ridges and spurs carry fires more easily than valley bottoms (though some topographies give a "funnel" effect); and one valley slope may burn more easily than the other. But these are exactly the sort of topographic particularities which Aboriginal groups use in planning fire tactics, as Lewis (n.d.) has demonstrated in the Arnhem Land.

Lewis has also shown that swamp margins are progressively burnt as soon as they will stand a fire. Swamp-burning was regularly practised in south-western Australia. Grey said of reeds (Typha) that "The natives must be admitted to bestow a sort of cultivation upon this root as they frequently burn the leaves of the plant in dry seasons, in order to improve it" (Grey 1841, II: 294; Hallam 1975: 14). Burning along valley bottoms remained Aboriginal practice in the south-west into the early years of the present century, when the approach of Aboriginal groups to Nannup would be heralded by the smoke of their firing coming up corridors through the jarrah forest from the valley of the Donnelly, along its tributary the Barlee Brook, and down the Carlotta Brook to the flats along the Blackwood River, kept open by burning both by Aborigines and by early European settlers (information from Mervyn Roberts who farmed on the Blackwood River until 1914; c.f. also Bussell 1833a: 184-5; Hallam 1975: 27, 54).

Repeatedly in the savannah woodland belt, from Esperance to Kojonup to the Victoria Plains, it was the surrounds of soaks and watering-holes which were burnt (Hallam 1975: 74). Similar patterns prevailed in eastern woodlands - "The natives seem to have burnt the grass systematically along every watercourse and around every waterhole in order to have them surrounded with young grass as soon as the rain sets in ... Long strips of lately burnt grass are frequently observed, extending for many miles along the creeks. The banks of small isolated waterholes in the forest were equally attended to ..." These were not natural patterns of fire occurrence, but purposeful - "it is no doubt connected with the systematic management of their runs, to attract game to particular spots" (Leichhardt 1847: 354; Hallam 1975: 75). In the Aboriginal economy these effects were certainly not "miniscule" (Horton 1984: 244).

Horton (1982: 244) is of course quite right that "fire behaviour can create seemingly anomalous vegetation distributions without man's intervention". But it is also true that fire can create seemingly anomalous distributions through man's intervention - and there are plenty of instances where that has been seen to happen. Horton's statement is correct. But the implication that it follows that Aborigines did not affect vegetation is a "non sequitur" and patently untrue.

Horton's statement that Aboriginal burning is documented only where numbers of thunderdays per year are low is wrong. Jones (1975) and Lewis (n.d. & in press) provide ample documentation of Aboriginal burning in Arnhem Land, and it is also well known from Kimberley and Cape York, all subject to monsoon thunderstorms; also in south-western forest areas (not just fringes and not just semi-arid WA). Again, of course there

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* Landor (1847: 249-259) encountered large groups of Aborigines driving "thousands of kangaroos" in this general zone, near Beverley.

are and always have been some fires caused by lightning. But the present figures are probably absolutely, and certainly proportionally, higher because of the absence of Aboriginal burning. They tell us nothing about pre-European practices. It is difficult to see what is the relevance of the high proportion of fires now caused by lightning in Victoria, for no-one imagines that there can now be a high proportion due to Aboriginal burning in Victoria.

Horton avers that ethnohistorical sources tell us little more than that fires occurred. I can only conclude that he has not read the quotations from these sources in Hallam (1975), in Jones (1969, 1975) or in Lewis (n.d.). We have for several different regions detailed descriptions of the timing of firing, its frequency and effects; its place in the system of landholding, land management and responsibility for land maintenance; and the complex ecological knowledge and vocabulary of aboriginal land managers.

4.4 Extent, Frequency and Nature of Fires

Horton (1975: 246) dismisses the notion of "mosaic-burning" by Aborigines as a myth, and avers, again quite rightly, that "all fires are mosaic fires". Just so, but how big is the cell-size of the mosaic? If an area is fired earlier in the season than the time of maximum combustibility; or fewer years apart than lightning strike - litter will be less heavy, and fires less intense and less extensive, even discounting Aboriginal practices in setting fires to be limited by a natural barrier or previously fired area.

Overall, Horton's argument is not against the occurrence of Aboriginal burning. We find, somewhat as an anticlimax, he eventually allows this did and does happen. Rather he argues against a particular construct which he calls the "fire-stick farming model", which appears to be a creation of his own, for it is certainly not put forward by the authors he cites. One "demand" (Horton 1982: 247) of this "model" is that areas be fired at a fixed high rate - he cites three-year intervals (Hallam) or one-year intervals (Jones) or 5000 bushfires per year over 30 km square (also Jones) which he sees as an "un-imaginably high rate". 5000 fires over 30 km x 30 km, i.e. 900 km^2 , is not much more than 5 fires to one square km, so that if burns averaged a couple of hectares in extent Jones' second figure also implies an average firing rate of once a year, some areas being burnt two or even three times (as Lewis also has observed), some only every few years.

Quibbles apart, no-one except Horton, has ever tried to twist either the ethnographic or the historic material to mean that Aboriginal firing occurred at an even rate irrespective of soil or ecological zones; and certainly no-one has for one moment suggested that it was applied evenly over the broad concentric ecological zones of the Australian continent.

Far from implying an even rate, all the evidence, and all the deductions from it by Hallam and Jones and Lewis, stress the diversity and adaptability of firing patterns (e.g. Hallam 1975: 52-55, 63, 74-5). In general open country carried more frequent (but less intense) fires than forest or scrub; so that concentric climatic belts affected firing patterns and frequency. Again, in general, firing was a function of productivity and population, and thus of soil types. This might work in the contrary direction. The poor upland laterites of the Darling Plateau supported fewer resources, people or fires than the laterite-free soils of the Avon valley to the east, or the well-watered coastal plain to the west, with its estuaries, lakes and swamps and river alluvium rich in fish and fowl; crustaceans, frogs and turtles; reed rhizomes, yams and large game. George Fletcher Moore linked burning activities to carrying capacity - "over the hills grants ... are less burned being less frequented" than on the coastal plain (Moore 1884a: 219; Hallam 1975: 37, 121).

But productivity, while partly a function of climate and soil, was also a function of past history. The west coastal plain piedmont alluvium (along the Swan, Helena, Canning, Serpentine, Dandalup, Murray, and around Geographe Bay) comprised rich well-watered soils capable of carrying heavy timber, but now parklike. Bunbury described the Pinjarra Plain in 1836 as "fine open country studded with groups of large trees ...", "an extensive plain with scattered clumps of very large straight gum trees" (Bunbury 1930: 168, 65; Hallam 1975: 59-60). Landor cantered "to the neighbourhood of the Canning River. The country hereabouts resembles a wild English park. The trees are all of the eucalypti species, large and dispersed; the surface of the ground is level, affording a view of the Darling Hills" (Landor 1847: 157-8; Hallam 1975: 59). On the alluvium of the Swan "The whole country of the middle and upper Swan resembles a vast English park" (Landor 1847: 19 ; Hallam 1975: 597). Irwin built his house at upper Swan of "mahogany (jarrah) cut down on the estate" (Hallam 1975: 57), and Chauncy in his 1843 map showed "open level country. Thinly wooded with Red Gums" (ibid. 58). This resembles a parkland with clumps of oak which Lewis (in press) reports as a product of firing in Oregon.

If the state of the Western Australian coastal plain were dependent on climatic zonation it would have remained heavily forested, with thick underbush. Further south the tuart forest between Bunbury and Busselton has been overgrown by peppermint scrub since burning ceased. The openness of parts of the coastal plain at European contact was not consonant with the vegetational and firing zonation to be expected on the basis of climatic zonation. Its openness was not a function of aridity or humidity, but of population; not of precipitation, but of resources.

These parklike landscapes show that Horton is wrong to suppose that fired vegetation can comprise only seral stages of a few years growth. Large trees, once established, would be relatively unharmed by frequent light fires across herbaceous vegetation between them. Their initial establishment may depend on the randomness of gaps in the fire mosaic; or on deliberate protection, such as was afforded certainly to concentrations of yam-vines (Hallam 1975: 58; 1984). Parklike landscapes are the product of Aboriginal penetration and impact on heavily vegetated landscapes over many generations.

5. Conclusion

Horton (1982a, 1982b) seems to deny the importance of Aboriginal burning because it does not accord with his mental template of "farming". Let us not be led astray by Jones' colorful phrase "fire-stick" farming. We are looking at flexible, productive and knowledgable systems of land management, in which the use of fire was an important element. The main elements were:- (1) Opening-up of landscape to easy movement and access to resources. (2) Prevention of accumulation of old non-nutritious growth, "cleaning-up" to avoid the risk of intense destructive fires. (3) Encouraging new protein-rich nutritious growth, and hence a concentration of animal resources. (4) The use of fire to drive large game (e.g. Landor 1847: 249-59; Nind 1831: 28; Hallam 1975: 64); or on a smaller scale to catch snakes and lizards (Nind 1831: 28, 36-7; Hallam 1975: 32). (5) Maintenance of a close mosaic of areas with different fire-regimes and at different seral stages - frequently burned open valleys running through less frequently burned forest, in which some areas are frequently, others infrequently, reached by fire; some recently, others less recently. This fine-grain mosaic is particularly important to maintaining a range of animal species, with different forage and shelter requirements. (6) Usage rights and responsibilities for the management of land tracts and resources was vested in particular groups and individuals, and this included firing rights and responsibilities. In Salvado's words "each family regards one particular district as belonging exclusively to itself, though the use of it is freely shared by nearby friendly families". "Every individual has his own territory for hunting, gathering gum, and picking up yams" (Salvado 1851 in Storman 1977: 130-131). (7) Frequency and seasonality of firing were adjusted to the potentialities of an area, the objectives and the seasonal schedule of subsistence activities e.g. at King George Sound burning could be carried out on a small scale in grassland by the women to get snakes and lizards; or on a large scale by great gatherings to carry out kangaroo drives (Hallam 1975: 29-33). (8) Firing in myth and ceremony. In the Jeramungup area great fire drives followed assemblages of different groups for fire rituals. The general importance of fire in myth and ritual mirrored its ecological importance; and the ceremonial round interlocked with seasonal subsistence and firing schedules (Hallam 1975). (9) Finally, firing knowledge was very much part of the cognitive patterns of Aboriginal groups, tied in to their knowledge of ceremonies and seasons, the ritual and ecological potentialities of particular places and times. From the word "Kalla - fire" is derived, the word "Kallip - denoting a knowledge of localities; familiar acquaintance with a range of country ... also used to express property in land" (Moore 1884b: 39; Hallam 1975: 43).

Fire was an intimate and essential component of Aboriginal ritual "law" and ecological lore. It has been so for at least the 50,000 years of their presence in this continent, and perhaps for 150,000 years. Over that time Aborigines have fired at different places, different seasons, with different frequency, extent and control from lightning fires; and in so doing created vegetation distributions and total landscapes very different from any which existed before their advent.

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BURNING THE "TOP END": KANGAROOS AND CATTLE

Henry T. Lewis

> Fire, grass, kangaroos, and human inhabitants seem all dependent on each other for existence in Australia; for any one of these being wanting, the others could no longer continue. Fire is necessary to burn the grass, and from those open forests, in which we find the large forest-kangaroo; the native applied that fire to the grass at certain seasons, in order that a young green crop may subsequently spring up, and so attract and enable him to kill or take the kangaroo with nets. In summer, the burning of long grass also discloses vermin, birds' nests, etc., on which the females and children, who chiefly burn the grass, feed. But for this simple process, the Australian woods had probably contained as thick a jungle as those of New Zealand or America, instead of the open forests in which the white men now find grass for their cattle, to the exclusion of the kangaroo....(Major Thomas J. Mitchell, 1848, Journal of an Expedition into the Interior of Tropical Australia).

Introduction

Across much of the northern half of Australia two "groups" employ technologies of fire, technological practices that are deceptively simple to use but which require sophisticated understandings of natural systems in order for them to be adaptive over time. Prescribed burning is applied in a variety of environmental zones and, within them, a range of habitat types as an important feature, a "tool", of both hunting-gathering and pastoral adaptations. Despite significant mechanical changes in making and setting fires - from the use of fire drills to butane lighters, and from cowboys throwing matches from horseback to dropping chemical incendiaries out of airplanes - the requisite understandings of how particular fires can behave at given times in a range of habitats, how they can be controlled and limited in intensity and extent, how it is possible to predict immediate short-term benefits, and how to judge long-term environmental consequences are the subject matter of these two "folk sciences" and the still relatively new field of fire ecology.

Environmental indications are reasonably clear that since the arrival of Aborigines in Australia more than 30,000 years ago, fires have been used to influence communities of plants and animals. Though the prehistoric evidence on indigenous uses of fire is indeterminate and limited to inference (cf. Singh et al. 1981; Clark 1981; Horton 1982), historical references are quite clear. Two interpretative studies, both based on historical descriptions of Aboriginal uses of fire in Western Australia, provide excellent evidence of habitat management by prescribed burning at the time of European contact and settlement (Hallam 1975, 1985).

Much more detailed information on indigenous burning technologies is found in a number of studies that outline contemporary Aboriginal adaptations in remote areas where habitat burning is still employed to affect the distribution and relative abundance of preferred plants and animals (Haynes 1983; Jones 1980; Kimber 1983). This combination of historic and ethnographic accounts does add strength to the hypothetical arguments that Aboriginal burning practices were significant in prehistoric times.

Though we can do little more than speculate on the background of fire as it has been used by Euro-Australians, throughout the history of Australia cattle and sheep pastoralists set fires to influence the development of pasturelands. It is also the case that pastoralists were frequently in a position to observe the effects of Aboriginal burning and, in north and central Australia, large numbers of Aborigines were employed as cowboys.

For stockmen in northern and central Australia fire remains their most important management tool, for without the prescribed use of fire the understorey grasses of both closed and open forests, as well as most of the forage in more arid regions, have little pastoral value. On a very large scale, pastoralists employ fires to induce a more uniform growth of grasses and, on a much more limited basis, to convert local paddocks to the growth of introduced grasses and legumes. As Johnson and Purdie (1981) have summarised from various sources, the use of fire in combination with heavy grazing ultimately results in the reduction of weedy or undesirable species and an increased dominance of grasses over trees and shrubs.

In northern Australia as elsewhere the burning practices of both stockmen and hunter-gatherers are heavily influenced, though not specifically determined, by annual climatic events. Natural fires (i.e. lightning fires) normally occur at the end of the dry season, about mid-December, with the build-up of cumulus clouds which herald the onset of the wet season. Thunder storms, sometimes accompanied by rain, but more often not, precede the monsoon rains that persist until early or even late April, with an annual rainfall of 1200-1500 mm. Except for the occasional brief dry periods that can occur in January and February, burning is all but impossible during the "wet". From mid-April to mid-May intense storms, sometimes cyclones, occur and the two-metre high stands of Sorghum (Sorghum intrans), Spear Grass (Heteropogon triticeus), and other subtropical species are knocked down at that time. Humidity remains high until early or mid-May and it is at this time that burning is begun by both pastoralists and foragers. The dry season is initially marked by cooler and drier weather, which becomes increasingly hot by mid-August, and the "dry" persists until the return of the monsoon rains in December.

The following discussion of pastoral burning practices is based upon a general consensus of the practices used and described to me by eighteen stockmen and former stockmen (including station owners, head stockmen and cowboys) interviewed during 1983 in an area that extended east to the Arnhemland border, west to the Ord River, south to Wave Hill, and east again to an area south of Katherine. Variations in burning practices reported by informants largely concern environmental differences between coastal plains, interior eucalypt woodlands, and the open country still further inland. Most of the individuals involved (15 of the 18) were over 65 years of age. Four of them were Aborigines who were equally aware of the different aims and practices of stockmen and hunter-gatherer burning.[1] All of the informants were either born and raised in the north or had spent most of their working lives there.

For reasons suggested below, Euro-Australian pastoralists did not understand the overall logic of hunter-gatherer burning practices, though most acknowledge that Aborigines did set fires for particular reasons, the most common being to "hunt roos", "clear off the snakes", or "make it easier to travel about the country". However, even the most sympathetic of Euro-Australians understand very little about the local logic of indigenous practices and the overwhelming majority consider Aboriginal burning to be in keeping with other "primitive" aspects of traditional Aboriginal life.

The outline of hunting-gathering burning practices is largely based upon the work (1982, 1983) and personal collaboration of C.D. Haynes plus my own observations and interviews with Aborigines in Kakadu National Park during two months in 1980 and four months in 1983. For those Aborigines in "outback" areas, where hunting and gathering still constitute important components of subsistence activities, the use of habitat fires remains an integral and significant feature of subsistence technology.[2] Whereas rifles have largely replaced spears and boomerangs, while matches and butane lighters have supplanted fire sticks, and the movement from area to area is now in four-wheel drive vehicles rather than on foot, many aspects of traditional hunting and gathering are still found as important features of Aboriginal life in more or less remote areas. Within and as an integral part of these practices fire continues to be a significant technological feature of bush life. It is through the uses of selected burning that these populations of "part-time" hunter-gatherers still make a pronounced impact on local environments and they do so in ways that are not fundamentally different from what was done in the historical past. The ability to create and apply fire to local habitats has meant that Aborigines, in ways similar to foragers in other parts of the world (Lewis 1982a), have been able to use burning as an environmentally limiting factor by altering the seasonality, frequency, intensity and distribution of fires over the Australian landscape for thousands of years.

Though we can never actually measure or do more than roughly estimate the impact of hunter-gatherer uses of fire in the prehistoric or historic past, to ignore the potential that Aborigines would have had for influencing local resources and, ultimately, the overall environment is simply naive. For reasons that I have discussed elsewhere (Lewis 1972, 1982b), this important feature of hunting-gathering adaptations has been largely ignored by anthropologists when reconstructing human prehistory. Given our understanding of Aboriginal burning technologies and our growing appreciation of the multiple effects of fire, it is difficult to imagine that some 300,000 to 500,000 nomadic foragers would have made an impact any less significant than what it was and is now made by a smaller number of pastoralists.

Hunter-Gatherer Fires in Northern Australia

If asked why they burn, Aboriginal answers can vary considerably from area to area, and from one micro-habitat to another: improving the relative abundance of preferred plants, altering or maintaining the habitats of animals, cleaning a campsite to rid it of insects and snakes, encircling game during a hunt, reducing accumulations of fuel, establishing fire guards around patches of rainforest, and even for the sheer joy that marks the beginning of the dry season. Yet, even the broadest inventory of reasons for burning only touches upon a people's more comprehensive knowledge of the effects and counter-effects of using fire.

Behind the reasons for why fires are set, Aborigines have a theory of what is involved. That is, they know how, when and where to use (and not use) fires, and they also understand what the range of effects will be over space and time. They perceive and then attempt to control events in a coherent way, but their answers as to why they set this or that fire reveal nothing about their wider understanding of how fire functions in particular settings or in the overall environmental mosaic of managed habitats.

Inland from the coastal fringes of sand dunes and mangrove forests the coastal region between Darwin in the west and Gove Peninsula on the eastern tip of Arnhemland is covered by eucalypt dominated open forests (about 30%) and woodlands (about 40%). The trees of the open forest, of which Stringybark (Eucalyptus tetrodonta) and Woollybutt (E. miniata) are the most common, are taller (15-19 m), with a patchy understorey of shrubs, palms and grasses. Woodlands, which are found on poorer, more shallow soils, are composed of smaller trees (10-12 m), especially Boxwood (E. tectifica) and Bloodwood (E. latifolia), more widely dispersed, and with a greater uniformity of understorey grasses. In both kinds of habitat open spaces are dominated by sorghum grasses (1-2 m), which in the dry season are highly flammable and which, when mature, are a poor source of nutrients for either game or domestic animals.

The remaining areas are composed of freshwater floodplains, paperbark swamps, and isolated stands of rainforest. Inland the coastal plain is bordered by a sandstone escarpment of vertical and stepped cliffs. All of these biological zones are exploited to varying degrees; all are fire managed in distinctive ways. The way that particular areas are burned depends upon their value, accessibility, and the characteristics of the overall community of plants and animals at any given time.

A number of seasonal calendars have been produced by researchers for Aborigines of the north coast. For example, the calendar for the South Alligator River area, represented by the Gundjeidmi language, has six major seasons (Fig. 1). Whereas it can be roughly aligned with the Gregorian calendar, specific parts of a given year are derived from climatic and biological events and not merely the passage of days and weeks. It is the combinations of seasonally based incidents (e.g. the swarming of dragonflies, the final storms of the year, the blooming of various fruit trees, etc.) that indicate seasonal changes for the setting of fires in particular habitats. Like any other hunting-gathering activity, setting a fire is triggered by natural conditions and not mechanical demarcations of time.

Though largely restricted to the dry months, a few fires may be set during short breaks (**gularr gaimigo**, or "fine hot spells") in the monsoon season, the **gudjewg** (approx. February). These are usually limited to clearing local campsites and settlement areas, with ground cover being a problem at this time of year when snakes move to high ground, a concern for people living in an area which has the world's five most venomous species, the most common being the Deaf (or Death) Adder, Taipan, and King Brown.

The first dry season fires are lit after the monsoon rains have stopped but before the last convective storms have passed - the **banggereng** (approx. April) or "knock'em down storms" in which the sorghum grasses are levelled. This burning starts along the margins of the floodplains where water levels have dropped and the exposed grasses and sedges are dried before those in other habitats. In addition to the animals that will be drawn to the new "green pick" when it emerges, adjacent stands of rainforest and paperbark swamps are fire guarded against the larger and hotter fires that are set a few weeks later on the floodplains and in adjacent stands of tall forest and woodland.

At the very start of the dry season floodplain fires burn only a few square metres and for a brief time before going out. As water levels recede and fuels progressively dry, larger and larger areas are consumed. Thus, floodplain fires are set in stages, weeks apart, and burn from the previously burned strips towards the wetter, lower lying areas where they simply go out as they reach the damper green growth. As a consequence, the central parts of a floodplain can be safely fired as late as mid-November, months after burning was initiated on the margins. With a fire induced production of green pick, the larger macropods (specifically the Antilopine Kangaroo and the Agile Wallaby) will frequent these sites well into the dry season. In some instances, where continued soil moisture allows for a complete recovery of grasses, portions of the floodplain will be fired a second time in the same season.

Waterfowl are an important floodplain resource, especially Magpie Geese which are exploited for both eggs and meat, and burning is considered by the Aborigines to be significant to the birds' nesting and feeding requirements. Geese, it is stated, must be able to feed around the nest, but where unburned detritus has accumulated in thick, matted layers it is harder for the goose to obtain new roots and quantities of sand. Without the calcium from sand, eggshells are said to be soft and the number of goslings reduced. Finally, as the dry season progresses, many snakes withdraw into the limited areas of tall grass and they become increasingly hazardous for hunters. Burning reduces this danger and the last fires are set well before geese and ducks begin to nest following the first rains of mid-December.

By about the beginning of May, and specifically with the flowering of the Woollybutt trees, fires are begun well beyond campsites and settlement areas. This is the start of the **wurrgeng**, the "cold weather season", marked by the arrival of cool south-easterly winds and lower night-time temperatures. Three broad considerations are effectively the same for burning open forests and woodlands, though, overall, the two areas are valued and managed in somewhat different ways.

First of all, informants emphasise that fires should be set under the windiest conditions during the middle of the day. In addition to the fact that fires can be more easily directed as a result of knowing and using seasonal wind patterns and thus controlled, flames and convection columns are bent forward with the result that the height of scorch damage is reduced to less than 3 m and often less than 1.5 m. This is considered to be important for protecting the flowers of fruiting trees, those trees that provide a component of the diet for both Aborigines and some of the animals that they hunt, such as flying fox and possum.

Secondly, fires at this time are irregular and substantial tracts of intervening vegetation are left unburnt, and within burnt sections the effects are uneven and patchy. By contrast, larger, late season fires leave much less of a mixed habitat and individual sites are burned more severely and evenly. As much as forty to fifty percent of a given area of woodland and tall forest may remain unburned as a result of early fires and there is a pronounced diversity in the stages of growth and recovery.

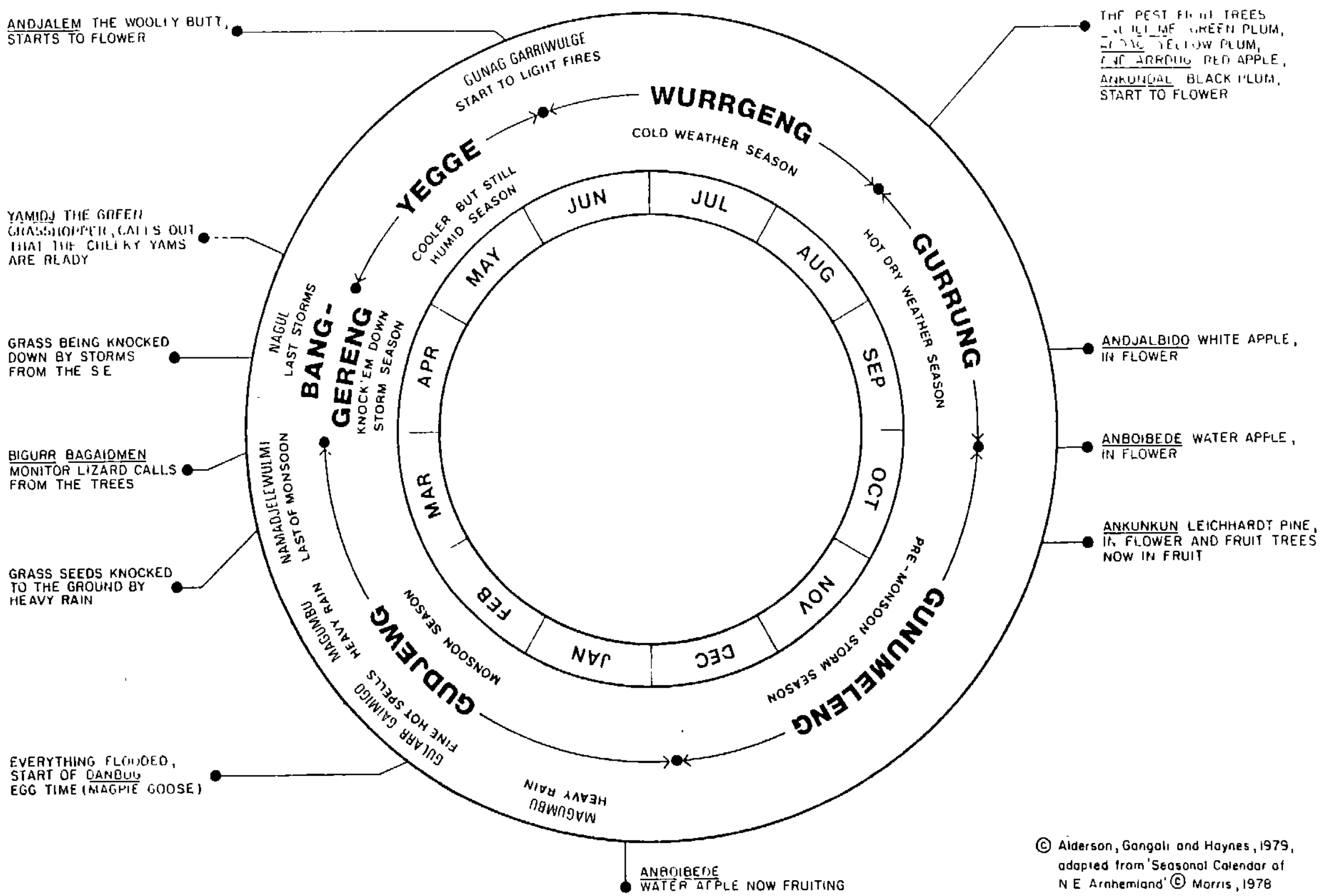

Figure 1. Seasonal calendar for the Kakadu region in Gundjeidmi (Maiili) language.

Thirdly, early season fires burn out during the late afternoon or early evening. Whereas at the beginning of the season each fire lasts for little more than an hour, by mid-July fires burn late into the night before going out with the early morning dew. The mosaic of burnt and unburnt areas makes it possible to control fires in the late part of the season because it is then possible to "aim" them towards burnt sites.

Relative humidity reaches its lowest point in mid-August with the arrival of the gurrung, the "hot-weather time", by which time burning should be completed within the open forest. The only fires still set there at this time are for purposes of encircling kangaroos and wallabies with flame and hunting them as the animals move about in confusion. As a part of the mosaic, the unburned sites are places where the animals hide during the day. In addition to the larger macropods, smaller animals such as bandicoots, marsupial rats, and goannas can be taken by hunters. Human foragers are not alone in exploiting fire drives: Fork-tailed Kites or "fire hawks" and other opportunistic, predatory birds are attracted in large numbers at the first signs of smoke. Sweeping close to the ground just ahead of the fire, they catch insects, lizards, and other small animals that are moving away from the flames.

In the immediate hours and days following a fire, considerably before the emergence of new growth, kangaroos, wallabies, and goannas come from surrounding areas to newly burned sites to dig for the roots of grasses and wild yams. Aborigines are well aware of the behavioural responses that animals have to fire and post-fire conditions, in various habitats and at different times of the year, and desired species are hunted accordingly. Their understanding of these relationships and their selective employment of fire allows them to manage and predict what are otherwise natural events.

Whereas the general patterns of woodland fires are similar to those of open forests, both the characteristics of woodland stands and their different resource values result in somewhat different practices of burning. Fires in eucalypt woodlands are generally larger and hotter because, with reduced shade and with winds less modified by the canopy of trees, the more uniform understorey of sorghum grasses burns with greater intensity. In addition, many woodland fires are set much later, some as late as mid-November with the onset of the pre-monsoon storm season, the gunemeleng. The range of resources more limited within the eucalypt woodland, with hunting largely focused on the kangaroos and wallabies that feed upon the green pick. Given the characteristics of the woodland habitat and the more limited spectrum of resources, the major differences between it and the open forest concern the scale, intensity, and length of burning periods involved.

The patches of rainforest and paperbark swamps are normally not burned. The concerns which Aborigines have for monsoon forests relate to the plant community type as a whole (which is much less fire tolerant), the animals which use rainforest for concealment, and the significance that these areas have in ritual and totemic meanings. However comments by informants indicate a degree of variation regarding fires in rainforest stands. Whereas some Aborigines maintain that fires are not set, others have indicated that they are "sometimes", but only after they have been fireguarded against late season fires from surrounding vegetation types, and at a time when the fires merely burn along the floor of the rainforest stand, with flames no more than a few inches high. These occasional fires, it was said, are necessary to clean up leaf litter which, over time, can inhibit and conceal the growth of yams. Paperbark swamps are also areas that are said not to be burned but in fact they usually are burnt every 5-10 years. As with rainforest, the accumulation of litter is the main factor involved and after a few years the ground is said to be "dirty". The areas under paperbark trees can only be burned after water levels have receded and when fuels are dry enough to carry a fire. They are burned, however, before fuels are fully cured so as to limit possible damage to paperbark trees and other less fire tolerant plants.

Partly because of the difficulty in traversing the rough, deeply fissured escarpment country, resource exploitation on the plateau is much more limited than in lower lying habitats. Spinifex and the other wiry grasses and shrubs of the plateau country are extremely flammable, and the fires that occur in the pockets of eucalypt woodland and the stands of heath and scrub can be very intense, especially those set late in the dry season.

Hunting fires atop the escarpment are frequently set from the base of a cliff by igniting strands of spinifex at places where a stream or river has cut deep into the plateau. These are timed to take advantage of the prevailing midday winds from the southeast so that when the fire crests it will be blown back towards the face of the escarpment. The animals which are caught in its path are forced down game trails where waiting hunters are able to shoot or snare them. Additional species pursued here include the Black Wallaroo and the Rock Wallaby. Though pockets of woodland may be reached by trail, the sandstone plateau is a less important area for people of the coastal plains and the management of resources there is rather desultory by comparison with lowlying areas.

All of the practical considerations are important, but esthetic concerns are involved as well. The themes of "cleaning" and "taking care" of one's country are particularly strong motivations for using fire. A country which is "dirty" with rank grass, thick leaf litter, or a tangle of undergrowth is considered not to have been cared for and, on entering or returning to such areas, fires are set to "make it right". Corrective burning is instituted irrespective of the time of year since, in the view of informants, further delays can only make a bad situation worse. Aborigines sometimes give the impression of having an almost manic compulsion about re-establishing fires in neglected environments.

The fires that result from their concern to clean an environment, especially those torched late in the dry season, are not infrequently destructive conflagrations. Aborigines are well aware that the consequences of corrective burning demonstrate the problems which develop when fuels accumulate over a number of years. The offence is in having allowed such an unkept condition to develop, not in the seemingly draconian means necessary to remedy the situation. Aborigines have very strong emotive and ethical concerns regarding the uses of fire, and their actions cannot be explained away by our own overly simplified view of fire as being essentially bad or inherently dangerous.

Traditional Aboriginal burning practices thus involve the selective setting of fires (in some cases withholding of fires), at various times of the year (or even day), across a variety of habitats (burned with varying frequencies and intensities), in order to influence the relative productivity and spatial distribution of a broad spectrum of plant and animal resources. The apparent casualness with which all of this is done gives little or no indication of the hunter-gatherer's understanding of the wide range and variable effects that fires have for local habitats. At the same time, much of how the fire technology of hunter-gatherers differs from that of cattle pastoralists derives from the fact that the former exploit a broad spectrum of resources and the latter a much narrower one. Much more is involved than the fact that the one hunts kangaroos and the other "hunts" cattle.

Pastoral Fires in Northern Australia

The burning technology described to me by cattlemen differs not only from that of Aboriginal hunter-gatherers but it also varies from the prescribed burning practices of the Bush Fires Council of the Northern Territory, the government agency primarily concerned with the prevention and control of bushfires. As noted previously, the cattleman's burning practices are different from those of the hunter-gatherer in terms of the concentration upon the maintenance and productivity of a single species: cattle. It differs from the activities of the Bush Fires Council in its focus upon the distribution and quality of forage and not, as in the case of the Bush Fires Council, primarily the reduction or mitigation of fire hazards.

The practices of the Bush Fires Council are rationalised and coordinated through five regional offices in Darwin, Batchelor, Katherine, Tennant Creek and Alice Springs. The most dramatic service provided by the Council is its "Protective Aerial Controlled Burning Programme" which involves aerial ignitions along the several hundred kilometres that make up the boundaries of a typical cattle station - all at no cost to owners. Set early in the dry season when fires burn out during the night, these wide and irregular shaped firebreaks then provide a protective line against the spread of fire from or into adjacent properties.

Within the boundaries of a station some firing will already have begun well before the perimeter firebreaks are in place. Traditionally carried out by Aboriginal cowboys from horseback, most burning, like most mustering, is now almost entirely done from helicopters or four-wheel drive vehicles[3]. Except for the advantage of speed the older cattlemen interviewed have a negative view of "copter cowboys". Their complaints are that helicopters are "too removed" from what happens on the ground, be it setting fires or mustering cattle, with a consequent loss of contact with and understanding of plant and animal conditions in remote areas.

Like hunter-gatherers, cattlemen schedule burning in terms of biological factors that are close at hand or at least no further removed than from the back of a horse. Rather than being based on regional weather forecasts and the availability of aircraft, the traditional stockman pattern for burning is based on the biological characteristics of particular places: the swarming of dragonflies, the flowering of selected trees and bushes, the seasonal arrival of certain migratory birds, and while grass stems are still tinged with green - this is an indication that there is sufficient moisture in the soil to affect a growth of green pick. Older stockmen maintained that these local conditions simply cannot be adequately judged from a plane or helicopter, and that aerial ignitions are simply too alienated from conditions on the ground to assure that fires can be set at the right time or in the appropriate places.

Burning the understorey grasses and shrubs of eucalypt woodlands and open forests normally occurs during the first two months (May and June) of the dry season. The timing differs slightly from the Aboriginal pattern in that it begins and ends a few weeks earlier, and this relates directly to the fact that cattlemen have only the one resource and, correspondingly, all habitats are managed with this in mind. The very first fires are set adjacent to homesteads and corrals as fire guards. Nearby fenced paddocks of native grasses are also fired and the subsequent emergence of green pick acts as a lure for cattle from surrounding areas. Depending upon the duration and intensity of an extended wet season, these fires can be ignited as early as mid-March or, in exceptionally wet years, as late as early May. During this time cowboys are posted to outlying paddocks and corrals to set similar guard fires and initiate mustering. By clearing detritus (making cross-country travel easier and safer) and initiating new growth (concentrating cattle in selected areas) mustering is made possible while palatable forage is available for stock until the onset of the following wet season.

Because the understorey fuels of eucalypt woodlands become dry two to three weeks earlier than those in stands of open forest, fires are intitiated there first, beginning with the drier hills and ridge tops. These burnt out corridors will limit the spread of fires which are set later in the lower, intervening areas. Open forests are torched in essentially the same way as fuels become sufficiently dry. Though readily recognised as a different habitat type, for the stockman the open forest does not involve a different range of resources as it does for the Aboriginal hunter-gatherer. The delay in burning open forests occurs only because of the different conditions involved, i.e. damper fuels.

An important consideration of the somewhat earlier pattern of dry season burning by cattlemen is that the fired areas become a mix of green pick, partially burned, and unburned grasses. Though mature native grasses provide low levels of nutrients, cattlemen stated that old growth is needed as a supplement to green pick, which by itself is inadequate. The cattlemen pattern of burning within open forest also differs from that of hunter-gatherers in that individual fires are larger (20-1,000 ha versus 0.5-25 ha), the aim being to create a maximum effect for cattle rather than a mosaic of burned and unburned patches, are set over a longer period (by 4-6 weeks longer), and do not provide an optimum of micro-habitats for a broad range of plant and animal resources. Pastoral burning within both eucalypt woodlands and open forests is completed by mid-June, after which soil moisture is normally insufficient to initiate further green pick.

The amount of eucalypt and open forest burnt during the early part of the dry season was variously stated as being between 40% and 60%. A major difference from that of hunter-gatherer burning is that the remaining unburned areas, and even some of the partially burned areas, are fired at the end of the dry season, usually after one or two mid-December rains. The result is that as much as 90% or more of the total area is burned each year, two to three times the total area burned by Aborigines. In addition to providing still more new growth at the end of the year, the cattlemen claim that these end-of-the-year fires reduce the amounts of sorghum and increase the productivity of preferred native types such as Kangaroo Grass (**Themida australis**).

The estimated carrying capacity of cattle for eucalypt woodlands is more than twice that of open forests - 6 versus $3/km^2$ (Perry 1960) - and cattlemen claim that with careful management (limiting over grazing and burning to increase preferred grasses) considerably larger numbers of cattle can be maintained in both areas. The pastoral advantage of eucalypt woodlands derives from the greater uniformity of grasses, whereas open forests exhibit the much greater diversity of plant and animal species, the advantage mentioned for hunting-gathering.

Although limited in area and restricted to coastal regions, floodplains are important areas for the northernmost cattle stations. When waters recede permitting cattle into these areas, the reeds and grasses provide excellent grazing. Informants were less precise about burning floodplains, this in part depending upon the amount of grazing pressure involved, with those floodplains most heavily grazed not fired.

The main argument for firing the floodplains was the necessity to reduce the numbers of ticks - a problem in all areas and one of several overall considerations for burning. All informants qualified their comments about burning floodplains by emphasising the necessity for considering particular local conditions. Because the soils remain moisture laden longer, floodplains are fired at much later times than surrounding areas, with the lowest portions being burned as late as November and early December.

Similarly, highly variable practices are also true for swamps and the grass fringes of rivers, areas which involve the same kinds of pressures and considerations as floodplains. Smaller and more interior flood basins or "flats" were also burned as conditions permit and, like floodplains and swamps, later into the dry season than nearby stands of eucalypt woodlands or open forest. Unlike the subcoastal floodplains, interior flats are more often composed of "sour grass" or "blady grass" (probably **Imperata var.**), which are only palatable during early stages of growth.

The small, intermittent stands of monsoon rainforest or "jungles" found within tall-open forests and nearby floodplains were not mentioned as being important and, though occasionally "scorched", informants stated that the early season fires that they set within tall-open forests seldom carry into these stands. However, where cattle might use rainforest to hide in during some of the hotter and drier periods, stands of monsoon forest might be burned to drive the animals into the open, thus causing greater damage than was usually the case. Unlike the Aborigines, cattlemen do not specifically fireguard rainforest, though they argue that the decreases in such habitats are a consequence of "developers" and water buffalo hunters ("buffos") rather than their own practices of firing.

Other than sometimes fireguarding the margins of coastal floodplains, cattlemen in the northern part of the Territory normally set fireguards only around stations and cultivated paddocks, man-made structures and fenced pastures of introduced grasses. Further south, however, in the Mitchell Grass country which ranges from the Barkly Tablelands intermittently across to the Victoria and Ord rivers, fires are purposefully excluded, though corridors of spinifex and other fire responsive grasses and shrubs are fired. Mitchell Grass (**Astrebla pectinata**), which is adversely effected by regular burning, is the most nutritious forage in northern Australia and is found on flat or gently sloping, treeless plains south of the area considered here. However, just under half (8) of the informants had worked in the region at various times and were well familiar with the need for excluding fire from stands of Mitchell Grass while at the same time burning other forage types.[4]

The essential differences between cattlemen and hunter-gatherers are, as noted earlier, related to the kinds of resources exploited by each.

Within a stand of open forest cattlemen are not concerned with the varieties of plants and animals taken by hunter-gatherers nor with the food chains involved. For instance, the fact that fires might damage wild yams within a rainforest stand, or that the flowers of fruit trees might be damaged in the absence of a wind, or that large fires reduce the necessary mix of areas that macropods and smaller ground dwelling species need for feeding, hiding and reproducing are of no particular importance to cattlemen, but are, along with other considerations, of great significance to hunter-gatherers.

In this respect the fundamental, systematic difference is that the fire technology of Aboriginal hunter-gatherers is more complexly structured than is that of cattlemen - and necessarily so. I would not and do not argue on the basis of some abstract and idealised view of the environment that one system is better than the other. It is simply the case that given the resource base of each, the two fire technologies are reasonable and coherent systems of knowledge in their own right. However, in terms of one group understanding the fire technology and ecology of the other, Aboriginal hunter-gatherers have been in a better position to appreciate the needs of a pastoral economy than the cattlemen have been for understanding the needs of a hunting-gathering economy. This is the case if for no other reason than the obvious fact that large numbers of Aborigines became cowboys and an infinitesimally small number of, if any, Europeans became hunter-gatherers.

Most Euro-Australian cattlemen, along with the vast majority of other non-Aborigines, have little understanding of, much less appreciation for, traditional Aboriginal technology within which burning was an integral part. Most "Territorians" merely denigrate traditional burning practices, even those who have been in a position to observe Aboriginal practice for a long period of time. As put to me by one station owner when approached about the comparison I was doing,

> You're not one of those anthropologists who's going to try and tell me that the Black Fellas knew what they were about ... that they were some kind of conservationist? What a lot of bloody nonsense!

Even those who are reasonably sympathetic to or prejudiced for Aborigines usually lack any real understanding of what habitat maintenance and modification by fire involves. As one such individual, a missionary, stated to me when asked about his longterm observations: it was one of the "unfortunate customs" that Aborigines still practice.

However, not all non-Aborigines are negative and two of the Euro-Australian stockmen that I interviewed demonstrated a fairly objective and receptive understanding of what indigenous practices involved and how these practices related to pastoral burning technology. One of these individuals, now retired and living south of Darwin near Howard Springs, stated that,

> Aboriginal stockmen didn't have to be taught to burn; they grew up with it ... it was important to their hunting way of life. All we had to do was give them a few boxes of matches and they went off and burned the places that they were supposed to and left the rest alone ... and that's the way we learned about burning this country.

The other individual, also retired and living in Darwin, had come to the north in the early 1920s and, though he knew about burning for sheep and cattle pasture in South Australia, the needs for pastoral burning in the Top End were entirely new. His "education" about burning, he said, came from Aborigines, many of whom were alternately cowboys and hunters during different times of the year.

> For Abos the change from hunting and burning for roos to hunting and burning for cattle was easy. It just meant that they had to deal with one animal instead of a hundred-and-one other damn things.

Conclusion

Aboriginal technologies, like those of hunting-gathering peoples elsewhere, have frequently been described as "simple" or "primitive" compared to those of "more advanced" or "modern" societies. Perspectives such as this are commonly couched in evolutionary assumptions and supported by the superficial equation that tools equal technology. However useful this may be for organising museum displays, it is much too simplistic for characterising the technologies of modern hunter-gatherers as represented over the past twenty to thirty thousand years. Robin Riddington has argued for a much more meaningful approach to understanding hunting-gathering technologies.

> Perhaps because our own culture is obsessed with the production, exchange, and possession of artifacts, we inadvertently overlook the artiface behind technology in favour of the artifacts that it produces ... I suggest that technology should be seen as a system of knowledge rather than an inventory of objects ... The essence of hunting and gathering adaptive strategy is to retain, and be able to act upon, information about the possible relationships between people and the natural environment (Riddington 1982: 471).

In this respect, an increasing number of studies by anthropologists and others are showing the considerable complexity of hunter-gatherer technologies when seen as systems of information which affect human-environmental relationships, and not merely as catalogues of tools and traits (e.g. Blurton, Jones & Kooner 1976; Feit 1978, 1981; Freeman 1979, 1982, 1985; Gladwin 1970; Johannes 1981; Jones 1980; Lewis 1982; Nietschmann 1973). As the above outline of Aboriginal burning practices has shown, the knowledge of how plants and animals in a variety of habitats are influenced by variable uses of fire is infinitely more complex than merely the knowledge that underlies the tools and techniques for making fire. Given the diversity of environments inhabited and the variety of resources exploited by Post-Pleistocene hunters and gatherers, it is difficult to imagine that they could have successfully adapted with only "simple" or "primitive" conceptions of environmental relationships. These adaptations would, of necessity, have required complex and sophisticated understandings of local ecosystems.

As indigenous or folk theories that "explain" the role of fire in a variety of ecosystems over time, the fire technology of Aboriginal hunter-gatherers is much more complex than the equivalent knowledge system of cattle pastoralists. Because hunter-gatherers exploit a broad spectrum of resources they must know "more" about the effects and counter-effects of burning. Though both groups have occupied the same kinds of environments, the "hypervolume" or "multidimensional niche" of Aboriginal hunters and gatherers is greater and, correspondingly, more complex than that of the cattlemen.

As some studies have recently shown (Freeman 1985; Johannes 1981), the knowledge that indigenous peoples have regarding environmental phenomena can provide important insights for and guidelines to scientific research and habitat management policy. In the Northern Territory, a few scientists, most of them working with the CSIRO (Commonwealth Scientific and Industrial Research Organisation) Division of Wildlife and Rangelands Research in Alice Springs, have been looking at questions relating to the remaining numbers and distributions of endangered small animal species in the central deserts. Aboriginal knowledge of plants, animals and fire has played an important role in this research (Burbidge 1985; Latz & Griffin 1978). At the same time, both the Federal and Northern Territory governments have involved Aborigines in the management and operation of National Parks, most notably Kakadu, Uluru (Ayers Rock), and Cobourg Peninsula. Though their involvement in the direct management of the parks appears to be constrained and overly institutionalised (Weaver 1984), they continue to carry out part-time hunting and gathering activities and, as an integral part of that, habitat burning.

In parts of Asia, Africa, Australia, the Sub-Arctic and Arctic, and South and Central America, where remnant populations of hunters and gatherers are still found, it is possible for conservationists and environmentalists to benefit from indigenous systems of knowledge and perspectives on wildlife management. If national governments recognise the potential wealth of information that foraging peoples have, hunter-gatherers could continue to make an important contribution to the preservation of at least small portions of the once enormous areas that their forebears - and ours - managed over past millennia.

Footnotes

1
Two other informants were "part-Aborigine" but, in terms of their attitudes and statements, they are culturally Euro-Australian and demonstrated little knowledge of or interest in hunter-gatherer uses of fire.

2
Much of Aboriginal life in the more remote areas of northern and central Australia is today related to the "outstation movement" whereby Aborigines have returned to traditional tribal lands after years of residence in and dependence on missionary or government settlements and pastoral stations (Meehan & Jones 1980). The knowledge about traditional subsistence activities which is known and remembered varies from individual to individual and place to place, but it is clearly the case, as a number of recent studies have shown (e.g. Bell 1983; Meehan 1982), the dynamics of earlier human-environmental relationships are remembered by many elders and still applied in northern and central regions of the country.

3
I write of the "traditional" cattleman's practices in the present tense partly for ease of writing and partly because they are still employed in some areas. Horses and cowboys, though now much reduced in numbers, are still used, especially on some of the smaller, less highly capitalised, less mechanised stations including a few that are operated by Aborigines.

4
Both Euro-Australians and Aborigines were asked whether Aboriginal hunter-gatherers were ever seen or reported to have set "hunting fires" in Mitchell Grass areas. All answers were negative, with the Aborigines interviewed stating that burning was neither necessary nor desirable for purposes of hunting-gathering. If Aborigines did regularly attempt to exclude fire from these regions, discontinuous areas of rangeland totalling something like 1,000,000km , this would be a most impressive example of fire exclusion similar to what they do on a much smaller scale with rainforests in the north. Though prescribed fires would have at various times accidentally ignited stands of Mitchell Grass, as would lightning at other times, it appears that Aborigines did not regularly fire these areas and may in fact have purposefully worked to exclude fires when burning adjoining habitat types.

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ASPECTS OF RESPONSE TO FIRE IN THE NORTHERN SANDPLAIN HEATHLANDS

David T. Bell

Abstract

The floristic composition of shrub-dominated plant communities in the northern sandplain of Western Australia is influenced primarily by edaphic conditions but fire is an environmental factor which does influence community composition. Although having only minor effects on floristic composition, pyric events have major impacts on quantitative measures of plant community structure. Biomass recovers quickly following fire, reaching 4 t/ha after 2 years and near pre-fire conditions of around 16 t/ha after 10 years. The rapid recovery of biomass can be related to the large proportion of resprouting species in the heath communities of the northern sandplains. More than 2/3rds of the floristic composition of the kwongan of this region resprout following fire. However, the rapid recovery of kwongan vegetation can present problems of determining ages of sites older than 4 or 5 years. Two techniques for determining the age of more mature kwongan are described. The first is based on extrapolating the spectral signature of LANDSAT imagery from areas of known ground truth to areas of unknown age and biomass. Regression equations based on biotic characteristics of particular heathland species developed from plants growing in areas of known age are used to date regions of unknown age.

Introduction

In the Northern Sandplains between Badgingarra and Dongara lies a region of multiple land use dominated by wheat production, sheep grazing and mineral sands mining. This region, however also contains considerable areas of native vegetation. The native plant regions, containing predominantly kwongan and woodland elements, are generally crownlands or reserves and, therefore, under the management of various Governmental agencies. The fire management of the crownlands in the region is controlled by the W.A. Bushfires Board. Of primary concern of the Bushfires Board is the protection of human life and property although multi-use objectives of crownlands are recognised. Current research by the Bushfires Board in the region is centred on the determination of rates of fuel loads accumulation by shrubland vegetation (Schneider & Bell 1985) and fire behaviour. Fire controls in the region attempt to stop wildfires which begin within kwongan from spreading to developed properties. It also attempts to stop fires which commence in farm and pasture lands or urban areas from decimating native bushland areas.

The Northern Sandplain kwongan is also a valuable apicultural resource used primarily by commercial beekeepers in the winter and early spring-flowering periods. One C-class Reserve of native kwongan and woodlands, The Beekeepers Reserve, is a 90,000 ha region which stretches between Jurien and Dongara. A disastrous fire in January 1984 burned out much of the reserve and was estimated to have cost the apicultural industry of Western Australia more than $4 million (Burking & Kessell 1984).

Designated beekeeping areas occur throughout the crownlands and reserves of the region. The apiarists prefer heath vegetation to be at least 10 years since the last fire for maximum pollen and honey production. This is primarily due to a preference of honeybees for several of the species requiring reseeding following fire (e.g. **Dryandra sessilis, Hakea trifurcata** and **Leucopogon striatus**). Several years growth can be required before the first season of flowering occurs in these species and peak flowering generally occurs between 10 and 20 years since last fire. At 20 years following fire, many species of the kwongan begin to senesce. Short interval control burning of native plant community regions would therefore be disastrous to the apicultural industry. Clearly, therefore, a management conflict arises between a desire on the one hand for fuel reduction control burns to prevent shrubland wildfire from spreading into developed areas and a desire on the other hand for relatively mature "beepastures".

A third point of view, that of plant conservation, also must be considered in the fire management of the heathlands. The kwongan flora is extremely rich. Lamont et al. (1984) suggest that at least 2,540 species occur in kwongan vegetation of the Southwest Botanical provence. The flora tends to have a high level of endemism, with many local endemics (Hopper & Muir 1984) and the plant taxa are by no means evenly distributed (Griffin et al. 1983). In addition to the above points a lack of knowledge on the modes of reproduction make more difficult the development of an ecologically appropriate plan of management for heathlands to reduce the potential of wildfires escaping from the Crownlands into developed adjacent lands while maintaining sufficiently productive bee pastures for apicultural requirements and conserving endangered species and plant communities (Bell et al. 1984).

Research carried out since 1979 by the Department of Botany in the kwongan of the Northern Sandplain region has centred on 1) the determination of species of the area and their associations in plant communities and 2) the description of the response of communities to fire with emphasis on species important to beekeeping and conservation. These data have provided important base-line information for the development of systems of fire management for the region. The objective of this paper is to describe aspects of plant community distribution in the region and the influence of fire on plant community structure, and to describe two techniques which have been developed to determine biomass and fire fuel levels over large areas of the region.

Community Patterns

In a region of kwongan in the Coomallo Creek drainage near the junction of the Brand Highway and the Jurien Road (30°13'S, 115°23'E), eight sites each with five sampling plots provided initial information on the flora of this region and the relationship of fire and soil type to floristic patterns (Bell & Loneragan 1985). Percentage cover values for these 40 plots were analysed by a classification procedure which aggomerates sites on mutual information (Orloci 1969). Initial sorting of the plots was by major soil characteristic; deep sand versus laterite outcrop, with secondary groups relating to relative age since last burn (Fig. 1). This initial survey indicated that although the community structure was primarily related to edaphic conditions, particularly soil depth, the impact of recent fires was sufficient to be a major characteristic underlying the vegetative structure of the region. Differentiation of sites on shallow substrates of the laterite outcrops from those sites of the deeper soil profiles of the valley slopes was mainly based on floristic differences as similar patterns were differentiated using qualitative data alone (Bell & Loneragan 1985).

One method of comparing the vegetation structure between sites is to use an Index of Community Similarity such as Percentage Similarity (Sorensen 1948). Sites which share the same floristic composition and the same quantative values for each of those species have a Percentage Similarity Index of 1.00. Sites that have no species in common and, therefore, no quantitative similarity as well have Percentage Similarity values of 0.00. Completely similar plot samples, in which both the species composition and the quantitative measure are identical, almost never occur, however, and research from North America has shown that replicate plots within homogeneous communities have Percentage Similarity Index values of the order of 0.75 (Whittaker & Woodwell 1973). Mean values between plots of the laterite outcrop origin and deep sand areas at Coomallo Creek was only 0.23 compared to a mean of 0.40 for the plots within the same edaphic region. The low Percentage Similarity values indicate that the two edaphic communities contain very different species composition but never the less do have some species and their quantitative values in common. Within plots of the same edaphic and pyric condition, structural similarity tended to be even greater. Recently burnt (< 3 years), deep sand sites had a mean value of 0.43. The recently burnt laterite outcrop sites and older laterite outcrop sites had mean indices of 0.47 and 0.43 respectively. Percentage Similarity values of the five plots within a single study site had a mean of 0.49. The low within community values indicate that the distribution of species tends to be very dispersed and plots within a region of kwongan which appears visually similar can be quite different once sampled.

Proportions of Resprouters

It is not difficult to understand why sites affected recently by fire are floristically similar to prefire vegetation, as a high proportion of the species resprout from protected buds following fire and the remaining species generally have seed present in the soil which is stimulated to germinate following fire or carry seed in protective fruit which disseminate following fire. In a collection of 152 species from deep sand habitats in the Badgingarra - Jurien region, resprouter species represented 66% of the total (Bell et al. 1984). The sclerophyllous shrub-dominated understorey of the jarrah forest of the Darling Range also contains a similar proportion of resprouting species (Christensen & Kimber 1975; Bell & Koch 1980). Resprouting species proportions in the sites Brand Highway - Jurien Road study sites tended to be even higher (Table 1), however, this probably is partly an artifact of insufficient knowledge of regeneration modes when the samples were taken.

Table 1. Species richness and percentage resprouters in study sites near Badgingarra, Western Australia (after Bell & Loneragan 1985).

Site No.	Plot Nos.	Ecological Edaphic	Category Pyric	Overall Site Species Richness	Percentage Resprouters
1	1- 5	Sand	> 8 years	74	83
7	31-35	Sand	> 8 years	72	
3	11-15	Sand	< 3 years	71	80
5	21-25	Sand	< 3 years	62	
2	6-10	Laterite	> 8 years	79	85
8	36-40	Laterite	> 8 years	77	
4	16-20	Laterite	< 3 years	90	81
6	26-30	Laterite	< 3 years	72	

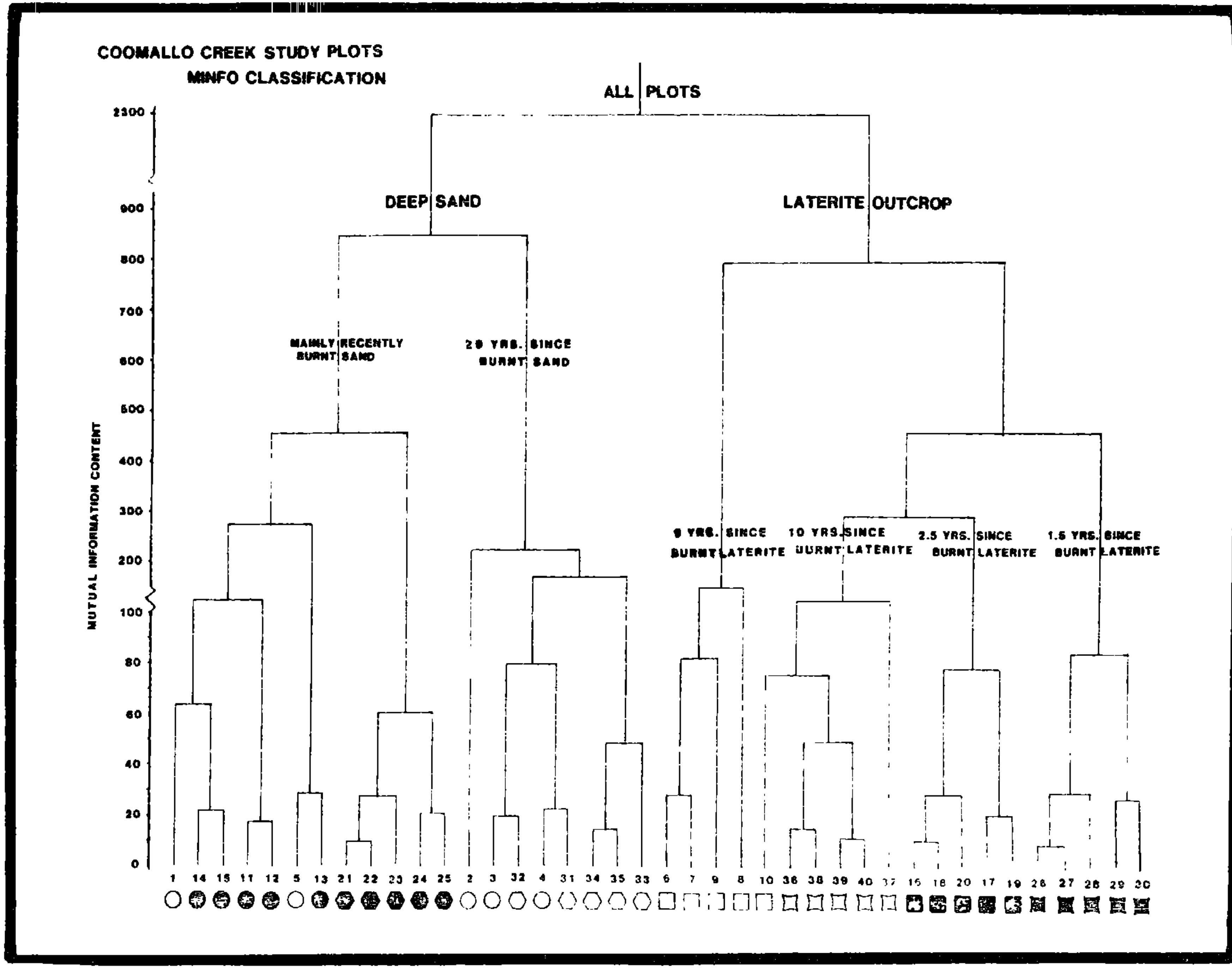

Figure 1. Mutual Information Analysis (MINFO) plot classification of the plot cover value data (after Bell & Loneragan 1985). Plots within a single study site have the same symbol. Sites with closed symbols are from sites < 3 years since last burn; sites with open symbols > 8 years since last burn. Square symbols are from laterite outcrop regions; more circular symbols from deep sand sites.

The percentage of the flora capable of resprouting provides clues to the expected fire frequency in plant communities. Keeley & Zedler (1978) hypothesise that long intervals between fires promote the success of seeders. Proportions of resprouters in a range of community-types in the region north of Esperance ranged between 0-29% (van de Moezel & Bell 1984). Estimates of the fire interval in this area may be of the order of 50-100 years. In a similar accounting, the proportion of resprouters in a region of hummock grasslands of the Great Sandy Desert near Telfer was 24% (Goble-Garratt & Bell, unpub. data). This low proportion of resprouters would indicate that the natural fire frequency in these more arid communities is much longer than in the kwongan of the Northern Sandplain or the northern jarrah forest. The current best estimate of the mean frequency of fires found under natural conditions in the Northern Sandplain kwongan is of the order of 25-50 years (Bell et al. 1984). The current predominance of resprouters in the Western Australian kwongan may reflect the fact that fires have become progressively more common in recent times.

Biomass Recovery Following Fire

The large predominance of resprouting species results in a rapid recovery of above-ground biomass following fire. Within a year following fire, the biomass is more than 4 t/ha and at 2 years mean biomass is more than 11 t/ha (Fig. 2). The pattern of recovery produces a significant logarithmic relationship between age and total biomass:

Biomass (t/ha) = $0.34 \log_e \text{Age} + 0.73$, d.f=10, $r=0.93$, $p < 0.01$.

Biomass in the kwongan of the Northern Sandplains tends to level off at approximately 16 t/ha.

Comparisons with published records elsewhere are interesting (Fig. 3). The heath vegetation of inland Victoria responds to fire in a similar way to the Western Australian equivalents with a rapid early recovery period followed by a near plateau reaching the 16 t/ha level reached in Western Australia at 20 years following fire (Jones et al. 1969). In contrast the coastal heaths in Victoria (Jones et al. 1969) and South Australia (Specht et al. 1958) recover from fire more slowly, although eventually surpassing the biomass totals accumulated in both the inland Victorian heaths and the Western Australian deep sand shrublands near Badgingarra (Bell et al. 1984). The major differences are explained in the dominance of the coastal heaths of southern Australia by the reseeding species of **Banksia**. Without the regenerative buds, stores of nutrients and energy, and an already established root system available to resprouting species, the recovery pattern of communities dominated by reseeders is generally much slower and shows a more regular rate of biomass accumulation.

LANDSAT Imagery and Recovery Following Fire

Effective management of large regions of heathland vegetation requires a knowledge of biomass and fire fuel loads. Traditional use of aerial photography to map topography and characterise land use patterns has been limited when applied to assessing levels of biomass in the Northern Sandplains kwongan. LANDSAT imagery, however, provides reflectance definition in four spectral bands on an effective scale of approximately 80 m x 80 m on the land surface. This minimum effective unit area of just less than a hectare allows only generalised characterisation of the land surface but careful "ground truth" acquisition and spectral differentiation can lead to regional classification of vegetation age and biomass. A region of the Badgingarra National Park with known age since last fire was used to characterise the reflectance characteristics of three areas: 5 yrs since last fire, 6 yrs, and an area older than 12 yrs. Differences in the four bands of spectral reflectance were determined and used to differentiate (or "classify") the reflectance signature of the three known regions and then used to find regions of similar reflectance patterns which presumably were of similar biomass and age (Fig. 4). Once the biomass of areas within the region are known, a more carefully reasoned plan of fire management can be developed.

Regrowth Characteristics of Selected Species

Areas of known age since last fire also provide a potential age gradient to determine patterns of regrowth for individual species of the kwongan. The most-usual method of aging woody plants, that of counting annual growth rings, has proved to be difficult in Australian species (Dunwiddie & LaMarche 1980) and preliminary work with kwongan species confirmed this belief. For this reason, a number of other botanical attributes related to age were explored for this purpose. The most successful of these involved reseeding species which tend to have a more gradual and regular pattern of growth. Plant height in each of the species, **Beaufortia elegans, Leucopogon conostephioides, Petrophile media** and **Hakea obligna** was directly related to known age (Table 2). Other plant related variables such as numbers of fruits per plants were also related to time since last fire (Table 2), but practical difficulties, primarily those related to the time required to get the appropriate data, would probably curtail use of those parameters under field conditions.

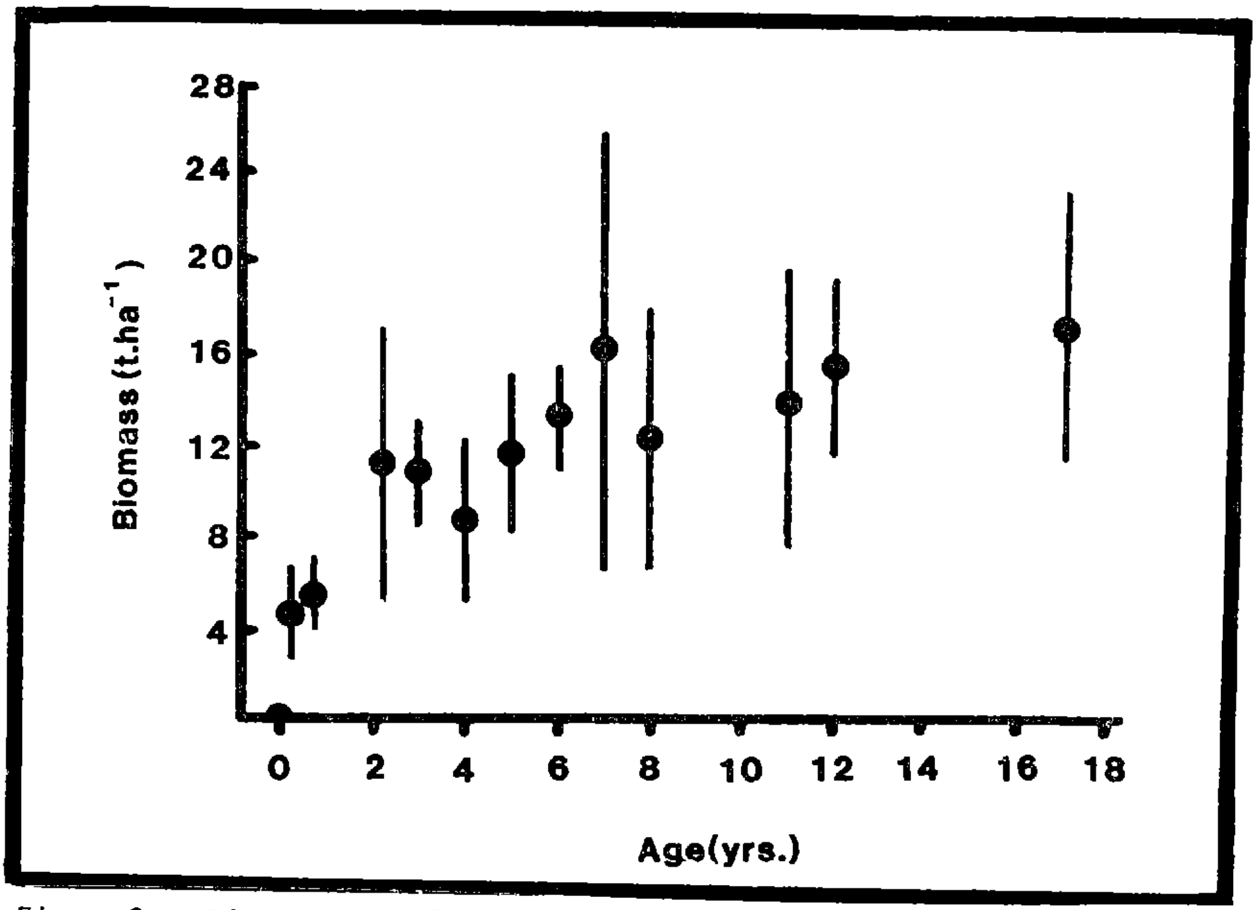

Figure 2. Biomass accumulation in Northern Sandplain kwongan from deep sand sites (after Rullo 1982).

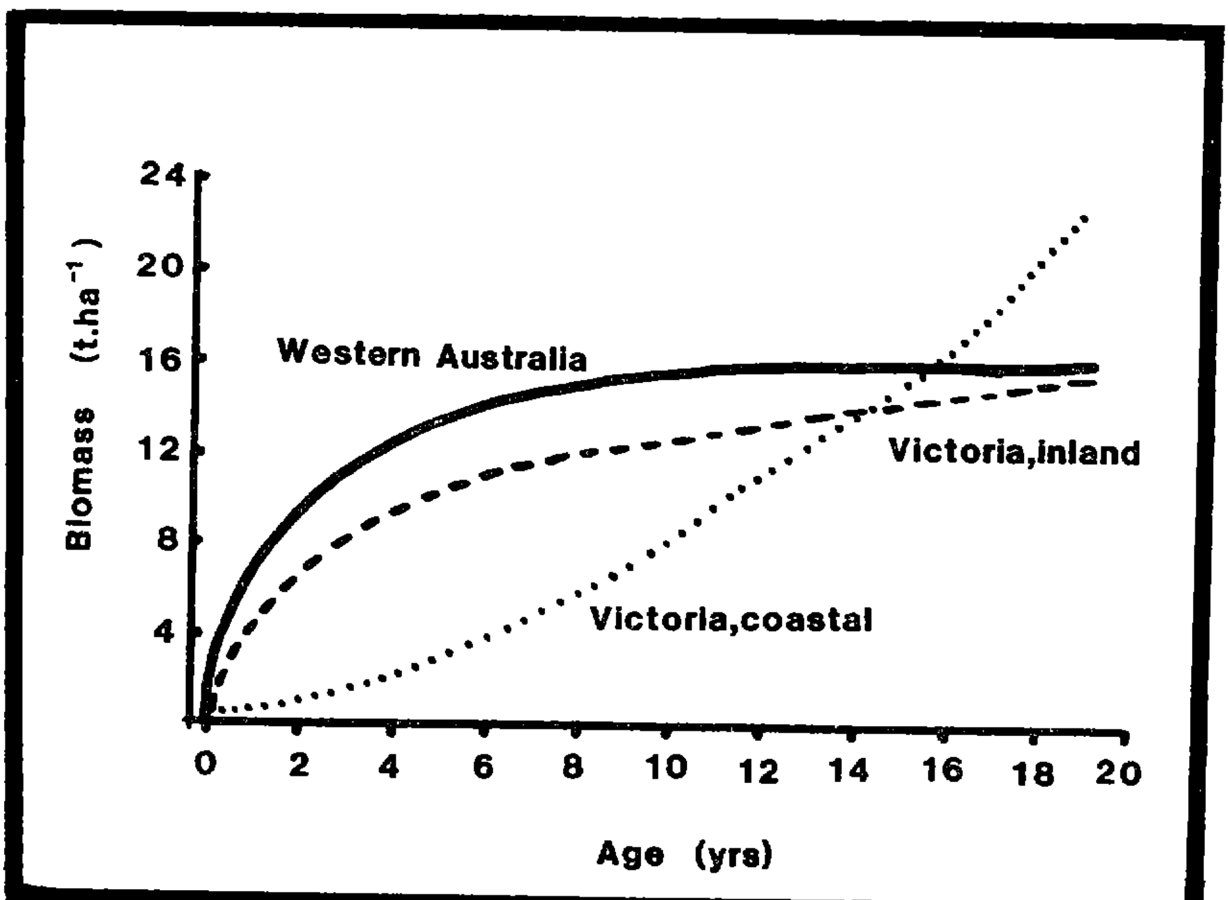

Figure 3. Biomass accumulation curves from the Northern Sandplain kwongan and reported curves from inland and coastal Victorian heaths (after Jones et al. 1969).

Table 2. Relationships between age and a variety of botanical variables of species of the Northern Sandplain of Western Australia.

Regression Equations	d.f.	r	P
Age = -2.89 + 0.21 **Beaufortia elegans height**	8	0.94	<0.01
Age = -1.32 + 0.41 **Leucopogon conostephioides height**	5	0.99	<0.01
Age = -4.28 + 0.29 **Petrophile media height**	4	0.96	<0.01
Age = -2.90 + 0.07 **Hakea obliqua height**	9	0.94	<0.01
Age = 3.89 + 2.20 **Hakea obliqua fruits per plant**	10	0.98	<0.01
Age = 3.94 + 0.80 **Beaufortia elegans fruits per plant**	10	0.95	<0.01

The pattern of branching in some species, e.g. particular **Banksia** and **Petrophile** species, can also be useful in ageing plants (see Lamont, this volume). These species have terminal fruits or branch just below a senescent bud following summer. This pattern of growth allows a count of branching junctions and bud scale scars to provide an estimate of plant age. **Petrophile media** is a species of scattered occurrence in the Northern Sandplain which must reseed following fires. In an area which has been burnt, the oldest branching pattern of **Petrophile media** observed is usually close to the time since the last fire. In the harsh environmental conditions of the Northern Sandplain, it would be rare to have two growth periods in one year and therefore, it would be unlikely that an area would be younger than the age determined for the "oldest" plant determined by this method. Although this method appears quite reliable it has the disadvantage of being based on a species which is not abundant through these heathlands.

The use of these individual species-related techniques were used to determine the approximate ages of regions of heath in the Coomallo Creek area that had no known record of last fire occurrence (Fig. 5). Because age and biomass can be related for this region, a more careful assessment of potential control burning prescription can now be made.

Conclusions

Fire has been shown to influence both the floristic composition and quantitative structure of the heathland communities in the Northern Sandplain region of Western Australia. Progress has been made in determining the modes of regeneration following fire for many species of the region. A complete record, however, is essential before a better prediction of the impact of fire on the plant communities, and especially to the conservation status of rare and endangered plant species can be made.

Satellite-based technology and simple botanical characteristics have contributed to the ability to produce regional maps of biomass accumulation in the region. These data, coupled with the growing knowledge of fire behaviour in shrub-dominated vegetation developed by the W.A. Bushfires Board and the W.A. Department of Conservation and Land Management should result in a more rational use of fire in the management of the Crownlands and Reserves of the Northern Sandplain.

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Figure 4. Region near Badgingarra characterised for age since last burn from LANDSAT spectral signature of a growth truth site within the Badgingarra National Park.

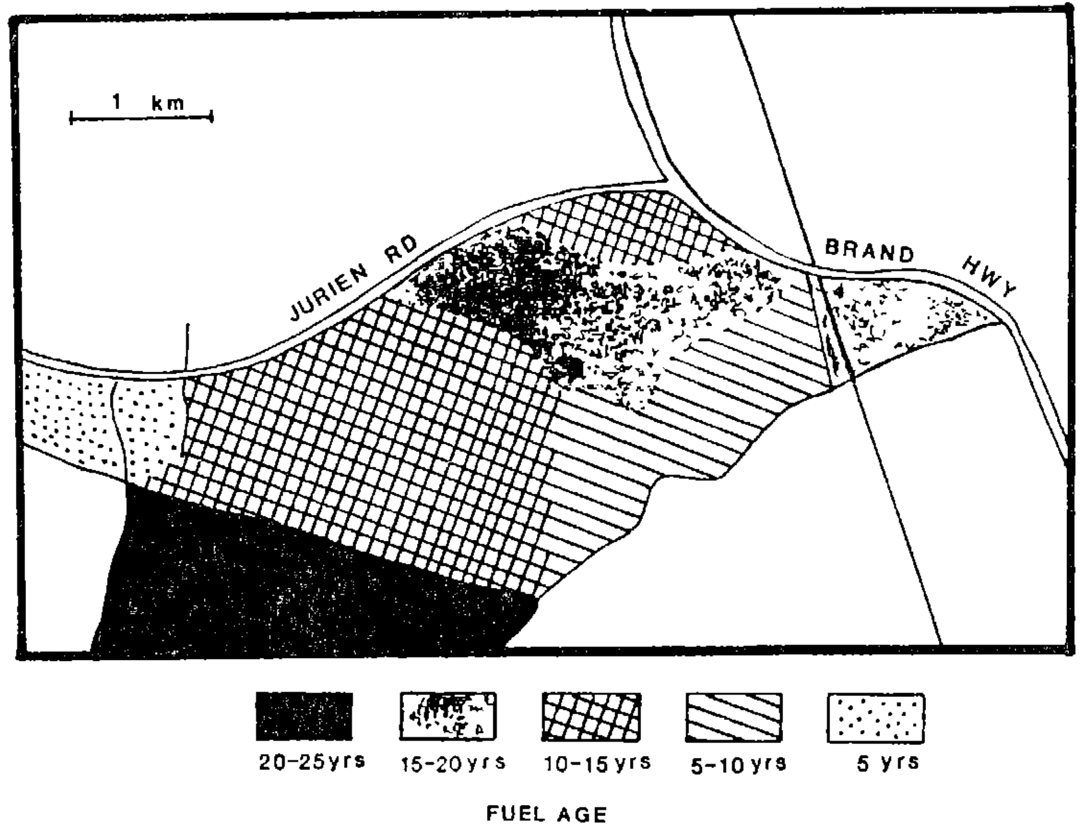

Figure 5. Region of heathland near the junction of Jurien Road and the Brand Highway aged by plant height regression equations and Petrophile media branching pattern estimates.

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FIRE RESPONSES OF SCLEROPHYLL SHRUBLANDS - A POPULATION ECOLOGY APPROACH, WITH PARTICULAR REFERENCE TO THE GENUS BANKSIA

Byron Lamont

Introduction

There is considerable information available about the responses of various parts of plants (eg. fruits, buds) to fire. There is also a reasonable number of observations on whether particular species survive or are killed by fire. Both approaches, however, are only a first step towards achieving the final goal of fire management, ecosystem conservation. Additional requirements are that these responses should be stated in relation to the three major components of the fire regime - frequency, intensity and season. Secondly, plant responses also depend on demographic factors, such as plant age, as well as the organ under consideration.

Independent of the mechanisms, what ultimately is important is the net effect of the above on the abundance of the species before the next fire. Knowledge about this aspect requires a rigorous population approach (Fig. 1). I know of no study which has considered the full cycle of population changes in relation to a range of fire regimes, although a number have made useful contributions to the total jigsaw puzzle. What follows is an attempt to raise some of the issues relevant to a population ecology approach to fire responses, and to place them in a sequential framework. Where possible, examples are provided from the genus **Banksia**. Banksias are a major component of the flora of southwestern Australia, accounting for 58 of the total 73 species in the genus, and the population biology of selected species is currently receiving considerable attention in the sclerophyll shrublands of south-western Australia.

Population Structure

During the inter-fire period, it is desirable to know the size (number of individuals) or areal extent of the population and average density (number of individuals per unit area) of the population or area under consideration. We are concerned to see in what way the population size or area and density changes after the fire. In practice, identification of the population boundary may sometimes prove impossible. In this case, random plots or points placed in the study area can at least be used to detect overall changes in density with time. In our own work, we have dealt with population sizes varying from one (**Banksia tricuspis**) to over 5000 (**B. burdettii**), and from < 1/ha (**B. grossa**) to 1056/ha (**B. hookerana**) for 5 co-occurring species in the latter example. After an autumn fire 15 years since the previous fire, plant density after two years varied from unchanged (**B. menziesii**) to 16 times greater (**B. prionotes**) (Cowling & Lamont, unpub.).

Seed Production

There is a lot of data available on percentage follicle set in Banksias, but this is not as useful, for our purposes, as number of follicles/cone and number of seeds/follicle (to 2 decimal places). If all the cones on a plant are assessed for these, the total seed crop at a given date can be determined. In practice, this is a very onerous task, and sampling is usually necessary. One solution is to collect all the cones from one or two major branches leading from the ground or trunk. These are used for follicle and seed count. The remaining cones not collected are simply counted. Total seed crop is then given by mean follicles/cone x mean seeds/follicle x total cones/plant. In a 15 year-old stand in the Mt Adams area, canopy-stored seed varied from 16 (**B. menziesii**) to 1537 (**B. leptophylla**) per plant (Cowling and Lamont 1984).

Care should be taken to distinguish firm seed with white, intact kernels from aborted seed (thin and papery), predated seed (empty kernel with frass) and decayed seed (mouldy, empty or discoloured kernel). A preliminary study relating "firmness" to viability is desirable. There is the traditional tetrazolium test or germination at the optimal constant temperature. At the optimum of 15°C, germination of freshly-harvested, firm, 2-year-old seed of 3 widespread **Banksia** species was 11-76%, and of 8-year-old seed, 7-51% (Cowling & Lamont 1985a). To determine "effective" seed store, the total number should be multiplied by the mean proportion of viable seed.

Seed production varies from year to year, and it is desirable to know what seed would be available should a fire occur in any given year. One of the most obvious parameters (though of limited value) is the length of time after fire to first flowering and (more importantly) fruiting. The minimum recorded so far appears to be 4 of 20 lignotuberous plants of **B. attenuata** which flowered and set fruit 21 months after an autumn fire (Lamont, unpub.). Seedling **B. attenuata** have been observed to commence flowering at 4 years (B. Muir, pers. comm.). At the other extreme, we have observed plants of **B. tricuspis** up to 17 years old (mean of 15.5 years), 18 years after a fire, which have yet to flower (Lamont & van Leeuwen, unpub.). We have yet to establish if seed is set in the first year, or how long it takes seed to mature in this rare species. Very little information is available generally on the latter point, although Cowling (unpub.) found it took 4-8 months for four species of **Banksia**.

Time to achieve the first crop of mature seed is the first step in predicting the extent of recovery via seedlings following fire after a certain fire interval. To predict recruitment once the population has started annual flowering requires either counts of seeds on plants at matched sites with wide variations in time since the last fire, or knowledge of the history of annual seed production within old plants. The

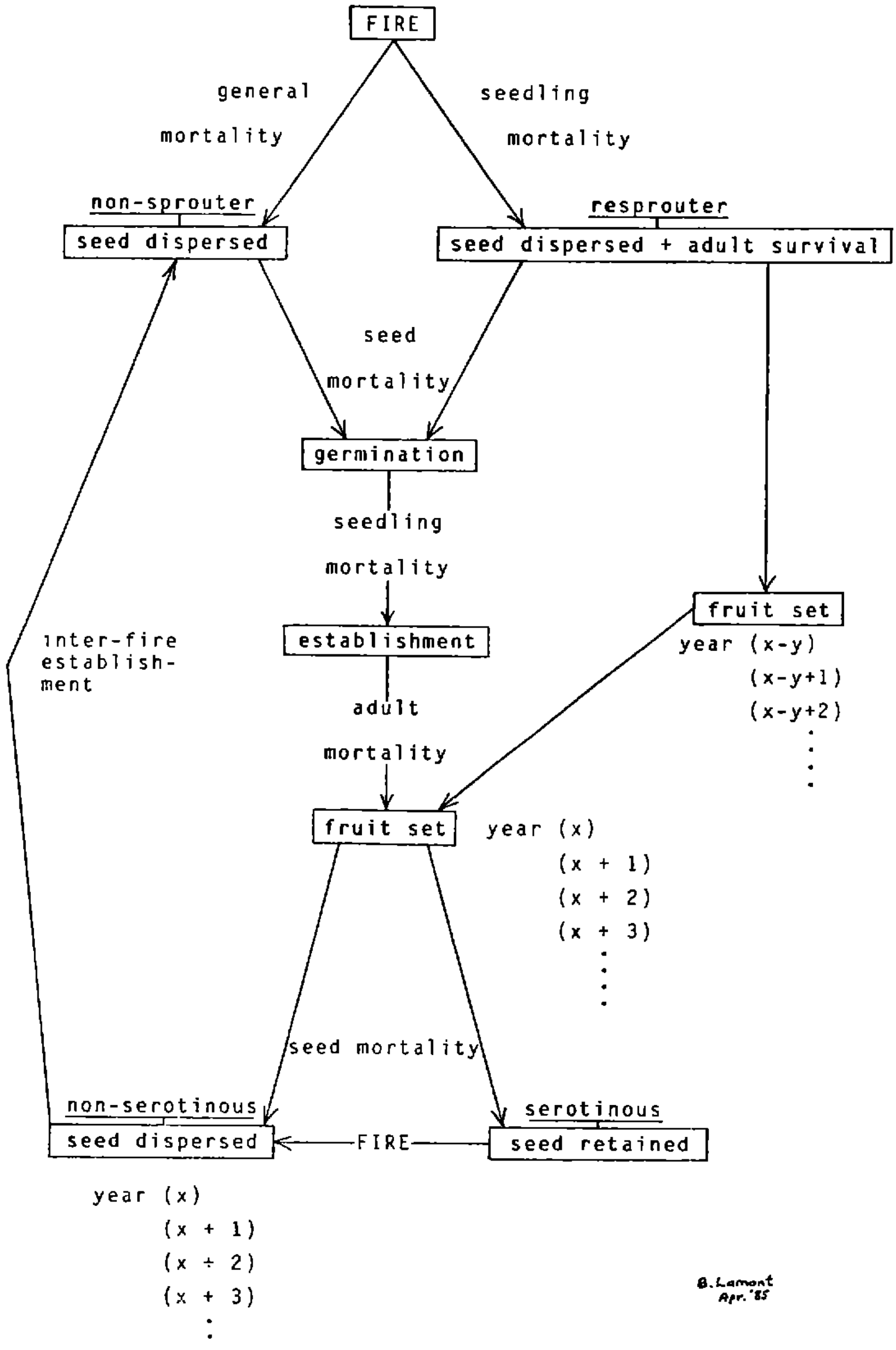

Figure 1. Flow diagram of events after a fire. Major events are boxed while changes in numbers of individuals or propagules are shown beside the arrows.

latter is facilitated in Banksias (and many other Proteaceae) by the nature of the annual branching pattern of the stems (Fig. 2). As the growing season ends, the terminal leaves tend to cluster. The new season's growth starts with closely spaced scale leaves which later become widely separated, scale leaves, often accompanied by axillary branching and diameter and colour changes. While this method heralds a convenient new approach to population studies (eg. Cowling & Lamont 1984, 1985a; Lamont 1985; Lamont et al. 1985) it is not without its teething problems. There is a tendency to underestimate stem age, as not all current year's terminal buds shoot that season. Cross-referencing between adjacent stems can help minimise this problem. Another difficulty is that, as the stems age, the growth pattern information is lost, especially prior to branching of the main trunk. Here, comparison with co-occurring young plants which still retain the signs can solve the problem.

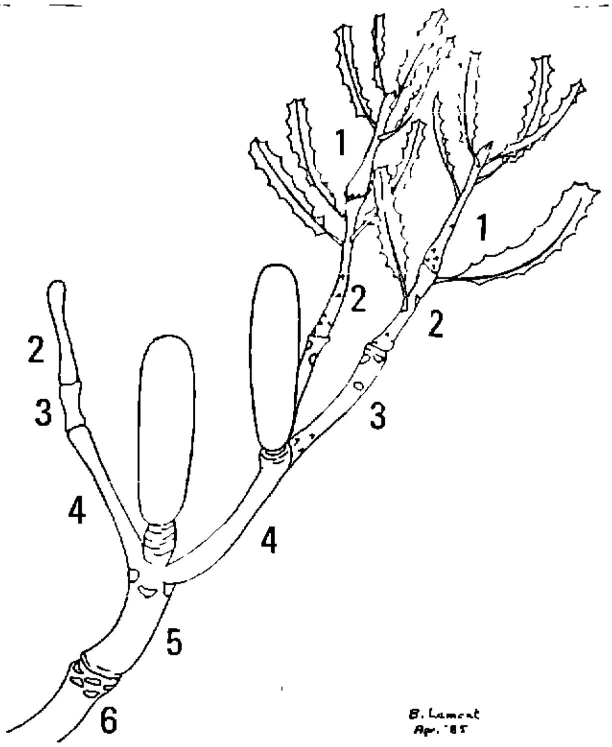

Figure 2. Annual stem increments in **Banksia menziesii**. The method can be used for ageing cones and whole plants.

In ageing cones, care has to be taken to distinguish those which terminate the current season's growth without a period of dormancy (eg. **B. hookerana**) and those which develop from a dormant terminal bud the next season (eg. **B. attenuata**), when the current season's stem arises from the base of the senescing cone (Fig. 3). The approach is unworkable for species in which the cones arise from within the canopy, ie

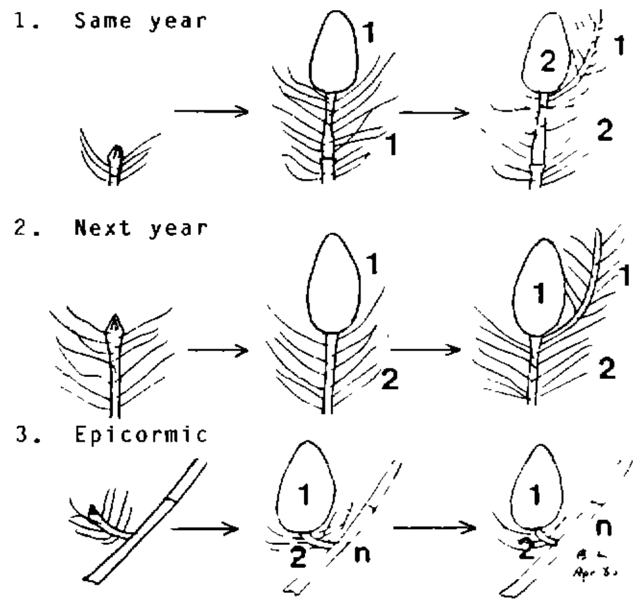

Figure 3. Age relationship of cones to the adjacent branches in Banksias. An example of 1 is **B. hookerana**, of 2 is **B. attenuata**, of 3 is **B. telmatiaea**.

out of sequence with the dominant growth pattern (the whole section of Banksias with hooked styles (George 1981)). In these cases, colour and condition of the cones can sometimes be used to estimate age. For each projected year of the fire, a correction factor should be applied to the total seed store to take into account changes in seed viability with time. Using the "node count" method, cones of 25 year-old resprouting B. attenuata were found to retain some firm seed up to 17 years at Northampton, diminishing progressively with more southerly populations (Cowling & Lamont 1985a).

Table 1. Percentage open follicles in one to 5 year-old cones of 3 Banksia species at 4 sites (Cowling & Lamont 1985a; van Leeuwen & Lamont, unpub.).

Species:	**B. prionotes**	**B. tricuspis**	**B. attenuata**	
Location:	Kings Park	Mt Lesueur	Cataby	Mt Adams
Year 1	0	1	19	0
2	100	31	45	0
3	100	79	79	18
4	100	97	96	22
5	100	100	100	20

Seed Bank

The seed available at the time of the fire is the summation of annual seed production minus annual seed loss for all years. Most seed loss is due to spontaneous seed release and, to a lesser extent, predation by insect larvae and cockatoos. The rate at which seed is released from the plant can be used to predict the effects of particular fire intervals on re-establishment by seedlings. Serotiny refers to the storage of seed on the plant, and "degree of serotiny" refers to the rate of seed release. This can be formalised by taking the slope of the linear regression fit to the percentage of open follicles in each successive year up to the first year with 100% open follicles (Cowling & Lamont 1985a). For B. **prionotes** in Kings Park, Table 1 shows that seed production immediately prior to the fire controls the size of the seed bank.

The seed bank of B. **tricuspis** and the Cataby population of B. **attenuata** is restricted to the 4 years before the fire, while the seed bank of the Mt Adams population of B. **attenuata** continues to build up over a much longer period. Geographical variation is probably important for other attributes as well, such as time to first flower (B. Muir, pers. comm.).

So far the concept of the seed bank has been restricted to that stored on the plant. But it is not necessarily true that dispersed seed no longer contributes to the seed bank. The issue is whether soil-borne seed survives fire, but no data are available. Siddiqi et al. (1976) reported survival of seed of two **Banksia** species at 100°C for 7 min. which needs confirmation.

We recorded a severe reduction in viability of seed of 4 Banksia species placed on the soil surface during September-February, apparently due to summer heat (Cowling & Lamont 1984), while seed of B. **integrifolia** was found to be inviable after burial for 2 years (Weiss 1984). With respect to canopy-stored seed, there are no reports of heat death of seed after fire has passed over the follicles. We found that 100% germination was achieved for seeds of B. **hookerana** from cones whose surface reached 288°C during flaming (Lamont & Cowling 1984 & unpub.). Soil-borne seeds are further depleted by predation (Abbott 1984), especially after spring fires (Cowling & Lamont 1984).

Immediate Fire Responses

Fire-sensitive parts (leaves, thin stems, buds, florets, young fruits, disintegrating old cones) are usually destroyed by the fire, depending on its intensity. Whole-plant sensitivity varies greatly between species: a mild summer burn which only scorched the leaves and left 88% of the cones unburnt, still resulted in death of all 15-year-old plants of B. **burdetti** (Barker & Lamont, unpub.). A hot autumn burn resulted in no death of 15-year-old plants of B. **attenuata**, which resprouted vigorously from the lignotuber (Cowling & Lamont, 1984). If the aim of management is to increase the population size of a particular species (whether or not serotinous or a resprouter) this is achieved by maximising both seed release and percentage of propagules that establish. Given a constant age of the stand, current indications are that, for many sclerophyll species, this is most likely to occur following a hot, autumn burn (Bond et al. 1984; Cowling & Lamont 1984; McMahon 1984). The reasons relate to the requirements for follicle-opening (Gill 1976; Lamont & Cowling 1984), seed release (Cowling & Lamont 1985b), germination (Sonia & Heslehurst 1978), and minimising length of exposure to summer heat and seed predators (Cowling & Lamont 1984). For example, if the cones of B. **burdettii** escape burning because of the mildness of the fire, < 5% of their follicles open after the fire compared with 92% of follicles in the burnt cones (Barker & Lamont, unpub.).

The distance seeds are dispersed from the parent plant is relevant to the effects of fire on population dynamics. The seeds of **Banksias** are winged and thus wind-dispersed, but no studies on dispersal patterns have been made.

In **Banksia**, 49% of the taxa are resprouters (Lamont **et al.** 1985). The others are killed by fire. This varies with the intensity of the fire and age of the plant, but there is almost no information available on the minimum age before a resprouting species will survive a hot fire. Our work on B. **elegans** showed over 98% regenerated from the lignotuber after a hot, summer fire (Barrett & Lamont, unpub.). Those whose main stem diameter was > 5.6 cm, at a height of 25 cm, also resprouted from the trunk, while those with a diameter < 1.4 cm were killed. Protection of the epicormic buds is clearly dependent of bark thickness, which contributed over 40% of stem width in a 8.4 cm wide sample of this species.

Delayed Fire Responses

Fires not only destroy the current crop of flowers but delay flowering by resprouting individuals for at least a further 2 years. This may well be followed by a period of enhanced seed set (J. Scott, unpub. thesis) but data are scarce. For non-sprouters, the delay is probably even longer, but the net effect of the fire on the seed bank needs to be compared against changes in seed production as the plant ages in the absence of fire. Table 2 shows that B. **hookerana** first sets seed in its fourth year. While cone production continues to increase, seed set per cone drops markedly after year 12. Any fire before this time would greatly reduce the potential seed bank in this species. Extrapolation indicates that by 20 years the seed bank in B. **hookerana** may have fallen to that at 6 years, so that the effect of fire on seedling recruitment at either time would be about the same. In B. **burdettii**, annual seed production was still rising in 18 year-old plants, the oldest available for study (Barker, unpub.).

Table 2. Annual cone and follicle production by a single, 14 year-old plant of Banksia hookerana at Eneabba (Lamont, unpub.).

Age (years)	Cones/plant	Follicles/cone	Follicles/plant
14	88	0.7	64
13	40	0.0	0
12	40	2.9	116
11	28	6.3	176
10	28	9.1	256
9	36	9.8	362
8	16	8.0	128
7	12	2.7	32
6	8	5.0	40
5	4	4.0	16
4	4	5.0	20
3	0	-	0
2	0	-	0
1	0	-	0

The importance of the so-called "ash-bed effect" in establishment of Banksia seedlings is uncertain at present. Weakly serotinous species, such as B. prionotes which forms uneven-aged stands, clearly establish in the inter-fire period without the benefit of additional nutrients, moisture and light that such an effect implies. Siddiqi et al. (1976) found that nutrient supplements had no effect on germination of 3 Banksia species, but no benefit on early growth either. We are currently assessing any possible interaction between the presence of ash and seed size in controlling the establishment of weakly and strongly serotinous Banksias.

The extent of post-fire seedling establishment will depend on the size of the seed bank (itself dependent on the previous fire interval, growing conditions during that time and vagaries of predation), growing conditions and extent of post-fire seed and seedling predation. For predictive purposes, data are needed on seedling establishment for a wide range of fire regimes (intensity, interval, season) at otherwise matched sites. McMahon (1984) showed that fires at intervals less than 4 years eliminated the non-sprouter, B. ornata, while seedling recruitment was still increasing 20 years after a fire. On the other hand, he concluded that the fire regime has no effect on the density of resprouters. In contrast, Zammit (1984) has reported greater plasticity in post-fire reproductive traits in a non-sprouting, than a resprouting, Banksia. In our work, 2 non-sprouting species had larger canopy-stored seed banks and greater seedling recruitment than the 2 co-occurring resprouters, 2 years after an autumn burn (Cowling & Lamont 1984 & unpub.).

B. elegans is one of only 3 Banksias which reproduces vegetatively. Suckering from the roots is stimulated by fire (or root disturbance), while establishment via seedlings has yet to be observed (Table 3).

Table 3. Presence of young suckers and seedlings of Banksia elegans in 200m plots before and after a hot fire at Lake Indoon (Barrett & Lamont, unpub.).

Fire	Mature Plants	Young Suckers	Seedlings
Before	100%	0%	0%
After	37%	63%	0%

Conclusions

This account has emphasised the value of research on the pattern of build-up of seeds by a population or stand of plants in the inter-fire period, followed by the pattern of events leading to the iminent and progressive reduction of the progeny before and after a fire. The rate of whittling down of propagules prior to establishment of the new generation very much depends on the fire regime.

The data already available highlight the wide range of possible responses to fire by different species, even in the same genus. A species by species analysis is clearly essential. The challenge is greatest in the species-rich sandplains. So far, even for one species, a piecemeal approach has been adopted, leaving many parts of the jigsaw puzzle incomplete. Elucidation of the full population responses to fire of any one key species will require a much more concerted effort. Only then will we be in a position to develop a predictive model of population dynamics that will assist fire management decisions aimed at ecosystem conservation.

Acknowledgements

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FIRE IN MULGA - STUDIES AT THE MARGINS

J.E.D. Fox

Introduction

It is axiomatic that one should only deal with what one knows. This explains my title. The most effort expended on studying the effects of fire in mulga has been in two localities, one in the south-west of the distribution of *Acacia aneura*, and one near the northern limit in the Pilbara. In the intervening region, mulga occurs in a range of landscapes, on several soil types and mixed with varying degrees of species associates. As we may characterise the general region of mulga occurrence as 'semi-arid to desert' in terms of climate, so, in a south to north direction, we must also note the predominance of winter rainfall at the southern margin and of summer rainfall in the north.

Economists lay great store by examining marginal costs, and many Australians' lives appear to be ruled by marginal tax rates. My justification for dealing with margins is basically historical - the sites are areas where the community has suggested studies would be valuable. In a realistic sense if margins are secure can we extrapolate to the centre? The reader must judge as to whether or not I skirt around the issues.

Definition of Mulga

Land which carries vegetation including trees or shrubs of *Acacia aneura* is spoken of as 'the mulga' or 'mulga country'. The definition is often extended to include vegetation communities dominated by other species of *Acacia* and to include communities inside what is generally perceived of as 'the mulga zone'. The vegetation can be determined floristically by the presence of the species *Acacia aneura* and structurally by the mean height of the dominant plants as either shrubland or woodland.

In describing the vegetation of the approximately 65,000 km^2 Wiluna-Meekatharra area, Speck (1963) utilised some 75 communities. Of these only the more saline areas, drainage lines and lake fringes may not have *Acacia aneura*. In the mulga communities *Eucalyptus* is generally infrequent. In the southwest stands of *E. oleosa*, *E. salmonophloia* and *E. loxophleba* may interdigitate with mulga communities on red earths while *E. comitae-vallis*, *E. leptopoda*, *E. kingsmillii* and *E. oldfieldii* are frequent on red sand plains. In the north different suites of species occur within hummock grasslands of *Triodia*. These include *E. leucophloia* on hills, *E. dichromophloia*, *E. gamophylla* and *E. setosa* on slopes and *E. patellaris*, *E. microtheca* and *E. camaldulensis* in valleys.

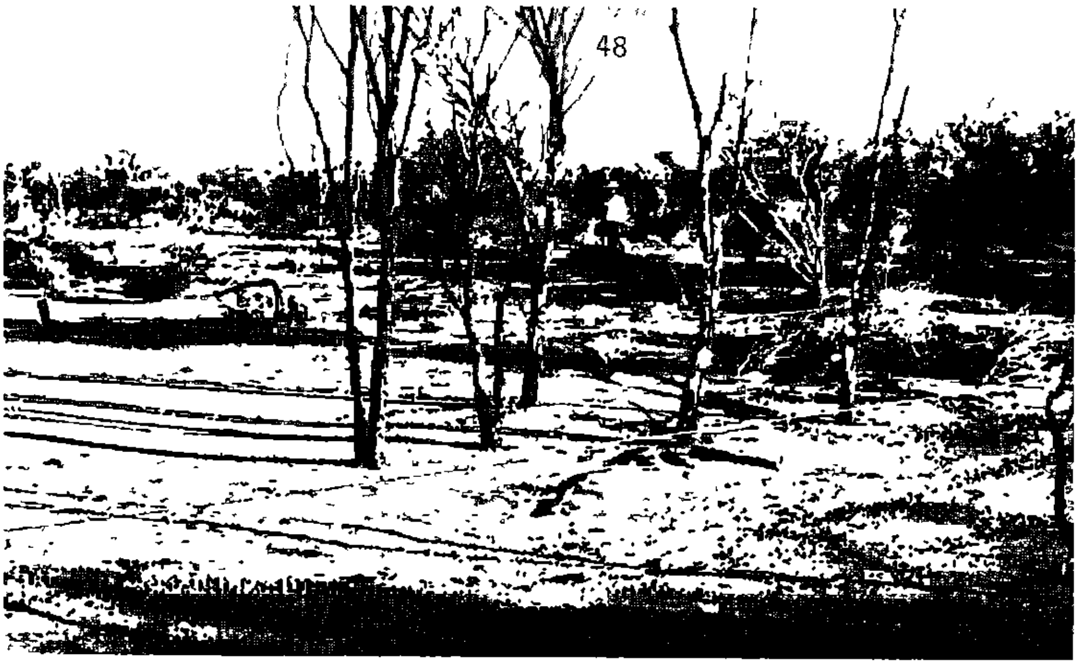
Most mulga communities can be characterised by the presence of other species of *Acacia* and by well developed shrub layers of *Eremophila*, *Cassia*, *Dodonaea* and Malvaceae. Speck (1963) found that species of *Eremophila* tended to be selective in relation to substrate and found they could be used to indicate particular communities. Grasses and daisies are seasonally abundant in mulga communities, and particular species may dominate local regions within mulga. In the north the spinifex hummock grasslands of *Triodia pungens*, *T. basedowii* and *T. wiseana* impinge on, and are often mixed with stands of *Acacia aneura*. In the south the spinifex grasses occupy more discrete communities with sharper boundaries and are represented by *Plectrachne melvillei* and *Triodia basedowii*, mainly on sand plain soils.

Ecological Ramifications of Fire in Natural Environments

Fire provides the most dramatic perturbation to mulga communities in contrast to the effects of domestic stock grazing, mining activities, urbanisation, and harvesting of wood produce. The main land uses for mulga woodlands are pastoral leases and unallocated crown land. In the latter case fire is neutral in terms of perceived land use. The main question in relation to pastoral activities is - does mulga enhance carrying capacity? In general, it is believed that it does, and that the vegetation in pastoral country is best utilised as grazing climax systems.

Other land uses include aboriginal occupation. Whether this is semi-traditional or not, fire can probably be classed as neutral again. In the case of mining exploration fire is beneficial in removing surface cover. In terms of the historical uses - production of mining timber, fuelwood, charcoal and producer gas, fire is disadvantageous in that it is destructive of wood.

The two localities examined are Menangina (29°50'S, 121°55'E) in the south, and West Angelas (23°05'S, 118°40'E) in the north. Heavy rainfall in 1973-1974 led to an abundance of grass growth in the goldfields. Fires swept across from the east in the summer of 1974-75 and covered large areas of mulga country. Menangina is a sheep station, and large areas were burnt in that first summer, and again in the two following years. These were the first fires recorded for the region since settlement, and the holder of the pastoral lease hypothesised that as long as 200 years might have elapsed since any earlier fire on the same scale (Fox 1980). Some suggest that the spectacular fires of the 1970s were exaggerated by fire exclusion (e.g. Griffin & Friedel 1984). For tne eastern Goldfields of Western Australia, this is difficult to accept. What had been a more or less stable, balanced system was at once changed. Both sheep and native herbivores had to make adjustments to available feed, and management came to terms with lost fencing, stock loss and a changed environment (Plate 1).



1. January 1978

2. July 1979

3. July 1982

PLATE 1. Plot 7, Area C Menangina, burnt January 1976 at 24, 42, 78 months from fire.

Lightning is frequent during summer thunderstorms in the north and it is certain that the increased level of human occupation in the Pilbara since the iron-ore boom has been associated with increased frequency of fires. The hummock grasslands of the Pilbara will burn after about 5 years of growth. Many fires started by lightning do not burn extensive areas as rain often follows. For this reason the spinifex/mulga edge is often sharply defined (Plate 2.1). The vegetation communities are varied, however, and there are many examples in which **Acacia aneura**, near its northern limits, occurs intimately mixed with **Triodia pungens**. A series of fires within the general vicinity of West Angelas occurred between 1973 and 1982. As this region is unallocated crown land, there are no important humanistic considerations involved. However, loss of scenic value may be ascribed to the nearby Hamersley Range National Park, where similar fires have occurred. Here it seems important to disentangle long-term natural fires, from changes in fire regime consequent on development.

Thus fire is a natural occurrence. The time scale is important and where changes in timing occur we need knowledge of the likely consequent changes to the ecological systems. The frequencies which some authors have postulated (e.g. Hodgkinson 1983) appear to bear little relation to the mulga woodlands at margins in Western Australia.

The dominant grass species influencing fuel availability are **Stipa variabilis** in the south (Leigh and Noble 1981) and east, and **Aristida contorta** in the west (Curry 1984). In groved mulga **Digitaria brownii** may be the dominant fuel. **Stipa** and **Aristida** fuels are ephemeral in contrast with the persistent **Triodia** fuels of the north. Pastoral use has led to some long term changes in grass species dominance. For example Suijdendorp (1981) suggests that tussock grasses of **Chrysopogon** and **Setaria** disappear in the north under heavy grazing pressure, to be replaced by **Triodia longiceps** on alluvial sites. The naturalised buffel grass, **Cenchrus ciliaris**, can colonise these areas if grazing pressure is reduced and the **Triodia** burnt.

Ecological Effects of Fire

Fire can be considered as an interruption to the normal state. Prior to fire, fuel will have accumulated and will stand ready to be consumed. After the fire, the cleansing effect will allow biomass accumulation to proceed more rapidly than before. The following effects have ecological significance in mulga woodlands:

1. Recycling of nutrients from biomass to soil.
2. Loss of foliage and litter cover.
3. Changes to surface soil structure.
4. Destruction of parasites.
5. Redistribution of herbivore pressure.
6. Creation of boundaries.

Each of these effects is discussed in turn.

1. The natural tendency is towards dominance by woody perennials. These eventually lock up much of the phosphorus within the system. Fire creates ash beds which play an important role in development of regeneration. Nutrients may be lost from particular sites by enhanced erodibility. The heat of the fire will condition hard seeds for germination, but a proportion of the seed bank will be lost through incineration.

2. Plant litter on the soil surface provides a more favourable site for seedling establishment of the dominant species, than does bare soil. Exposure reduces competition and enhances light availability. Seedlings of intolerant species can grow rapidly and take advantage of light and decreased transpiration draw. Loss of foliage stimulates the production of new growth from intact root systems. In the short term sprouting species will have considerable advantages over new plants of similar ecological requirements. Fire has a major role in governing species diversity in determining the entry and exit of species.

3. Surface structural changes to the soil may allow easier penetration by seedling roots. Movement of moisture into and within the soil will be enhanced, at least in the short term. Summer and winter burns may produce differential effects on realised soil moisture storage. Loosening of the soil-surface crusts will tend to minimise surface run off.

4. Fire will reduce population levels of parasites, predators, disease organisms and invading species. Of importance to **Acacia aneura** are mistletoes of the genera **Lysiana** and **Amyema** which accumulate on older trees in well watered sites. Insect herbivores tend to be more important on intolerant, invasive, species and the same is probably true for fungal disease organisms although **Uromycladium tepperanium** will also accumulate on older **Acacia aneura** on some sites.

5. Herbivore pressure tends to concentrate on new grass growth and this may permit new seedlings to become establisned in areas devoid of grass species. Larger animals may be expected to spend more time in refugia where shade is available. Cyclical changes in herbivore numbers are clearly going to be primarily influenced by the incidence of rainfall events after fire. If herbaceous and grass growth is delayed then more attention will be paid to regrowth from root stocks.

1. Area E burnt 3.5 years prior to photograph. Tall mulga in picture are dead, but form focii of some sprout and seedling regrowth.

2. Area E sprouts from near surface roots of Acacia aneura.

. Seedling growth of Acacia pruinocarpa at Area A, 2 years after fire.

PLATE 2
Regrowth at West Angelas

6. Fire reinforces boundaries and edge effects. These are most obvious between Chenopod communities (which are not at all fire susceptible) and mulga in the south, and between hummock grasslands on rocky soil and mulga on red earths in the north. Fire provides a barrier to another fire because fuel is consumed. However, post-fire grass growth might be more strongly stimulated by good following rain, so encouraging fire susceptibility. In the north the tendency is for a gradual loss of trees and shrubs in hummock grassland, with such thick barked species as **Hakea suberea**, **Acacia inaequilatera** and **Eucalyptus setosa** increasing relative to **Acacia aneura**.

Floristic Responses

Examination of floristic changes is useful to develop prediction capacity in relation to future fire, as well as documenting change. In Eastern Australia it has become fashionable to refer to the less palatable shrubby components of grazed mulga lands as 'useless woody weeds'. In Western Australia the more cautious term 'increaser species' is used to describe apparent changes in species numbers (density) associated with grazing. Fire is one of the few options that landholders have if they wish to influence species composition and stocking.

Species vary in their response to fire (Wilson & Mulham 1979). Two main strategies are resprouting and death followed by seed germination (Hodgkinson & Griffin 1982). Tables 1 and 2 document responses observed at Menangina and West Angelas respectively. I divide species into two categories: those characteristic of the mature vegetation 'the pre-existing species'; and those which occur after fire 'the invasive species'. Figures 1 and 2 illustrate typical growth patterns for selected species.

a) The pre-existing species

So far as we have been able to discover mechanisms to date, there is very little spasmodic or continuous recruitment of seedling **Acacia aneura**. Most natural stands are even-aged and reflect episodic/intermittent mass recruitment. In general regeneration is most prolific after heavy summer rain. At Menangina trees of **Acacia aneura** were killed by fire (Plate 1). Where the crown was scorched, death occurred within five years. Seedling recruitment was massive in response to subsequent rainfall where trees were burnt to ash, but very light and intermittent where the fire was not hot enough to consume the trees. No sprouting of pre-existing **A. aneura** has been recorded. By contrast at West Angelas sprouting (Plate 2.2; 3.2) has been observed in about half of the **A. aneura** at some sites, although in a number of sites all trees were killed. The early growth of sprouts, in height, is about double that of seedlings.

	West Angelas A1 (ht in cm) 1 year	5 years
seedlings	27.4	53.6
sprouts	63.3	126.3

At both localities the first year height growth for seedlings tends to be greater than for subsequent years. The mean seedling annual height growth at West Angelas is about double that for Menangina, presumably a reflection of the climate.

At Menangina the following, in addition to **Acacia aneura**, were killed by fire and may subsequently have produced seedling regeneration: **A. acuminata**, **A. stowardii**, **Casuarina cristata**, **Eremophila** species (e.g. **E. leucophylla**, **E. maculata**), **Ptilotus** species (e.g. **P. nobilis**) and **Solanum lasiophyllum**. Other studies suggest that **Cassia nemophila**, **Dodonaea angustissima**, **D. viscosa** (Hodgkinson 1982) and **D. attenuata** (Pressland et al. 1984) are killed and regenerate from seed, while a number of **Eremophila** species can resprout (Hodgkinson 1982). However some, e.g. **E. gilesii** (Griffin & Friedel 1982) will not survive fire and regenerate well from seed.

Acacia ligulata was also killed at Menangina, but seedling regrowth was much greater than those listed. Definite resprouting was observed in **Acacia hemiteles**, **A. ramulosa**, **A. tetragonophylla**, **Canthium lineare**, the mallee eucalypts (e.g. **E. leptopoda**) and **Exocarpus aphyllus**. Both **A. hemiteles** and **A. ramulosa** show a tendency to suckering. **Melaleuca uncinata** shrubs were burnt back to a lignotuberous base which produced basal sprouts. A number of species produced basal sprouts (though no doubt not from all pre-existing plants) as well as seedling germination. These included **Cassia artemisioides**, **C. nemophila**, **Dodonaea** species, **Eremophila** (at least in **E. longifolia**, possibly other species), **Grevillea nematophylla**, the vine **Leichardtia australis**, **Ptilotus** species (e.g. **P. obovatus**, **P. astrolasius**) and **Scaevola spinescens**. The sandalwood **Santalum spicatum** showed some resprouting ability but generally died.

Species which survived the fire at Menangina included **Alyxia buxifolia**, **Brachychiton gregorii** (small plants sprouted, trees regrew foliage or were too tall to be scorched), **Dianella revoluta**, **Eucalyptus oleosa**, **Olearia pimelioides** and **Ptilotus helipteroides**. Survival was associated with a tendency to solitary growth in some cases, lack of grass fuel or with **Alyxia** the foliage being somewhat resistant to fire.

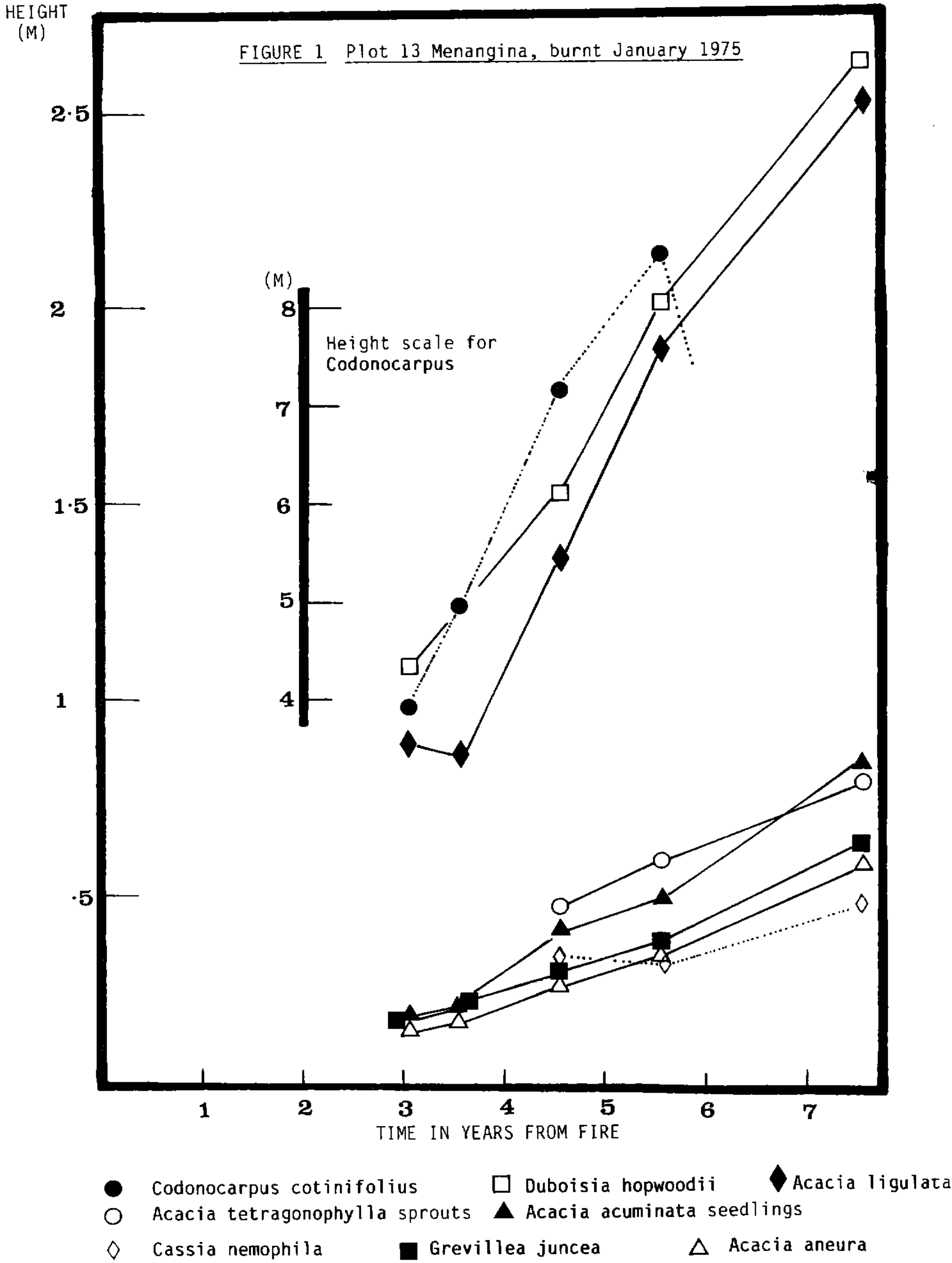

HEIGHT (M)
FIGURE 1 Plot 13 Menangina, burnt January 1975
2·5
2
1·5
1
·5
(M)
8
7
6
5
4
Height scale for Codonocarpus
1
2
3
4
5
6
7
TIME IN YEARS FROM FIRE
Codonocarpus cotinifolius
Duboisia hopwoodii
Acacia ligulata
Acacia tetragonophylla sprouts
Acacia acuminata seedlings
Cassia nemophila
Grevillea juncea
Acacia aneura

FIGURE 2 Site B1 West Angelas burnt about November 1978

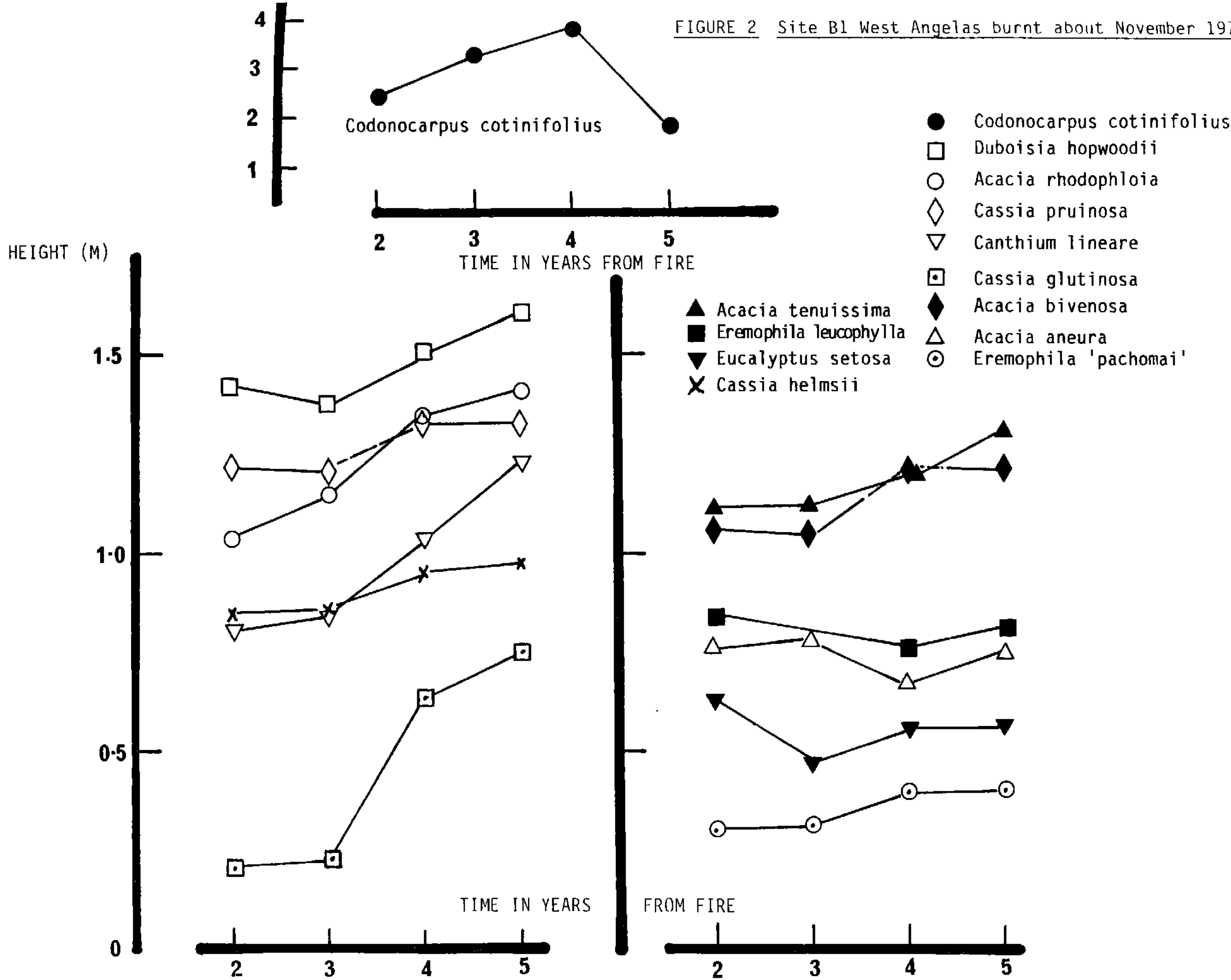


TABLE 1. Response to fire of the common perennial trees and shrubs encountered at Menangina, Eastern Goldfields, in mulga vegetation.

A - Burnt about January 1975, 8 plots sampled, total area 4000 m^2
B - Burnt about January 1975, and again in January 1976, 2 plots, 1000 m^2
C - Burnt about January 1976, 9 plots sampled, total area 4500 m^2
D - Burnt January 1977, 8 plots sampled, total area 4000 m^2
+ Present in the area sampled

SPECIES	A	B	C	D	Response: mode of regeneration
Acacia acuminata	+	-	+	+	Shrubs killed, seedling regeneration
Acacia aneura	+	+	+	+	Trees killed, seedling regeneration
Acacia hemiteles	+	+	+	+	Resprouts from base, root suckers & seedlings
Acacia jennerae	-	-	-	+	Pioneer, rapid growth from seed
Acacia ligulata	+	+	-	-	Killed, seedlings rapid growth
Acacia murrayana	+	+	+	-	Pioneer, rapid growth from seed
Acacia ramulosa	+	+	+	-	Resprouts from roots & seedlings
Acacia stowardii	-	+	-	-	Killed, seedling regeneration
Acacia tetragonophylla	+	+	+	-	Resprouts from base
Acacia warramba	+	-	-	-	Pioneer, rapid growth from seed
Alyxia buxifolia	-	-	+	-	Survives
Brachychiton gregori	+	+	-	-	Trees survive, small plants resprout
Canthium lineare	-	-	+	-	Resprouts from roots
Cassia artemisioides	+	+	+	-	Resprouts from base & seedlings
Cassia cardiosperma	-	+	-	-	Invader, seedling regeneration
Cassia nemophila	+	+	+	+	Resprouts from base & seedlings
Cassia pleurocarpa	+	-	+	-	Pioneer, rapid growth, short life span
Casuarina cristata	+	-	+	+	Trees killed, seedling regeneration
Codonocarpus continifolius	+	+	+	+	Pioneer, rapid growth, survives c. 6 years
Dampiera linearis	-	+	+	-	Invader, seedling regeneration
Dianella revoluta	+	-	-	-	Survives
Dodonaea attenuata	-	-	-	+	Invader, seedling regeneration
Dodonaea filifolia	+	-	+	-	Resprouts & seedlings
Dodonaea lobulata	+	+	-	+	Resprouts & seedlings
Duboisia hopwoodii	+	-	-	+	Pioneer, rapid growth from seed
Enchylaena tomentosa	-	-	+	-	Invader, seedling regeneration
Eremophila decipiens	-	-	+	-	Response unknown
Eremophila leucophylla	+	-	+	-	Killed (usually avoids fire)
Eremophila longifolia	+	-	-	-	Some sprouting & seedlings
Eremophila maculata	+	-	-	+	Killed (usually avoids fire)
Eremophila metallicorum	-	-	+	-	Response unknown
Eremophila scoparia	-	-	+	+	Response unknown
Eremophila serrulata	+	-	-	-	Invader, seedling regeneration
Eucalyptus comitaevallis	-	-	-	+	Mallee, resprouts
Eucalyptus concinnia	-	-	-	+	Mallee, resprouts
Eucalyptus leptopoda	-	-	+	-	Mallee, resprouts
Eucalyptus loxophleba	-	-	-	+	Resprouts & seedlings
Eucalyptus oleosa	+	-	-	-	Survives or resprouts
Exocarpus aphyllus	+	-	+	-	Resprouts from base
Grevillea nematophylla	+	-	-	-	Resprouts from base & seedlings
Grevillea ninghanensis	-	-	-	+	Invader, seedling regeneration
Halgania viscosa	-	+	-	-	Pioneer, locally prolific, small size
Indigofera australis	-	-	+	-	Invader, seedling regeneration
Lachnostachyus verbascifolium	-	-	+	-	Killed, seedling regeneration
Lachnostachyus coolgardiensis	-	-	+	-	Invader, seedling regeneration
Leichardtia australis	+	+	+	+	Resprouts from roots & seedlings. Rapid growth.
Maireana georgei	-	-	+	-	Seedling regeneration
Maireana planifolia	-	-	+	+	Seedling regeneration
Melaleuca uncinata	+	-	-	-	Shrubs, tops killed, resprouts from base
Nicotiana rosulata	-	-	+	-	Pioneer, rapid growth from seed
Olearia pimelioides	-	-	-	+	Survives
Ptilotus astrolasius	+	-	-	-	Resprouts & seedlings
Ptilotus helipteroides	+	-	-	-	Survives
Ptilotus nobilis	-	-	-	+	Killed, seedling regeneration
Ptilotus obovatus	-	+	-	+	Some sprouting & seedlings
Santalum spicatum	-	-	+	-	Some sprouting
Scaevola spinescens	+	+	+	+	Resprouts from base & seedlings
Sclerolaena diacantha	-	-	-	+	Invader, seedling regeneration
Solanum ellipticum	+	-	-	-	Seedling regeneration
Solanum hoplopetalum	+	-	-	-	Seedling regeneration
Solanum lasiophyllum	+	+	+	+	Killed, seedlings rapid growth to 20-50cm
Solanum orbiculatum	+	-	-	-	Seedling regeneration
Solanum numullarium	-	+	-	-	Invader, seedling regeneration
Solanum plicatile	-	-	+	-	Invader, seedling regeneration
Swainsonia kingii	+	-	-	+	Invader, seedling regeneration
Swainsonia oroboides	-	-	-	+	Invader, seedling regeneration

TABLE 2. Response to fire of the common perennial trees and shrubs encountered at West Angelas, Pilbara, in mulga vegetation.

A - Burnt between November 1979 and February 1980, 5 sites examined, total area 2500 m^2
B - Burnt November 1978, 4 sites examined, 2000 m^2
C - Burnt May 1973, 4 sites examined, 2000 m^2
D - 8 sites examined, previously unburnt from about 1970, 4000 m^2: of these 3 sites burnt January 1982
E - Burnt May 1978, 5 sites examined, about 2500 m^2
\+ Present in the area sampled

SPECIES	A	B	C	D	E	Response: mode of regeneration
Abutilon andrewsianum	+	-	-	-	-	Invader, seedling regeneration
Acacia aneura	+	+	+	+	+	Mainly killed, some sprouting, seedling regeneration
Acacia bivenosa	+	+	-	-	+	Killed, prolific seedling regeneration
Acacia citrinoviridis	+	-	-	-	-	Resprouts from base & seedlings
Acacia cowleana	+	-	-	+	+	Invader, seedling regeneration
Acacia dictyophleba	+	-	-	-	-	Some sprouting from base, seedling regeneration
Acacia farnesiana	+	-	-	-	-	Evades fire
Acacia inaequilatera	+	+	+	+	+	Survives, resprouts all over & seedlings. Thick bark
Acacia maitlandii	+	-	-	+	+	Pioneer, rapid growth, short life span
Acacia marramamba	+	-	-	+	-	Resprouts from base & seedlings
Acacia monticola	+	+	-	-	-	Killed, seedling regeneration
Acacia pachyacra	-	+	-	-	+	Pioneer, will also resprout from base
Acacia pruinocarpa	+	+	+	+	+	Resprouts at base, sometimes crown & seedlings, few persist
Acacia pyrifolia	+	+	-	+	+	Killed, seedling regeneration
Acacia rhodophloia	+	+	-	+	+	Mainly killed, some basal growth, seedling regeneration
Acacia tenuissima	+	+	-	+	+	Some sprouting from base, seedling regeneration
Acacia tetragonophylla	-	+	+	+	+	Resprouts from base
Acacia victoriae	-	-	+	-	-	Some sprouting from base
Anthobolus leptomerioides	+	-	+	+	-	Resprouts from roots
Canthium latifolium	+	+	-	-	-	Resistant, if burnt killed
Canthium lineare	+	+	-	+	+	Resprouts from roots
Cassia glutinosa	+	+	+	+	-	Resprouts from base & seedlings
Cassia helmsii	-	+	+	-	+	Resprouts from base & seedlings
Cassia notabilis	+	+	-	+	-	Pioneer, rapid growth, very short life span
Cassia oligophylla	+	-	+	+	+	Resprouts from base
Cassia pleurocarpa	+	-	-	-	-	Pioneer, rapid growth, short life span
Cassia pruinosa	+	+	+	+	+	Resprouts from base & seedlings
Capparis lasiantha	-	+	-	+	-	Killed, seedling regeneration
Codonocarpus cotinifolius	+	+	-	-	+	Pioneer, rapid growth, survives c.6 years
Dodonaea lanceolata	-	-	-	-	+	Response unknown
Dodonaea lobulata	-	-	-	+	-	Resprouts & seedlings
Dodonaea viscosa	+	+	-	+	-	Resprouts & seedlings
Duboisia hopwoodii	-	+	-	-	-	Pioneer, rapid growth from seed
Eremophila compacta	-	+	-	+	-	Resprouts & seedlings
Eremophila cuneifolia	-	+	-	-	-	Response unknown
Eremophila exilifolia	-	+	-	-	-	Response unknown
Eremophila fraseri	-	-	-	+	-	Killed, seedling regeneration
Eremophila freelingii	-	-	-	+	-	Killed, seedling regeneration
Eremophila leucophylla	+	+	+	+	-	Killed, seedling regeneration
Eremophila platycalyx	-	-	+	-	-	Resprouts & seedlings
Eremophila punicea	-	-	+	-	-	Resprouts & seedlings
Eucalyptus camaldulensis	+	-	-	-	-	Evades fire, some epicormic growth & seedlings
Eucalyptus dichromophloia	+	-	-	+	-	Resprouts all over, few seedlings
Eucalyptus gamophylla	+	+	-	+	-	Mallee, resprouts, seedlings rare
Eucalyptus leucophloia	+	-	-	+	-	Resprouts all over, seedlings rare
Eucalyptus microtheca	+	-	-	-	-	Evades fire, some epicormic growth & seedlings
Eucalyptus oleosa	-	-	-	+	-	Mallee, resprouts
Eucalyptus patellaris	-	-	+	-	-	Resprouts all over
Eucalyptus setosa	+	+	-	+	+	Survives, resprouts all over
Gossypium robinsonii	+	+	-	-	+	Invader, seedling regeneration
Grevillea berryana	+	-	-	+	-	Response unknown
Hakea suberea	+	-	-	+	+	Survives, resprouts all over. Thick bark.
Indigofera georgei	+	-	-	-	-	Invader, seedling regeneration
Indigofera monophylla	+	-	-	+	-	Pioneer, rapid growth, short life, small plant

SPECIES	A	B	C	D	E	Response: mode of regeneration
Jasminium lineare	+	-	-	-	-	Some sprouting & seedlings
Kallstroemia platyptera	+	+	+	+	-	Resprouts & seedlings
Kerandrenia integrifolia	+	-	-	-	+	Invader, seedling regeneration
Maireana georgei	+	+	-	-	-	Seedling regeneration
Maireana triptera	+	+	-	-	-	Seedling regeneration
Petalostyles labichioides	+	-	-	+	+	Pioneer, rapid growth to large bark
Ptilotus exaltatus	+	-	-	-	-	Killed, seedling regeneration
Ptilotus gomphrenoides	+	-	-	-	-	Killed, seedling regeneration
Ptilotus helipteroides	+	-	-	-	-	Killed, seedling regeneration
Ptilotus obovatus	-	+	+	-	-	Some sprouting & seedlings
Ptilotus rotundifolius	-	-	-	-	+	Killed, seedling regeneration
Ptilotus schwartzii	+	-	-	-	-	Killed, seedling regeneration
Rulingia rotundifolia	+	-	-	-	+	Invader, seedling regeneration
Santalum lanceolatum	+	-	+	-	+	Some sprouting
Sida cryphiopetala	+	-	+	-	-	Invader, seedling regeneration
Solanum lasiophyllum	+	-	+	+	-	Killed, seedlings rapid growth to 20-50 cm.
Tephrosia bidwillii	+	-	-	-	-	Invader, seedling regeneration
Trichodesma zeylanicum	+	-	-	-	-	Pioneer, rapid growth, short life

At West Angelas fire killed a number of species which were then replaced (if at all) by seedlings. These included Acacia bivenosa, A. monticola, A. pyrifolia, A. rhodophloia (this species showed some resprouting), Capparis lasiantha, Eremophila species (e.g. E. fraseri, E. leucophylla), Ptilotus species (e.g. P. exaltatus, P. gomphrenoides) and Solanum lasiophyllum.

In addition to Acacia aneura some sprouting combined with seedling regeneration was observed in Acacia citrinoviridis, A. dictyophleba, A. marramamba, A. pruinocarpa and A. tenuissima. Of these A. pruinocarpa sprouted most frequently and tended to produce many seedlings which did not survive for very long (Plate 2.3). Members of the genera Cassia (C. glutinosa, C. helmsii, C. pruinosa), Dodonaea (D. lobulata, D. viscosa) and Eremophila (e.g. E. compacta, E. platycalyx and E. punicea) also sprouted and showed seedling regeneration. Other species in this category included Jasminum lineare, Kallstroemia platyptera and Ptilotus obovatus. Of these Kallstroemia has thick corky bark, a feature also found in Acacia inaequilatera and Hakea suberea, both of which tend to survive fire well. They can regenerate new foliage from the crown, or if burnt back to the base, from the rootstock.

Other West Angelas species producing sprouts after fire include the wattles Acacia tetragonophylla and Acacia victoriae, the root parasite Anthobolus leptomerioides, Canthium lineare and Cassia oligophylla. Seedlings of these species are absent to infrequent after fire. Several other eucalypts which sprout but produce few, and then ephemeral, seedlings are the trees Eucalyptus dichromophloia, E. leucophloia and E. patellaris, and the mallees E. gamophylla and E. oleosa. The tree Eucalyptus setosa generally survives by profuse epicormic crown shoots, but is sometimes burnt out, when seedlings become established.

Species which survive fire include Acacia farnesiana and Eucalyptus camaldulensis. Their riveraine habitats are not usually subject to fire. Both will die if burnt, though E. camaldulensis has been noted along the Marillana River with profuse epicormic growth. Hodgkinson (1983) suggests that the fire sensitivity of this species may justify fire control to preserve it. At West Angelas E. microtheca also tends to survive fire by virtue of its habitat escaping fire. Canthium latifolium, an understorey shrub, may be damaged by fire - it does not resprout effectively and seedlings are rare - but it generally avoids fire for similar reasons to those given for Alyxia buxifolia at Menangina.

It must be emphasised that, for both localities, it is not yet clear whether the species recorded as sprouters can persist and regain their former stature. The growth differential between sprouts and seedlings of the same species is similar to that quoted for Acacia aneura at West Angelas. Persistence of sprout growth can be readily confirmed in the mallee Eucalyptus gamophylla (Plate 3.3)and in the case of E. patellaris by reference to a range of older stands (e.g. Plate 3.1). The former retains the mallee habit whereas the latter develops a single dominant stem with some old specimens consisting of a broad clump of up to a dozen tree like stems presumably joined to one large underground lignotuberous mass. In these cases survival is not in doubt. However it is possible that for the Acacia and Cassia species in particular sprouting ability may be related to the species' ability to survive drought rather than fire.

1. Eucalyptus patellaris, burnt at least five years (possibly 10) prior to photograph.

2. Acacia aneura Area C. Resprout 8.5 years after fire.

3. Eucalyptus gamophylla Area B, burnt 3 years before photograph taken.

PLATE 3. Regrowth strategies observed at West Angelas.

b) The invasive species

Here two groups are proposed. The first group consists of 'pioneers': species which are absent in mature stands and which tend to have a comparatively short life span. The second group 'invaders' includes species which occur in unburnt stands and may also be present in creek beds or other sites of unstable long term habitat. These tend to occur in greater numbers on burnt sites.

A total of 14 species are considered to possess the attributes of pioneer species. Of these three are common to Menangina and West Angelas, five are present at Menangina only and six at West Angelas only. The most spectacular of the pioneer species is the desert poplar **Codonocarpus cotinifolius**. This tree grows rapidly to 8-10 m and then dies. The specimen illustrated in Figure 1 was 4 m tall three years after fire and attained 8.6 m at 66 months after the fire and then died. This tree is illustrated in Plate 4, scenes 1 and 2. Following the Eastern Goldfields fires this species could be seen towering above the blackened remains of dead Acacia trees over a broad area. In the Pilbara early height growth is similar but attained height appears to be lower. It sets profuse seed which is difficult to germinate under laboratory conditions. The fast grown wood is soft and readily attacked by wood borers while the foliage becomes infested with swarms of Pentatomoidea bugs. **Duboisia hopwoodii** is a Solanaceous shrub which also appeared in large numbers at Menangina after the fires (Plate 4.3). It is much less common in the Pilbara. This species is poisonous to sheep and presents a severe hazard to pastoral activity in the first year or so after fire. Its life span is considerably longer than that of desert poplar, with maximum height reaching about 4 m. The third species common to both areas is Cassia pleurocarpa. At Menangina this species was observed in 2 sites. Well spaced plants on heavy ash developed at one site (that shown in Plate 1), to a mean height of 37 cm at 2 years, 73 cm at 2.5 years and 151 cm at 3.5 years. All plants died at 4 years after the fire. At the second site, more, smaller, plants developed on less ash to 25 cm at 2 years and 73 cm at 3.5 years. Again all were dead at 4 years from fire. **Cassia pleurocarpa** is less common at West Angelas. The only record is of one plant at 46 cm tall one year after fire. This had died by the second year.

Cassia notabilis is a common pioneer in the Pilbara area. It reaches 50 cm in a year at West Angelas and, like the preceding species, rarely survives more than two years. Two Acacia species at West Angelas are classed as pioneers, viz. **A. maitlandii** and **A. pachyacra**. The former attains a height of 1.5 m on favourable sites and survives to about 8 years, with a high attrition of numbers between 2-4 years after fire. The latter is capable of rapid growth to 1.5 m and can survive a second fire by resprouting from the base. It is more frequently found in areas with **Triodia pungens** than **A. maitlandii**. **Indigofera monophylla** is a low shrub < 50 cm of short life, often abundant during the first year after fire on stony ground around burnt mulga trees. **Petalostyles labichioides** attains heights of 2 m in moist flushes and narrow creeks. It behaves as a pioneer on upland mulga sites attaining 1 m in 3 years after fire. On these sites it rarely survives more than 5 years. The final species designated a pioneer for the West Angelas area is the cattle bush **Trichodesma zeylanicum**. This herbaceous perennial grows rapidly on or near ash beds to 1.5 m tall generally dying off at 2-3 years after fire.

At Menangina three rapidly growing species of Acacia are classed as pioneers. Of these **A. jennerae** and **A. warramba** are uncommon. The third is **A. murrayana** which can attain 3.5 m at 4 years after fire and 6 m at 8 years. The life spans of these three are not known but probably do not exceed 15 years. Elsewhere **Acacia murrayana** will sprout and is said to have a life span of 15-25 years (Maconochie 1982). The small shrub **Halgania viscosa** was particularly abundant at a twice burnt site at Menangina. It can persist for several years. **Nicotiana rosulata** is also classed as a pioneer, but little is known of this species.

Finally, turning to species classed as invaders, some dozen or so may be designated for each location (Tables 1 and 2). Both sets include representatives from the legumes including a **Cassia** and **Swainsonia** species for Menangina, a **Tephrosia** and an **Acacia** at West Angelas, and an **Indigofera** for both. The West Angelas area has several Malvaceae (**Abutilon**, **Gossypium** and **Sida** species), Sterculiaceae (**Keraudrenia** and **Rulingia**) and Chenopodiaceae (**Maireana** species). Chenopods are also common at Menangina (**Euchylaena**, **Maireana**, **Sclerolaena**) along with **Solanum** species. Species of **Ptilotus** are common in both areas but owe their abundance more to seasonal rainfall than fire per se. **Eremophila serrulata** is an invader at Menangina together with **Dodonaea attenuata**.

1. Codonocarpus cotinifolius No 45 in Plot 13, Area A at 4.5 years from fire.

2. The same tree 12 months later.

3. Duboisia hopwoodii No 77 in Plot 13, Area A at 5.5 years from fire.

PLATE 4. Pioneer species at Menangina.

Conclusions

In this broad survey a number of ecological consequences of fire have been alluded to. It is contended that fire in mulga is uncommon, that when it occurs it sets in train a succession sequence which is only now coming to be understood. At the northern margins mulga is under constant threat from spinifex fires and spinifex encroachment. In the Goldfields recent devastating fires may lead to a decline in cover and may predispose the landscape to more fire on a shorter cycle. Where grazing pressure is high (sheep, rabbits) then irreversible change may have been initiated (Lay 1984, of South Australia).

Fire has the biggest impact on change to mulga communities. Its effects include turnover of nutrients, invasion of temporary species, temporary loss of species and gradual regeneration towards the pre-existing condition. All dry vegetable matter will burn under appropriate circumstances. The major fuel sources in mulga country are the ground layer of grasses. The presence of sufficient fuel to carry fire is a function of prior rainfall history, whereas what happens after fire tends to be a function of the ecological community affected. The greatest fire risk in dense mulga follows above average periods of rainfall when abundant grass-growth dries off. This material may be so dense that the available herbivores are unable to make much impression on it.

In the southern, sheep-carrying areas, most pastoralists are wary of fire, see no value in its use and will probably only experience the 1975-1977 scale of fire at very infrequent intervals. Increased emphasis on fire breaks may reduce damage caused by fires.

In the north the position is far from clear. It would appear that increased frequency of fire has occurred, and that if this trend continues the spinifex hummock grasslands may encroach into areas now carrying woodlands. Educational programmes directed at the new mining communities may be useful. Attempts by northern pastoralists at stock management by vegetation manipulation in areas which are not presently understood should avoid the use of fire. Fire management requires investigation before fire can be advocated. Indeed fire may turn out to be the least useful management tool available to northern pastoralists.

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FIRE IN THE NORTHERN JARRAH FOREST

F.J. Hingston

Introduction

Plant species in the jarrah forest and the biological processes that sustain the ecosystem have evolved with fire. Fire was used by Aboriginal man for thousands of years before Europeans arrived (Hallam, this symposium) and has been a factor shaping the composition of Australian plant communities. In the south west of Western Australia charcoal layers and burnt peat deposits found in palynological studies of lake sediments by Churchill (1968) have provided C14 dates for fire episodes extending back in time for at least 7000 years. On the continental scale biogeographic studies (Keast 1981) give evidence for the presence of fire during evolution of Australian flora since the mid-Miocene period, about 50 million years ago. During this period the Australian climate began to get drier and rainforests began to retreat, leaving xerophytic plant communities in which eucalypts and other fire-adapted species became dominant.

Factors predisposing jarrah forest to periodic fires are the build-up of litter, the flammability of shrubs and trees and the long, hot and dry summer, when conditions are favourable for ignition and spread. Natural events such as lightning strikes are responsible for some fires but the increase in population and development of the region has markedly increased the chance of accidental ignition. As a means of reducing the risks of destructive wildfires, sections of the forest are burnt under controlled conditions on about five to seven year rotations.

The objective of this brief review is to discuss some of the ways in which the jarrah forest ecosystem is affected by fire.

Location and Description

The northern jarrah forest extends from the catchment of the Helena River in the north to the catchment of the Collie River in the south (approx. 200 km) and from the western edge of the Darling Scarp eastwards to a line joining the eastern extremities of the two catchments (approx. 27 km) (Fig. 1).

It is a complex ecosystem in which Havel (1975) recognised and described nineteen site-vegetation units. Plant communities on the most extensive units have an overstorey dominated by Jarrah (Eucalyptus marginata) with Marri (E. calophylla) making up a third of the trees on lower hillslopes in the higher rainfall areas to the west, and Wandoo (E. wandoo) is a prominent component in the east. Common understorey species are Banksia grandis, Allocasuarina fraserana and Persoonia species. Numerous woody perennials up to about 1.4 m high form a shrub layer (Havel 1975).

How Does Fire Affect Plants?

Species in jarrah forest communities are well adapted to cope with periodic fires. The mechanism of survival varies with species and the effects of fire intensity, fire frequency and the season when burning occurs, add further dimensions to the response of the plant community.

Examples of all of the mechanisms through which plants survive burning (Gill 1981) can be found in jarrah forest.

If fires are intense enough to scorch mature plants completely, some species are killed and can only be replaced by germination from seed stores in the soil (eg. Acacia pulchella) or seed dropped to the ground after protective woody fruit held on mature plants split open following fires.

Large trees such as jarrah suffering 100% leafscorch survive even after intense fires because of their thick insulating bark. They regenerate from epicormic buds and undamaged active pre-fire buds.

Many shrubs are completely scorched but regenerate from subterranean buds on root suckers, basal stem sprouts and horizontal and vertical rhizomes. In fact approximately 70% of species in the dry sclerophyll forest survive in this way. Among the first species to reappear after intense fires are Pteridum esculentum (bracken) and Macrozamia riedlei both of which regenerate from subterranean organs. Increases in the numbers of Pteridium esculentum and lignotuberous jarrah plants in areas regularly burnt by low intensity fires compared with adjacent unburnt forest (Christensen & Kimber 1975) are due to ready vegetative regeneration.

An important consideration in survival of plant communities is that fires in native forest result in a mosaic burning pattern (Christensen & Kimber 1975) in which the intensity of burning varies widely. Therefore even those species not highly adapted to cope with burning, can survive in patches that fires by-pass and are recruited from these to more intensively burnt areas.

The available evidence for jarrah forest communities shows that the numbers of plant species and their density in an area are only slightly altered by burning (Peet 1971; Christensen & Kimber 1975). The number of species in regularly burnt areas is slightly higher than on areas unburnt for long periods. Frequent low intensity fires result in communities with low numbers of hard-seeded species (Peet 1971). Conversely hard-seeded species commonly regenerate in large numbers from seed stores in soils (Shea et al. 1979) following high intensity fires.

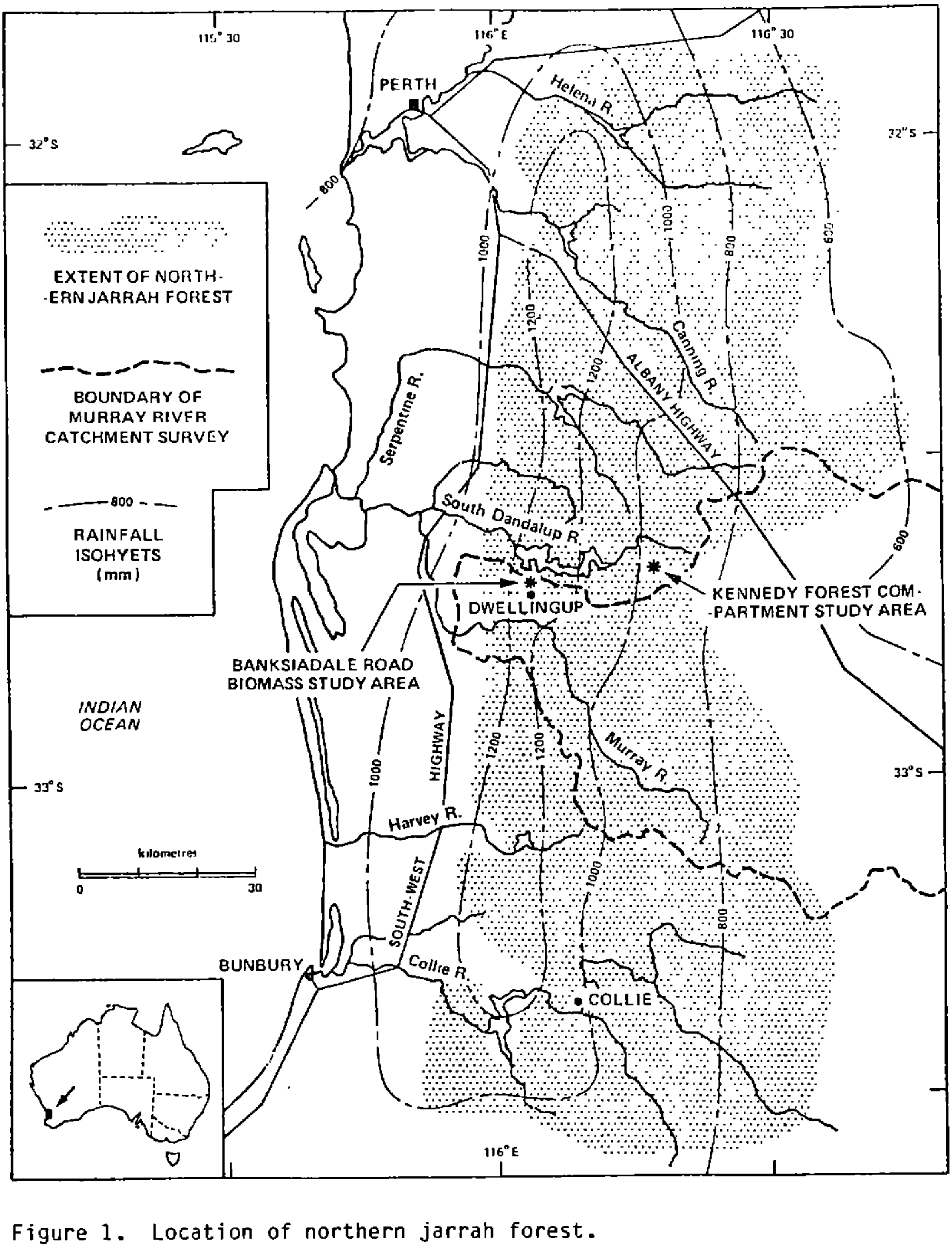

Figure 1. Location of northern jarrah forest.

How Does Fire Affect Nutrient Stores in the Ecosystem?

The amounts of nutrients transferred from one part of the ecosystem to another or lost as a consequence of burning depend on the intensity of the fire and the initial state of the stand. A conceptual scheme indicating transfers of nutrients and effects of fire is shown in Figure 2.

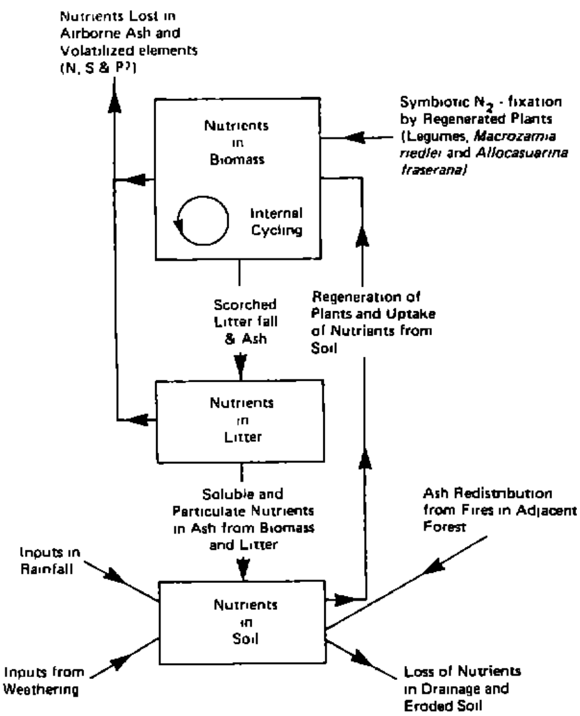

Figure 2. Effect of fire on nutrient cycling in the jarrah forest ecosystem.

Regular (5 to 7 years) low-intensity fires, used to limit litter build-up, mainly affect the litter layer and groundcover. Combustion of this material is usually incomplete and non-volatile elements are transferred to the soil surface in ash. The elements N and S are volatilised but because of the low fire intensity the proportion lost will be much less than for wildfires and high-intensity prescribed burns. Hatch (1959) found no significant differences in the nutrient concentrations or other properties in the surface (0-9 cm) of soils sampled from adjacent areas of regularly burnt and unburnt forest. Thus the long-term effect of ash additions was too small to detect in the soil.

Intense prescribed fires and wildfires result in combustion of litter, bark on trees, green shrubs, leaves in the overstorey and large fallen logs. Green leaves in tree crowns that are scorched, subsequently fall as litter containing higher concentrations of nutrients than normal senescent leaf litter (O'Connell et al. 1979). Glossop et al. (1980) found slight decreases in the concentrations of N and P in scorched jarrah leaves compared with pre-fire concentrations in green leaves. These decreases were accompanied by slight increases in these elements in branch tissues, indicating that there was translocation within the tree as a result of burning and some nutrients in scorched leaves were retained. Substantial quantities of nutrient elements are transferred from the above-ground biomass and litter to the soil. A proportion of the volatile elements (N and S) is lost to the atmosphere. However estimates of the amounts of elements transferred and volatilised made from field studies are very approximate because of the variability of forest systems and the need to make assumptions about the proportions of components burnt. Grove and his co-workers (T.S. Grove, pers. comm.) have found significant increases in the easily extractable forms of elements by sampling shallow depths (0-3 cm) of soils before and immediately following an intense fire. One year later concentrations of extractable elements returned close to the pre-burn levels. The initial increases, due to addition of ash to the surface soil and heat, were well correlated with the amounts of elements in pre-burn litter.

Jarrah forest soils generally contain low concentrations of nutrients in readily extractable forms (Hingston et al. 1981) and plants are therefore responsive to nutrient additions. Elements contributed in ash are probably readily taken up by regenerating trees and shrubs. Evidence of increased uptake for Macrozamia riedlei is provided by the increase in growth rates and nutrient concentrations in green leaves for several years following an intense fire (Grove et al. 1980). After intense fires Wallace (1966) observed short-term increases in the growth rate of jarrah but measurements made over longer periods showed no evidence of a long-term effect (Abbott & Loneragan 1983).

Do Fires Result in Losses of Nutrients?

It is well known that fire volatilises a large proportion of the C, N and S during combustion of organic material (DeBell & Ralston 1970). Other constituent elements are converted to ash, some of which is carried into the air by convection and transported away from the site by wind. Raison (1980) estimated 50-60 kg N, 5 kg S and 3 kg P per hectare are lost during combustion of 17 tonnes per hectare of E. pauciflora forest fuel (components < 10 mm), i.e. 60% of the N and S and 50% of the P in the fuel. More recent studies by Raison **et al.** (in press) suggest likely significant losses of P in non-particulate in addition to particulate forms. Grove and his co-workers (T.S. Grove, pers. comm.) interpret their results from studies of soil nutrient contents before and after an intense burn at seven sites in jarrah forest as showing that substantial losses of N, S and K are possible. Losses of all elements in ash can occur in particulates, while N, S and possibly P may be lost in non-particulate forms. Processes capable of balancing these losses are N_2-fixation, accession of S, K and other elements in rainfall, contributions of ash from fires in adjacent forests. The additions of N to the ecosystem, through N_2-fixation by legumes (Hingston **et al.** 1982) and by non-legumes such as Macrozamia riedlei (Grove **et al.** 1980), depend on factors such as burning history, availability of P in soils, weather conditions, and plant density. Estimates of inputs are therefore only approximate, but at common plant densities about 3 kg N per hectare per year may be added by legumes for several years following fire and, on average, about 5 kg N per hectare per year by **M.** riedlei for the first seven years following fire. Non-symbiotic fixation in the litter layer of jarrah forest (O'Connell **et al.** 1979) makes a further small addition to the ecosystem (possibly 1 kg N per hectare per year).

Annual accessions of S and K in rainfall for the jarrah forest region are approximately 5 kg per hectare per year (Hingston & Gailitis 1976).

Although airborne ash is lost from the sites of fires, particularly intense fires, Hingston & Galbraith (1984) showed that significant quantities of nutrients are redistributed as ash fallout in adjacent forest. Therefore some of the elements lost in particulate form during one fire, may be deposited as inputs at another time from fires on adjacent areas.

Release of elements through weathering is difficult to estimate, but the predominant soils in jarrah forest are lateritic with low concentrations of elements in weatherable mineral forms. It could be expected therefore that nutrient contributions from this source would be very low.

Summary

Fire has been an integral component of the jarrah forest environment extending into prehistory. Indigenous plant species are well equipped to survive burning and regenerate rapidly. For the most part effects of burning on botanical composition of forest communities appear to be transitory.

Burning as it affects nutrient cycling is responsible for loss of nutrients and transfer of nutrients in litter and combustible biomass to soils. Thus nutrients in litter are rapidly released in available form rather than slowly released by litter decomposition. The available evidence suggests that these nutrients are rapidly taken up by the vegetation and the system returns to its pre-burn state.

Nutrients such as N and S are partially volatilised during fires and are readily lost from the ecosystem. There are natural, to some extent compensating, processes resulting in inputs of both these elements and their accumulation in biomass. However it is difficult to determine with certainty whether balances of inputs and outputs are achieved.

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FIRE IN SOUTHERN TALL FORESTS

P. Christensen and A. Annels

Introduction

It is now well established that fire is an inevitable and recurrent event in most eucalypt forests in Australia (Gill et al. 1981). In the southern tall forests of Western Australia fires are also known to have occurred long before the arrival of Europeans (Churchill 1968; Hallam 1975).

If fire is a natural part of the environment, what role does it have to play in the continuation of natural processes in these forests? There is a considerable body of literature on this topic throughout Australia (Gill et al. 1981; Gill 1975) and some work has also been done in the southern tall forests of Western Australia (e.g. Christensen & Kimber 1975).

The results indicate a very wide range of adaptation to cope with fire regimes. No one plant- or animal-species appears to have quite the same requirements. Some species require periodic fire in order for viable populations to continue to exist (Christensen & Kimber 1975; Christensen 1980).

It has also been amply demonstrated both here and in eastern Australia that if forest areas are left unburnt for prolonged periods they ultimately catch fire resulting in devastating wildfires which cannot be controlled. Forest managers recognise this and since the 1950s and 1960s have carried out a programme of regular prescribed fire to prevent the buildup of fuels to dangerous levels (Underwood & Christensen 1981; Underwood & Sneeuwjagt, this symposium).

For these reasons fire exclusion is not a practical option in the southern forests: prescribed fires are necessary both for fuel reduction purposes and for ecological reasons.

How do we reconcile this need to burn with the lack of ecological data on the requirements of the majority of plant and animal species? The manager simply cannot wait for scientists to complete studies on all species before initiating burning programmes. To do so would endanger human as well as ecological values.

We suggest that it is possible to modify present burning programmes, based largely on fuel reduction criteria, using data on past fire regimes. Evidence of pre-European fire regimes in the southern forests is available from a number of different sources. The object of this paper is to examine some of these and to suggest ways in which the information may be used in fire management.

Evidence of Past Fire Regimes

For the purposes of this paper we have chosen to define the southern forests as vegetation associations within the 1140 mm isohyet (Fig. 1). This will include all the tall open forest of Karri (Eucalyptus diversicolor) and Tingle (E. jacksonii, E. guilfoylii), large areas of forest composed of Jarrah (E. marginata) and Marri (E. calophylla), also included are woodlands of Peppermint (Agonis flexuosa), Banksia spp. and Allocasuarina fraseriana, treeless sedgelands, shrublands, and coastal heathlands all of which are associated with these forests. We consider all of these plant associations as part of the tall southern forests (Fig. 2).

Fire Frequency

Churchill (1968) found charcoal in peat cores extracted from a number of south-west swamps. In one instance he accurately dated these charcoal occurrences in a core from the Weld Swamp in Karri forest south of the Shannon River (Fig. 3). Fires severe enough to burn out the swamp have occurred at regular but fairly infrequent intervals over the last 5000 years or more. Fires appear to become slightly more frequent towards the present, occurring every few hundred years.

More recent evidence of infrequent intense fires may be obtained by examination of fire scars and evidence of epicormic growth in cross sections of trees cut for timber. Karri trees reach an age of approximately 350-400 years (unpub. F.D. data on growth ring counts) and Jarrah 400 plus years (Jacobs 1955; Abbott & Loneragan 1983). No quantitative data are available but examination of trees and wood at sawmills gives the overriding impression that few such intense fires occurred during the life of most trees.

The work of Lamont & Downes (1979) and Abbott & Loneragan (1983) in the Jarrah forests to the north support the conclusion that intense fires were an infrequent event in the past.

There are however indications suggesting that low to moderate intensity fires occurred at regular and comparatively frequent intervals in the past. Work by Briedahl (pers. comm.) shows that the Karri forest, at least in the areas he studied, is composed of uneven aged stands of trees (Fig. 4). Such stands can only be achieved by continued germination and survival of seedling Karri. This can occur only in the absence of a dense litter and scrub layer, following fire or other disturbance. Evidence obtained by Kimber (pers. comm.) suggests that Karri seedlings seldom develop in the absence of fire (Table 1). These facts would tend to suggest that fire occurred fairly frequently in Karri forests.

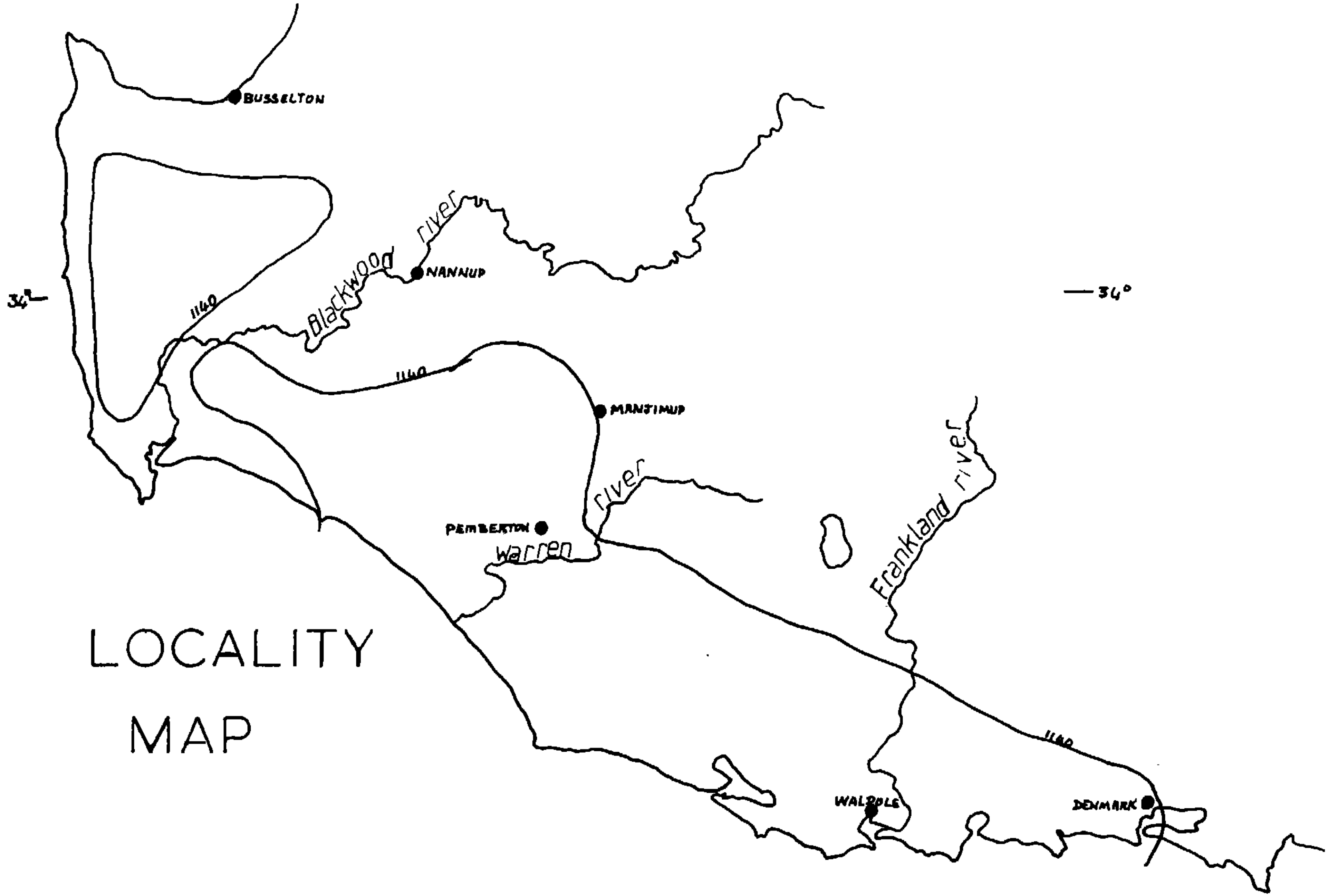

Figure 1. South-western Australia showing the area within the 1140 isohyet referred to here as the southern forests.

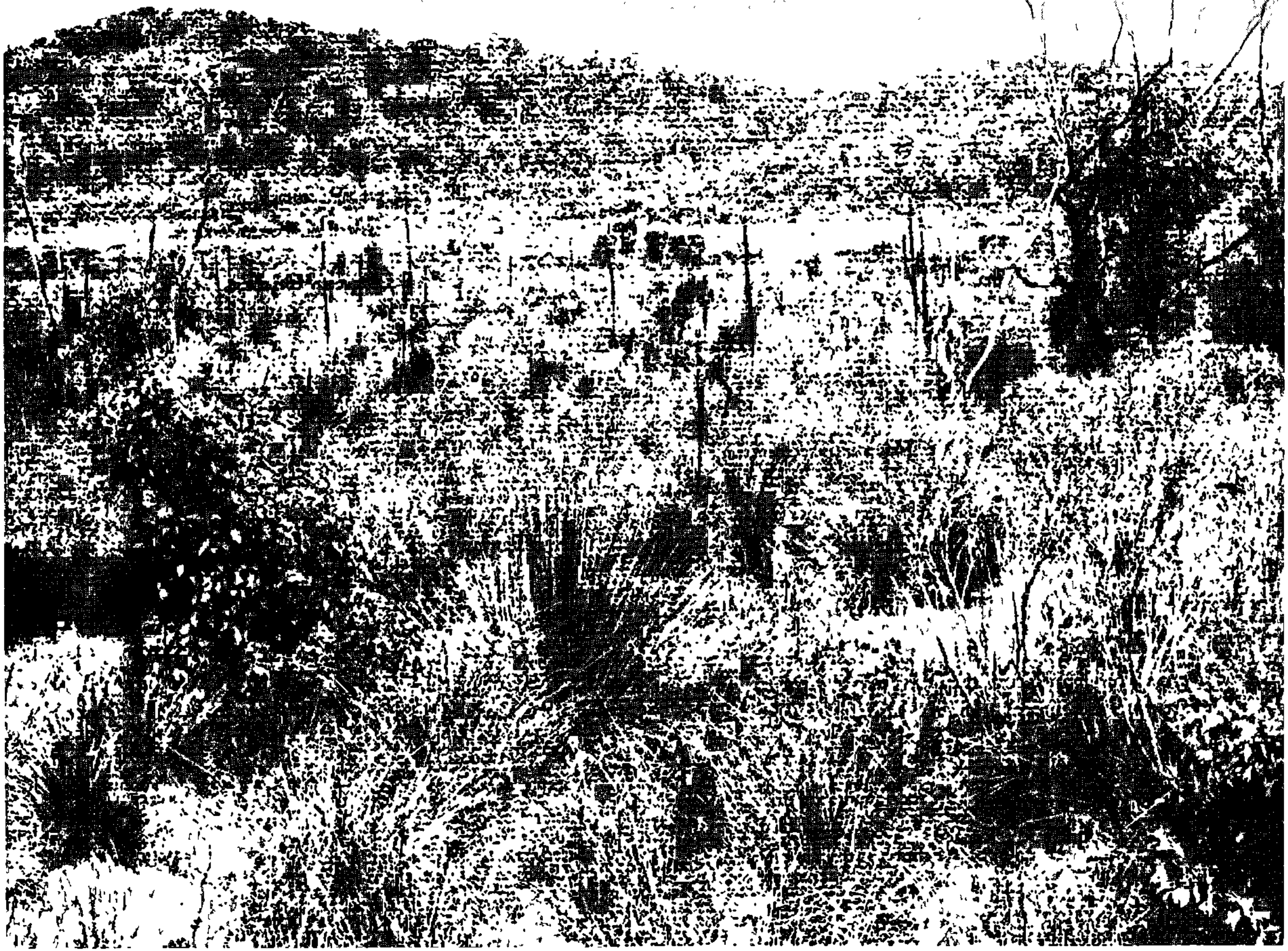

Figure 2. The southern forests comprise a mixture of forest types. North of Walpole seasonally wet treeless flats, are fringed with **Banksia attenuata** woodland and jarrah forest, with karri forest on the higher ground.

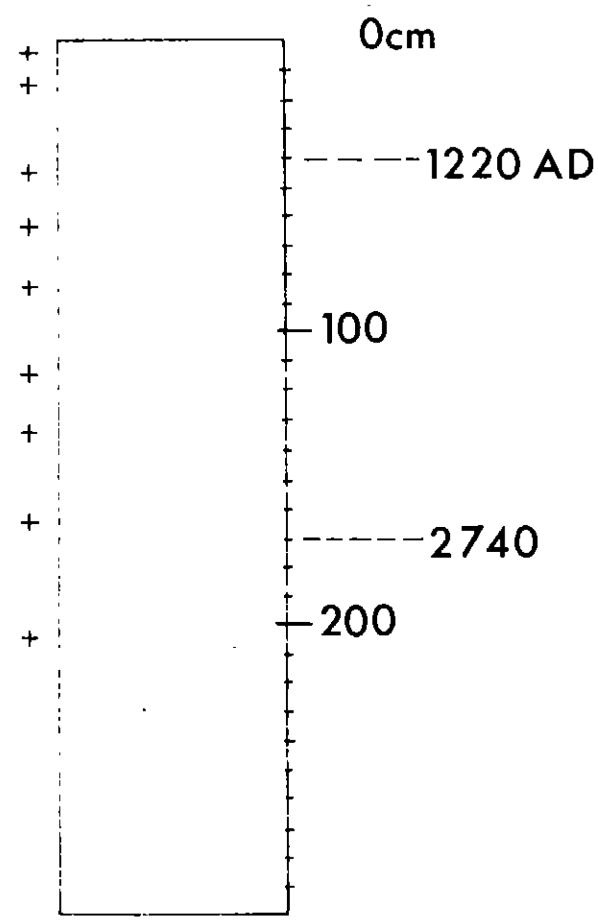

Figure 3. Charcoal presence in peat core from Weld River Swamp (after Churchill 1968).

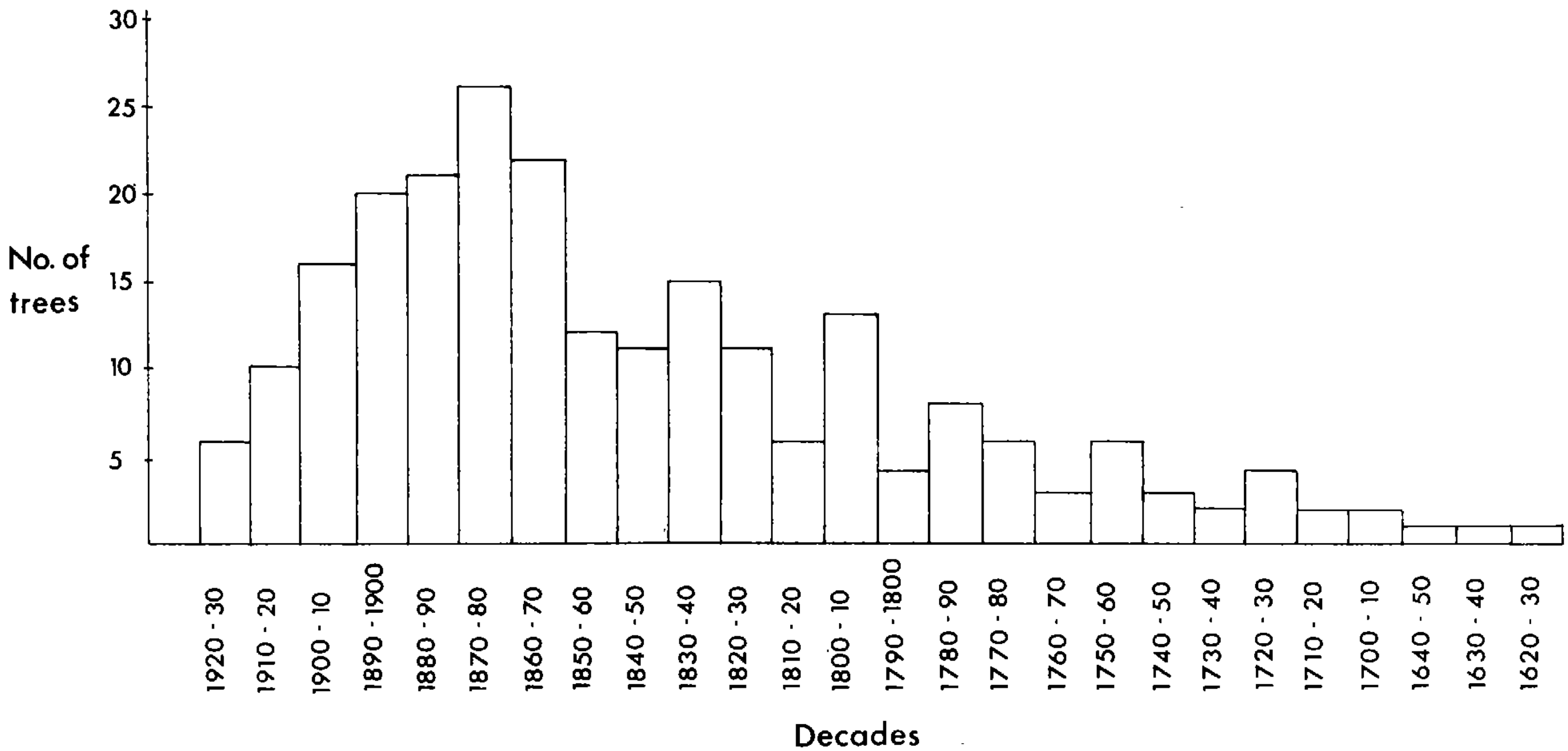

Figure 4. Frequency distribution of age classes of karri trees in block near Pemberton.

Table 1. Karri regeneration related to burning (P. Kimber, pers. comm.).

Period since burn (years)	No. of quadrats	Quadrats stocked with Karri seedlings	95% Confidence intervals
45	120	0	-
25	120	0	-
6	120	1	0- 3
2	120	8	3-13
1	50	20	15-25

If indeed fires were a frequent event in the past, how frequent were they? The absence of natural grassland suggests that fire frequencies were more than 3 years on the average. Forests and woodland with grassy understorey support very frequent fire.

A frequency of more than 3 years is also suggested by the flowering cycles of understorey scrub species. Flowering has occurred in most Jarrah forest understorey scrub-species by 3 years after fire. In the Karri forest some species take longer (e.g. **Trymalium spathulatum**, about 5 years and **Bossiaea laidlawiana** 4 years (Skinner 1984)).

The vertebrate fauna provides further clues. The southern forests, in particular the tall open forests of Karri and Tingle, contain few mammals which can be considered late successional species. With the exception of the Mardo (**Antechinus flavipes**) and possibly the Quokka, (**Setonix brachyurus**), all mammals in these forests are early successional species, breeding populations being well established within five years following fire. The Mardo and Quokka may take 10-15 years to occupy new habitat.

It has been suggested by Christensen et al. (in press) that the absence of a distinct fauna which displays typically K selective traits (of longevity, late sexual maturity, and low fecundity) from the tall open forest may be an indication of a high fire frequency in these forests. Similar tall open forests in eastern Australia which are considered to have an infrequent fire regime (Ashton 1981) support a suit of resident dependent species which are more typically K selected viz. the Greater Glider (**Shoenobates volans**) and the Mountain Possum (**Trichosaurus canninus**) (Tynedale, Biscoe & Calaby 1975).

It is also of note that several species of understorey and heath inhabiting birds which are poor fliers and relatively sedentary in their habits, namely the Noisy Scrub-bird (**Atrichornis clamosus**) and the Rufous Bristle-bird (**Dasyornis broadbenti**) had very restricted distributions in the South-West at the time of arrival of Europeans last century. They are remnants of formerly more widely distributed southern wet-country (Bassian) species (Serventy & Whittel 1967). These birds, the former in particular, have been the subject of intense study suggesting that they are confined to long unburnt habitats (Smith, this publication). We suggest that the increase in fire frequency which could be expected to accompany the climatic changes which caused the shrinking of the Bassian fauna may be at least partly responsible for the decline of these birds.

These things suggest to us a relatively high fire frequency in the southern forests in the past.

Season

The relative proportion of sprouting and seeding species amongst the understorey plants have been used by Christensen & Kimber (1975) as an indication of relative fire frequency. They suggest that the high proportion of sprouters in the Jarrah forest indicates a higher fire frequency than in the Karri forest where seed species are dominant in the understorey. Those plants whose major occurrence lies within the southern forest show an even greater proportion of seed species (Fig. 5).

The relative proportion of sprouters and seed species may also be an indication of season of burning in the past. Baird (1977) has shown that sprouters are favoured by spring and early season fires whereas seed species tend to be more favoured by late season, summer and autumn fires.

The SDI fire danger index (Mount 1972), an indicator of how and when forest fules will burn, clearly illustrates the differences in season when Karri and Jarrah forest will burn (Fig. 6). Jarrah will burn almost anytime from October through to April, whereas the Karri burns only during the summer and autumn months. Significantly, these data support the sprouters/seed species conclusions on season of burning.

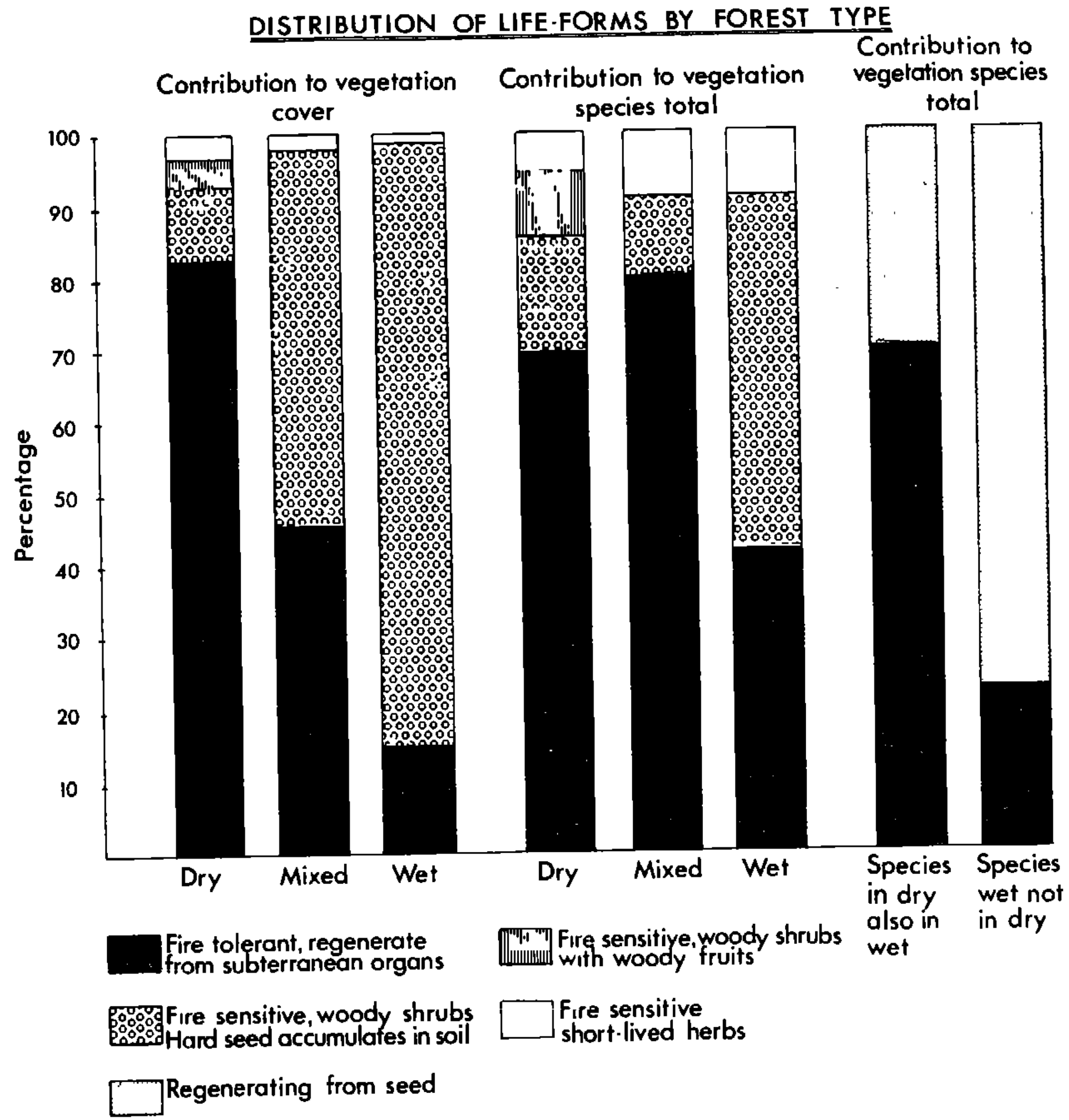

Figure 5. Relative composition of understorey species by life forms in major forest types. Wet = karri forest, Dry = jarrah forest, Mixed = marri/karri forest.

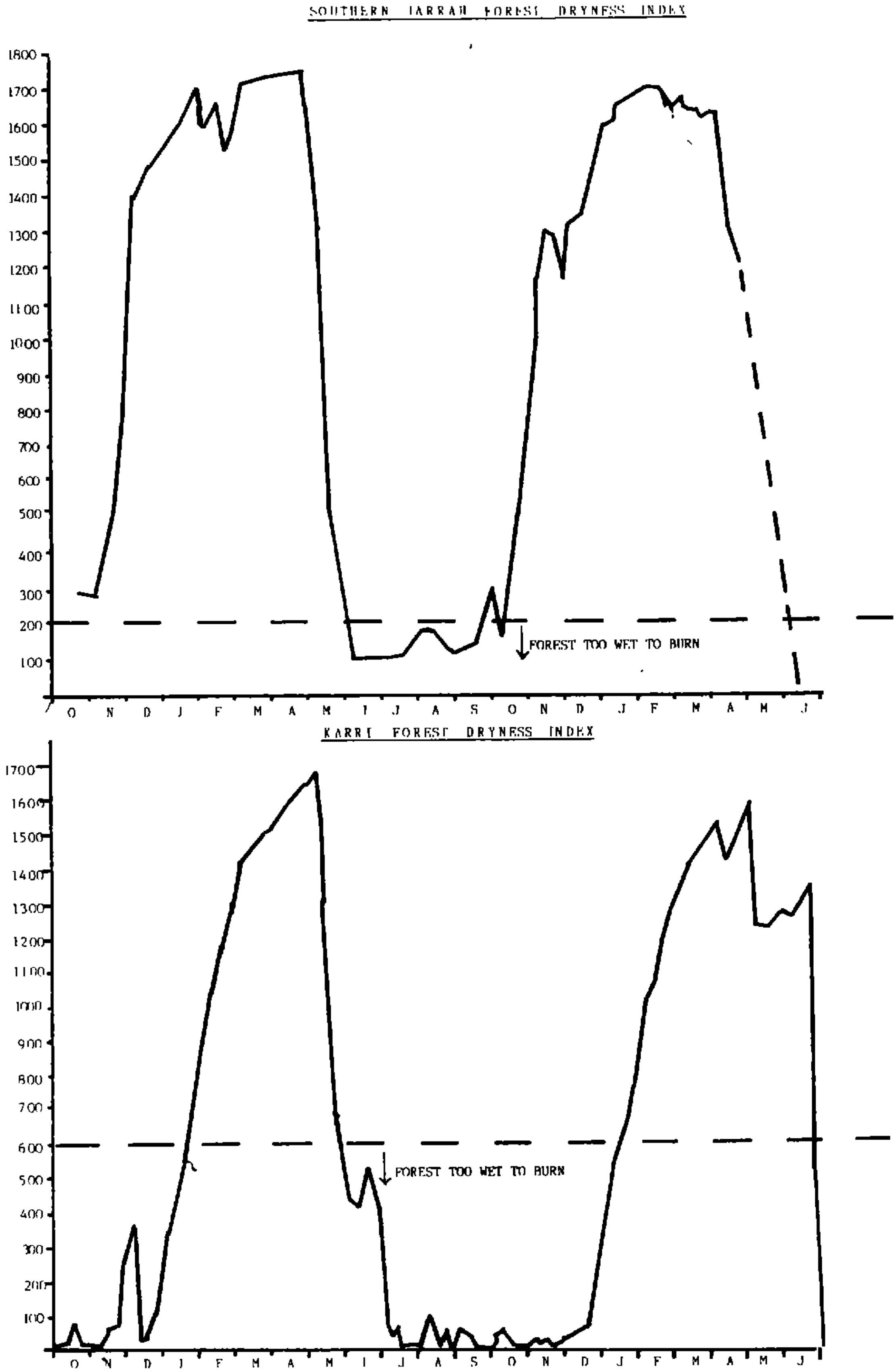

Figure 6. Soil dryness index (see Mount 1972) as an indicator of when the forest will burn.

Intensity

It is well established that fires in different forest types vary in intensity: for example, fires in tall open sclerophyll forests are capable of reaching higher intensities than fires in open sclerophyll forests (Luke & McArthur 1978).

Evidence of variability in fire intensities in the past are suggested by extreme variability in the reaction of the seeds of southern forest species to heat treatments.

This variability is present both within and between species (Fig. 7) and appears to relate to the fire regime of the forest type in which the species is found (Christensen & Kimber 1975).

Variability in fire regimes in the past is indicated by Churchill's (1968) data on pollen profiles (Fig. 8). These show that the area covered by different major forest types, Jarrah, Marri and Karri has varied considerably over the last 5000-7000 years presumably as a result of climate changes. Given that fire regimes are different in each of these forest types this would suggest major changes through time in the sorts of fire regimes experienced in the southern forests. This is supported by evidence of Aboriginal activity from archaeological sites (Hallam, this publication).

Present Fire Regimes

Much of the southern forest is prescribed burned with low intensity fires for fuel reduction purposes (Peet 1967). These fires are lit mostly in spring and early summer. Depending on the season a proportion, varying, from 5-15 percent, may be burned in autumn. The frequency of these prescribed fires varies between 5 to 7 years in the Jarrah and 7-9 years in the Karri forest.

Fire intensity in these burns is generally low for safety reasons. However, due to natural features, slope, changes in vegetation, variation in fuels, coalescence and other factors, a wide range of fire intensities are experienced. Twenty to 30 percent of the area normally remains unburnt (Fig. 9). The remainder of each burn may be burned at a range of intensities. Usually over most of the area only the understorey is burned, leaving the tree canopy unaffected. In isolated patches where fire behaviour is more violent the tree canopy may be scorched or at times trees may be defoliated where the fire flares up (Fig. 9).

Variation in fire behaviour is reflected by the range of temperatures experienced in the upper soil levels during a fire (Fig. 10).

In addition to prescribed fires for fuel reduction purposes, fires are prescribed for special purposes. Each year the slash on some 2000-3000 ha of clear felled Karri forest is burned to provide suitable conditions for the regeneration of young Karri trees. These fires reach very high intensities at ground level which approximate extreme wildfire conditions, the blow-up situation described by Luke & McArthur (1978).

In some areas set aside for the conservation of flora and fauna, special fires may be prescribed (Christensen 1983). Burning is carried out on longer rotation than fuel reduction burning, 15 to 20 years, and burning during summer and autumn months is also prescribed.

In these areas sections may also be set aside for fire exclusion where it is considered that there is a reasonable chance fire can be kept out and it is safe to do so. Some 13,000 ha have been set aside for fire exclusions in the southern forest and there exists further areas within national parks and nature reserves.

Wildfire

Wildfires are seldom taken into account when considering present fire regimes, yet they are part and parcel of the total fire regime. In spite of the effectiveness of the fuel reduction burning system (Underwood & Sneeuwjagt, this publication), wildfires still occur and will no doubt continue to do so albeit in a changed pattern.

Information on wildfires occurring over the last 30 years on a sample area, approximately 10% of the southern forests, indicates that a surprisingly large proportion of the area was burnt by wildfires during this period. Two hundred and forty five wildfires covered an area of some 42,323 ha. During the last decade there has been some reduction in the number of such fires; moreover, the greatest change has been in the reduction in the average size of the fires (Table 2). This change is attributed to the fact that broadscale prescribed burning did not take effect in the south until the late 1960s. Along with the burning, improved detection and suppression, have also contributed to the reduction of the area burned by wildfires.

A break-up of the fires by forest type indicates that relatively more woodland, scrub and Jarrah forest types were burned than Karri forest (Table 3). These data support the conclusion reached earlier about fire frequencies in different forest types in the past.

It is obvious from this that wildfires contribute substantially to the total fire diversity in the southern forests and that this differs with forest type. It is also apparent that this contribution appears to be diminishing.

Table 2. Analysis of wildfires in the Pemberton area over the last three decades.

Decade	No. of Fires	Mean Size Hectare	% Total Area Burnt
50-59	82	266	18
60-69	117	147	14
70-79	46	73	3

Table 3. Analysis of wildfires in the Pemberton area over the last three decades. Percentage area burnt by vegetation types.

Decade	Karri	Jarrah	Non/Forest	Pasture
50-59	13	26	20	9
60-69	11	15	20	13
70-79	1	3	5	4

Discussion

A single fire comprises the summation of many fire attributes (e.g. intensity, frequency, season, etc.), this, together with the pattern of occurrence in time and space, makes up the fire regime. From what we have seen it is obvious that most fire attributes vary considerably even within the smallest of fires, as they do between separate fires burning under different conditions in different seasons. For this reason, there can be no such thing as a specific or given fire regime: fires and fire regimes occurring in space and time must inevitably always be different. Certainly the limited evidence which we present of past fire regimes in the southern forests indicates that this is so. If it were otherwise the range of adaptations amongst plants and animals to cope with fire would not be so extensive.

How then do we sensibly compare past fires and fire regimes with the present, much less the future? The answer it seems, is that we do not, for we can only generalise. Thus if we regard each of the many fire attributes as a continuum, for example fire intensity which may vary from unburnt to over 60 000 kw/m, we can speculate which end of the continuum fires most frequently occurred.

If we do this the overriding impression we get from the past is one of great variability in fires and fire regimes. Nevertheless, certain patterns emerge. In most vegetation types fires of comparatively low intensities appear to have occurred regularly and at fairly frequent intervals of between 3 to perhaps 10 or 20 years intervals.

If fires occurred more frequently than every 3 years we suggest that grasslands would be present in the area. If fires occurred less frequently than every 10 to 20 years fuel build-ups (Table 4) would become excessively high resulting in intense fires when they burnt. There is little evidence suggesting that such fires occurred regularly and it seems unlikely that these areas would escape burning fairly regularly considering the evidence of fire-lighting by the Aborigines presented by Hallam (this publication) and the frequent incidence of lightning fires in the area (Underwood 1978). Once alight, there would have been little to prevent fires spreading and burning throughout the dry months of the year, covering huge areas.

Table 4. Rates of litter accumulation in tonnes/ha for Karri and Jarrah forest (from Sneeuwjagt & Peet 1976).

Years	Jarrah 60% Crown Cover	Karri 60% Crown Cover
1	2.5	7.0
2	3.5	9.7
3	4.7	12.2
4	6.2	14.5
5	8.0	16.7
6	9.7	18.7
7		20.7
8		22.5
9		24.5
10		26.2

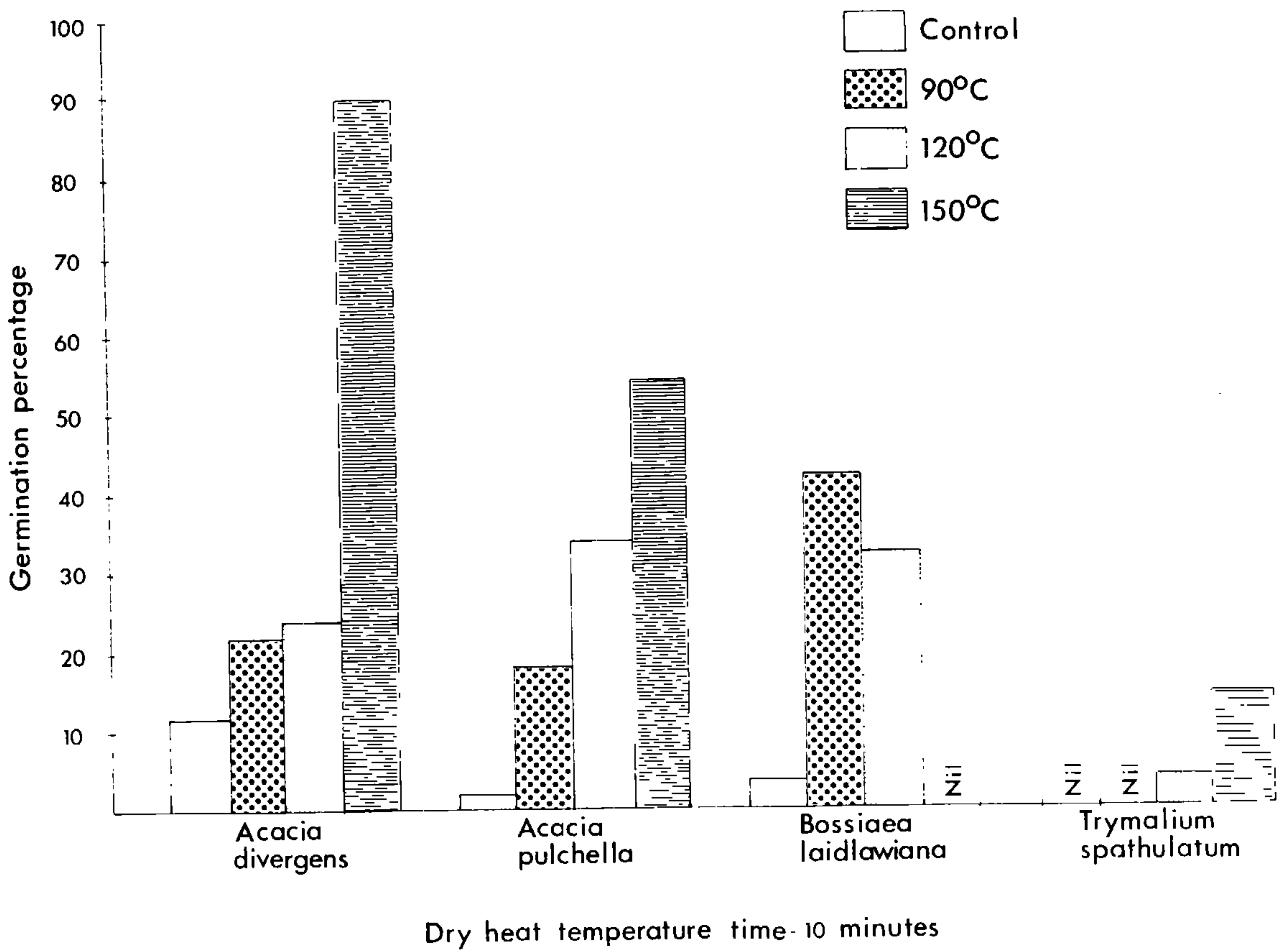

Figure 7. Germination of seed of understorey plant species following heat treatment.

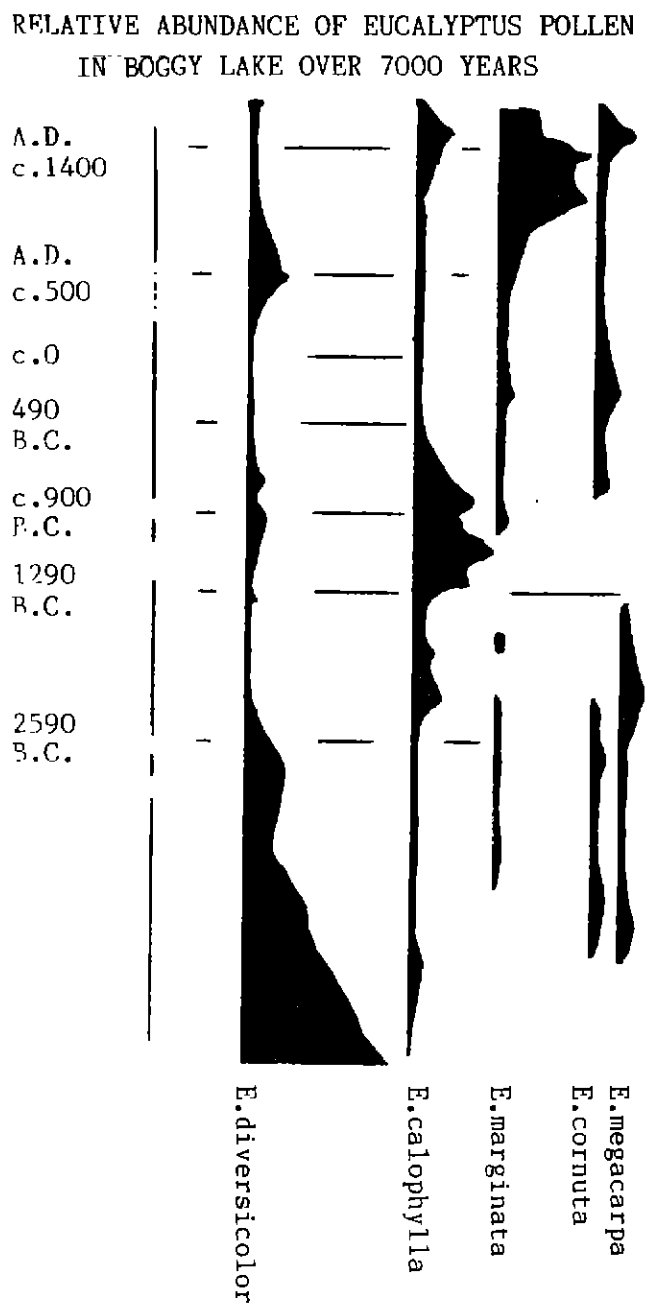

Figure 8. Pollen analysis of peat core from Boggy Lake near Pemberton (after Churchill 1968).

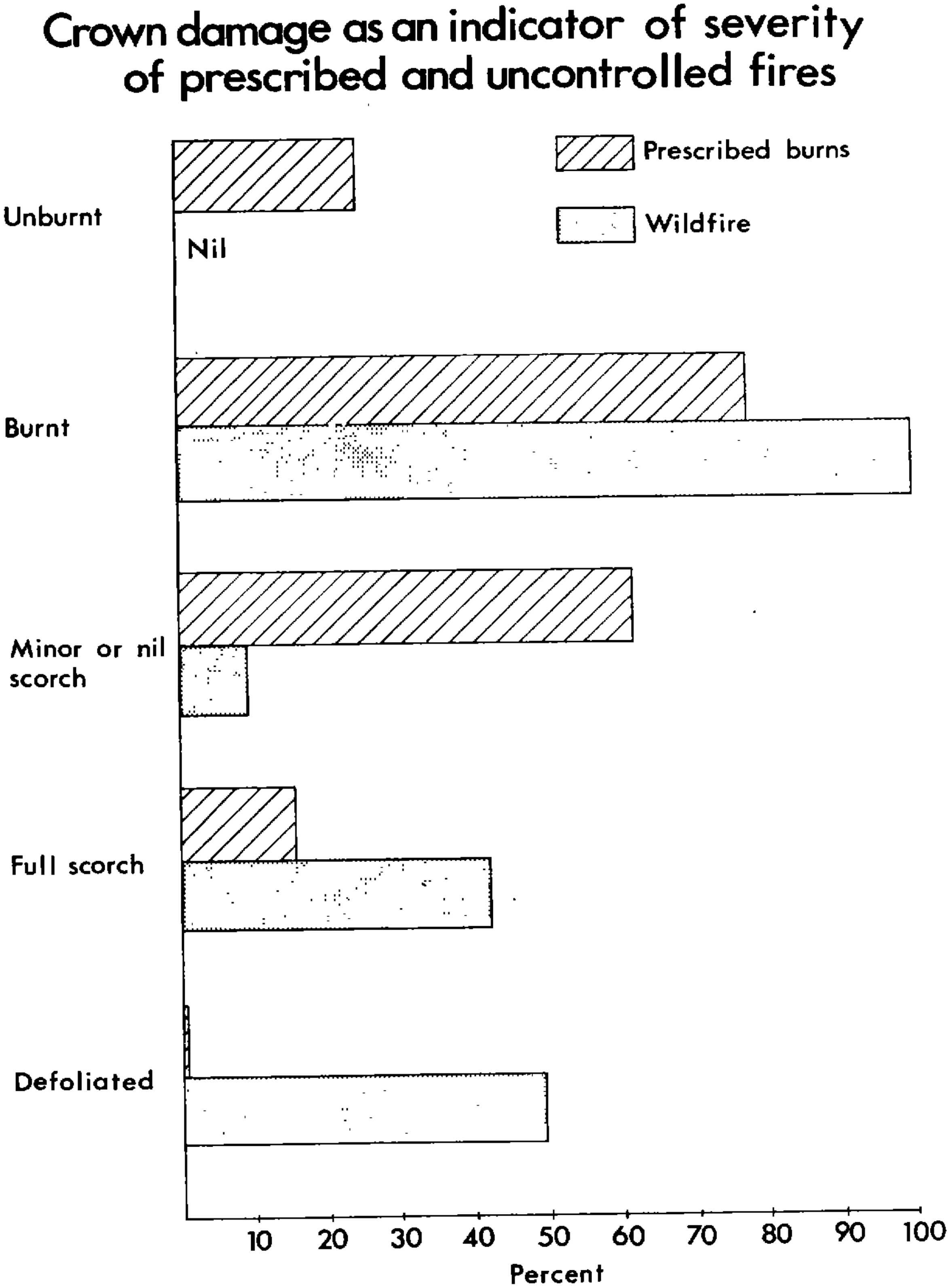

Figure 9. Mean percentage of area burnt and level of crown scorch in two prescribed burns and one wildfire in jarrah forest.

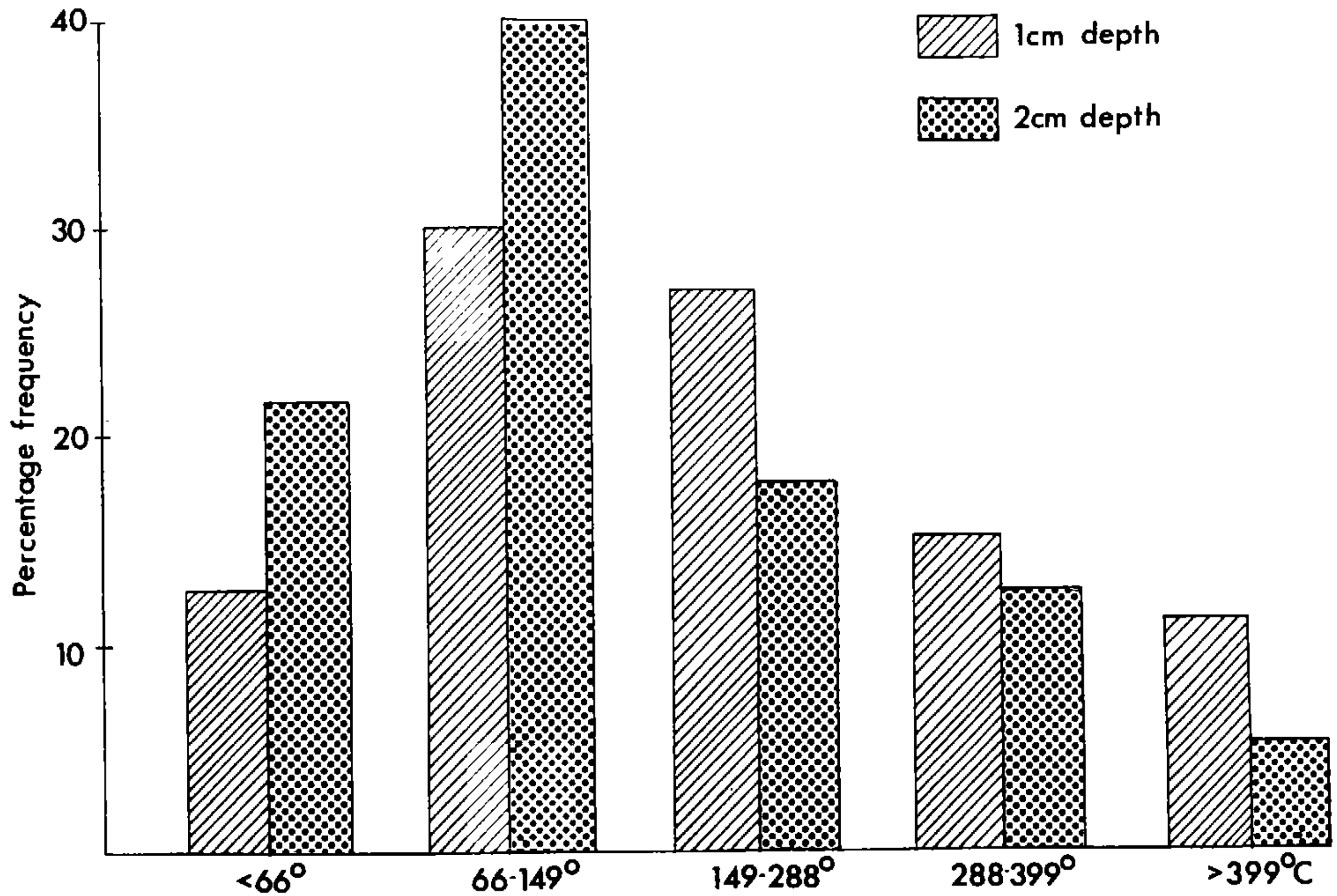

Figure 10. Soil temperatures during a hot fire in a wet sclerophyll forest (after Christensen & Kimber 1975).

We suggest, therefore, that fires occurred at fairly regular and frequent intervals particularly in the treeless flats, woodlands and Jarrah forest formations of the area mostly during summer and autumn and that these regularly spread into the Karri and Tingle forests. Occasionally, when fuel build-up coincided with severe weather conditions and an ignition source, intense wildfires may have developed but such events would seem to have been rare.

How does this compare with present fire regimes more recently imposed by Europeans? In one sense there is very little difference. Fires representative of the entire range of the continuum still occur. Thus, at the one end of the continuum, areas set aside from burning remain unburnt for comparatively long periods of time and, on the other, wildfires together with regeneration burns provide extreme wildfire conditions.

There do appear to be major differences, however, especially in terms of the proportion of the forests which burnt in different seasons. Thus we still do not know yet even the approximate area of each forest type which is likely to have burnt each year. When this becomes known we suspect that we will find that the present fire regime tends more towards the cooler, low intensity end of the continuum with larger areas burnt early in the season than was the case in the past. The percentage of the area which remains unburnt for long periods may also be smaller particularly in the tall open Karri and Tingle forests.

Although these differences are cause for concern we believe that the wide range of adaptation of species in the area to varying fire regimes, will ensure their survival. In the long term however, changes will occur, particularly in the relative abundance of species; for, some may become more common others will becomes less common.

What can we do to rectify this situation so that the present fire regime more closely approximates that of the past and so that changes are kept to a minimum?

It is certain that we will never again have a 'natural' situation. Land use in the area does not permit a 'let burn' policy. Indeed it is questionable what such a policy actually accomplishes. For example, fires which under 'natural' conditions would have entered the area from outside no longer are allowed to do so. A 'let burn' area can only burn as a result of internal ignition, which almost certainly will result in longer than natural fire frequencies. We cannot escape the fact that we are now managing the forest system, whether we like it or not.

If we accept this, what are the management options? Total fire exclusion, as advocated by some who want to wait for 'all the answers' before burning, we do not see as a viable option. Inevitably areas set aside for protection catch fire, usually resulting in extreme fire behaviour dangerous to human values and of doubtful ecological benefit.

We propose two practical options:

(a) attempt to emulate what is believed to have been the natural fire regime, based on the sort of evidence we have presented here.

(b) manage for a specific objective other than the supposed natural fire regime. This may be accomplished using data from detailed population studies (e.g. Christensen 1983).

Which of these options is chosen by the manager depends on many things not least of which is safety. In the tall open forests of the south-west the safety of humans and human values must always remain the overriding factor. Having said that, we believe that managers should always be conscious of their responsibility to the environment. They should be aware of the emphasis of the present system on low intensity fires early in the season. Wherever possible, areas should be set aside as longer rotation burns and burning during autumn and even summer should be attempted. Such attempts to emulate natural fire regimes can be accommodated in the various reserves, national parks, management priority areas whilst protection burning is concentrated in the production-forest areas.

Management for specific objectives may include fauna population management, managing for wildflower display, honey production and others, including prescribed fuel reduction burning.

Overall, emphasis should be on fire diversity or, more correctly, fire regime diversity. There is plenty of data available for innovative fire management, indeed much of what we are advocating is already in existence or being planned, albeit in limited areas (Burrows & Llewellyn, this publicaton).

Changes cannot be instituted overnight; they must go hand in hand with fire behaviour research and a programme of public education. Managers will find it difficult if not impossible to carry out innovative and ecologically beneficial programmes however sound they may be if public opinion is against them.

Lastly but not least, monitoring is essential to record the results of the various programmes. Fire management is a complex field which is continually evolving and flexibility is needed to accommodate new information as it becomes available.

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FIRE IN THE WOODLANDS AND ASSOCIATED FORMATIONS OF THE SEMI-ARID REGION OF SOUTH-WESTERN AUSTRALIA

A.J.M. Hopkins

Introduction

Fire is a most important consideration in the management of areas of natural vegetation in the semi-arid region of south-western Australia. Wildfire is a contingency to be planned for; the combination of long, hot, dry summers and dense, highly flammable vegetation creates a situation where extensive and intense unplanned fires can readily occur. Control measures will often involve fuel reduction burning. Consideration must also be given to the maintenance of ecological process in natural areas and the design and implementation of an appropriate fire regime is central to this. But the plant and animal communities of the semi-arid region are generally sensitive to disturbance and recover slowly. The essential fragility and vulnerability of these communities necessitates their careful management. In this paper I draw together the limited information on fire for the region in order to set out some general principles that may be useful for the future management of natural areas.

The Study Region

The area that constitutes the principal focus for this paper takes in the Avon, Roe and Coolgardie Botanical Districts as described by Beard (1980) (Fig. 1). It contains a great variety of vegetation types including woodlands (wandoo, york gum and salmon gum woodlands are well known examples), shrublands ranging from mallee Acacia and **Allocasuarina** thickets to the species-rich heathlands, and mixed herb and shrublands associated with granite outcrops and saline lakes. There are also areas where spinifex hummock grasses occur as an understorey; however most of this paper relates to the non-spinifex communities. Due mainly to the degree of dissection of the landscape, these vegetation types occur in a fine scale mosaic (Fig. 2) so that it is not possible to consider management of any one type in isolation. Many of the vegetation types also occur in the Irwin and Eyre Botanical Districts (the so-called northern and southern sandplains) but the predominant and widespread shrub vegetation, kwongan, of these two districts is discussed in detail by Lamont and Bell (these proceedings).

The climate of the study region is Mediterranean with an annual rainfall ranging from around 500 mm along the boundary with the forested region to 250 mm where it abuts the Eremaean Botanical Province (the desert region). The region has been much affected by major wetting and drying cycles over the past c. 2.5m years (Bowler 1982) and is sometimes referred to as the Transitional Rainfall Zone (Hopper 1979). This climatic flux, when coupled with other factors such as the topographic dissection, has promoted fragmentation and speciation with the result that there is now a rich flora that includes many rare species and unusual outlying (peripherally isolated) populations. In the Roe District, for example, it has been estimated that rare, geographically restricted and poorly known plant species make up almost 12% of the total flora (M.A. Burgman, pers. comm.).

The region also has a rich and varied vertebrate fauna that has been the subject of detailed surveys over the past decade or so particularly by the W.A. Museum and the Department of Fisheries and Wildlife (see Kitchener 1976 for surveys of the Avon District, McKenzie 1984 for surveys of the Coolgardie and Roe Districts). Of particular interest is the persistence in the region of some mammals that formerly had much more extensive ranges taking in parts of the central arid zone, e.g. the Woylie (**Bettongia penicillata**), the Numbat (**Myrmecobious fasciatus**) and the Red-tailed Wambenger (**Phascogale calura**) (Burbidge & Fuller 1979; Kitchener 1981). The invertebrate fauna of the region is scarcely known (cf. Majer 1985).

I have found very little documentary evidence that gives any indication of fire regimes of the study region prior to European occupation. Most of the information compiled by Hallam (1975) comes from sites on, or adjacent to, the coastal plain and particularly around the productive estuaries: places where Aboriginal people could be expected to congregate. Unfortunately little insight is gained into Aboriginal activities in the semi-arid region. The memoirs of Ethel Hassell (1975) from her time near Jerramungup at the south-western margin of the Roe District include reference to use of fire by Aboriginal people in that district. The account suggested annual burning for hunting and ceremonial purposes in late summer-early autumn and at other times when associated with marriages and death rites.

An attempt has been made to explore pre-European fire conditions at Tutanning Nature Reserve using the **Xanthorrhoea** technique of Lamont & Downes (1979) as applied to **X. reflexa**. Preliminary results have not been unequivocal but suggest fires were uncommon (i.e. once every 40-50 years) in the century prior to 1829 and rare before then. In the past 150 years, between 20 and 25 (depending on the particular site) fires have burnt in the area. These investigations are continuing.

Effects of Fire on Vegetation Structure

The results of a study of the effects of a single fire on woodland vegetation in the Roe District have been reported by Hopkins & Robinson (1981). At that particular site, a fire in about 1938 had burnt through eucalypt woodland (**Eucalyptus cylindriflora, E. diptera** and **E. eremophila** up to 7 m tall) leaving unburnt a small patch that could be studied to gain insight into the nature of the prefire vegetation. The 40 year old, regenerating vegetation was heath with emergent mallees up to 3 m in height. Of particular note was the change in architecture of the eucalypts: trees in the woodland were predominantly single

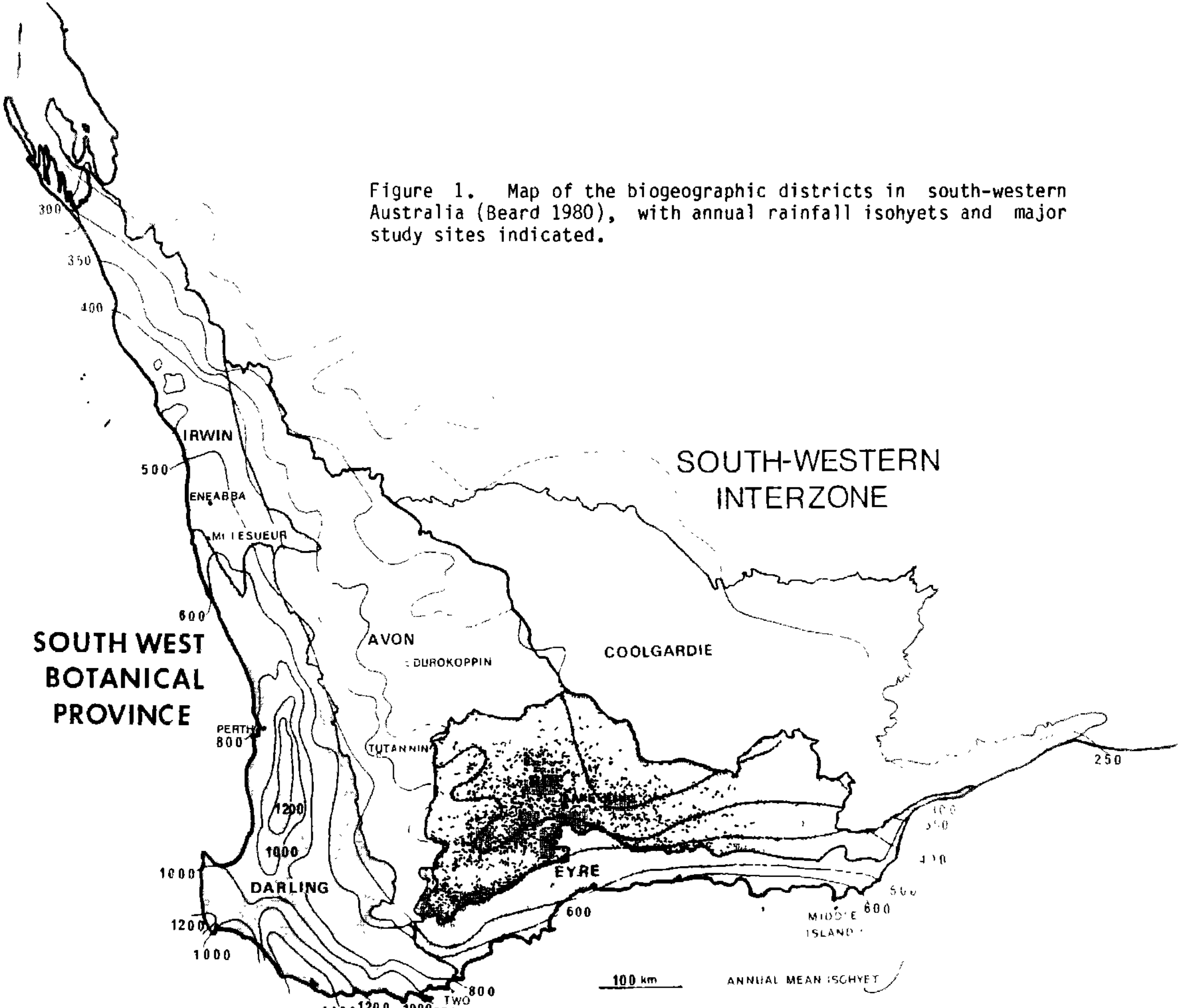
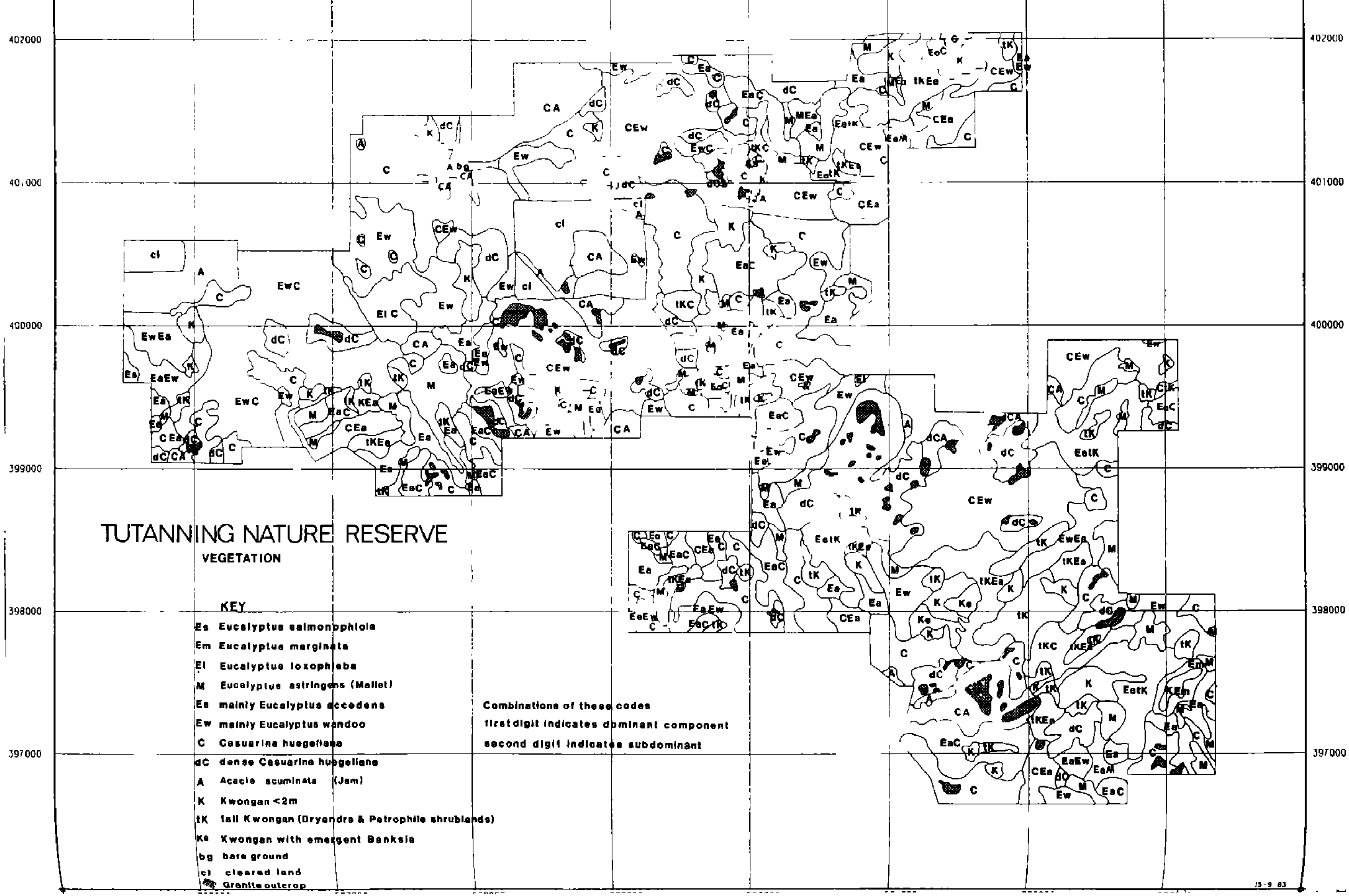


Figure 1. Map of the biogeographic districts in south-western Australia (Beard 1980), with annual rainfall isohyets and major study sites indicated.

Figure 2. Vegetation map of Tutanning Nature Reserve showing the fire-scale mosaic of types in that reserve (J.M. Brown & A.J.M. Hopkins unpubl. data).



stemmed whereas in the 40 year old area monopodial individuals were rare; the majority had a well developed multistemmed or mallee habit.

Two possible extreme scenarios were suggested for the 40-year old mallee heath. Firstly, it could remain unburnt for a further 50-60 years, in which time advance growth could lead to alteration of the eucalypts from mallee form to a taller, monopodial habit. The alternative is if the site were to experience a further fire in the foreseeable future. Such a fire would almost certainly lead to a reinforcement of the mallee-heath structure. Note, too, that the 40-year old vegetation, being low and quite dense, would probably carry a fire more readily than the more openly structured woodland. So it is conceivable that there is a feedback loop here: fire creates mallee heath that is more likely to burn and thus create more, dense mallee heath.

It may be claimed that this example of structural change reported by Hopkins & Robinson (1981) is unusual. However, my personal observations suggest that this type of change is a widespread phenomenon in the Roe District and may well apply in parts of the Avon and Coolgardie Districts too. Furthermore, study of the 1:250,000 scale vegetation maps of the Roe District reveal such comments as "**Eucalyptus oleosa** - E. **floctoniae** (woodland) mostly burnt and reduced to mallee" (Beard 1973).

Effects of Fire on Floristics

A variety of schemes now exist for classifying plant species according to their responses to fire (e.g. Bell et al. 1984) but, for the purposes of this discussion, three categories will suffice: fire ephemerals, resprouters and obligate seed regenerators.

Fire ephemerals, particularly polycarpic, perennial species, appear to be a prominent component of the flora of the Roe District but insufficient data are available to extend this generalisation to other Districts. Van der Moezel & Bell (1984) studied seven sites north of Esperance and observed an increased species richness in recently burnt quadrats relative to long unburnt quadrats that was attributable mainly to the appearance of fire emphemerals. Fire ephemerals that they observed included **Gyrostemon ramulosus**, **Goodenia laevis**, **Alyogyne hakeifolia**, **Pimelia brevifolia** and **P. nervosa** (van der Moezel, pers. comm.). I have also observed extensive stands of **A. hakeifolia** in areas to the north of Peak Charles after fires in about 1974. The rapid regeneration after fire and subsequent disappearance after 5 years of this latter species has been documented for Middle Island to the southeast (Hopkins 1981; see also Weston in these proceedings).

Van der Moezel & Bell (1984) also classified the other plant species at their seven sites and found that obligate seed regenerators predominated over resprouters (61-100% seed regenerators). This contrasts markedly with findings from a kwongan site in the Irwin District where some 66% of species were resprouters. They suggest that this preponderance of obligate seed regenerators is indicative of a very low natural fire frequency over evolutionary time.

It was noted in the study near Ninety Mile Tank (Hopkins & Robinson 1981) that there was little difference floristically between the long-unburnt woodland vegetation and the 40-year old mallee-heath. This is a generalisation that holds for most sclerophyllous plant communities in southern Australia: that a single fire has little long-term effect on the species compositon. However, the impact of recurrent fire may be quite different - local extinctions may occur.

Amongst the group of fire-sensitive, obligate seed regenerators are a number of species that have the seed store above-ground, in woody or papery fruits held in the canopy or off old woody stems. This habit is sometimes referred to as bradyspory (delayed dehiscence). This group includes such species as **Allocasuarina huegelii**, **Banksia media**, **Callitris preissii**, **var. verrucosa**, **C. roei**, **Dryandra nobilis**, **Eucalyptus astringens**, **Hakea laurina**, **Lambertia inermis** and **Melaleuca eleutherostachya**. If a population of any bradysporous, obligate seed regenerator species that is regenerating after a single fire is consumed by a subsequent fire before individuals can set seed (i.e. within the primary juvenile period), the species is likely to become locally extinct. Recurrent fire at an interval equal to, or even slightly longer than, the primary juvenile period can cause gradual attrition of the population leading to eventual extinction (e.g. see McMahon 1984a; Moll & Hoffman 1984; Zedler et al. 1983).

At the other end of the fire regime spectrum, if populations are left unburnt for extended periods of time the mature individuals may senesce and there may be little or no further recruitment; local extinction is again possible (Bond 1980; McMahon 1984b).

This group of plant species, the fire-sensitive, bradysporous, obligate seed regenerators, is the most vulnerable to mismanagement. But because of this, species in the group can be used to develop management guidelines for the communities in which they occur. All that is required in the first instance is some basic knowledge of life history details of the species. As an example, some provisional guidelines for management of sclerophyllous plant communities in south-western Australia with respect to fire are given in Figure 3. This figure was constructed using data from only a few sites in the South-West and so should be regarded as indicative rather than definitive.

Fire and the Fauna of the Region

Until recently there had been no attempt to systematically study relationships between fire and distribution of fauna in the region of interest here. In the last year, however, J.A. Friend has incorporated the burning of sites in his long-term studies of the Numbat at Dryandra State Forest. The Numbat feeds exclusively on

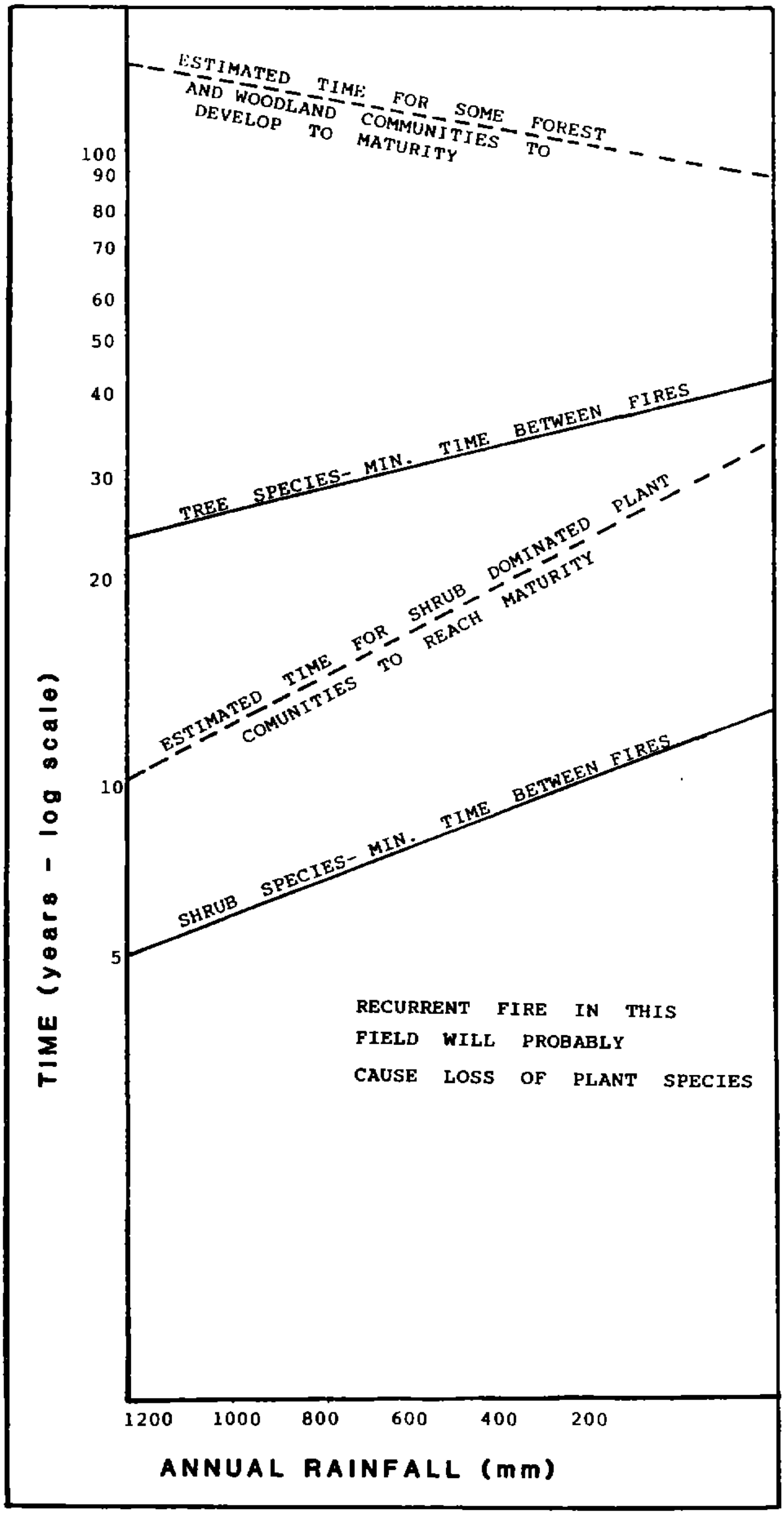


Figure 3. A provisional, management orientated scheme, based on life history details of fire sensitive, obligate seed regenerating tree and shrub species with a bradysporous habit, illustrating the possible effects of recurrent fire on sclerophyllous plant communities in south-western Australia.

termites and occupies tree and log hollows and ground burrows and thus is potentially vulnerable to the effects of over-burning since fire removes a termite food resource and may reduce the availability of hollows.

Some preliminary investigations into the ecology of the Woylie with respect to fire were conducted at Dryandra over a 16-month period in 1971-72 by A.A. Burbidge (pers. comm.). Difficulty was encountered during the study in establishing fire histories of areas where Woylies were observed or trapped. However, the trapping data suggested that the animals were feeding in all vegetation types except **E. accedens** woodlands on laterite, irrespective of fire age. Radio-tracking was used to locate diurnal refuges - all 29 located were in old, dense stands of shrubs (mainly **Gastrolobium microcarpum**) where these were associated with **E. accedens**, **E. calophylla** and **E. wandoo**. Burbidge observed that the dense stands were in areas that had suffered hot fires at least 10-15 years, and probably 20-30 years, prior to the study. My own studies at Dryandra (unpubl. data) indicate that such stands can persist for 50 years.

Habitat characteristics of sites used by the Tammar (**Macropus eugenii**) at Tutanning Nature Reserve were noted by Kelsall (1965) as part of a study of insular variability of that species. He found that the best sites consisted of close growing thickets of young **Allocasuarina huegelii** with a closed canopy 7-10 m high. These thickets which he termed "tammar scrub" provided good visibility low down (at Tammar eye-level) and good protective cover above. My own fire history records for Tutanning indicate that Kelsall's tammar scrub sites had been burnt about 30 years prior to his study.

These general observations on Woylie and Tammar habitat have been confirmed in the subsequent work of Christensen (1977) at Perup on the eastern margin of the jarrah forest.

Some other sources of information on fire and fauna remain to better explored. For example, Kitchener (1981) analysed some of his wheatbelt survey data for the Red-tailed Wambenger and found that all records were from long-unburnt **Allocasuarina** sites.

Clearly, our knowledge of the fauna of the region and the effects of fire on it is totally inadequate to allow proper management. But management of natural lands in the region goes on. I therefore judged that it was desirable to develop some generalisations to provide a basis for decision making. The following table (Table 1, from Hopkins 1982) gives a probable fire-effects sequence for a hypothetical site having an annual rainfall of around 400 mm and with vegetation consisting of a mixture of trees and shrubs with a minor herb and grass ground storey.

The site suffers an unplanned fire resulting from lightning strike ignition nearby. The fire is fanned by hot, dry summer winds and moves rapidly through the vegetation, affecting an extensive area which includes the site of interest. The litter layer is removed and much of the living foliage (including tree crowns to ca. 6 m high) and woody material up to ca. 1 cm diameter is consumed. For the animals, most escape direct incineration but the environment has suddenly become inhospitable; they have been deprived of food resources (there may be a time lag for higher order consumers) and habitat. Non-mobile species may persist throughout the burnt area in low abundances by utilising unburnt, refugial areas, while mobile species may either move out altogether (where territories are available) or may merely move to feed. Then as the food and habitat resources regenerate, the animal species gradually re-invade, the burnt site giving rise to the outlined faunal sequence.

This post-fire recolonisation must be related to some rather subtle and often difficult to measure features in the vegetation, such as structure (habitat) and relative importance and phenology of individual plant species (food resources). This is because there is little floristic change at a site during the regeneration period. Post-fire succession in most Australian sclerophyllous vegetation types accords with the Initial Composition Model, whereby most of the plant species ever to be found at a site will be present within 1-2 years after the fire (Purdie & Slatyer 1976). Thus the remainder of the idealised sequence (Table 1) deals with plants only as they affect the animals.

In the context of this management-orientated paper, two further considerations must be addressed. The first relates to grazing: feral and indigeneous vertebrates and invertebrates can have a profound impact on vegetation regenerating after fire. These impacts may be mitigated by burning large areas (say greater than 500 ha), by fencing and by control and eradication measures.

The second consideration is the significance of the ecotones that can be created by fire. At this stage, little is known of the role of the structural and floristic boundaries that can result from fire; procedures for translating such knowledge into management practice is a further problem.

This review has highlighted the lack of knowledge about fire in the semi-arid region of the South-West and the consequent uncertainties on which management decisions must be based. There is little doubt that fire must be a major planning consideration. But in the light of the uncertainties that exist and the potential for long-term and deleterious effects resulting from fire, management should have a conservative, fire minimisation orientation as a first priority.

Summary

1. The semi-arid region contains important biological resources. The vegetation types exist in a mosaic such that all must be managed together.

2. The climate and the flammable nature of the vegetation make consideration of fire an important facet of management.

3. The scant evidence suggests that fires were infrequent in the region prior to European colonisation.

4. A single fire can have dramatic effects on vegetation structure; repeated burning can cause permanent structural and floristic changes.

5. Regeneration rates are slow in these low rainfall areas.

6. Some generalisations about fire effects are made in order to provide a basis for future management of natural areas.

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Table 1. A generalised fire effects sequence for a hypothetical site in south-western Australia receiving 300-450 mm annual rainfall and supporting trees, shrubs, herbs and grasses.

TIME (years)	STAGE
-1	Mature vegetation with ample stores of seed on plants and in soil, relatively high fuel loading.
0	Hot fire. Death of large proportion of above-ground parts of plants, release of bradysporous seed, scarification of soil stored seed. Destruction of habitat and food resources and consequent death of fauna, particularly non-mobile and territorial species.
+1	Regeneration of vegetation by resprouting from below-ground parts (lignotubers etc.) and from seedlings. In general, all species ever present at a site are present at this early stage (Initial Floristic Composition Model). Increasing herbivore food resources. Poor habitat, low litter load and decomposer communities.
+2-5	Dense low shrub and herb layer, first flowers of some shrub species. Some seedling mortality through grazing pressures. Habitat slowly improving for ground and near-ground dwelling vertebrates. Minor litter build-up. Vegetation vulnerable: severe perturbation (i.e. another fire) may cause extinctions.
+5-10	Shrubs form closed canopy at ca. 1 m but becoming more open beneath - provides good cover for small mammals and other ground dwelling vertebrates. Good flowering and fruiting of shrub spp. Tree species emergent from shrub stratum but flowers rare. Mortality of short-lived perennial shrub spp. (fire emphemerals, now present only as seeds in soil). Gradual increase in litter load and commensurate increase in decomposer invertebrates and their predators.
10-25	Shrub stratum beginning to thin out, gradual mortality of shrub spp., and canopy opening. Slow increase in herbs and grasses. Less flowering and fruiting of shrub species but good seed store present. Small mammal habitat becoming sub-optimal but species persisting. Tree stratum maturing with some deaths. Litter standing crop reaches maximum (plateau) level as decomposers keep pace with litter-fall rates.
25-50	Shrub stratum quite sparse although all woody perennial plant species still present in low numbers. Continuing increase in importance of grasses. Habitat for small, ground dwelling vertebrates now poor and species persisting (in the absence of predators) at very low densities with large territories and utilising occasional thickets for nesting. Some senescence of trees providing tree hollows. Optimal habitat for decomposers and their predators.

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FIRE AND MAMMALS IN HUMMOCK GRASSLANDS OF THE ARID ZONE

Andrew A. Burbidge

Introduction

Hummock Grasslands, commonly called 'spinifex', are very widespread in the arid zone of Western Australia, dominating the vegetation of the Pilbara, Great Sandy Desert, Tanami Desert, Little Sandy Desert, Gibson Desert, Great Victoria Desert and Warburton Region (Beard 1969); together comprising more than half of the State. Hummock Grasslands may be formed by most species of the genus **Triodia** and a few of the genus **Plectrachne**, notably **P. schinzii**. Important species of **Triodia** include **T. basedowii**, **T. pungens** and **T. lanigera**.

Hummock grassland normally contains a number of scattered trees and shrubs (tree steppe), or shrubs only (shrub steppe); the absence of woody plants being a rare condition (Beard in Jessop 1981). It occurs on a wide variety of soil types from loose sand through sandy loams to rocks. The hummocks vary in size and density - some may be up to 1 m high and 2 m across but most are less than 50 cm high. Cover in typical hummock grasslands is around 30% and does not usually exceed 40%, there being significant areas of bare ground between the hummocks. A variety of small woody and herbaceous plants, many ephemeral, occupy some of the space between the hummocks.

In common with many other grasslands, spinifex burns readily. After fire the community is typified by the presence of annuals and short-lived perennials, as well as regenerating Triodia or Plechrachne. Gradually this develops to a mature hummock grassland with few ephemerals and few woody plants. Hummock grasses regenerate from seed but significantly, older hummocks can regenerate rapidly from root-stock. Depending on rainfall, hummock grasslands can carry a fire as soon as five years after a burn (N.T. Burbidge 1944; Suijendorp 1981).

Because of the high frequency of fire in hummock grassland, fire-sensitive species are largely absent or are restricted to areas that do not burn because of natural protection. In the Pilbara's Hamersley Ranges, for example, there are many species, including endemics, that occur only in the fire protected gorges. **Callitris columellaris** is another example of a fire-sensitive species that is absent from hummock grasslands, being restricted to those parts of ranges where it is afforded protection from fire. Where long-lived overstorey plants are present these are always species which can survive fire, being protected by thick, corky bark (**Allocasuarina decaisneana**, **Hakea suberea**, **Owenia reticulata**) or resprouting from roots, and stems both above or below ground (**Grevillea** spp., **Eucalyptus** spp.) (Maconochie 1982; Hodgkinson & Griffin 1982). One species, **Eremophila gilesii**, is known to avoid fire by suppressing grass growth (Hodgkinson & Griffin 1982).

Most species occurring in hummock grassland are short-lived annuals or perennials which complete their life cycle and set copious seed before the community develops once more to the fire-prone stage. Included in this category are a variety of soft grasses and sub-shrubs, especially legumes. Often germination of such species is promoted by fire.

Hummock grasslands are rich in species of vertebrate animals, the hummocks providing shelter from both extreme temperature and humidity and from predators. The fauna of the Great Sandy Desert, for example, includes at least 37 mammal species (McKenzie & Youngson 1983) and 75 reptile species (Burbidge 1983). The vast majority of these groups live in or under the hummocks.

The Decline of the Mammals

My interest in fire and spinifex developed from an investigation into the reasons for the decline of arid zone mammals. The first modern detailed investigations into the status of desert mammals carried out in the 1970s (Burbidge **et al.** 1976; McKenzie & Burbidge 1979; Burbidge & McKenzie 1983) failed to reveal the presence of a wide variety of mammals which were known to be common in the 1930s and before (Finlayson 1961; Ride 1970). My colleagues and I extended this work to include detailed interviews with the older desert Aborigines who are very familiar with the fauna of their land (Burbidge & Fuller 1979, 1984), paralleling work carried out by Dr K.A. Johnson and colleagues in the Northern Territory (e.g. Johnson & Roff 1982). This work, now almost complete, has for the first time delineated the current and former distribution of the larger (> 50 g) desert mammals and has provided information on the timing of the decline and disappearance of so many species (Burbidge, Johnson, Fuller & Southgate, in prep.). Examples of species which were once widespread and which are now extinct in the arid zone include the Burrowing Bettong (**Bettongia lesueur**), Western Quoll (**Dasyurus geoffroii**), Desert Bandicoot (**Perameles eremiana**) and the Stick-nest Rats (**Leporillus conditor** and **L. apicalis**). All species which have declined or become extinct have mean adult body weights between about 45 g and 5 kg, intermediate between the still abundant small dasyurids and rodents on one hand and the large kangaroos on the other (Burbidge & McKenzie 1983 & in prep.)

The possible causes of decline will be discussed in detail by Burbidge & McKenzie (in prep.) and discussion in this paper will be limited to the hypothesis that a change in the fire regime has been the major cause.

Aboriginal Use of Fire

Desert Aborigines used fire for a variety of purposes:

(a) Hunting. Fire was used to drive and flush game, both large and small. Finlayson (1943) gives a graphic account of the use of fire to hunt Rufous Hare-wallabies (**Lagorchestes hirsutus**).

(b) Regeneration of food plants. Aborigines ate a number of different parts including seeds, fruit, leaves, tubers and bulbs of a wide variety of plants. Latz & Griffin (1978) provide data on some of the more than 170 species which were utilised by desert Aborigines, either as food (ca. 100 species), for implements and medicines, or indirectly as hosts for edible invertebrates. Many of these occur abundantly only for a few years after fire.

(c) Signalling. **Triodia** and **Plectrachne** burn with a dense, black smoke. Fire enabled different individuals in a group to keep track of each other's movements while hunting or moving across country and it enabled different groups to be aware of each other's presence.

(d) Warmth. Desert winters are cold. As well as for keeping warm fire was used to cook food and fashion spears.

(e) Clearing ground and extension of man's habitat (Jones 1969). It was, and is, common practice for Aborigines to burn the country as they travelled.

There can be no doubt that burning was a common practice amongst desert Aborigines. As well as the recent descriptions by anthropologists of the use of fire (e.g. Jones 1969; Gould 1971; Kimber 1982; Hallam 1985), there are numerous accounts by early European explorers and settlers (e.g. Giles 1889; Carnegie 1898). The result of these practices was to produce a mosaic of patches of country at different stages of recovery from fire. As well as providing habitat for plants and animals which required differing stages of regeneration it also eliminated the risk of extensive wildfires. Fires which were started, either by Aborigines or by lightning, soon ran into areas of low fuel which acted as a firebreak. The fire mosaic provided adjacent areas of old hummocks that were used by many animals as shelter, and regenerating areas that were rich in the soft grasses, other ephemerals and legumes utilised as food by herbivores, which in turn supported carnivores (Bolton & Latz 1978).

It is clear that, consciously or not, desert Aborigines managed the land with fire to maximise food production. Jones (1969) called the use of fire by Aborigines in land management 'fire-stick farming' and suggested that this was the major element of technology that Aborigines had in manipulating their environment.

Changes in Land Management

When Aborigines moved from their traditional lands to European settlements they effectively abandoned enormous areas. The lack of frequent patch burning led to the development of extensive old stands of unproductive hummock grass. Fires which did start were extensive, often running for hundreds of kilometres and leaving little or no country unburnt.

Information collected on the timing of the disappearance of the medium-sized mammals shows that it coincided with the movement of Aborigines to settlements. Johnson & Roff (1982) have discussed the different time of disappearance of **Dasyurus geoffroii** in different parts of the Western Desert and similar data exist for many other species (Johnson **et al.** 1983 & pers. comm.; Burbidge & Fuller, unpub.). It is clear that most, if not all, desert mammals persisted until the 1940s and even into the 1950s in areas where Aborigines maintained their traditional lifestyle. This is especially so in those parts of the Gibson Desert of Western Australia occupied by Pintupi people until the 1950s.

The Future

Unfortunately some of the mammals which once occupied the hummock grasslands of Western Australia appear to be extinct e.g. Pig-footed Bandicoot (**Chaeropus ecaudatus**), Desert Bandicoot (**Perameles eremiana**), Central Hare-wallaby (**Lagorchestes asomatus**), Crescent Nailtail Wallaby (**Onychogalea lunata**) and Lesser Stick-nest Rat (**Leporillus apicalis**). Others, however, remain in very restricted parts of the arid zone e.g. Dalgyte (**Macrotis lagotis**), Rufous Hare-wallaby (**Lagorchestes hirsutus**) and Brush Possum (**Trichosurus vulpecula**); in adjoining better-watered country, e.g. Golden Bandicoot (**Isoodon auratus**), Brush-tailed Bettong (**Bettongia penicillata**), Numbat (**Myrmecobius fasciatus**) and Red-tailed Phascogale (**Phascogale calura**); or on islands e.g. Burrowing Bettong (**Bettongia lesueur**) and Greater Stick-nest Rat (**Leporillus conditor**). These species could easily be reintroduced to parts of the desert but could not be expected to re-establish unless the land was managed.

Western Australia has made a significant contribution to the conservation of hummock grassland communities by creating a series of large National Parks and Nature Reserves, and more are proposed. Reserves which protect extensive areas of hummock grassland include:

Hamersley Range National Park	617 606 ha
Rudall River National Park	1 569 459 ha
Gibson Desert Nature Reserve	1 859 286 ha
Neale Junction Nature Reserve	723 073 ha
Yeo Lakes Nature Reserve	321 946 ha

Plumridge Lakes Nature Reserve	308 990 ha
Queen Victoria Spring Nature Reserve	272 607 ha
Great Victoria Desert Nature Reserve	2 495 777 ha
TOTAL	8 168 744 ha

Together, these eight reserves comprise about 50% of the total area of land controlled by the Western Australian Department of Conservation and Land Management. The addition of reserves proposed in the Great Sandy Desert (Burbidge & McKenzie 1983) and those proposed by the Conservation Through Reserves Committee (1974) but yet to be declared, would give Western Australia a good representation of hummock grassland communities in protected areas.

At present these parks and reserves are not managed. From the information presented in this paper it follows that the best form of management would be to mimic Aboriginal burning. This can be achieved in part by encouraging Aborigines to use their traditional lands again and such is being gradually achieved by the "outstation" movement now occurring. However, it seems most unlikely that this will lead to the same firing pattern being established since:

(i) Aborigines are occupying fixed settlements or "outstations" and hunt only within a short distance of them and along roads between them.

(ii) Aborigines are now dependent to a large degree on European food and live a semi-European lifestyle, e.g. movement is by vehicle along graded roads.

Thus management by the Department of Conservation and Land Management will be necessary if the habitat in the National Parks and Nature Reserves is to become suitable for the re-establishment of the mammals.

Recently the Department advertised two positions - a Research Officer and a Technical Officer - to be based at Kalgoorlie to start work on resolving this problem. It will be their role to liaise with Aboriginal Communities and to set up experimental programs on the use of fire in the management of desert parks and reserves. The use of aircraft burning will be evaluated. Their task is a large one but we need to make a start now before it is too late to save some of the mammals which still remain in remnant populations.

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FIRE EFFECTS ON POPULATIONS OF THE NOISY SCRUB-BIRD (ATRICHORNIS CLAMOSUS), WESTERN BRISTLE-BIRD (DASYORNIS LONGIROSTRIS) AND WESTERN WHIP-BIRD (PSOPHODES NIGROGULARIS)

G.T. Smith

Introduction

Fire has been an integral part of the Australian environment, especially since the arrival of man (Singh et al. 1981), and it is thought to have been an important factor in the evolution of the biota (Recher & Christensen 1981). Despite the importance of fire, research into its effect on plant and animal communities has started to develop only in the last 15 to 20 years (Good 1981). Most attention has been focused on the effect of fire on the vegetation, and to a lesser extent on mammals. Studies on birds are few (see reviews by Recher & Christensen 1981; Catling & Newsome 1981), mostly opportunistic and short-term. Also, few attempts have been made to study the historical impact of fire on bird species or communities (Smith 1977). This paper documents the historical effect of fire on three rare passerines since the arrival of Europeans in Western Australia. Further, the role of fire in the population fluctuations of the three species at Two Peoples Bay Nature Reserve is discussed, as are the possible consequences of the fire exclusion management policy for the reserve.

Birds

The Noisy Scrub-bird **Atrichornis clamosus** is a small (35-50g) insectivorous and territorial bird with extremely limited powers of flight. Historically, its primary habitat was the dense vegetation in the ecotone between swamps and forest. At Two Peoples Bay its main habitat is low forest in the drainage lines.

The Western Bristle-bird **Dasyornis longirostris** is also a small (30g), territorial bird with limited powers of flight. Its primary habitat is closed heath, where it feeds on invertebrates and seeds.

The Western Whip-bird **Psophodes nigrogularis** is another small (50g) insectivorous and territorial bird with poor flight. Its habitat is dense thicket or mallee heath.

The territorial behaviour and physical characteristics of these birds suggest that they are poor dispersers. This assumption is supported by evidence from Two Peoples Bay where all three species have been increasing their range. In all cases expansion has been slow, over a broad front or along the distribution of suitable habitat. There is no evidence to suggest that any individual has moved more than a few kilometres from its natal territory.

Changes in Distribution

The Noisy Scrub-bird has been recorded in a number of isolated coastal or near coastal localities from Drakesbrook to Two Peoples Bay and as far inland as Mt Barker (Fig. 1). It was most common in the Albany district where the combination of topography and vegetation provided an abundance of habitat. After 1889 there were no further records until it was re-discovered at Two Peoples Bay in 1961 (Webster 1962; Smith 1977). No other populations have been found.

The Western Bristle-bird has been recorded from coastal areas from Perth to Hopetoun (Fig. 1). They were most common in the Albany district, occurring elsewhere in small isolated populations. John Gilbert implied that their distribution was similar to that of the Noisy Scrub-bird, which means he probably recorded the species south of Perth during his trip to Augusta. Specimens were collected from the Albany district in the 1880s, and they were observed near Denmark in 1907 (Whittell 1936; Smith 1977). By 1924, Carter (1924) noted that Bristle-birds were seen rarely in areas where they were common twenty years previously. Buller (1945) found the species at Two Peoples Bay in 1945 and later it was located at Mount Manypeaks (Ford 1965) and the Fitzgerald River National Park (Smith & Moore 1977).

The Western Whip-bird has been recorded in coastal districts from Perth to Hopetoun and inland to the north-west of Hopetoun as far as Wongan Hills (Fig. 1). While John Gilbert found the species widely distributed in the 1840s, there were only three records between 1900 and 1950. Subsequently, the species has been recorded in a number of localities from Two Peoples Bay to Hopetoun and inland as far as Pingrup (Smith 1977).

Since the arrival of Europeans, all three species have suffered a considerable reduction in their ranges. Basically, the populations in the areas that were first settled have become extinct.

Fire and Decline

In attempting to evaluate the role of fire in the decline of these species, it is worthwhile to first consider the effect of the Aboriginals' use of fire. The widespread and systematic use of fire by the Aborigines in the south-west has been documented by Hallam (1975) and it is reasonable to assume that it affected all populations of the species to some degree.

The only accounts of the use of fire by Aborigines in an area where all the species occurred is that of Scott Nind (Green 1979), and Stokes (Hallam 1975) for the Albany district. Aborigines from the surrounding districts gathered at Albany for the summer; the men burning off large areas of forest to hunt kangaroos while the women lit smaller fires in the swampy areas to hunt bandicoots and lizards.

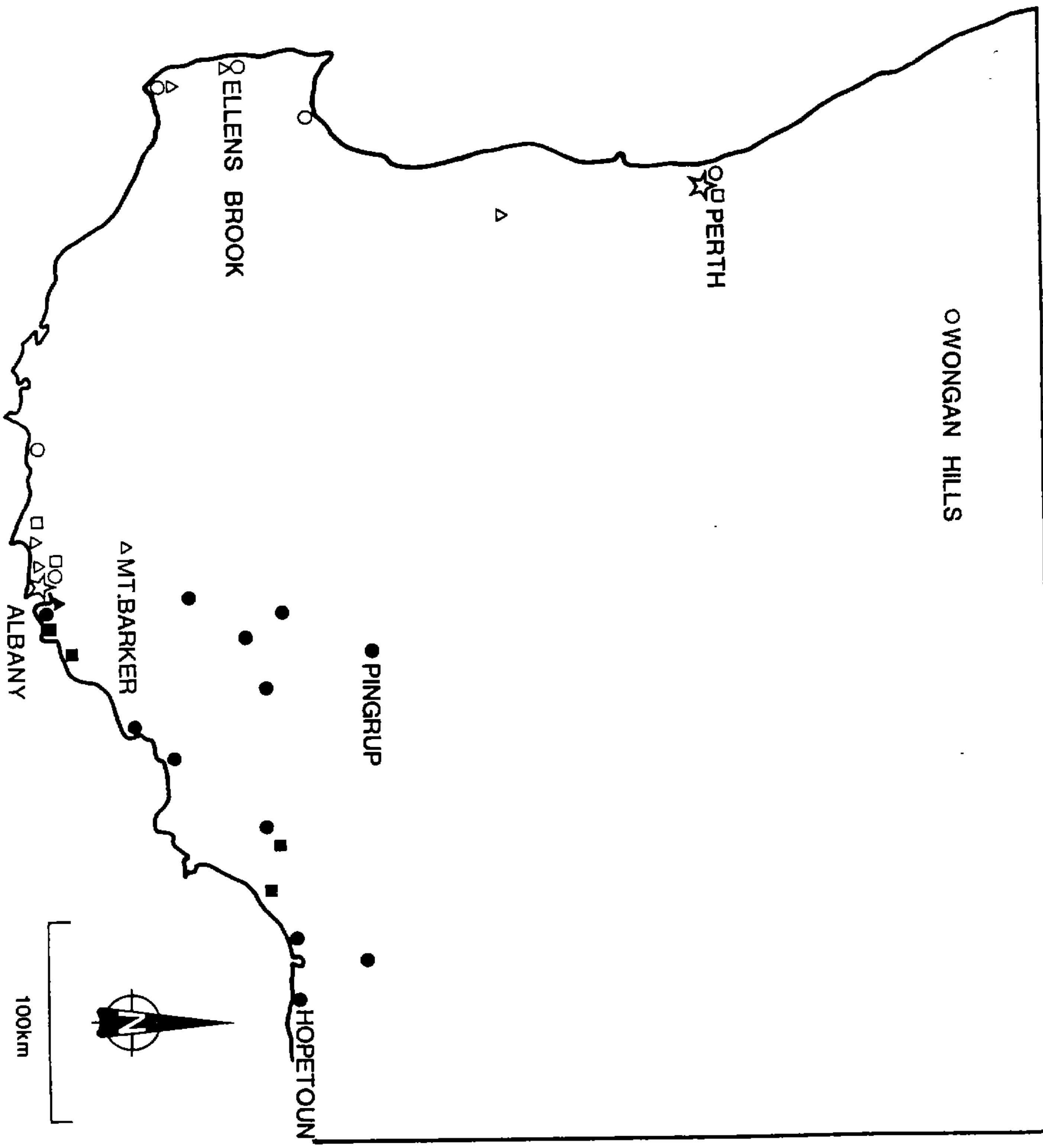

Figure 1. Past and present locations of Noisy Scrub-bird (△▲), Western Whip-bird (○●) and Western Bristle-bird (□■).

Areas were burnt consecutively so that no one area was burnt too frequently. Presumably, this practice was centuries old. Whatever effect this fire regime had on the vegetation, it is obvious that it had not destroyed the species habitat and may have helped maintain it, given that the Noisy Scrub-bird and Western Bristle-bird were relatively common in this area. The same conclusions probably apply to other areas. What cannot be determined is the role of Aboriginal fire in shaping the restricted pre-European distribution of the species.

The development of agricultural and pastoral industries and the growth of urban centres in Western Australia was slow; the population in 1891 was only 53,000. Areas used for agriculture at this time were small, about 14,000 ha within the species distribution. However, pastoral activities were extensive, with leases being taken up in most of the areas covered by the distribution of the species (Anon. 1979). Given this pattern of development, it is unlikely that destruction of habitat for agriculture or urban development would have had much effect on the species. Indirectly, however, Europeans wrought considerable changes to the environment.

Their arrival resulted in a rapid breakdown in Aboriginal society and by the 1880s traditional life had virtually disappeared (Berndt 1979). The gradual cessation of burning increased the fuel load in areas that had been traditionally burnt. In addition, the increased fuel from the timber cutters and the widespread use of fire for agricultural clearing led to an epidemic of intense fires in the early years of settlement (Cameron 1979). In coastal areas the practice of burning areas of heath and thicket every two to three years to provide new growth for stock became widespread. The effects of such fires on the vegetation in an area near Ellensbrook where Western Whip-birds, and the possibly extinct Rufous Bristle-bird **Dasyornis broadbenti** had been recorded in 1902 are described by Carter (1924): "Where there had been impenetrable scrub there was mostly loose sand drifts caused by fire made to improve the country for cattle grazing".

This change took place between 1902 and 1916 and is probably typical of many coastal areas. Boogidup Creek where Campbell recorded the Noisy Scrub-bird in 1889 (Serventy & Whittell 1976) is only a few kilometres to the south and would have been affected by similar fires. Further, Whitlock (in Whittell 1936) records the disappearance of the Western Bristle-bird from an area of heath near Denmark after fires swept the area in 1907 and 1913.

While these accounts are the only evidence that fire was responsible for the species' decline, it is clear that Europeans drastically altered the fire regime, from what might be called a control burn situation to one of too intense or too frequent fires. It was the one environmental variable that was significantly altered in the early days of the colony and it is reasonable to assume that it was the major cause of the decline.

Two Peoples Bay

The Two Peoples Bay Nature Reserve (4,637 ha) lies to the south and west of Two Peoples Bay, 40 km east of Albany. The vegetation in the south eastern portion of the reserve, where the three species occur, may be described broadly in terms of three major structural formations: heath, thicket and low forest. These formations are the primary habitat for Western Bristle-birds, Western Whip-birds and Noisy Scrub-birds respectively. Heath occurs mainly on the Isthmus (Fig. 2), the interfluves between the drainage lines and on the shallower gully walls around Mt Gardner. Thicket is mainly an ecotone formation on the break in slope between the valley walls and the interfluves, below the granite outcrops, and in the drier areas of the drainage lines. Low forest is confined mainly to the drainage lines, lake margins and in small areas below granite outcrops.

Fire History

It is likely that the reserve was affected by Aboriginal burning in a manner similar to that at Albany. Later, fires caused by Europeans would have affected the reserve, but we have no knowledge of them until 1946 when the first aerial photographs were taken. These photographs show that in the area where the birds occur, there had been a number of small fires in the Mt Gardner area and one moderately sized fire on the Isthmus in the previous three to five years (Fig. 2A). The presence of older fires can be inferred from the greater extent of exposed rock outcrops and the generally patchy look of the vegetation when compared with more recent photography. In the Mt Gardner area, the topography and bare granite ridges that lie across the prevailing winds limit the extent of any one fire. Thus, it is unlikely that the whole area has been burnt by a single fire. This probably explains why these species have survived in this area. Further information is available from aerial photography in 1965, 1969, 1970 and 1973, and eye witness accounts since 1961. These photographs show evidence of more extensive fires, mainly in the Isthmus area (Fig. 2B). Only two recent fires (1962 and 1964) have affected the Mt Gardner area. Since 1970, there have been no fires that have affected the species.

Fire and the Noisy Scrub-bird

The only practical index of the Noisy Scrub-bird population is the number of singing males (Smith & Forrester 1981). There are partial population data from the period 1962-66, 1968 and from the annual censuses 1970-76, 1979, 1980, 1982 and 1983. The data from 1962 to 1966 are a cumulative count of the males (52) in this period and suggests that the number of males in any one year was of the order of 40 to 45, rising to a possible 50 in 1968. However, in 1970 and 1971 there were 45 and 44 males respectively. Since then the population has steadily increased to 138 males in 1983 (Smith & Forrester 1981; Smith 1985).

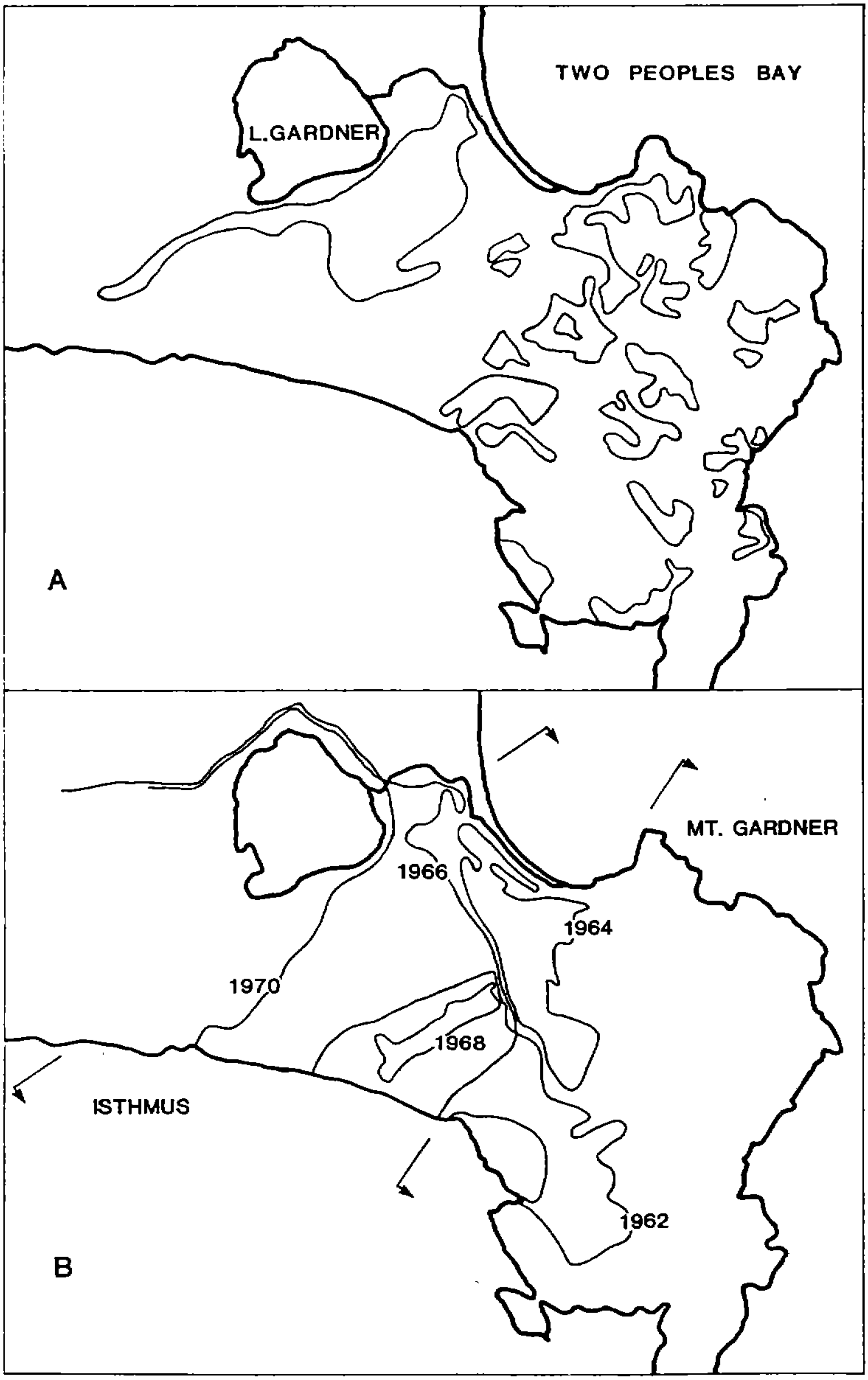

Figure 2. Fire history, Two Peoples Bay. A. 1946; B. 1962-1970.

There have been two features of this increase in the population. The first is that in the Mt Gardner area there has been an increase in the number of males using sub-optimal heath and thicket habitat (3 percent in 1970 to 28 percent in 1983). This suggests that most of the suitable areas of low forest (optimal habitat) have been occupied. The second feature has been the expansion of the population since 1975 along Gardner Creek and around Lake Gardner, to form a distinct sub-population.

The only information on the effect of fire on Noisy Scrub-birds comes from observations on the length of time taken for areas to be reoccupied after fire. Reoccupation of the sites of eight males after the 1962 fire suggests that the period required for the vegetation to grow to a stage suitable for scrub-birds ranges from 4 to 10 years, being faster in wet gullies where the dominant eucalypts have not been destroyed. There is no direct evidence for the period required for successful breeding, but in two wet gullies there is indirect evidence that breeding took place one or two years after the males occupied the areas. These periods, together with the low annual productivity of about 50 percent for the one egg clutch, help explain the slow increase in the population after the long absence from fire. They also illustrate the vulnerability of small, isolated populations of Noisy Scrub-birds to frequent fires.

If absence of fire has been the main factor allowing the increase in population, can estimates be made of the population in 1946, when fire was a regular feature of the reserve? In the period 1970 to 1983, 145 sites have been used by males in the Mt Gardner area. These sites are one to two ha in area and represent the core area of the males' territories (Smith 1976, 1985). The sites may be used over long periods, for example, 11 sites have been used continuously for 17 years. It is likely that these 145 sites represent most of the available habitat for the Noisy Scrub-bird in this area. These sites were rated on a four-point scale from recently-burnt to no evidence of burning, using the 1946, 1965 and 1969 aerial photography. In 1946, 67 sites showed evidence of having been burnt recently or in the near past, 67 had probably been burnt and only 9 showed no evidence of burning. The respective figures for 1965 and 1969 were 44, 43, 58 and 2, 34, 110.

Clearly the decline in the fire frequency has resulted in a substantial re-growth of the vegetation and from these figures one could predict that the population in 1946 would have been well below that of the 1970s.

In order to make some estimate of the population in 1946, the same 145 sites were assessed as to their suitability for scrub-birds, using the 1946 photography. The areas were ranked on a four-point scale from suitable to unsuitable.

After eliminating those sites in sub-optimal habitat, only 21 sites were ranked as suitable or probably suitable, while a further 10 were considered possibly suitable.

To test the accuracy of these figures, the sites were ranked for suitability, using the 1965 photography. Forty-four areas were considered suitable or probably suitable, while 12 areas were ranked as possibly suitable. These figures agree well with the 52 sites with males recorded in the period 1962-66 and the population estimate of 40-45 males. A further test was carried out using the areas occupied by the 38 males recorded in 1968 and ranking their degree of suitability on the 1969 photography. Thirty one of the thirty eight sites were ranked as suitable or probably suitable and three were ranked as unsuitable.

While the methods are partly subjective, it is reasonable to assume that in 1946 there were 21 to 31 males in the Mt Gardner area. Apart from one male near the outlet to Gardner Creek, there is no evidence that there were Noisy Scrub-birds around Lake Gardner in 1946 and we can conclude that the above estimate was the likely population for the reserve. The calculation of this estimate is also valuable in providing a guide to the number of birds that should be used in the translocation program for the species (Burbidge et al. 1984).

Fire and the Western Bristle-bird

Early records (Buller 1945; Ford 1965) suggest that Western Bristle-birds occurred in the Isthmus and Mt Gardner areas. However, a series of fires in the period 1962-1970 eliminated them from the Isthmus, and they did not return to the area until 1973. Since then there has been a steady expansion and they are now found throughout the area.

The fires in 1962 and 1964 burnt areas that in the following years were occupied by 32 pairs. In the wetter areas near the gullies, territories were first established nine years after the fire, while in the drier areas the period ranged from 11 to 14 years. While most of this difference is related to the different rates of regrowth, some may be caused by a lack of birds to reoccupy the areas. In contrast, bristle-birds had started to establish territories in swampy areas near Lake Gardner, five years after they had been burnt (1970 fire). The difference probably reflects differences in the availability of surplus birds. Visual assessment of the vegetation suggests that in wet areas like those around Lake Gardner, heath may be suitable for bristle-birds three years after a fire, while in drier areas it may take six to ten years. These periods may be extended by grazing pressure from Grey Kangaroos *Macropus fuliginosus*, which may be heavy, when small areas are burnt.

The only accurate estimate of the number of bristle-bird pairs, using the location of singing pairs, was made in 1976 when 86 pairs were located. A partial census in 1983 suggests that the population was about 100 pairs and had expanded throughout most of the Isthmus. Using the known distribution in the Mt Gardner area in 1970, and assuming that the density had not changed, the maximum population in 1970 would have been 60 pairs.

In order to estimate the effect of fire on the population prior to 1970, the areas of heath on the eastern half of the reserve (about 55 percent of area) were rated on a three-point scale using the 1946, 1969 and 1973 photography. Areas rated one were comparable in appearance to heath known to have been burnt for one or two years, those rated 2 had probably been burnt 2 to 5 years before, while those rated 3 had not been burnt for at least 5 years. The areas where bristle-birds were recorded in 1976 were also rated on the same scale using the same photographs. The data are presented in Table 1. The most important point in this data is that only 14 percent of the heath was ranked 3 in 1946, 34 percent in 1969 and 74 percent in 1973. Further, in 1946 only 6 of the 86 territories in 1976 were ranked 3, while in 1973, 63 were so ranked. From such data it is not possible to estimate the 1946 population, but clearly the population would have been significantly smaller than the estimated maximum population in 1970 of 60 pairs.

Table 1. A. Percentage of area of heath in eastern portion of the Two Peoples Bay Reserve that appear to have been burnt. 1, recently burnt; 2, 2 to 5 years ago; 3, not burnt for at least 5 years; on aerial photos from 1946, 1969 and 1973. B. The sites used by the pairs of Western Bristle-birds recorded in 1976 were rated as above.

	A			B		
	Heath (%)			Sites (N=86)		
	1	2	3	1	2	3
1946	28	58	14	33	47	6
1969	16	50	34	5	43	38
1973	1	25	74	1	22	63

Fire and the Western Whip-bird

The Western Whip-bird was first discovered at Two Peoples Bay by Webster (1966) in 1962, when it was only found in the Mt Gardner area. It did not start expanding into the Isthmus until 1976. In 1976, 87 pairs of Western Whip-birds were located in the Mt Gardner area, while a partial census in 1983 indicated that the population had increased to about 100 pairs, mainly by the establishment of territories throughout the Isthmus. The 1970 population was estimated to be a maximum of 60 pairs, by using the known distribution in 1970, and assuming that within this area the number of territories was the same as in 1976.

In areas burnt by the 1962 and 1964 fires, new territories were being established 7 to 10 years after the fires, and breeding is known to have occurred 7 years after a fire in one territory. In areas that were burnt on the Isthmus to provide a low fuel buffer, whip-birds have established territories 4 to 6 years after the fire. This period is probably the minimum period for suitable regrowth.

In order to obtain some idea of the population size before 1970, the position of the 1976 territories were ranked on a three-point scale (suitable, possibly suitable, unsuitable) on the 1946, 1969 and 1973 photography. The number of areas ranked suitable for 1946, 1969 and 1974 were 17, 49 and 74 respectively, and the number of areas ranked possibly suitable were 39, 35 and 13 respectively. Assuming that these areas were representative of the areas of available habitat in the Mt Gardner area, then the population in 1946 may have been between 17 and 56 pairs, but most likely of the order of 30 to 40 pairs.

Fire and Population Changes

In the period 1970 to 1983 the distributions and populations of all three species increased. While the estimates of the populations prior to 1970 are speculative, they clearly indicate that the populations of all three species at this time were significantly less than the populations in 1970. The simplest explanations for the increases in the populations is the change in the fire regime since 1946 and the prevention of fires since 1970. The survival of the species on the reserve can be attributed to the topography of the Mt Gardner area and the fire regime of numerous small fires. These two factors prevented the whole area being burnt out at one time, ensuring that there was always some suitable habitat available.

The Future

The management policy of excluding fire from the reserve has allowed the vegetation to grow and thus provide more habitat for the species. For the Noisy Scrub-bird, this has provided two immediate advantages. Firstly, it has resulted in the growth of a population around Lake Gardner that is well separated from the Mt Gardner area by fire breaks, roads and a control burn strip. Thus, it is unlikely that a catastrophic fire will destroy both populations. Secondly, the increase in population has allowed the Department of Conservation and Land Management to start a translocation program at Mt Manypeaks, thus providing added security for the long-term survival of the species.

While these are short term advantages, what are the consequences of the continued exclusion of fire from the reserve? In heath areas, it can be postulated that there is a succession of bird species after fire that reflects the regrowth of the vegetation. The sequence goes from Richard's Pipit (**Anthus novaeseelandiae**) to Field Wrens (**Sericornis fuliginosus**) to Western Bristle-birds to Western Whip-birds. Depending on the vegetation at a particular site, the sequence may end at any point or steps may be missed if there are no birds to occupy the area.

The first and last steps have been observed in different parts of the reserve. The step from Field Wrens to Western Bristle-birds has not been observed but is suggested by the expansion of the Western Bristle-bird from the Mt Gardner area into areas with Field Wrens. The consequences of these changes will be a gradual decrease in the area of heath suitable for the Western Bristle-bird and a concomitant increase in the areas suitable for the Western Whip-bird. The extent of the reduction in area of heath is unknown.

Studies by Angus Hopkins (pers. comm.) have shown that the above ground biomass of dry heath reaches its prefire levels after six years. This period agrees with 3 to 10 years of growth required before heath is suitable for bristle-birds. How long these heaths will remain suitable is not known. There are two areas around Mt Gardner that do not appear to have been burnt for at least 45 years. The density of bristle-birds in these areas is less than in areas of heath that were burnt 20 years ago. It may well be that structural changes in the heath may gradually make it less suitable for bristle-birds; whether it ever becomes totally unsuitable is unknown. A similar situation may apply to the thicket habitat of the Western Whip-bird.

The prime habitat for the Noisy Scrub-bird is low forest. Nothing is known of the long term structural changes that occur in this formation after fire. However, there are a number of observations that indicate that changes are taking place. In most territories studied from 1970 to 1983, there have been a number of small changes in the structure of areas of low forest. Generally, the lower and middle stories have become less dense and clumps of *Lepidosperma* spp., an important nest site, have died. So far, the small scale heterogeneity in the territories has ensured that there is always enough suitable habitat in the territory. Nine sites with scrub-birds probably have not been burnt for at least 45 years; of these, six have been occupied continuously since 1970 and three have been used intermittently. So far, no areas have become unsuitable for scrub-birds. It is possible that the small scale changes seen in some of these areas are part of a cycle of vegetation change that may maintain an area suitable for scrub-birds for a long time, (more than 50 years) after fire. However, just how long is not known.

There are sufficient data to indicate that the maximum fire frequency to maintain adequate populations of the three species should not be less than 20 years and perhaps should be of the order of 50 years. Initially in the absence of fire, the vegetation grows and provides an increasing amount of suitable habitat; however, there are observations that suggest that further growth may result in a decline in the amount of habitat. The effect of these changes and their time scale is unknown and it will require continual monitoring of the vegetation and bird populations to find out.

Summary

Changes in the fire regime caused by Europeans in the last century are thought to be the main cause in the decline of the three rare birds: the Noisy Scrub-bird (*Atrichornis clamosus*), Western Bristle-bird (*Dasyornis longirostris*), and Western Whip-bird (*Psophodes nigrogularis*), which survived as isolated populations on the Two Peoples Bay Nature Reserve. Population data from 1970 to 1983 show that the populations of the three species on the reserve have increased and that the populations in 1970 were significantly greater than those in 1946 as estimated from photo-interpretation of habitat availability. The simplest explanation for the increases is the change in the fire regime after 1946 and the elimination of fire from areas of the reserve within the distribution of the species since 1970. The possible consequences of the reserve on the long term availability of habitat are discussed.

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FIRE EFFECTS ON INVERTEBRATE FAUNA OF FOREST AND WOODLAND

J.D. Majer

Introduction

An understanding of the influence of fire on soil and litter invertebrates in Australian ecosystems is important in view of the important role of these animals in nutrient cycling (Hutson 1983), maintenance of soil structure (Greenslade & Greenslade 1983) and provision of food for certain vertebrate animals such as the mardo (Hindmarsh & Majer 1977).

To date, the Western Australian fire/invertebrate studies have been confined to the southwest in Jarrah forest (McNamara 1955; Springett 1976; Springett 1979; Majer 1984; Abbott 1984), Jarrah-Banksia woodland (Bornemissza 1969; Whelan et al. 1980), Karri forest (Springett 1976; Hindmarsh & Majer 1977), Wandoo woodland (Majer 1980, 1985) and Pine forests (Springett 1971, 1976). In addition, Campbell & Tanton (1981) have reviewed some of the Western Australian studies and offered new interpretations of the data.

A range of sometimes conflicting conclusions has resulted, including:

1. Prescribed burning causes an immediate reduction in the abundance of soil and/or litter invertebrates (all papers quoted above).

2. The fauna has not recovered in terms of its species or trophic level composition by the end of a normal prescribed burning rotation (Springett 1971, 1976).

3. When measured at the order level, the soil and/or litter fauna has recovered within a normal prescribed burning rotation (Majer 1980, 1984; Abbott 1984).

4. The litter fauna takes longer to recover after burning than does the soil fauna (Majer 1984).

5. Spring burning may be more detrimental to the soil surface fauna than autumn burning (Majer 1980).

6. Unburnt plants, logs and patches of litter are important refuges for fauna in burnt areas (Whelan et al. 1980; Majer 1980).

7. Inter-site variation in soil or litter fauna is as great as that between burnt and unburnt sites and this may undermine conclusions about fire effects (Campbell & Tanton 1981).

The reasons for these sometimes conflicting conclusions may be related to the intensity of fire studied, the type of experimental design or to the taxonomic treatment which was used in the study. Only when studies are performed which have adequate pre-fire data, adequate site replication, samples taken over a long period and animal indentifications made to the species level, will truly conclusive findings become available. Such studies would be immensely expensive and labour intensive to carry out and coordinate.

The aim of this paper is now to discuss two important aspects of prescription burning: first, the elasticity of invertebrate fauna to spring versus autumn burning, and secondly, the elasticity of the fauna in forest versus woodland fires. Elasticity here refers to the rate of recovery of the biota following a disturbance such as burning.

Elasticity of Fauna to Spring Versus Autumn Burning

The question of spring versus autumn burning cannot be resolved before discussing the phenology of soil and litter invertebrates.

Koch & Majer (1980) and Majer & Koch (1982) have described the phenology of pitfall trapped soil surface fauna of forests and woodlands at Perth, Dwellingup and Manjimup. These sites represent a southerly gradient of decreasing temperatures, increasing humidity and less marked seasonality of climatic variables. Figure 1 summarises the seasonal patterns and shows the seasonal relationships rather than the actual values for the index of activity.

The activity of herbivores is negatively correlated with rainfall at these three sites, and it increases during spring (Fig. 1). Spring is the period when many understorey shrubs exhibit leaf growth flushes, following the increase in available moisture and the warmer temperatures. The decrease in herbivore activity during the cooler months at all three sites might be connected with the contemporaneously slower leaf growth rate of certain plant species, the direct influence of climatic factors on the life cycles of the herbivores or it might be a combination of both factors. Thus the decreases in activity of the herbivores at Dwellingup (during August-September) and at Manjimup (during June-October) (Fig. 1) may be due to the low temperatures during these months.

The period when decomposers are active increases progressively from north to south (Fig. 1). It is largely restricted to the wetter months at Perth and Dwellingup but continues throughout the year at Manjimup. This is probably because humid conditions are apparently present for longer at Manjimup.

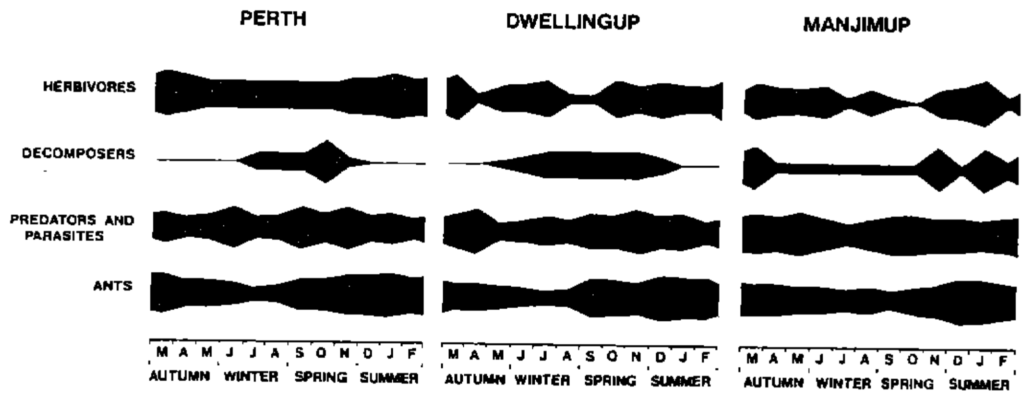


Figure 1. Schematic diagram of the seasonal activity of herbivores, decomposers and predators/parasites at Perth, Dwellingup and Manjimup. The width of the bar indicates the level of activity as measured by the numbers of species in each category collected in the pitfall traps (from Koch & Majer 1982).

Compared to the decomposers, the activity of the predator/parasite category appears less dependent on season. This may be because a wide range of organisms, with different feeding preferences and whose activities are not in phase, are preyed on or parasitised. The only trends detectable are slight increases in the activity of predators and parasites in the spring and autumn at Perth and Dwellingup (Fig. 1) and these may be associated with the increases in herbivore numbers during these seasons.

I shall now describe the climatic conditions and subsequent recovery of litter and vegetation after spring and autumn fires. An autumn fire occurs during a period of decreasing temperatures and increasing rainfall (Majer 1984). The litter layer rapidly builds up as new shoots and leaves fall from the scorched crown and plants grow during the moist winter and spring. By summer the ground is partly covered by litter and vegetation.

By contrast, a spring fire occurs when conditions are becoming hotter and drier. Subsequent summer plant growth appears to be less than that experienced in the first 6 months after an autumn fire. Consequently the hot, dry conditions of summer are aggravated by the absence of a buffering layer of vegetation.

By combining the comments on invertebrate phenology with those on climate and vegetation I propose an explanatory model which summarises and reconciles past studies and which will hopefully guide future research on optimal burning times. Autumn fires occur when the activity of many predators and herbivores is low or is decreasing. This means that relatively low numbers of these animals would be killed. Also, the absence of food during winter would not be extremely important as the activity or abundance of herbivores and predators is low then. Decomposer fauna would be most affected although the rapid build up of litter would provide some opportunities for post-fire recovery. The rapid plant leaf growth in winter, and particularly in the following spring would provide food for herbivores and would reduce summer mortality of fauna by buffering the soil and litter microclimate.

A spring fire on the other hand depletes the plant biomass and the invertebrate fauna at a time of increasing food demand by predator groups such as ants and spiders. The lower plant growth in the dry period immediately after the spring fire means that herbivorous invertebrates may have less food, and mortality of invertebrates during summer may be high due to exceptionally hot dry conditions on the highly insolated ground. The only component of the fauna which may not be so adversely affected, when compared with an autumn fire, is the decomposer group. This is because the spring fire occurs well in advance of the period of decomposer activity.

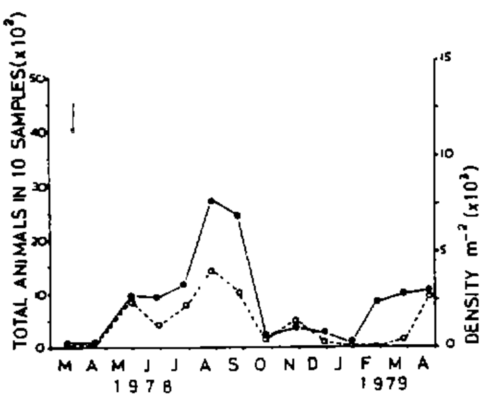
To date, little comparative work has been done to investigate these ideas. Majer (unpub. data) has compared the influence of fire on, and subsequent post-fire recovery of, ants in hot late-spring and autumn fires in Jarrah forest near Dwellingup. Grids of 36 pitfall traps were run for 7 day periods prior to the burns and up to about 100 weeks following the burn. By subtracting the number of ants caught in unburnt plots from those obtained in the burnt plots an index of ant recovery may be obtained. The results indicate that post-fire differences between unburnt and burnt plots are considerably greater in the spring burnt plot and that, although recovery is almost complete after 95 weeks in the autumn burnt plot, large differences in number of ants caught are still apparent in the spring burnt plot after 110 weeks (Boardman 1985). It should be stressed that these results could also be explained in terms of the spring fire being hotter than the autumn fire (1500 kW/m vs 500 kW/m) but they are nevertheless consistent with the postulation on the influence of the two types of burn. Furthermore, Boardman's (1985) analysis indicated that, for a given burn time, fire intensities such as these had similar impacts on the ant fauna. Ants are often specialists, feeding on saps, seeds, carrion or prey so the state of the ant fauna may reflect the state of their prey (Majer 1983). Thus, the differences in ant fauna between the two fires discussed here could be interpreted as reflecting a greater impact of spring burning on the invertebrate fauna in general.

Elasticity of Fauna in Jarrah Forest Versus Wandoo Woodland

Little comparative work has been performed on the elasticity of invertebrate fauna to fire in different vegetation types. The following description is based on the author's litter fauna studies in Jarrah forest at Karragullen and Wandoo woodland at Dryandra (mean annual rainfalls of 1241 and 478 mm respectively).

At Karragullen two plots were selected and the litter fauna was sampled by Berlese funnels. Samples were taken for 1 month prior to a 150-200 kW/m autumn fire and for 13 months after the fire. The fauna was scored and discussed at the order level by Majer (1984). It was concluded that, when scored at the broad taxonomic level, the litter fauna had substantially recovered to unburnt plot levels at the end of the 14 month sampling period (Fig. 2).

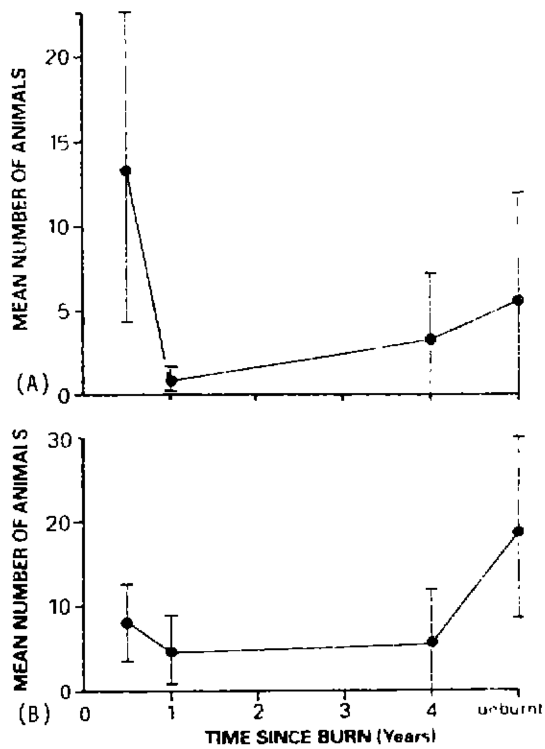
Figure 2. Total number of litter invertebrates sampled in unburnt (●——●) and burnt (o-----o) plots at Karragullen. Arrow indicates date of burn (from Majer 1984).



In the Dryandra study, the litter fauna of four plots was investigated in March 1983. The unburnt plot had not been burnt for at least 10 years while the old burnt plot had been burnt 4 years previously, the autumn burnt plot one year previously and the spring burnt had been burnt 6 months previously. Litter was sampled along transects in each plot both by Berlese funnels and by hand sorting the litter. The fauna were sorted and discussed at the order level by Majer (1985).

Figure 3 shows the number of litter animals in samples obtained by both Berlese funnels and hand sorting batches of litter which were corrected for differing litter masses in each plot. The high catches in the spring burnt plot (Fig. 3) were probably associated with the moist conditions prevailing in this plot. When the other two plots are compared with the unburnt plot the recovery of fauna appears to be incomplete, even after 4 years. By comparison with the Karragullen data, litter fauna in the drier Wandoo woodland seems to take much longer to return to pre-fire levels. It is also noteworthy that population densities of some soil and litter animals decrease in the Jarrah forest along a west to east gradient (I. Abbott, pers. comm.). Thus, disturbances may be more likely to cause extinction of animal populations in the low rainfall forests and woodlands than in areas where their density is higher.

Figure 3. Mean number of invertebrates (excluding ants and, for Berlese funnel samples only, Diptera) per (a) Berlese funnel and (b) hand sorted litter sample in the four 1983 Dryandra fire study plots. The standard deviations of each mean are also shown (from Majer 1985).



Discussion

The comments presented in the two sections above are certainly not conclusive but are presented here to promote discussion of the merits of different fire management regimes and to stress the need for more intensive research.

They indicate that, in southwest Australian ecosystems, hot autumn burning may be less detrimental to the soil and litter invertebrates than hot spring burning. This may have more general relevance to the ecosystem in view of the important role which these animals have in many of its component processes. Whether these findings for hot fires apply to the cool prescription fires which are normally carried out remains to be demonstrated. It should also be stressed that this finding applies to mediterranean climatic zones which experience cool wet winters and hot dry summers. In a study performed in warm temperate New South Wales, Moulton (1982) found that spring burning had less impact on soil arthropods than autumn burning. This area experienced a summer rainfall pattern so this finding does not conflict with the Western Australian experience.

Recovery of the invertebrate fauna after prescribed burning is important for the maintenance of essential ecosystem processes such as nutrient cycling (Springett 1976). The apparently slower recovery of litter fauna at Dryandra than at Karragullen could be related to the lower rainfall at the former site. Lower rainfall, and correspondingly drier conditions, may cause slower plant regeneration and create more harsh, arid conditions in the soil and litter layers. I postulate that the fauna may be even less resilient to fire in the more arid areas further inland than Dryandra.

If this trend is proved to be correct there are important implications to the management of fire in forests and conservation areas throughout Western Australia. All such areas are subject to prescription burning and there is a tendency to transpose the technology from one ecosystem to another. The findings from the Karragullen and Dryandra studies suggest that different, and longer rotation, prescription fires should be practiced in areas of decreasing rainfall.

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THE FIRE-RELATED DYNAMICS OF SMALL VERTEBRATES IN BANKSIA WOODLAND: A SUMMARY OF RESEARCH IN PROGRESS.

Michael J. Bamford

Introduction and Methods

This paper outlines a study on changes in the small vertebrate community of banksia woodland with increasing time after fire. The study area is located near Gingin, about 80 km north of Perth, on private property. Although the general area was settled in 1844, clearing for agriculture has not been intensive and the landscape today consists of a mosaic of uncleared vegetation and farmland. This mosaic, and the attitudes of a few land-holders, have protected some areas of banksia woodland from fire for considerable periods of time, while other areas have been burnt more recently. Thus, a range of sites, unburnt for different periods of time and only a few kilometres apart, was readily available for study. Field work began in April 1983 and will continue until March 1985.

Details of the fire histories of the six sites studied are given in Table 1. The intervals between all recorded fires are longer than is generally the case for banksia woodland near Perth. Although the sites were adjacent to farmland, they also had areas of woodland along part of their boundaries and there was no extensive area of cleared land between any of the sites. The two most distant sites were approximately eight kilometres apart.

This study encompassed all the small vertebrates which occurred in the banksia woodland with the exception of bats. For practical reasons, the larger mammals were not considered although some data were collected opportunistically on the Western Grey Kangaroo **Macropus fuliginosus** and the Brush Wallaby Macropus **irma**.

Amphibians, reptiles and small mammals (mammals with an adult body weight of less than 50 g) were studied using a mark-recapture trapping programme. The traps used were pitfalls 40 cm deep and 16 cm diameter deployed in grids of 50 with all pitfalls 5 m apart. Two grids were located at least 50 m apart within each site. Trapping was carried out for five nights each month and all captures were weighed, measured, sexed (where possible) and individually marked before release. Although box traps have been used in most studies of small mammals in Australia, they were found unsuitable for this study because a preliminary trapping programme with box traps captured only the two rodent species. No species that could escape from pitfall traps were caught in the box traps.

Birds were surveyed by recording the species present when the pitfalls in each site were checked. Essentially, the same location within each site was therefore censussed for birds on at least 5 mornings each month for a period of time that ranged from 20 minutes to an hour. The sampling effort in each site was approximately the same and most records were made by sound rather than sight so that the different densities of vegetation at sites did not greatly affect the resulting comparisons between sites.

Table 1. The known and estimated fire-histories of the six banksia woodland study sites, as determined from aerial photographs and discussions with long-term residents. Only the dates of fires from 1980 onwards are known accurately; earlier dates are best estimates.

		Fire history			
Site	Area (ha)	Last burnt	Previously burnt		Studied from
A	40	March 1985	Summer 1962/63	Summer 1940/41	August 1983
B	40	Sept. 1984	Summer 1962/63	Summer 1940/41	Nov. 1984
C	80	March 1983	Summer 1971/72	Summer 1940/41	April 1983
D	100	March 1980	Summer 1962/63	Summer 1940/41	April 1983
E	120	Summer 1971/72	Summer 1962/63	Summer 1940/41	April 1983
F	50	Summer 1962/63	Summer 1940/41	Unknown	April 1983

In addition to the direct study of the small vertebrates, other changes that occurred with increasing time after fire in banksia woodland were also documented. Floristic studies were carried out by other workers and I recorded structural changes in the vegetation and also changes in the quantity and depth of leaf-litter. Data on invertebrates were gathered by sampling leaf-litter and through the use of grids of small pitfalls placed in each site.

Results and Discussion

As the study is still in progress, final analysis of results is not yet complete and all that will be attempted here is to indicate the sort of information that is emerging.

The small vertebrate community has been found to consist of 8 frog-species, 32 reptile-species, 66 bird-species and 7 small mammal-species. A list of all species of vertebrate recorded is given in Table 2.

Most of the frog species appeared to be influenced more by the proximity of surface water than by the time since fire. However, species which do not burrow, such as Litoria adelaidensis, were only recorded in the site unburnt for longest, and the terrestrially breeding Myobatrachus gouldii was caught more frequently in the longer unburnt sites.

Low capture rates have led to difficulties in interpreting reptile data. Many species are represented by only a few specimens so that their apparent absence from some sites may not be real, while other species recorded in low numbers on all sites may actually be more abundant on one. For a few reptile species, however, distinct changes were found to occur with increasing time after fire. Tympanocryptis adelaidensis was caught often in site D and rarely in the other sites, Lerista elegans was caught most often in the two longer unburnt sites and Pogona minor was rare until the second summer following the fire in site C.

Table 2. Vertebrate species recorded in the study area. For the purposes of this study, small vertebrates were those species on which data could be collected by the techniques of trapping and censussing employed. This included all the amphibians, reptiles and birds, but only the mammal species with an adult body weight of less than 50 g. Mammal species not studied are given in parentheses.

AMPHIBIANS

Litoria adelaidensis
Crinia georgiana
Crinia glauerti
Crinia insignifera
Heleioporuseyrei
Limnodynastes dorsalis
Myobatrachus gouldii
Pseudophryne guentheri

REPTILES

Diplodactylus polyopthalmus
Diplodactylus spinigereus
Aprasia repens
Delma grayii
Delma fraserii
Lialis burtonis
Pletholax gracilis
Pygopus lepidopodus
Varanus gouldii
Varanus tristes
Pogona minor
Tympanocryptis adelaidensis
Cryptoblepharus plagiocephalus
Ctenotus fallens
Ctenotus leseurii
Ctenotus schomburgkii
Lerista christinae
Lerista elegans
Lerista praepedita
Menetia greyii
Morethia lineoocellata
Morethia obscura
Egernia multiscutata
Tiliqua rugosa
Ramphotyphlops australis
Demansia reticulata
Notechis curtus
Pseudonaja nuchalis
Rhinoplocephalus gouldii
Vermicella bertholdii
Vermicella calonotus
Vermicella semifasciata

MAMMALS

(Tachyglossus aculeatus)
(Isoodon obesulus)
Sminthopsis dolichura
Sminthopsis griseoventer
Sminthopsis granulipes
Cercartetus concinnus
Tarsipes rostratus
(Macropus fuliginosus)
(Macropus irma)
(Nyctophilus geoffroyii)
(Vulpes vulpes)
(Oryctolagus cuniculus)
Mus musculus
Pseudomys albocinereus

BIRDS

Emu	Dromaius novaehollandiae
Brown Goshawk	Accipiter fasciatus
Collared Sparrowhawk	Accipiter cirrhocephalus
Wedge-tailed Eagle	Aquila audax
Little Eagle	Hieraaetus morphnoides
Australian Hobby	Falco longipennis
Brown Falcon	Falco berigora
Nankeen Kestrel	Falco cenchroides
Stubble Quail	Coturnix novaezelandiae
Painted Button-quail	Turnix varia
Little Button-quail	Turnix velox
Laughing Turtle-Dove	Streptopelia senegalensis
Common Bronzewing	Phaps chalcoptera
Crested Pigeon	Ocyphaps lophotes
White-tailed Black-Cockatoo	Calyptorhynchus baudinii
Galah	Cacatua roseicapilla
Purple-crowned Lorikeet	Glossopsitta porphyrocephala
Red-capped Parrot	Purpureicephalus spurius
Port Lincoln Parrot	Barnardius zonarius
Pallid Cuckoo	Cuculus pallidus
Fan-tailed Cuckoo	Cuculus pyrrhophanus
Rufous-tailed Bronze-Cuckoo	Chrysococcyx basalis
Shining Bronze-Cuckoo	Chrysococcyx lucidus
Boobook Owl	Ninox novaeseelandiae
Barn Owl	Tyto alba
Tawny Frogmouth	Podargus strigiodes
Laughing Kookaburra	Dacelo novaeguineae
Sacred Kingfisher	Halcyon sancta
Rainbow Bee-eater	Merops ornatus
White-backed Swallow	Cheramoeca leucosternum
Welcome Swallow	Hirundo neoxena
Tree Martin	Cecropis nigricans
Richard's Pipit	Anthus novaeseelandiae
Black-faced Cuckoo-shrike	Coracina novaeseelandiae
White-winged Triller	Lalage sueurii
Scarlet Robin	Petroica multicolor
Red-capped Robin	Petroica goodenovii
Hooded Robin	Melanodryas cucullata
Rufous Whistler	Pachycephala rufiventris
Grey Shrike-thrush	Colluricincla harmonica
Crested Bellbird	Oreoica gutturalis
Restless Flycatcher	Myiagra inquieta
Grey Fantail	Rhipidura fuliginosa
Willie Wagtail	Rhipidura leucophrys
Rufous Songlark	Cinclorhamphus mathewsi
Splendid Fairy-wren	Malurus splendens
White-winged Fairy-wren	Malurus leucopterus
Western Gerygone	Gerygone fusca
Western Thornbill	Acanthiza inornata
Yellow-rumped Thornbill	Acanthiza chrysorrhoa
Varied Sittella	Daphoenositta chrysoptera
Red Wattlebird	Anthochaera carunculata
Little Wattlebird	Anthochaera chrysoptera
Singing Honeyeater	Lichenostomus virescens
Brown-headed Honeyeater	Melithreptus brevirostris
Brown Honeyeater	Lichmera indistincta
Western Spinebill	Acanthorhynchus superciliosus
Mistletoebird	Dicaeum hirundinaceum
Striated Pardalote	Pardalotus striatus
Silvereye	Zosterops lateralis
Australian Magpie-lark	Grallina cyanoleuca
Black-faced Woodswallow	Artamus cinereus
Dusky Woodswallow	Artamus cyanopterus
Grey Butcherbird	Cracticus torquatus
Australian Magpie	Gymnorhina tibicen
Australian Raven	Corvus coronoides

In general, it appeared that reptile species not favoured by habitat changes caused by fire disappeared following a fire, while some species present in low numbers before the fire actually increased for at least a few years. Other reptiles were apparently unaffected, and the result was slightly fewer species in more recently burnt sites but with little overall difference in the number of individual reptiles trapped across the range of sites.

The effect of a fire upon birds was found to be more abrupt than upon reptiles; presumably this results from the greater mobility of birds. Some species were found to be more abundant in the first year after fire, others less so for at least two years after fire, but few species went unrecorded for more than a few months after fire. The number of bird species was dramatically lower following the fire in site C but returned to pre-fire levels within one year. However, the total number of individuals of all bird species remained low for at least two years after the fire.

Over the period April 1983 to March 1985, the numbers of bird-species recorded on sites C, D, E and F were similar, but the number of individuals was lowest in C and highest in D. Numbers of individuals scored in sites E and F were similar and about half that scored in D. No species was recorded only in the longer unburnt sites and none even showed a clear preference for these sites. A few species were recorded only in the more recently burnt sites, but these were common on the farmland so their presence may have been an artifact of the clearing that has been carried out.

Small mammals were more greatly affected by fire than either reptiles or birds. Of five species recorded before the fire in site A, two species were not recorded at all after the fire (Pseudomys and Cercartetus), one disappeared within a few days (Tarsipes), and a fourth declined over a period of months (Sminthopsis griseoventer). Only the introduced Mus actually increased in numbers during the first few months after the fire. Using the full range of sites, it was found that Tarsipes reappeared within 12 months, Pseudomys after 18 months, Sminthopsis griseoventer after 27 months and Cercartetus after about 3 years. Tarsipes and Cercartetus were recorded most often in the two longest unburnt sites, Pseudomys in site D and Sminthopsis griseoventer was equally abundant on sites D, E and F. Mus was present on all sites and showed a post-fire peak lasting for about 2 years. The two remaining small mammal species, Sminthopsis dolichura and Sminthopsis granulipes, were both recorded infrequently. Sminthopsis dolichura was also found to occur in a different vegetation type on nearby lateritic soil and was caught most often at site C. Over the period from April 1983 to March 1985, the total number of small mammal captures was low in site C but very similar in sites D, E and F. On these last three sites, only the proportions of the different species in the catches differed.

In general, the changes in the small vertebrate community with increasing time after fire were greatest in the first few years with relatively small changes in the sites unburnt longest. Survival through fire was high and the impact upon the small vertebrates was through environmental changes caused by fire. Fires in banksia woodland consumed most of the leaf-litter, burnt and killed the aerial parts of the understorey and scorched the banksia overstorey, resulting in heavy leaf-fall in the weeks immediately after the fire. Regeneration was rapid with the overstorey recovering after about 12 months and the understorey achieving densities similar to pre-fire levels within 3 years. With greater time after fire the height of the understorey increased very slowly from about 1 m after 3 years to about 2 m after 22 years. Leaf-litter levels also increased rapidly in the first few years and more gradually thereafter.

Invertebrates were found to decline in numbers in the months after fire and then to peak sharply after about a year. However, this peak was due entirely to a dramatic increase in the number of ants; other invertebrates remained at about half their pre-fire levels. One to three years after fire ant numbers declined rapidly to just above their pre-fire levels and then declined gradually thereafter. Other invertebrates showed a steady increase in numbers which continued across the range of sites. The abundance of other invertebrates in the site burnt 20 years earlier was approximately twice that in the site burnt one year ago.

The initial decline in many small vertebrate-species shortly after fire could be due to reduction in food supply and/or loss of vegetation cover. However, the dramatic changes that occurred among the small vertebrates in the first few years after fire seemed related only to the period of rapid vegetation regeneration. Numbers of invertebrates other than ants increased little at this time and, while ant numbers did show a peak, ants were found to be scarce in dietary samples from reptiles and small mammals. Furthermore, the increase in numbers of other invertebrates that occurred after fire was not associated with any increase in small vertebrates; total reptile and small mammal numbers were relatively constant after 3 years and birds actually declined in numbers between 5 and 11 years after fire. Thus, the post-fire dynamics of vertebrates in banksia woodland appeared more affected by changes in vegetation structure than by changes in invertebrate abundance.

FIRE - AND PERSISTENCE OF THE FLORA ON MIDDLE ISLAND, A SOUTHWESTERN AUSTRALIAN OFFSHORE ISLAND

Arthur S. Weston

Introduction

The wide acceptance of the importance of fire in the development and modification of Australian vegetation and flora is reflected in the extensive literature on the topic, much of which is reviewed by Gill, Groves & Noble (1981). Most research described in this literature is short-term or inferential. It is concerned, firstly, with relatively short-term responses of particular species or types of plants to fire (e.g. Gardner 1957; Lamont & Cowling 1984): secondly, with direct observation of vegetation succession during relatively short periods following burning which is, in broad senses, either natural (e.g. Hopkins & Robinson 1981; Baird 1977) or experimental (e.g. Griffin & Friedel 1984a, 1984b; Peet 1971); and, thirdly, with succession inferred from contemporaneous observations of several sites that have similar vegetation but differ in their fire histories (e.g. Bell & Koch 1980). Although research of these types does give us a better understanding of the role of fire in Australian ecosystems, the conclusions drawn from it, and the research designs, are highly controversial, as demonstrated in the debate over some of the papers given at this symposium and elsewhere (e.g. in Search Vols 11 & 12).

Long-term, direct studies of floristic and vegetation change on single sites provide more conclusive evidence about the impacts of burning on native plant communities, yet few descriptions of long-term projects have been published. Their paucity is easy to understand; very long-term studies require commitments lasting decades or even lifetimes and research designs that do not become obsolete before the studies are completed. Furthermore, they require controlled conditions that are difficult, if not impossible, to achieve, especially on the Australian mainland. The condition that requires strictest control is also the one whose effects are the subject of the research, namely fire.

Uninhabited islands off the Australian coast have several advantages over the mainland as sites for long-term observations of responses of both plant and animal communities to fire. In general, offshore islands are burnt much less frequently than comparable mainland sites, and they have simpler communities in terms of species richness and diversity. Alien species are often less important in indigenous communities on islands than on the mainland, and some islands have no established alien vertebrate animals at all. Furthermore, the ocean surrounding islands acts as a mote that protects them from immigration of aliens and other unwanted disturbances far better than any kind of fence or wall protects mainland reserves.

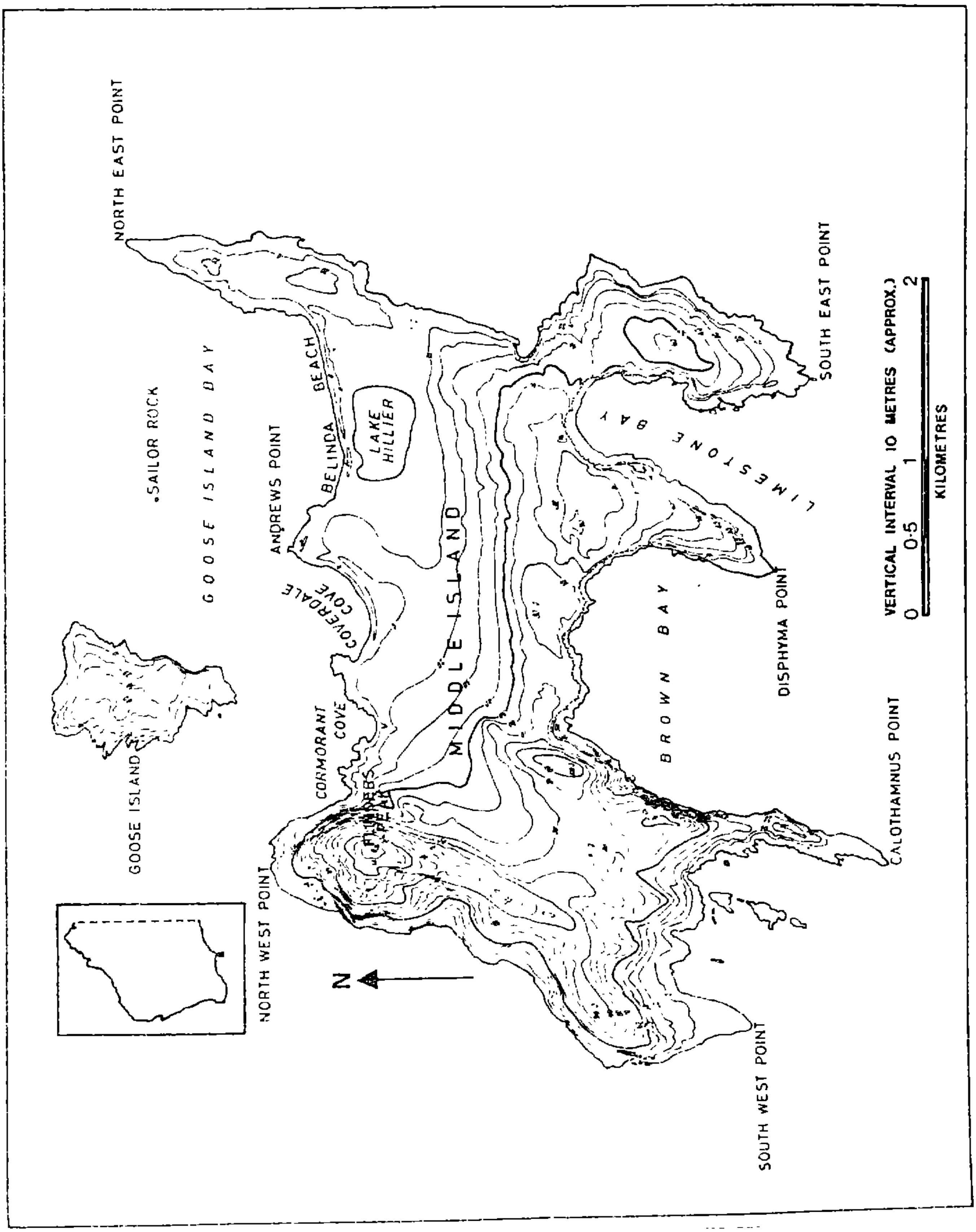
Middle Island, a continental island off Australia's south-west coast, is a natural laboratory particularly well-suited for long-term ecological research. Its type and condition of vegetation and lack of resident vertebrate animals combined with its unique histories of botanising and burning make Middle Island especially valuable for studying the impact of frequency, severity and seasonality of wildfires on indigenous plant communities. Long-term quantitative studies of vegetation changes on the island begun in 1973 after severe wildfire swept through the eastern half of the island are described elsewhere (Hopkins, Weston & Trudgen, in press). This paper briefly describes Middle Island and the history of observations and botanising on it, presents two hypotheses based on these factors, and others, and tests them against available evidence.

Middle Island, a Description

Middle Island (34°06'S, 123°11'E) is, with an area of approximately 11 km^2, the largest island in the Archipelago of the Recherche (Willis 1953) and has a more varied geology, topography and coastline than any other island in the group. The island lies 9 km south-south-east of Cape Arid and is some 130 km by sea to the east of Esperance, the nearest town (Fig. 1). Middle Island has a Mesomediterranean climate, with an attenuated dry season and a probable mean annual rainfall of around 600mm (Hopkins, Trudgen & Weston, in press).

Like other islands in the archipelago, Middle Island is primarily granitic but with minor schistose and granular quartz rock outcrops. The south-eastern portion of the island is covered in travertine-capped coastal limestone that forms abrupt, 60 m high southern cliffs and slopes northwards to pink Lake Hillier. A narrow, steep, 10 m high dune separates Lake Hillier from the beach north of it. The island's soils are mostly sandy and shallow and are developed from the underlying limestone and granitic rock.

The mature vegetation of Middle Island is generally dense and ranges from limited low mats on exposed rock surfaces to thickets of **Leucopogon revolutus** and **Melaleuca globifera** and widespread eucalypt forests in monospecific stands of three species: E. **platypus** var. **heterophylla**, E. **angulosa** and E. **conferruminata** (Weston & Trudgen, in press). None of the three eucalypt forest associations that dominate the island's vegetation has been recorded on the mainland. For instance, on the mainland, **Eucalyptus angulosa** is a mallee to 4.5 m tall (Chippendale 1973; Blakely 1965), while on Middle Island it is, like E. platypus var. **heterophylla**, a tree generally 6 m to 8 m tall but sometimes exceeding 15 m in height. Furthermore, these mature forests and other forests and woodlands on Middle Island lack lower strata other than a **Cheilanthes** fern, an herbaceous **Trachymene** and a **Poa** tussock grass as ground layers.


NORTH EAST POINT
SAILOR ROCK
GOOSE ISLAND BAY
BELINDA BEACH
LAKE HILLIER
ANDREWS POINT
COVERDALE COVE
MIDDLE ISLAND
CORMORANT COVE
FLINDERS PEAK
GOOSE ISLAND
NORTH WEST POINT
N
SOUTH WEST POINT
CALOTHAMNUS POINT
BROWN BAY
DISPHYMA POINT
LIMESTONE BAY
SOUTH EAST POINT
VERTICAL INTERVAL 10 METRES (APPROX.)
0 0·5 1 2
KILOMETRES

History of Visits to Middle Island

Although parts of the Recherche Archipelago were charted by Nuyts in 1627 and Vancouver in 1791, the earliest recorded sighting of Middle Island was by D'Entrecasteaux, in December 1792 (Hopkins, Trudgen & Weston, in press). Matthew Flinders, who in 1802 was in the first known party of Europeans to set foot on Middle Island, reported that when they first explored the island there was "no trace of the island having been visited, either by Europeans or the natives of the mainland" (Flinders 1814).

Nor is there any more recent evidence to suggest that Middle Island was visited voluntarily by natives of the mainland after it was cut off by rising sea levels at least 9000 years ago. In fact, a recent archaeological survey on Middle Island by Dortch & Morse (1984) yielded 350 artefacts, none of which was identified as dating from the time between inundation of Middle Island and its discovery by Europeans. Most of the artefacts appear to date from the late Pleistocene to middle Holocene epochs, when the Recherche Archipelago was part of the mainland. No distinctive late Holocene artefact forms have been found on either Middle Island or other nearby islands. The lack of such artefacts is not surprising if, as ethnohistorical evidence suggests, south-western Australian aborigines did not have any kind of watercraft (Dortch & Morse 1984); there are reports, however, that Aboriginal people swam to some islands, presumably closer to the mainland (Moya Smith, pers. comm.). About 80 of the 350 Middle Island artefacts date from the 19th and, possibly, early 20th centuries, during the period when sealers and the Aborigines with them had camps on the island.

Sealers and whalers began operating in the archipelago at least as early as the 1820s (Bechervaise 1954) and occupied Middle Island for periods of several months or more between 1824 and the 1840s (Bateson 1972; Bechervaise 1954; Hicks 1966). Some of the sealers and whalers built stone houses and gardens at the western end of Lake Hillier, from which various successful and unsuccessful enterprises to extract salt were undertaken between 1890 and 1924 (Hopkins, Trudgen & Weston, in press).

The numerous visits during the last 60 to 65 years all appear to have been by fishing parties, tourists, treasure hunters, salvage crews and survey and research teams, none of whom spent more than a few weeks on the island, generally near Lake Hillier.

Evidence for Fires and their Absence on Middle Island

There is no reference in the records left by any of the visitors to Middle Island before the summer of 1972-73 to any bushfire or signs of a bushfire on Middle Island. Nor are there any documented reports of fire on Middle Island prior to the one in the summer of 1972-73. That fire, which burned for about two months, consumed the vegetation of most of the eastern portion of the island (Fig. 2). A local press report of the fire suggested it was the first wild fire known to have burned on Middle Island ('The Esperance Advertiser' (newspaper) 8 December 1972).

Consequently, the first hypothesis is that:

> the 1972-73 bushfire was the first major bushfire on Middle Island since an earlier one near the beginning of the 19th Century. (It appears, for reasons given below, that there was a major bushfire on Middle Island near the beginning of the 19th Century.)

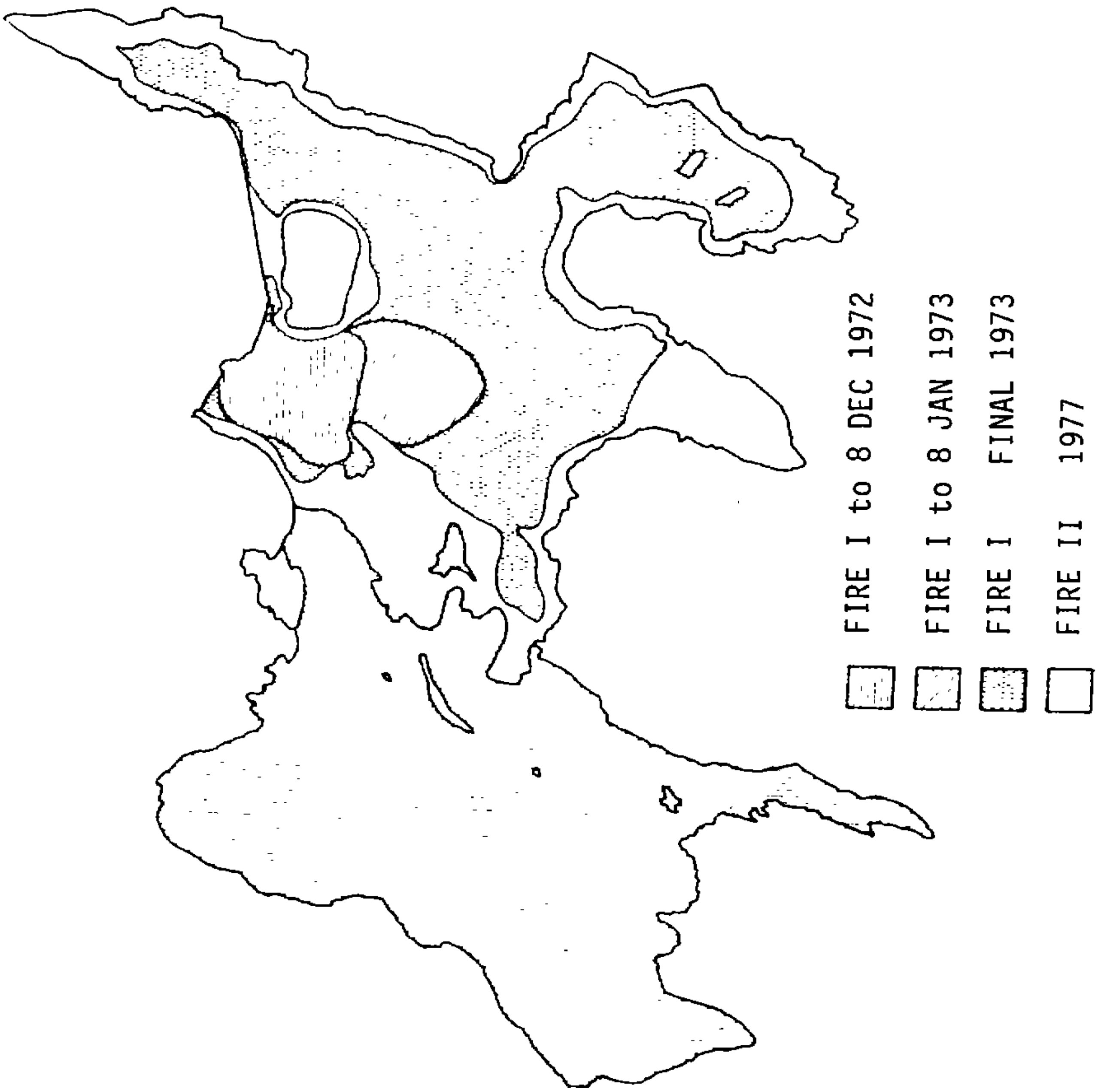
Admittedly, the absence of fire, or of any other transient phenomenon, during an extensive period of time is difficult or impossible to prove without regular monitoring throughout the period. There is, however, circumstantial evidence to support the hypothesis and no evidence to contradict it.

The lack of reference to fires on Middle Island, especially by early explorers, may be more significant than it at first appears. There are frequent references in the journals of early explorers to fires and smoke on the mainland but none to fires on islands of the archipelago. Furthermore, any fire or area conspicuously burnt since the late 19th Century would probably have been recorded by 'The West Australian', the Esperance newspaper or the Department of Lands and Surveys, yet none was.

If any of the proposals to use the island for pastoral or agricultural purposes had ever reached fruition, there would have been practical reasons for burning it. However, although the island was leased between 1883 and 1958 for a series of purposes that included sheep grazing, poultry farming, vegetable production and irrigation farming, apparently none of the projects was actually begun.

One source of evidence of past fires would be charred wood such as branches and tree trunks, either on the surface of the ground or buried. None was seen during traverses of unburnt lowland vegetation on Middle Island after the 1972-73 fire. Charred wood near the summit of Flinders Peak did indicate one or more small localised lightning-initiated fires, which did not, however, spread far over the rock or beyond it. One buried piece of charred wood found recently near the north coast may have been the remains of a campfire or been burnt during the more recent, 1977 fire.

The sizes of the eucalypts and some of the wattles on the island that are fire-sensitive suggest that they were very old. Counting growth rings in the trunks of these trees might verify the suggestion, although inferring ages of eucalypts from counting tree rings often produces ambiguous results (M. Barbetti, pers. comm.).


FIRE I to 8 DEC 1972
FIRE I to 8 JAN 1973
FIRE I FINAL 1973
FIRE II 1977

Observations of stands of vegetation that escaped the 1972-73 fire and examination of aerial photographs taken before the fire reinforce other evidence that there was no major fire on Middle Island for many years before the one in 1972-73. All of the unburnt vegetation appeared to be climax and mature. The rates at which the dominant, fire-sensitive eucalypt communities on Middle Island are regenerating after the 1972-73 fire suggest that a period as long as 100 years or more may be necessary for their pre-fire character to develop (Hopkins, Weston & Trudgen, in press). There are patterns and sharp boundaries on aerial photographs taken before the 1972-73 fire, but they do not appear to reflect old burn patterns.

by D.L. Serventy, in November 1950 by J. Willis, in February 1960 by R.D. Royce and eight times between 1973 and 1984 by A. Weston or M. Trudgen or both.

Robert Brown, the first botanist on Middle Island, collected a total of 47 species of vascular plants on the island and its small neighbour, Goose Island (Willis 1959). Jim Willis' collections on Middle Island during the Australian Geographical Society's 1950 expedition totalled about 130 species (Willis 1953, 1959). Malcolm Trudgen and the author collected approximately 235 species between 1973 and 1981 (Weston et al., in press).

Figure 3. Alogyne hakeifolia.

The strongest evidence that supports the hypothesis is, in addition to the absence of any references to fires on the island, floristic.

Botanical Collecting

Middle Island has a long history of botanical collecting, which begins with Robert Brown's visit in 1802. This history and information from the collectors, together with recent observations on the flora, provide corroborative evidence that there was no significant wildfire on Middle Island between the beginning of the 19th Century and 1972.

Robert Brown, the botanist accompanying Matthew Flinders, was the first to collect on Middle Island, in January 1802 and again in May 1803. D'Entrecasteaux's botanist, La Billardiere, appears to have made the first collections in the archipelago, but on Observatory Island, 150 km west of Middle Island (Carr & Carr 1976). Following Brown, botanical collections and observations were made on Middle Island in January 1818 by A. Cunningham, in 1863 and, possibly, 1875 by G. Maxwell, before 1909 by F. Stoward and G. Simmonds, in the winter of 1948

The Plants

It is tempting and not unreasonable to assume that Willis' collections included the species that Brown collected and that the Weston and Trudgen collections included the species that Willis collected. Although the assumption is true for most species, eleven of the species collected by Brown were not found by Willis.

Three of the eleven were found in 1973 and subsequently in small populations on Middle Island and Goose Island. Five others of the eleven were abundant on Middle Island after the 1972-73 fire. In 1974, twenty months after the 1972-73 fire, these species - **Alyogyne hakeifolia, Alyogyne huegelii, Scaevola aemula, Solanum simile** and **Villarsia parnassifolia** - were very abundant in the burnt area, though in more or less exclusive populations. Three formed dense carpets which were, in the case of the **Alyogyne** species, up to two metres tall (Fig. 3). Because the flowers and inflorescences of all five species are amongst the largest and most conspicuous of any on the island, the species would be difficult to miss when present. Five years after the fire the Alyogynes were still conspicuous but no longer common, and **Alygone hakeifolia** was totally absent from the **Eucalyptus angulosa** regeneration photo six years after the fire (Brown et al. 1984).

Willis, though he traversed the island and did a very creditable job of collecting during his brief visit there, found none of the five species. Since his visit coincided with their flowering period, it is unlikely that he would have missed them had they been present. The obvious conclusion which can be drawn is that the five species were not present as adult flowering plants but only as viable seed in the soil at the time of Willis' visit, seed which may have been lying dormant there for decades or longer. Other early succession plant species have attracted comment for the remarkable persistence of their seeds (Salisbury 1942; Thurston 1960; Thompson 1978).

Brown's collection of these short-lived species, the germination of whose seeds is stimulated by fire, provides indirect but conclusive botanical evidence that Middle Island suffered a fire no more than a few years prior to the 1802 visit by Flinders and Brown, when Brown collected them. The cause of the fire was probably lightning although sealers, who were certainly operating off the southern Australian coast at least as early as 1803 (Wace & Lovett 1973) and may have ventured as far as Middle Island, cannot be ruled out. Had there been no fire within the few years preceding 1802, it is very unlikely that all five species would have attracted his attention.

It is also unlikely that these conspicuous species would have been missed by the other collectors who visited the island if the plants had been there.

Fire Exclusion and Floristic Persistence

Evidence that supports the first hypothesis also helps to support a second:

> long-term fire exclusion does not necessarily alter floristic composition or diminish floristic richness of south-western plant communities.

Direct botanical evidence from collections by Brown, Willis, Trudgen and Weston also supports this hypothesis, if the three sets of collections are compared. Of particular relevance are the number of species collected by Brown which were not recollected by Weston and Trudgen and the number of species collected by Willis which were not recollected by Trudgen and Weston.

Over ninety eight percent of the species collected by Willis on Middle Island were recollected by Trudgen and Weston, and forty four, or 94%, of the forty seven species collected on Middle Island and Goose Island by Robert Brown in 1802 and 1803 were also recollected there by Weston and Trudgen. The three Brown species not recollected may yet be found, although they have already been searched for extensively. Even if the three are presumed to be extinct on the island and if, furthermore, it is assumed that they have become extinct due to the long period of fire absence, a loss of 6% of the species of a small flora over a 170 year period, or a rate of 0.018 species per year, cannot be considered large. The low rate of loss indicates that Middle Island plant communities are not adversely affected by long-term fire exclusion, at least in terms of the commonly measured parameters of species richness and species persistence.

Island Extinctions

Plant species extinction rates cited by MacArthur & Wilson (1967), Abbott (1977) and Abbott & Black (1980) for islands with ten or more species are all much higher than the Middle Island rate. Compared with the losses of species over a 16 year period on the two largest southwestern islands surveyed by Abbott (1977), 10% on Garnac Island and 18% on Penguin Island, the rate of species loss on Middle Island is very low indeed.

However, the islands cited by Wilson, MacArthur, Abbott and Black are all much smaller than Middle Island and have much smaller floras. The sizes of plant populations on Middle Island and the botanical size of the island may exceed the maxima to which Wilson and MacArthur island biogeography theory can be applied.

Conclusions and Discussion

The evidence and arguments presented in this paper support the hypotheses that:

> The 1972-73 fire was the first major bushfire on Middle Island since an earlier one at the beginning of the 1800s, and
>
> Long-term fire exclusion does not necessarily alter floristic composition or diminish floristic richness of southwestern communities.

The support is, though not conclusive, strong enough to provide a firm foundation for questioning the view, both explicit and implied, that the flora of Western Australia is so fire-dependent that plant species may become extinct and plant communities impoverished in the absence of burning.

There is an understandable tendency among field botanists to regard plant communities as comprising only those species they see when surveying them. They exclude such species represented by only seeds and other perennating structures, species that are actually there but with delayed or intermittent visual expression.

Long periods of fire-exclusion and, in some mallee, shrub and heath vegetation, periodic but not frequent burning appear to be essential for the full expression of total floras and of vegetation structure and complexity. However, the Middle Island studies and others described by Muir, Hopkins and Lamont in these proceedings indicate that even fire-adapted species are not lost during periods of fire-exclusion lasting decades or even centuries. Frequent burning, on the other hand, may lead to local loss or extinction of species and repression of full structural expression and complexity.

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FIRE EXCLUSION: A BASELINE FOR CHANGE?

B.G. Muir

Introduction

Since the turn of the century a great deal has been written about fire chemistry and behaviour, the effects of fire on the environment and many other aspects of relationships between fire and the flora and fauna of the Australian landscape. There have been comprehensive books prepared (e.g. Gill et al. 1981), many reviews of available literature (e.g. Gill 1975) and symposia held to discuss the state of the art and to determine possible directions for the future (e.g. Heislers et al. 1981).

On examination of this abundance of information two aspects of fire research become strikingly obvious. First, despite the available data, fire behaviour is still largely unpredictable and its effects on many aspects of the environment remain unknown. Secondly, almost every study which has been made on post-fire succession has concentrated on the first days, weeks, months or few years following a fire. Very little research has been aimed at vegetation which has not experienced fire for very long periods of time.

There is a considerable body of literature showing that fire, originally caused mostly by lightning strikes, and later by man, has long been a part of Mediterranean climatic zones (Naveh 1975; King 1963; Jones 1968).

There is evidence suggesting that fire frequency in Australia might have increased following arrival of Aboriginal man (Hallam 1975; Jones 1968; Merrilees 1968) although some early records (e.g. Bannister in 1833 (Hallam ibid.)) indicate that burning may not have been common in some areas. There is, however, little doubt that the arrival of European man, with his practice of land clearing greatly increased fire frequency (Wakefield 1970; Wallace 1966).

Although details are not precisely known, and there is geographical variation in fire frequency, it is reasonable to conclude that a progressive increase in fires has occurred from the time when they were caused only naturally, through the period when Aboriginal-man also caused them, to the present time involving the impact of European-man.

It is also reasonable to presume that the extant Western Australian vegetation differs in structure and floristics to that which occurred prior to the arrival of Aboriginal-man. Some of this change would have been induced by climatic and landscape variations during the late-Quaternary, but conceivably fire had a significant influence. In more recent times, since European settlement, factors such as biological evolution and gross climatic change would have had limited effect but the influence of fire has become much more important in changing the vegetation.

Examination of long-unburned vegetation may give an insight into the structure and floristics of vegetation in its more mature stages, and may provide some indication of the appearance of parts of the Australian bushland prior to European settlement.

This paper is a call for greater research into the structure and floristics of vegetation that has developed in the absence of fire, as this may well provide insight and baselines for evaluation of changes in the future.

Discussion

The most difficult task in studies of long-unburned bushland is simply to find some. This simple fact alone gives ample support to the view that man's influence, especially European man, on the environment has been enormous. Further, when one does find long unburned bush it rapidly becomes relatively famous (e.g. Amphion 6 in the Jarrah forest near Dwellingup, and Hilltop in the Walpole-Nornalup National Park).

In dry environments where fuel accumulation is slow there is a direct relationship between reserve size and the number and frequency of fires which occur in them (Muir 1979a). This is illustrated in Figure 1. In the West Australian wheatbelt this relationship might result from the perception of local farmers that large areas of bush are a greater fire danger than small areas. Consequently the latter are left unburned.

Large reserves have longer perimeters than small reserves and so are more likely to have fires entering them from adjacent land; they are more often used for recreation and other purposes which increases their fire risk; and they provide bigger targets for lightning strikes. These aspects were discussed by Anderson & Muir (1981), who showed that 30% of fires in National Parks were deliberately lit, 25% were from fires lit outside the Parks, 2.7% were from lightning strikes outside the Parks and 9.2% arose from lightning strikes inside Park boundaries.

In parts of the State with high rainfall, plant growth and fuel accumulation are rapid and fear of fire leads to much more frequent fuel-reduction burns. Additionally, the concentration of people in the wet southern parts of W.A. leads to a high incidence of deliberate or accidental fires (Table 1 from Anderson & Muir 1981). As a consequence, pockets of old bushland are rare in the wetter regions.

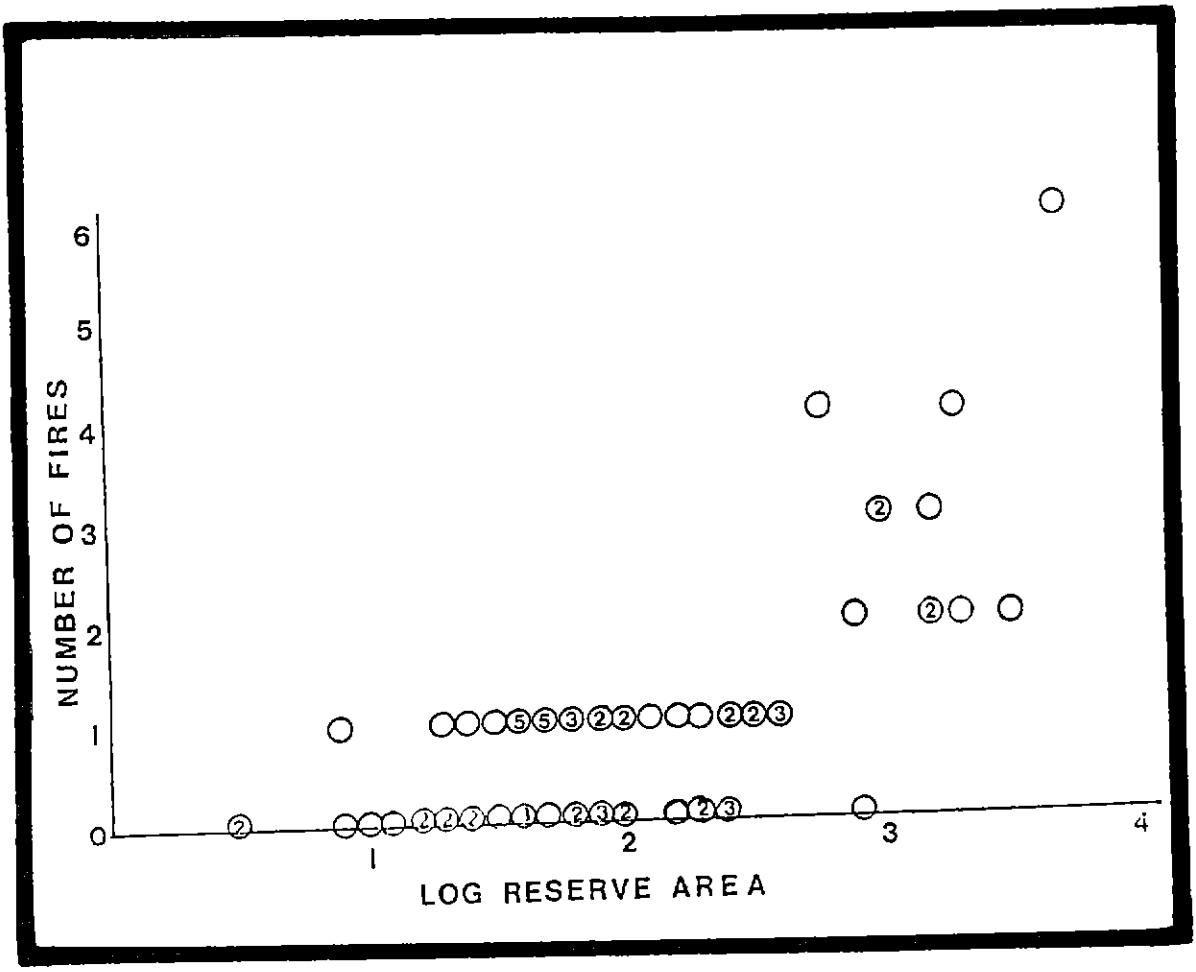

Figure 1. Number of fires on reserves in the central wheatbelt between 1949 and 1979, plotted against logarithm of reserve area. 72 reserves are illustrated. Numbers within circles represent number of coincident points. Data is from Muir (1979).

Table 1. Regions within the State, the percentage of Western Australia's population within each region, and the number of fires of unnatural causes in National Parks between 1976 and 1980. Derived from Anderson & Muir (1981).

REGION	% POPULATION	No. FIRES (excluding lightning) within National Parks between 1976 and 1980
Kimberley	1	0
Pilbara & Exmouth	3	2
Gascoyne & Sandplains	5	7
Metropolitan	68	55
South-West & Esperance	15	39

The occurrence of areas of long-unburned vegetation is generally a consequence of isolation from ignition sources, natural low-flammability, or chance. The wheatbelt reserves illustrated in Figure 1 are examples of reduced ignitions because of isolation, the reserves being surrounded by farmlands and paddocks and being effectively "islands in a sea of wheat". The adjacent farmland is carefully protected from fire, and hence accidental ignition of the small reserves from outside sources is reduced. Similarly, marine islands are naturally protected from fires and may not be burned for very long periods (Hopkins 1981).

Low flammability of some vegetation types may be due simply to their sparse structure. Some woodlands in the wheatbelt and goldfields, where there is insufficient understorey to carry a ground fire, have this characteristic. Other natural features, such as salt marshes and rock outcrops, often form natural firebreaks preventing the spread of wildfire into pockets of flammable vegetation within their perimeter.

The presence of fire-resistant or fire-retardant vegetation is a little known field of study, although some records exist (e.g. Webb 1968; King & Vines 1969; Wakefield 1970).

Chance also plays a significant role in preservation of some areas from fire. The patchy mosaic nature of some burns is well recognised, leaving pockets of unburned vegetation surrounded by a lower fuel zone which may protect the unburned area for many years. Changes in wind direction during a fire, differences in vegetation types, and many other factors may contribute to the preservation of such mosaics. Mount (1982) gives an excellent example from south-west Tasmania, where pockets of wet sclerophyll forest remained unburnt for 26-32 years and rainforest for 60 years despite the occurrence of 12 fires in the vicinity since 1898. He indicated that studies have shown some forest types could remain unburned for up to 400 years in this way.

If one examines aerial photographs or locations in the drier south-west of Western Australia, where unburned pockets have been left inside otherwise widespread fire-damaged areas, the unburned locations are often associated with relatively dense woodlands with little understorey. This is a frequent occurrence in the wheatbelt and Kalgoorlie Goldfields. Similarly, granite and other rocky outcrops and monadnocks which act as firebreaks, breakaways and salt-flats which will not burn easily, and aquatic systems such as swamps, and watercourses, may also protect some areas from fire.

It is an interesting exercise to examine "rare" plants and determine if there is any relationship between rarity and these fire protected habitats, as fire could easily be a factor in destruction of some plant species, just as it is known that some rare plants are promoted by fire.

Using the 100 gazetted rare species of plants listed in Rye & Hopper (1981), dividing their habitats into broad categories and estimating if such habitats tend to be relatively low or relatively high fire-risk vegetation types, a pattern emerges (Table 2).

Thirty four of the 100 species (34%) are found on monadnocks, rocky outcrops and breakaways, yet these habitat types occupy only a very small proportion of the total land area of the South-west. Significantly, these are also the most likely areas to be partly protected from fire, so this association might not be coincidental. Salt flats are also not prone to fire and are much more widespread than rock outcrops and could therefore be expected to carry a high proportion of rare plants. However, this habitat is stressful, experiencing very high radiation and exposure levels, is strongly alkaline (compared to other habitats) and has high levels of salt which greatly limit the number of plant-species.

Table 2. Broad habitat types in which the 100 rare plants of Rye & Hopper (1981) are found, the number of species in each type, and the number in low and in high fire risk vegetation.

Habitat type	Number of Rare Plants	Number in low fire risk vegetation	Number in high fire risk vegetation
Woodlands & forests	12	6	6
Shrublands & heaths	35	9	27
Monadnocks & rock outcrops	24	16	7
Breakaways	10	8	2
Salt flats	2	2	-
Dune systems	1	1	-
Aquatic	2	2	-
TOTAL	100	58	42

Further, there is a slightly higher number of gazetted rare plants in the relatively lower fire risk areas compared to high fire-risk areas but the difference is not great. Interestingly, of the 42 species which exist in high fire risk and flammable habitats, two-thirds occur in shrublands and heathlands, both very fire-prone environments. A similar lack of correlation between the location of rare species and habitat has been found in Victoria by Parsons & Browne (1982). This apparent contradiction may be explained by examining the nature of the land on which the particular habitats occur (Table 3).

Table 3. The number of rare species as listed by Rye & Hopper (1981) occurring in pockets of vegetation within the Western Australian wheatbelt, and in National Parks or Nature Reserves.

Wheatbelt vegetation pockets	29
National Parks and Nature Reserves	41
TOTAL	70

It may be more than coincidence that 70% of the gazetted rare plants listed in Rye & Hopper (ibid.) occur in isolated pockets of bushland ("islands in a sea of wheat") in the W.A. wheatbelt, and in National Parks and Nature Reserves which, incidentally, were not designed to protect the gazetted rare species, and which are partly or wholly protected from fire as a deliberate management action.

Thus, 70% of the gazetted rare species occur in habitats which are protected from fire by deliberate management or certain circumstances such as isolation. Again, this might only be coincidence but it raises the point that an unusually high proportion of gazetted rare species occur primarily in locations or habitats protected from fire. This in turn raises the question: were the rare species once much more widespread than at present, and has fire been instrumental in creating their rarity, in addition to land clearing and other more obvious factors?

Another feature of long unburned bushland is its physiognomy both in terms of age-class structure and in the presence of very large individuals of some species of plants. With regards to age-class structure, some observations at two locations have illustrated interesting trends. One locality was a small, privately owned reserve (100 acres or 40 ha) of woodland on a property at Mawson, c.20 km west of Quairading. Here an examination of *Casuarina huegeliana* trees showed the following size-class structure (Table 4). The woodland has not been burned for 63 years, a most unusual event in the W.A. wheatbelt, considering the average age of 402 locations studied in the wheatbelt was 21 years (Kitchener 1976; Muir 1978-79).

Table 4. Size-class structure of living and dead Casuarina huegeliana trees in a stand 63 years old at Mawson Siding near Quairading, showing the number of stems in each size-class.

SIZE-CLASS Diam. at BH(cm)	LIVING TREES Number of stems	DEAD TREES Number of stems
0-2	20	21
2.1-4	30	11
4.1-6	17	2
6.1-8	7	1
8.1-10	4	1
10.1-12	6	0
12.1-14	2	0
14.1-16	3	0
16.1-18	1	0
18.1-20	1	0
> 20 cm	6	7

The following conclusions follow from these data:

1. Despite the considerable time since fire, Casuarina huegeliana is regenerating well from seedlings.

2. Only about 6% of living trees reach 20 cm or more in diameter despite the long absence of fire.

3. The greatest mortality occurred in the 0-2 cm diameter BH range and that once the trees had reached about 10 cm diameter at BH most persisted to a considerable age.

4. The presence of some dead trees at > 30 cm in diameter suggests that this is natural senescence and represents the maximum diameter this species can reach in the given environmental conditions at the Mawson site.

The significance of these observations is that Casuarina huegeliana can reproduce successfully without fire for at least 63 years and that the majority of plants die in their early years, leaving a relative minority to grow through to senescence. The overall visual impression of the stand is one of youthfulness, only the thick leaf litter layer and fallen timber indicating the actual age of the stand. It should be noted that C. huegeliana is a fast growing species (growth rate up to one cm stem diameter per year in the first few years) and so the smaller age classes are young plants, not retarded 63-year-old saplings.

Start (pers. comm.) examined the size class structure of Karri Wattle (Acacia pentadenia) in relatively young and very old stands of Karri (Eucalyptus diversicolor) at Walpole in 1977. His results are presented in Table 5.

In the 10-year-old stands, Karri Wattle was abundant (1670 trees/ha.) and mostly in the 2-6 cm diameter BH size class, and very few were fallen.

In contrast, in the 30 year stand there were slightly fewer trees (1620 trees/ha.), but most were > 10 cm diameter and a large number were fallen. This trend was even more obvious in 1985 when the stand was 38 years old, and only 80 trees/ha. remained standing. In this situation most of the Acacia pentadenia had reached maximum diameter and had fallen over, suggesting a rapid decline in number of individuals between 30 and 38 years after fire. Relatively few young trees were present although a few saplings were still coming through to maturity. As with the Casuarina huegeliana at Mawson, the advanced age of the vegetation had not prevented successful establishment of seedlings and young trees, at least up until about 30 years. Fire was apparently not necessary to ensure regenerative survival, at least in the short term.

Table 5. Size-class structure of Acacia pentadenia in 20 x 30m plots at Hilltop, Walpole-Nornalup National Park.

SIZE-CLASS Diam. BH (cm)	10 YEARS OLD No. of stems	30 YEARS OLD No. of stems	38 YEARS OLD No. of stems
0-1	7	3	0
1-2	0	12	4
2-3	38	3	0
3-4	27	2	0
4-5	14	4	1
5-6	15	2	0
6-7	5	4	0
7-8	4	4	0
8-9	2	0	0
9-10	0	5	0
>10	0	58	0
FALLEN	3	52	88

In the mature community, mature Acacia pentadenia had died and fallen over. This created a completely new appearance in the understorey; the extremely dense undershrub layers of the younger stand having been replaced by an open character where Lepidosperma gladiatum rather than Acacia pentadenia dominated.

Figure 2 suggests a possible sequence of generalised changes in structure of vegetation with age based on the Acacia pentadenia and Casuarina huegeliana data. It is seen that there are numerous similarities between the two species, the main differences being that the A. pentadenia is a stratum 2 dominant beneath Karri forest, whereas in the C. huegeliana stands the seedlings/saplings are effectively stratum 2 dominants beneath C. huegeliana woodland. It is also suggested that the process occurs over a shorter period in C. huegeliana stands so that continued germination leads to a slightly denser stratum 2 than in A. pentadenia stands. Nevertheless, the stages remain the same. Continued protection of these old vegetation stands and long term monitoring will be necessary to determine if the sequence of generalised stages proposed here actually persist.

However, one cannot help wondering if Vancouver's Report in 1791 of open park-like forest understorey near Albany and Bannister's 1833 report of open areas amongst the impenetrable Karri forest (Hallam 1975) were the result of a long ABSENCE of fire as proposed in steps 4 and 5 of Figure 2 rather than of RECENT fire as has been assumed. Hallam also notes comments on open park-like country on the Swan Coastal Plain by Fraser in 1827, near York by Dale in 1830 and Irwin in 1835, and near Narrogin by Landor in 1847. It seems remarkable that with so many comments by early explorers of fires, newly burned areas and "impenetrable thickets" that they mention "open park-like areas" as distinct from newly burned areas. Perhaps these open areas were NOT recently burned, but had lost much of the understorey as a consequence of considerable age. Wakefield (1970) proposed the hypothesis that widespread change from open grassy forests to dense shrub dominated formations in the Victorian sclerophyll forests as a consequence of less frequent burning might be the opposite to the truth, and suggested that increases in fire frequency since settlement may be the cause of the greater vegetation density. Similarly, as shown in Figure 2, the occurrence of fire at frequent intervals would retain the vegetation in stages 2 or 3, "impenetrable thickets".

The large size reached by some plant species when they remain unburned for long periods is remarkable. A few examples encountered by the author in the Western Australian wheatbelt are set out in Table 6.

These maximum recorded sizes give insight into the possible appearance of some of the bushland in the wheatbelt prior to clearing and burning by Europeans. Species such as Eremaea pauciflora and the melaleucas may well have been found predominantly as upper stratum species in woodlands, whereas today they mostly occupy lower strata shrublands under a canopy of Eucalyptus trees.

Table 6. Maximum sizes recorded for some species of plants in the Western Australian wheatbelt. Reserve names are as follows: Yuna = East Yuna Nature Reserve (C28415 & C29231, 65 km ENE Geraldton, (Muir 1981)), 27639 = unnamed reserve for "Preservation of Natural Vegetation", (located 19 km E of Hyden (Muir 1979b)), Mawson = private land in vicinity of Mawson Siding (20 km W of Quairading), Ben = Bendering Nature Reserve (A20338, 23 km NNE of Kondinin (Muir 1977a)), and WBR = West Bendering Nature Reserve (A25681, 16 km NNE of Kondinin (Muir 1977b)). The maximum height recorded, the average height of other plants of the same species in the area, and circumference at breast height for some species are tabulated. In every case the tallest individuals had not experienced fire for a long time whereas the "average" ones showed evidence of fire in relatively recent times.

SPECIES	LOCATION	MAX HT (m) RECORDED	AVE HT (m) IN AREA	CIRCUM (cm) AT BREAST HT
Acacia signata	Yuna	9	4	69
Banksia ashbyi	Yuna	11	6	188
Eremaea pauciflora	Yuna	4	1.5	47
Eucalyptus calycogona	27639	18	6.5	
E. macrocarpa	Mawson	8	1.5	
E. redunca	Ben	16	9	
E. salmonophloia	Ben	20	15	
E. salmonophloia	WBR	26	10	
Melaleuca acuminata	Yuna	12	6	65
M. eleutherostachya	Yuna	9	2.3	52
M. eleutherostachya	Yuna	16	2.3	62
M. nematophylla	Yuna	7	2	54
M. uncinata	Yuna	12	2.8	52

GENERALISED STAGE	AGE OF STAND	DIFFERENCES BETWEEN SPECIES BEHAVIOUR
1..Entire understorey, litter and debris removed.	0 yrs	none
2..Extremely dense stratum 2 development. Abundant litter but minimal debris.	A.p<20yrs C.h<5yrs	none
3..Degeneration of stratum 2. Sedges and other moisture-loving species become established in stratum 3. Deep litter and abundant debris keep soil moist.	A.p20-30yrs C.h5-20yrs	In C.h establishment of moisture-loving species is slow because of allelopathic effects of litter.
4..Stratum 2 sparse but a few plants still germinating. Litter and debris decomposition reaches equilibrium and drier conditions prevail. Sedges, etc, decline and heathy species invade stratum 3.	A.p30-80yrs C.h20+yrs	Stratum 2 still moderately dense in C. huegeliana.
5..Stratum 2 very sparse. Stratum 3 heathy. Debris relatively sparse except for recently fallen limbs and normal litter fall.	A.p80+yrs C.h30+yrs	Stratum 2 remains moderately dense in C.huegeliana.

Figure 2. Possible sequence of stages in conversion of dense stands of Acacia pentadenia or Casuarina huegeliana to open understoreys after long periods of time without the influence of fire. A fire at any point in the sequence would return the vegetation to stage 1. In the "age of stand" column A.p refers to A. pentadenia and C.h to Casuarina huegeliana. Stages 1 to 3 are based on observations in the field, but stages 4 and 5 are purely speculative.

Such changes to gross physiognomy of vegetation have been hinted at by several botanists in reference to the Badgingarra district (Griffin, Blackwell, Bell, pers. comms.), and in my opinion are well founded. Some of the broad expanses of heathland in the region of Coomallo Creek, Badgingarra and Drovers National Park show remnants of burnt Banksia attenuata and B. menziesii cones scattered throughout the heath in areas where these trees are no longer to be found. It is therefore feasible that the heaths and low shrubland found so commonly in these areas today may be fire-caused and that the areas were previously wooded. The presence of remnant cones, moreover, indicates that this change occurred in relatively recent times. A similar change from woodland to mallee-heath in the Lake King area has been documented by Hopkins & Robinson (1981) and fire-caused reduction of vine thickets to grassy woodlands in tropical Australia is now well recorded (Stocker 1969; Beard 1976; Hnatiuk & Kenneally 1981). Removal of Mulga (Acacia aneura) in certain areas as a result of burning has also been documented (Ralph 1984; Dunlop 1985). Moll et al. (1980) even suggest that fire-caused changes to physiognomy may have occurred on a regional scale in South Africa, where they propose that the Fynbos heathlands may be the result of loss of tree species caused by too frequent burning. McPhail (1983) also gives several examples of gross vegetational changes as a result of fire in various parts of the world.

Similarly, flowering abundance might have been altered since changes in fire regimes occurred. Lamont & Downes (1979) have produced data for flowering of Xanthorrhoea preissii and Kingia australis which suggests that fire frequency has increased greatly since European settlement, fires occurring 12-22 times in the last 150 years, and only 1-3 times in the previous 150 years.

This at first might be taken to suggest that not only has fire frequency increased enormously since settlement but, for species where flowering is promoted by fire, availability of nectar, pollen and seeds may also have increased in the last 150 years. The extension of this point is whether native plant-species produce more or less flowers and hence nectar, etc., depending on their age since fire. Dryandra sessilis, for example, is well known to apiarists as flowering freely after 3-4 years but not setting seed until 8 years or reaching maximum honey production until 12-15 years old. Burning at say a 6-year cycle in Dryandra sessilis shrublands may thus produce visually abundant flowers and therefore one assumes abundant seeds, nectar and pollen. However, in fact there may never be a surfiet of nectar until ten years or more after fire, and native fauna and introduced honeybees may compete severely as a result. If this is so, and if the above species is typical in that flowering and nectar production is relatively low within the first few years after fire and fire is now more frequent, one can speculate that available nectar prior to the coming of European man might have been considerably more than at present. If so, it could be speculated that the "brave but apparently losing battle" of certain native insect and bird species (Bond & Brown 1979; Douglas 1977; Paton 1979) to compete with introduced bees might be because of a decrease in nectar production associated with fires.

This suggestion can only be clarified by studies to determine flowering abundance in a wide range of native plant-species in relation to time since fire, and studies to determine the nectar productivity regime over long intervals. Certainly, recent studies (Lenegan 1981) on several plant species support this view.

Similarly, one could suggest that expansion of the distribution of seed-eating bird species (Serventy & Whittell 1976) such as the Crested Pigeon, Galah, Smoker Parrot and Common Bronzewing may have been in part related to increased seed availability in bushland burned more frequently. Certainly introduction of crops and dams to the wheatbelt provided much food and water, but the greatest range expansions of birds apparently occurred around 1915-1925 when only about 0.5 million hectares of the wheatbelt were under crop; the greatest expansion of agricultural crops did not occur until 1930 (1.5 million ha) to 1960 (2 million hectares) (Malcolm 1983). Serventy (ibid.) suggests that climatic changes may have played a major role in the expansion, and considers it more important than the growing of crops during this period. I suggest that increased fire frequency as a consequence of clearing burns and other fires may also have increased production of natural seed supplies and formed the foundation for expansion of the ranges of these birds slightly earlier than the crops themselves. Seed fall (output) in very old, long unburned, vegetation requires study to compare it with seed fall in more frequently burned vegetation. The apparent relationship with, and perhaps dependence of, some animal species on long unburned bushland is now also recognised, for example, the Noisy Scrub-Bird (Atrichornis clamosus) in dense thickets (Robinson & Smith 1976; Smith 1977; Smith & Forrester 1981), Ground Parrot (Pezoporus wallicus) in unburned heaths (Meredith & Isles 1980; Watkins, pers. comm.), Spectacled Hare Wallaby (Lagorchestes hirsutus) in very old spinifex and shrubland (Bolton & Latz 1978), and Dibbler (Parantechinus apicalis) in shrublands probably older than 35 years (Muir 1985). Even differences in morphometrics have been observed between crickets from long unburned and recently burned Jarrah forest (Dolva 1984).

Concluding Remarks

Much criticism may be levelled at the comments and suggestions presented in this paper. If they lead to some researcher setting out to disprove my suggestions, I will be more than happy that the paper has served its purpose. In short, this paper is aimed at promoting an interest in very old, long unburned vegetation, the biology of which I consider to have been largely ignored, and to suggest that the study of such areas may provide valuable and worthwhile insight into both the dynamics and structure of vegetation and perhaps also into the changes observed in some faunal populations since European settlement. I would call upon land managing agencies to protect zealously any long-unburned bushland of which they are aware and to incorporate fire exclusion zones within future management plans. These areas, kept free of fire, may well prove to be our baselines for the future.

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PLANNING FIRE REGIMES FOR NATURE CONSERVATION FORESTS IN SOUTH WESTERN AUSTRALIA

N.D. Burrows

Summary

Planning fire regimes to meet European human needs has been an evolutionary process in the fire prone forest lands of Western Australia. Early colonial forest users regarded fire as a destructive force and attempted to exclude it from the forest. Recently, the prescribed use of fire under well defined fuel and weather conditions has been used to minimise the impact of devastating wildfires on people, property and forest values. Managed fire is also used as a natural environment variable to meet conservation objectives in certain defined forest areas.

The success of managed fire regimes in meeting long term conservation objectives and in minimising the impact of wildfires is largely dependent on scientific knowledge, planning and resources to do the job. Forest fires behave according to reasonably well understood physical laws and are predictable within limits. However, fire effects on plants and animals require more detailed study and local knowledge. Management cannot always be delayed until the complex fire ecology of a nature conservation forest is completely understood.

This paper traces development in fire planning and management in nature conservation forests in the south west of Western Australia. Some biological indicators and other important considerations necessary to formulate appropriate fire regimes are discussed.

1. Introduction

Fire has been used as a cultural technology and as an environmental modifier on the Australian continent for many thousands of years. Aborigines deliberately and skillfully used fire to improve hunting, to gain access and for a variety of other purposes (Hallam 1974). To early European settlers, fire was a tool which aided in the clearing of the bush for grazing and crop and pasture establishment. Indiscriminate use of fire often resulted in severe bushfires which burnt uncontrollably for many days. To the early forest users, fire was a destructive agent which damaged trees and threatened the lives and property of those who lived and worked in the bush.

Not until the early 1920s did the newly formed Forests Department devise the first forest fire policy in Western Australia (Underwood & Christensen 1981). With the Department's meagre resources, this policy was essentially one of fire exclusion with some strategically placed strips which were control burnt every three to four years. This regime persisted with mixed success, for some 30 years. However, as forest fuels accumulated in the long protected zones, wildfires became more intense and more damaging. It became very obvious that prescribed fuel reduction by burning under carefully defined conditions of fuel and weather (McArthur 1962) was one direct measure of reducing the severity of wildfires. This renewed emphasis on the use of fire as a tool to reduce the hazard of high intensity wildfires required considerable research, planning, training and on ground action.

While phrases such as "fire management planning" and "appropriate fire regimes" may be new, the concepts certainly are not. Since the 1920s, planning fire and fire management has been an on going evolutionary process in the forested areas of the south-west and in response to needs as they arose.

The Forests Department of Western Australia had a policy of multiple use management to cater for increasing public demands on a broader range of forest values. The concept of multiple use management developed by the Forests Department defines the forest according to the priorities for land use and is explained by Beggs (1982).

Within State Forest, priority use areas are referred to as Management Priority Areas (MPAs) and any operation must favour the designated priority while being compatible with the other nominated secondary uses. There are eight major priority use classifications, including nature conservation forests. The latter have been selected as representative of forest communities, systems or species. They are regarded as having an important role in the conservation of flora, fauna and landscape values and act as biological reference areas. Management objectives for nature conservation forests are not usually specific, for example, "to ensure the preservation, maintenance and enhancement of forest species and communities". In forested areas of the south west, two types of nature conservation forest are recognised. These are: forest sanctuaries, in which the aim is to preserve the integrity of the original forest; and managed nature conservation forests, where a certain degree of environmental manipulation is deemed necessary to maintain specific ecological aspects of the forest community.

Fire management policy in nature conservation forests must be based on an understanding of the role of fire in the area and of the protection requirements of adjacent land users and values and is the most recent development in the continuing evolution of forest fire management. In this paper, I trace the progress made by forest fire managers in the south-west of Western Australia in their attempts to reconcile the role of fire in forests specifically set aside for nature conservation.

2. Fauna Priority Areas in State Forest

Even before the Forests Department developed the concept of Mangement Priority Areas, it was recognised that some of the richest areas of fauna and flora existed in State forest (Christensen 1973). Further, the relatively intact and unbroken belt of 1.9 million hectares of State forest is one of the most valuable nature reserves in the State. Within State forests, Christensen (1973) identified a large block of low rainfall jarrah forest between the Perup and Tone Rivers as being particularly rich in fauna. This section (about 60,000 ha) was designated a Fauna Priority Area in 1971 and represented the first large area of State Forest to be managed exclusively for fauna. The broad objectives in creating this fauna priority area were (after Christensen 1973):

(1) To conserve and manage the total forest environment with particular reference to the fauna.

(2) To use the area as a centre for research aimed at establishing the basic principles for sound fauna management in other forest areas.

Foresters soon recognised that while frequent, low intensity fires prescribed for fuel reduction do result in a variety of fauna habitats (Christensen 1973), it might be necessary to develop specific fire management strategies to cater for the protection and enhancement of specific animals in certain areas.

The burning plan for the Perup Fauna Priority Area (PFPA) was the first of these which was put into operation. In conceiving this plan it was accepted that wildfires were not desirable both from the point of view of protection of neighbours and the protection of conservation values within the Fauna Priority Area. In order to have definite and specific management objectives, the Perup fire management plan was based on selected species management. The species selected were those about which something of the biology was known and which were considered uncommon or rare. The Woylie (**Bettongia penicillata**), the Tammar (**Macropus eugenii**) and the Numbat (**Myrmecobius fasciatus**), were the species selected. The data on which the current burning plan is based were obtained from studies of these species, particularly the Woylie and the Tammar, made over 10-12 years (Christensen 1980). Factors taken into account when devising the burning plan included the animals food, cover, life span, distribution, behavioural pattern, breeding biology and mortality (Christensen 1982).

A fire management plan was developed which consisted of three fire regimes (Figure 1). The first of these is fuel reduction burning, on a 6-7 year cycle, of strategic areas to assist in control and minimise the impact of wildfires. The second regime is one of burning large blocks on a 9-12 year rotation, either in spring or autumn. This is designed to cater for Numbats and allow for several generations of Woylies between burns (Christensen 1982). Every second or third fire rotation (18-24 years) is set under dry autumn conditions to regenerate tammar thickets (**Gastrolobium bilobium**). Blocks to be burnt and the timing of the burns are such that there are always areas nearby from which recently burnt areas can be recolonised (Figure 2). The third regime is to attempt to exclude fire from two areas. These serve as biological reference areas. The burning plan for the PFPA is continually reviewed and revised according to advances in fire ecology research, management constraints and wildfire outbreaks.

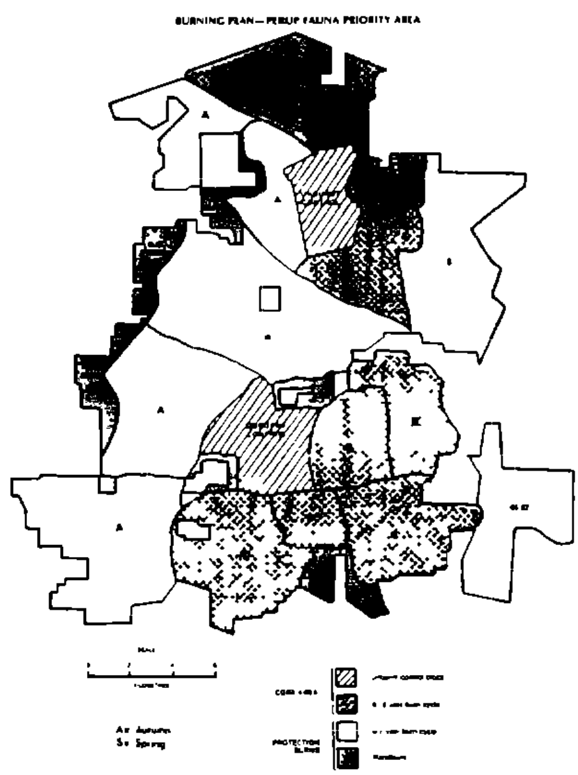

Figure 1. Burning plan for the Perup Fauna Priority Area (after Christensen 1982). The burning plan caters for protection from wildfire by frequent, low intensity burns and for fauna habitat regeneration and diversity. (Reproduced with the permission of the Conservator of Forests, Forest Department of Western Australia).

3. Recent Developments in Fire Management Planning

The fire management plan developed for the PFPA was the first of its kind in State Forest areas. Much has been learnt by researchers, planners and fire managers about the numerous complexities of the role of fire in the natural environment and management constraints in applying planned fire regimes to meet specific objectives. Individual fire management plans for different forest priority use areas are now common in the south-west of Western Australia. This is because planners and managers recognise the importance of tailoring fire management to local ecosystem processes, and local social and human factors.

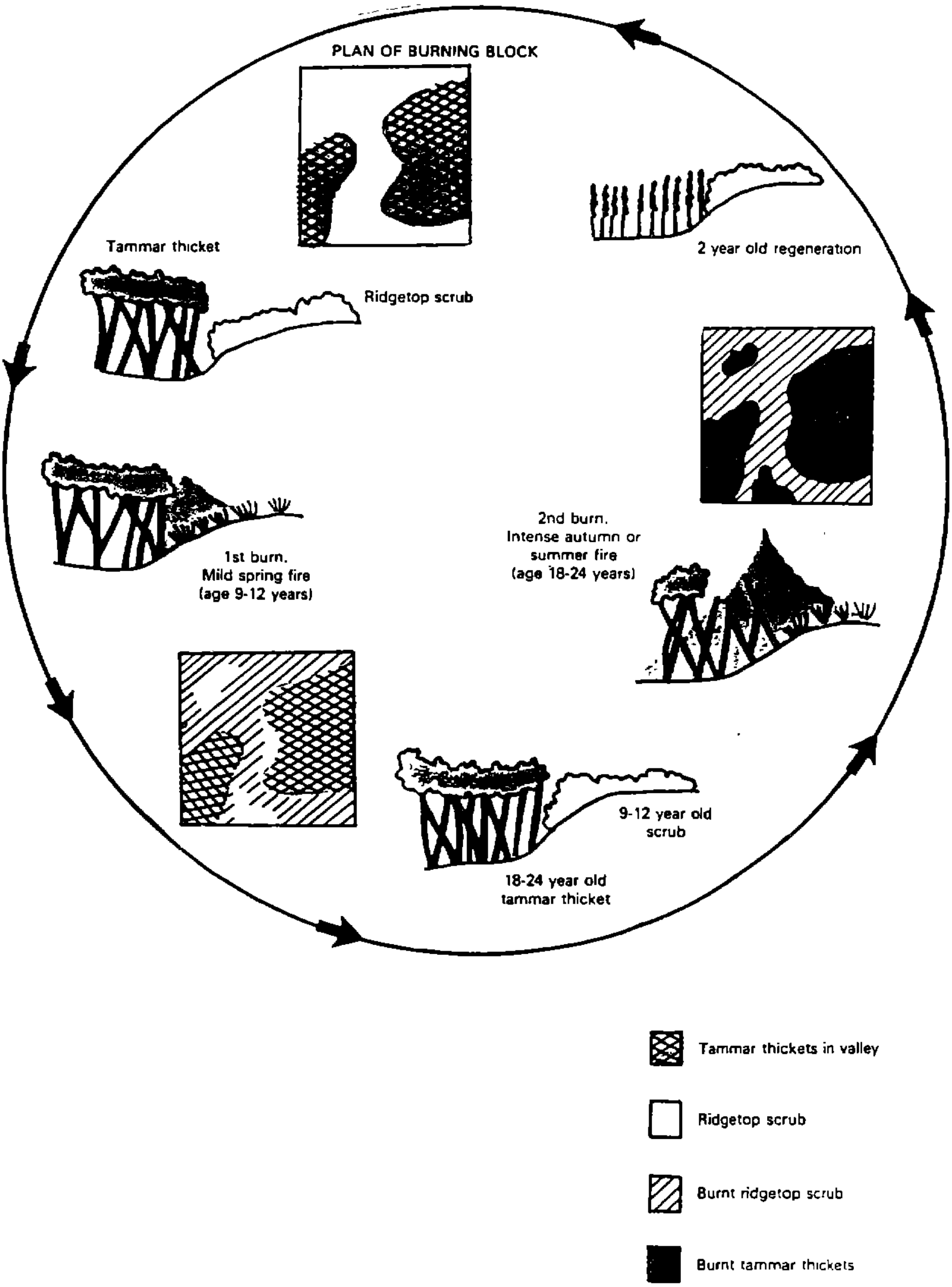

Figure 2. This diagram illustrates a fire regime devised for a forest block in the Perup Fauna Priority Area in south west Western Australia. The regime of cyclic burning in spring and in summer/autumn affords some protection against devastating wildfires but also caters for the regeneration of thickets necessary for the tammar wallaby. (Reprinted with the permission of the Conservator of Forests, Forests Department of Western Australia).

Knowledge of ecological processes and the role of fires in nature conservation forests in the south-west is not complete. While it is acknowledged that a defined fire regime, planned for nature conservation, should be based on detailed research relevant to conservation objectives (Good 1981), such information may take many years to gather and to analyse. Even then, it is unlikely that there will ever be enough known. To use fire as a controllable management tool, the manager must have a good knowledge of fire behaviour and of long and short term effects, both ecological and social. Fire behaviour obeys reasonably well understood physical laws and is predictable to within certain limits. However, the effects of fire on plants and animals requires a much more detailed understanding of local conditions. In the absence of this knowledge and with the increasing requirement and use of fire in land management, managers around Australia have adopted a number of philosophies as guidelines to decision making. These philosophies have been discussed by Gill (1977) and Parsons (1978) and some are presented here because they are real fire management options open to managers of nature conservation forests.

One widely held philosophy is "let nature take its own course". It is often argued that native animal and plant communities have managed very well without interference by man, so it is best to do nothing and allow natural processes to continue. If there are no management problems, or there is very little known about the role of fire, or resources are too limiting, then this is probably the only course of action open to managers. This is acceptable to the point that unplanned, or wildfires, are a management problem. Severe fire behaviour displayed by high intensity fires, such as long distance spotting, often make such fires uncontrollable. While such fires may have occurred naturally in the past, they can be devastating to small reserves and to human values. The most serious problem with allowing nature to take its course, is that in south-west forests, most fires are caused by people. Together with the introduction of feral animals and exotic plants, a situation of natural fire regimes and interactions does not exist (Bridgewater & Backshall 1981).

Managers may also justify almost any fire regime imposed on a native conservation forest by adopting philosophies such as "flora and fauna are adapted to fire". This is not strictly true. Flora and fauna might be adapted to survive a particular fire regime or regimes (Gill 1975).

Gill (1977) has defined fire in the natural landscape as "a natural environmental variable whose effects vary according to the fire regime and ecosystem properties". For present-day management objectives in nature conservation forest, this allows scope for the use of prescribed fire under some circumstances. If there is to be effective fire management, then objectives need to be clear and there needs to be base line data on the resources being managed. The need to have clear objectives is critical for determining the role of fire. An understanding of the effects of fire regimes on natural processes and of fire behaviour is essential. Appropriate modification to these fire regimes may be necessary to protect values within and outside the reserve from wildfire or in accordance with the managers resources.

Fire management planning is a process for determining the role of fire in achieving well defined objectives. It is not a prescription for management. This is the child of the broader level of planning.

Because fire management decisions in nature conservation forests must be based on an understanding of the natural role of fire in the area, certain basic information is needed. With very few exceptions (such as the PFPA), a detailed ecological resource inventory and a firm knowledge of the role of fire does not exist for many nature conservation forests. While certain principles and knowledge of fire effects are transferable from one area to another, it is necessary to examine each forest separately. All reserves differ, if even only in the space they occupy. In most circumstances, managers cannot "do nothing" until researchers provide a detailed knowledge of long term fire effects. However, a general understanding of the role of fire in achieving management objectives can be gained in a relatively short time. A basic biological inventory can provide useful guidelines for managers and can be gathered relatively quickly and cheaply. Until continued research and monitoring provides more detailed information, an initial biological survey and fact finding mission can provide managers with enough information to carry out some form of decisive management. The following procedure for gathering information and developing ideas will assist with making decisions about the ecological role of fire in nature conservation forests. This process is one of measuring, observing, recording and analysing certain bio-geographical indicators which will assist in determining the biological role of fire in the management of nature conservation forests.

4. Core Data for Fire Management Planning

4.1 Geography

It is clearly important to know the size, shape and boundaries of the reserve and its location in relation to surrounding land use. Good (1978) observed that small reserves (less than 4,000 ha) play a less significant role in the effective conservation of flora and fauna than large reserves and are seldom managed. However, where small, island reserves harbour special ecological values, their management may need to be more intensive than for very large reserves surrounded by relatively undisturbed forest, as is the case with most reserves in State forest. The importance of the reserve and its location will effect the attitude of management in terms of the intensity of management and the level of resource allocation. For example, small (4,000 ha) reserves surrounded by wheatlands are probably more vulnerable to degradation by wildfire and by weed invasion (Bridgewater & Backshall 1981) and may be seen by adjacent land owners as a source of destructive wildfires. By contrast a large (60,000 ha plus) reserve surrounded by relatively intact and protectable forest is considerably less vulnerable to ecological degradation.

4.2 People

Regular, constructive liaison with adjacent land owners, forest users, communities, local authorities and bush fire brigades will ease the burden on the manager. It is important in the eyes of the public and ultimately for the reserve, that the reserve is seen to be managed, that the managers presence is felt and that local people have an opportunity to contribute to management plans and operations. Neglected reserves can become rubbish dumps, shooting galleries or nearby land owners can take fire "management" into their own hands.

4.3 Climatic Factors

Climate and weather will determine the level of "fire proneness" of an area. Vegetation and fuel dryness are affected by rainfall and daily drying influences such as temperature, relative humidity and wind. Meteorological records and daily records of Fire Danger Rating (Sneeuwjagt & Peet 1976) will reveal the length and severity of the "fire season" or the period when living vegetation and litter are dry enough to burn. Severe fire weather conditions are often associated with particular wind directions and local weather conditions. An examination of climate and fire history can place the fire proneness of the reserve into perspective and enable a balanced judgement of the likely wildfire frequency and severity (McCutchan 1977). This can help in planning the level of presuppression and suppression actions.

5. Biological Factors

Initially, an extensive biological survey of the reserve (and surrounding areas) is needed to aid in understanding the role of fire. Information about the occurrence and distribution of plants and animals is necessary. Vegetation is especially important as it becomes the fuel, provides food and shelter for animals and is important in its own right. Pyro-botanical features such as structure, biomass and distribution of vegetation in relation to landforms can provide clues to possible fire frequencies and intensities.

5.1 Vegetation Survival Strategies and Fire Regimes

Before the possible effects of fires on an ecosystem can be examined, there are several fire factors which must be considered. These factors are: fire intensity, fire frequency and season (Gill 1975). Most plant species and vegetation associations have adaptive traits (Gill 1977) which enable them to survive and regenerate under finite combinations of these factors. Studying the survival strategies and the adaptive traits displayed by plants can provide indicators of fire dependency, fire sensitivity and fire regimes which favour or disadvantage certain species and communities. Fire adaptive traits, including re-sprouting from stem and roots, soil stored seed, hard seededness, protective bark, woody fruits, fire stimulated synchronized seed dispersal, fire initiated flowering response and other traits, may occur singularly or in combination within and between plant communities. The occurrence or absence of one or more of these traits reveals much about the past fire regimes which have moulded natural ecosystems as seen today and which maintain natural processes.

For example, a species which cannot re-sprout following fire and which relies on either soil stored seed or seed stored on the parent plant may be seriously disadvantaged by a series of frequent fires intense enough to kill the parent plant. The intervening fire free period will need to be longer than the period taken for build up of a viable seed store. Even then, if the fire is either of low intensity or burning under cool, moist conditions, then seeds buried in the soil may not be heated sufficiently to stimulate germination. If the fires frequently occur in springs and seeds do germinate, then on exposed sites they may not survive the ensuing summer drought or grazing pressures. Low intensity spring fires may not stimulate massive and synchronized seed release from woody fruits. These fires may not produce the ideal seedbed produced by moderate to high intensity summer fires which also temporarily reduce all litter, scrub competition, seed predators and grazers. Total fire exclusion may result in decreased species richness and possible nutrient lock-up on some sites. Intense wildfires can kill certain plants and animals, which may take many years to regenerate and re-colonize.

Frequent, low intensity fires generally favour re-sprouters over seeders (Vogle 1977) but very frequent fires can exhaust the root-stock reserves (Baird 1977) and prevent woody species from reaching flowering age. Plant growth rate, longevity and flowering age are critical in defining fire frequency. It is necessary to understand these characteristics and to formulate the appropriate fire regime on the basis of the most fire sensitive species or community.

5.2 Animals

Animals are directly affected by the physical presence of fire and indirectly affected by the effect of fire on vegetation. A basic understanding of the dependence of animals on vegetation is necessary. It is essential to determine something of the vegetation types, structure and successional stages utilized by various animals. This basic information can be obtained by trapping and censusing techniques repeated over a long time. Detailed knowledge about the biology of every animal requires long term research and is not available for most areas of State forest. Research carried out in other areas may be relevant but long term study in representative ecosystems must continue. It is necessary to study both the long term effects of fire and of fire exclusion on ecosystems.

6. Fuels and Fire Behaviour

A description of the major fuel types within a reserve is essential not only to predict fire behaviour, but also in determining the fire proneness of the area. Fuel accumulation rates (of both ground litter and living vegetation) enable managers to estimate the rate at which the fire hazard generated by fuel build-up is increasing. Appropriate protection burning or suppression action can then be designed. The continuity and flammability of fuels also enables an evaluation of the level of wildfire severity. The rate of fuel accumulation in low rainfall woodlands east of the main forest belt is slow and patchy. Generally, the quantity of fuel in these areas is a function of fuel age, vegetation type and tree basal area and rarely develops beyond 12-14 tonnes per hectare. For example, fuel measurements made in Wandoo (**Eucalyptus wandoo**) in the Dryandra State Forest near Narrogin reveal that even after 46 years without fire 60% of the area carries less than 8 tonnes per hectare of fuel (Figures 3 & 4). This contrasts with higher rainfall western jarrah forest (**E. marginata**) in which litter fuel accumulates at 1-1.5 tonnes/hectare/annum. Measurements of litter fuel bulk density indicate that fuels in wandoo forest are more compact, hence less flammable than typical leaf litter fuels in higher rainfall western forests. The patchiness of fuel build up in certain vegetation types precludes using a mean fuel load as a criterion for setting prescribed burning rotations. Moreover, the types, range, structure and distribution of fuels is a more meaningful measure than simply the mean fuel weight (Figure 4).

Areas of high wildfire risk in terms of fires entering or leaving, or starting in or around the reserve, must be identified. Utilities and other properties should be identified and mapped so that they can be considered in planning and management.

These core data are the minimum for determining the role of fire in maintaining natural processes within the reserve and for assessing the "fire proneness" of the area. By analysing and interpreting this information, the manager can devise a fire regime pertinent to conservation objectives. One observer (Sampson 1944) commented that "the most outstanding fact consistently appearing in the literature on fire and plant succession is that no single criteria or formula may safely be used to predict the outcome". Despite this, a fire plan based on a biological interpretation of the role of fire in the reserve and revised and refined by continued research is still the soundest basis from which to start.

However, managers will instantly recognize that what may be the best plan from the biological view point may not be practicable. There are many other important considerations. This is especially so in multiple use forests or managed nature conservation forest in the south west of Western Australia.

7. Management Considerations

7.1 Wildfire Control

A fire management plan for nature conservation forest may include either "letting nature take its course", or a program of deliberate fire regime manipulation through prescribed burning. Whatever, the managing authority will always be under pressure to suppress or contain wildfires for legal and moral reasons. The methods adopted for minimizing the impact, and maximizing control of wildfires will vary according to the values threatened, the size and intensity of the fire, impending weather and fuel conditions, the level of understanding of fire behaviour and the managers detection and suppression capabilities. There are basically three response options to wildfires: (i) The manager can let the fire run wild within the reserve and try to contain it from strategically placed fuel reduced areas or fire breaks; (ii) the manager can leave the wildfire run until it rains, or (iii) the manager can attempt to suppress the fire immediately. In forest situations in the south-west of Western Australia, the last option is usually favoured. Wildfires in forest areas quickly develop in size and intensity and once they become large (say in excess of several hundred hectares) and intense (in excess of 2,000 kW/m), they can rarely be stopped at fire breaks. Direct headfire attack with bulldozers usually fails above intensities of 2,000 kW/m (Burrows 1984). In the south-west forest region, there are too many values at stake to risk allowing fires to burn out with a change in weather. On the other hand, wildfire suppression is expensive and may conflict with conservation values. Bulldozed fire breaks can cause considerable disturbance to soil and fragile plant communities and can aid in the spread of diseases such as **Phytophthora cinnamoni** (Shea 1975). Therefore, the fire manager must be acutely aware of pre-suppression and suppression options and their effects on the landscape and on conservation values. Alternative suppression techniques such as back-burning or burning out the area to consolidated edges, although more risky, may be more appropriate and this is automatically weighed up when fires start in dieback quarantine areas. In forest areas, strategic fuel reduction burning must be done if wildfires are to be controlled. The extent, positioning and frequency of fuel reduction burning will be determined by the "fire proneness" of the area, available resources, expertise to carry out the operation and its effects on conservation objectives. In most instances there will be a trade off between wildfire amelioration activities and conservation objectives.

7.2 Implementing Planned Fire Regimes

The manager must be able to safely implement and control fires of desired intensity, size and time of year. This requires sound planning, drawing up of prescriptions, allocation of resources and a firm knowledge of fire behaviour and effects. Fire can only be a management tool if it can be controlled and its effects are reasonably well understood.

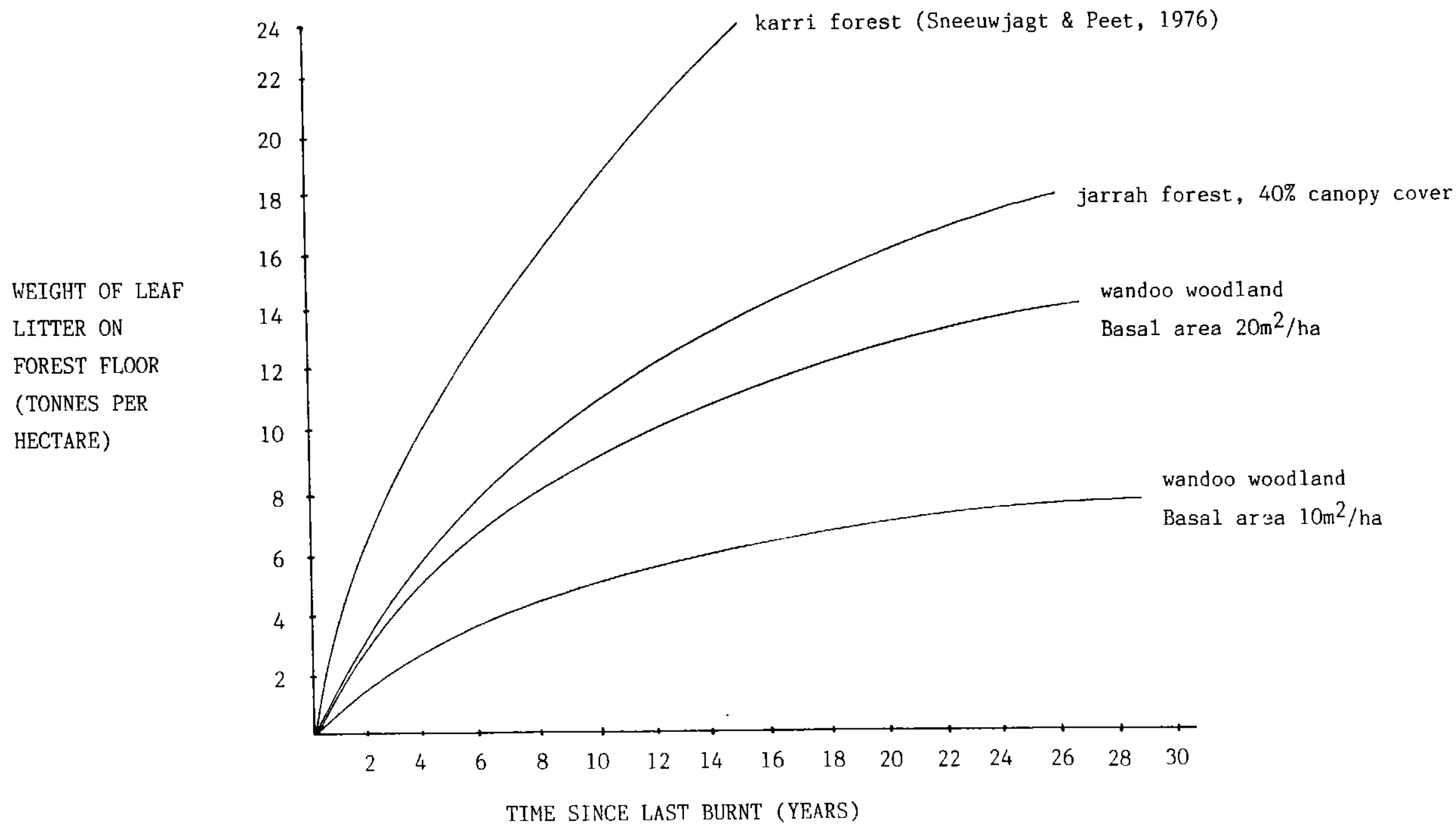

Figure 3. A comparison of leaf litter fuel accumulation rates for three different forest types found in the south west of Western Australia.

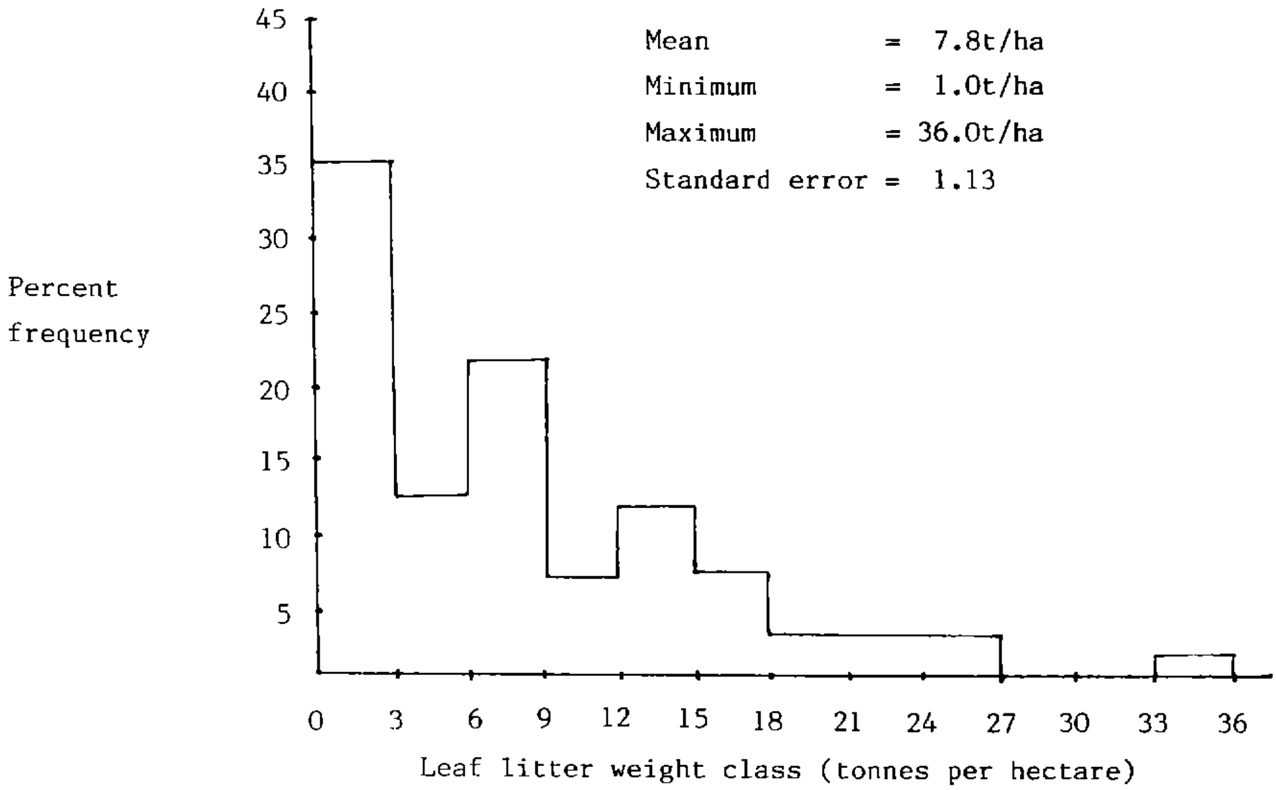

Figure 4. Percent frequency distribution of leaf litter weight for a 250 hectare block of wandoo woodland in Dryandra forest near Narrogin. The block has remained unburnt for 46 years.

7.3 Other Operational Constraints

These include; accessibility to the area, the extent and severity of the "fire season" (weather conditions), equipment, manpower and money. There are legal constraints (such as Bushfires Act) and may be dangers of spreading diseases and encouraging weed invasion. In multiple use forests, consideration must be given to other values such as recreation utilities, water production, scientific research, landscape and areas of special biological significance.

Provision must also be made for continued monitoring and research. Planning is an ongoing process which responds to management ojectives and new information.

8. The Management Function

With this knowledge and information, it is the managers job to devise fire management plans. These plans must be translatable into prescriptions which can be carried out on the ground. Often, this is in the form of a map or a burning plan which shows the forest subdivided into blocks which are burnt at different frequencies and at different times of the year to create "diversity" or species richness. Diversity is not an end in itself, but is usually justifiable where management objectives are broad or there is a poor understanding of the role of fire in ecosystem functioning.

A fire management technique which may be appropriate to island reserves and woodland reserves in low rainfall areas east of the main forest belt is one whereby the manager decides to burn only after measuring various environmental parameters. This technique requires a good knowledge of all aspects discussed earlier and does not necessarily commit an area to a set fire regime (except fuel reduced buffer areas). Rather, it allows managers to forecast if, when and how to burn by using a combination of dynamic biological indicators. These may include; species diversity and composition, vegetation structure, vegetation vigour, the level of animal populations and the level and rate of fuel accumulation. The management function would then include regularly measuring these indicators and with guidelines prepared from a firm understanding of natural processes, make decisions on the necessity to burn an area, how, when and how intense etc. A real problem with the transition from scientific research through the planning stage to management is that managers are rarely provided with the information and opportunity to fully understand the biological implications of their actions. Continuous monitoring provides managers with a qualitative description of natural processes and can be a measure of their success in terms of meeting set objectives.

9. Conclusion

The controlled use of fires has played a major role in the management of forest areas in the south-west of Western Australia. Scientific knowledge, planning and resources to do the job have always been necessary ingredients for success in meeting management objectives. Fire frequency, season of burn and fire intensity are key factors to be considered when assessing the effects of fire on natural ecosystems and on achieving specific goals.

Appropriate fire regimes in nature conservation forests must consider the role of fire in maintaining ecological processes and the desirability or otherwise, of uncontrollable and intense wildfires.

Biological burning (or burning for conservation objectives) as a management function, must be based on a firm understanding of the historical role of fire as well as ecosystem changes likely to be induced by discriminant wildfires or by the exclusion of fire. It is unlikely that the effects of fire in natural ecosystems will ever be fully understood. Continued research, monitoring and a holistic view of ecosystem processes are essential if long term conservation objectives are to be met in forested areas of the south west.

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PREPLAN AND THE MANAGEMENT OF NATIONAL PARKS

R.B. Good

Major wildfires as have occurred in the eastern states in 1982-83 and 1984-85 have again highlighted and emphasised the need for better planning and more effective fire management than currently exists in all but a few natural areas.

Wildfire control and suppression has been the basis of all fire management plans to date with little cognizance being taken of the impacts of fire, planned or unplanned on the ecosystems or the likely responses of the native flora and fauna to a fire regime. Extensive research although still inadequate in many areas provides a background to fire management planning and this together with ready access to computers now enables a much more aggressive, effective and scientifically based approach to fire management to be taken. The PREPLAN concept and the suite of programs which support it, has been used in the preparation of a number of fire management plans and general park plans of management and have led to a considerable change in approaches to planning, resulting in vastly improved management.

The PREPLAN Program

PREPLAN is actually a number of programs linked together to provide various printouts of resource data and simulation and predictive capabilities. PREPLAN is a computer-based system that combines a natural resource inventory and models of vegetation, fuel and fire into a single integrated package (Fig. 1; Kessell et al. 1980). PREPLAN can be used simply as a geographical information system (G.I.S.) for the storage and retrieval of resource data, but the real value of PREPLAN is its ability to simulate potential results of any planning and management strategies before actual implementation, as well as the prediction of the impact of major wildfire events. During major wildfire control and suppression actions PREPLAN can be accessed to provide real-time fire growth maps as an aid to suppression planning (Fig. 2).

Hazard Reduction Burning

Since the mid 1960s prescribed burning for hazard level fuel reduction has been the basis of and major strategy for wildfire control and hence fire management. The development of aerial incendiary burning enabled prescribed burning to be applied to vast areas of natural vegetation to the extent that it has dominated fire management philosophy and planning. Basing fire management in parks and reserves on a defined program of fuel reduction burning suggests and implies that most natural areas carry hazardous fuels and that wildfire is always a threat to the environment. This is obviously not the case as fire is a process in nearly all natural ecosystems and occurs as a response to other processes in the system. It is thus a natural resource which must be managed as an integral part of the management of other resources.

The difficulty in managing fire in natural areas is that it is a very complex process, as exhibited through the great range of intensities which occur in any one fire. Managers and planners alike tend to simplify but complicate the fire management process by considering fire as a single entity and hence all fires are a hazard and threat inferring a degree of risk where life and property exists in close proximity to potential fire areas. On this premise the need for fuel reduction has become an 'accepted' concept and strategy.

Two shortcomings in current fire management are thus readily identified, the first being that all natural vegetation fuels are considered to be a hazard and that wildfire is always perceived to be destructive and a threat to the natural or built environments.

Basic Fire Management Concepts

To address these shortcomings and to be able to plan for effective fire management, planners and field managers must first define the range or maximum fire intensities for which they are planning. Fires of the intensity ranges of the Ash Wednesday events are not manageable in the context of control by any existing strategy. Only when the manageable fire limits are set can the hazards, threats and risks associated with any wildfire be determined and from which the need for any fuel manipulation strategies identified. Fuel management is but one aspect of fire management. The role and effects of any fire regime, planned and unplanned in and upon the very resources parks are established to conserve, must be the dominant issues considered in fire management planning.

Planning Approaches

Park fire management plans are usually prepared as a major section of a plan of management or as a separate planning document, as fire is recognised as the most complex and significant variable in resource management. To address this complexity a detailed knowledge of the natural resources which influence fire occurrence and behaviour and those impacted by fire must be accumulated upon which rational and sound planning concepts can be formulated. These basic resources are:

* topographic data (slope, aspect, elevation)

* vegetation

* fuels

* soils

Topographic, vegetation and fuels data can be used to simulate and predict fire behaviour as rate of spread, intensity and flame length under any weather data set. This capability then provides for the assessment of any fire event and through integration with vegetation succession data an appreciation of the desirability of vegetation responses to any fire (Fig. 3). To be useful in management, planners must be able to convert fire behaviour

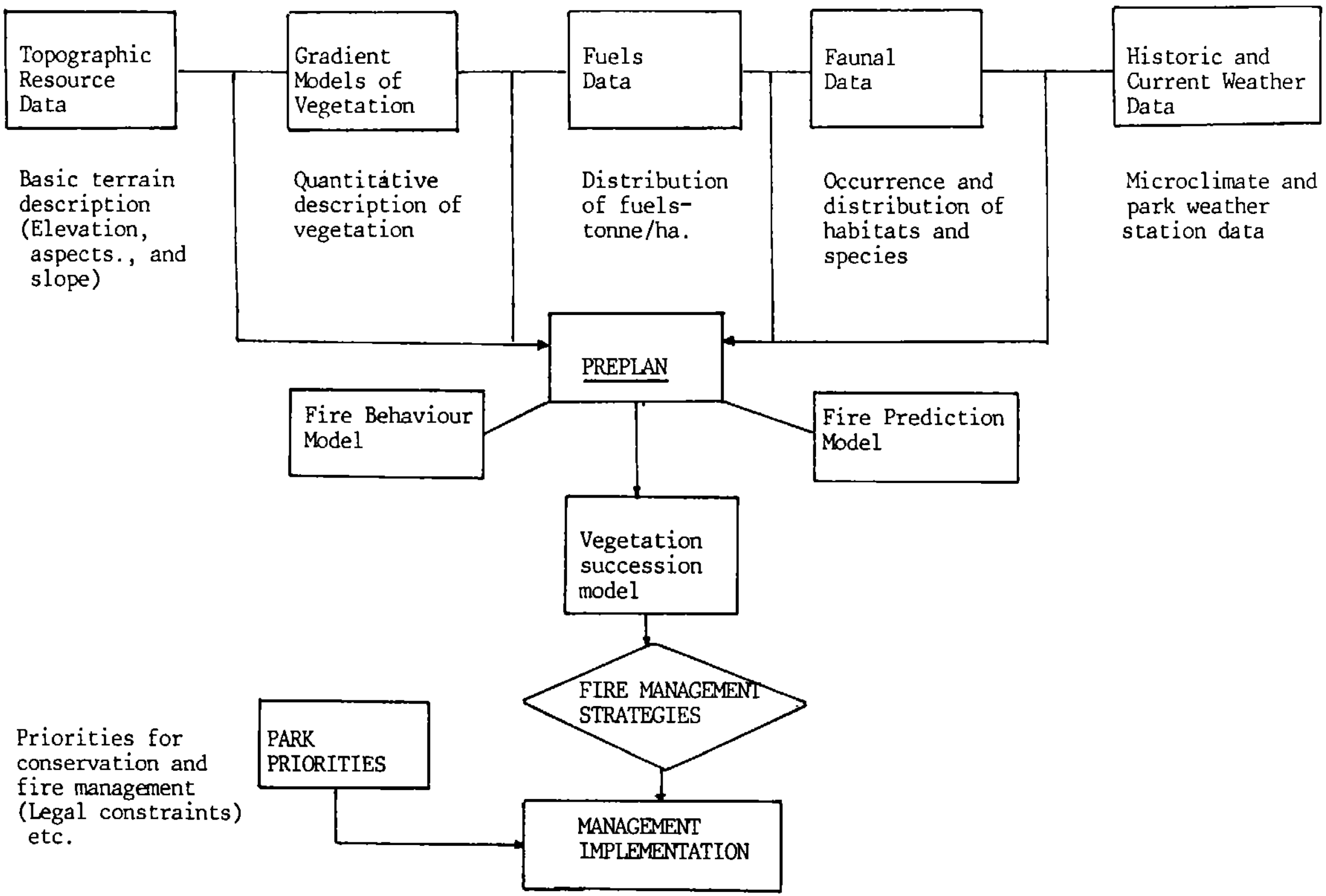

Figure 1. PREPLAN Integrated data bases.

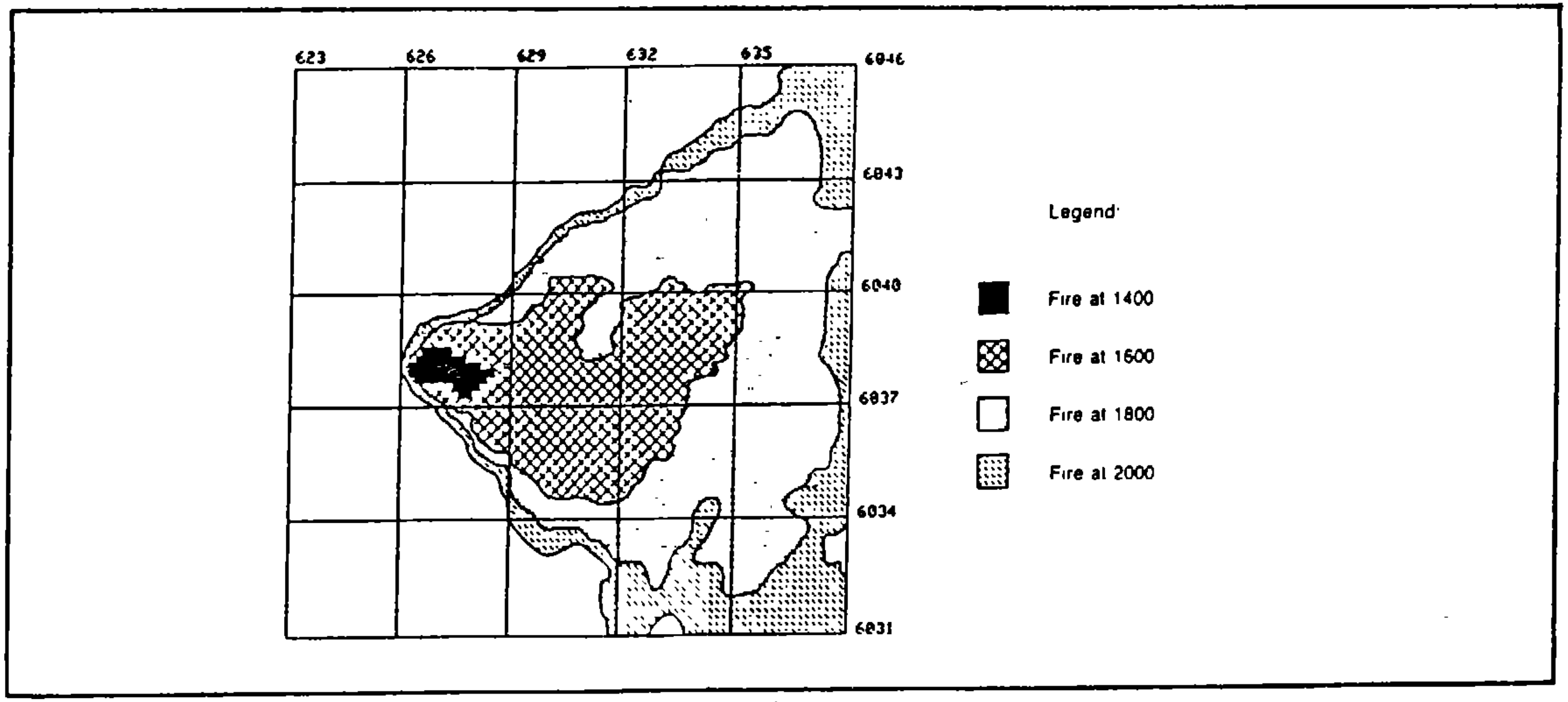

Figure 2. Real-time fire event.

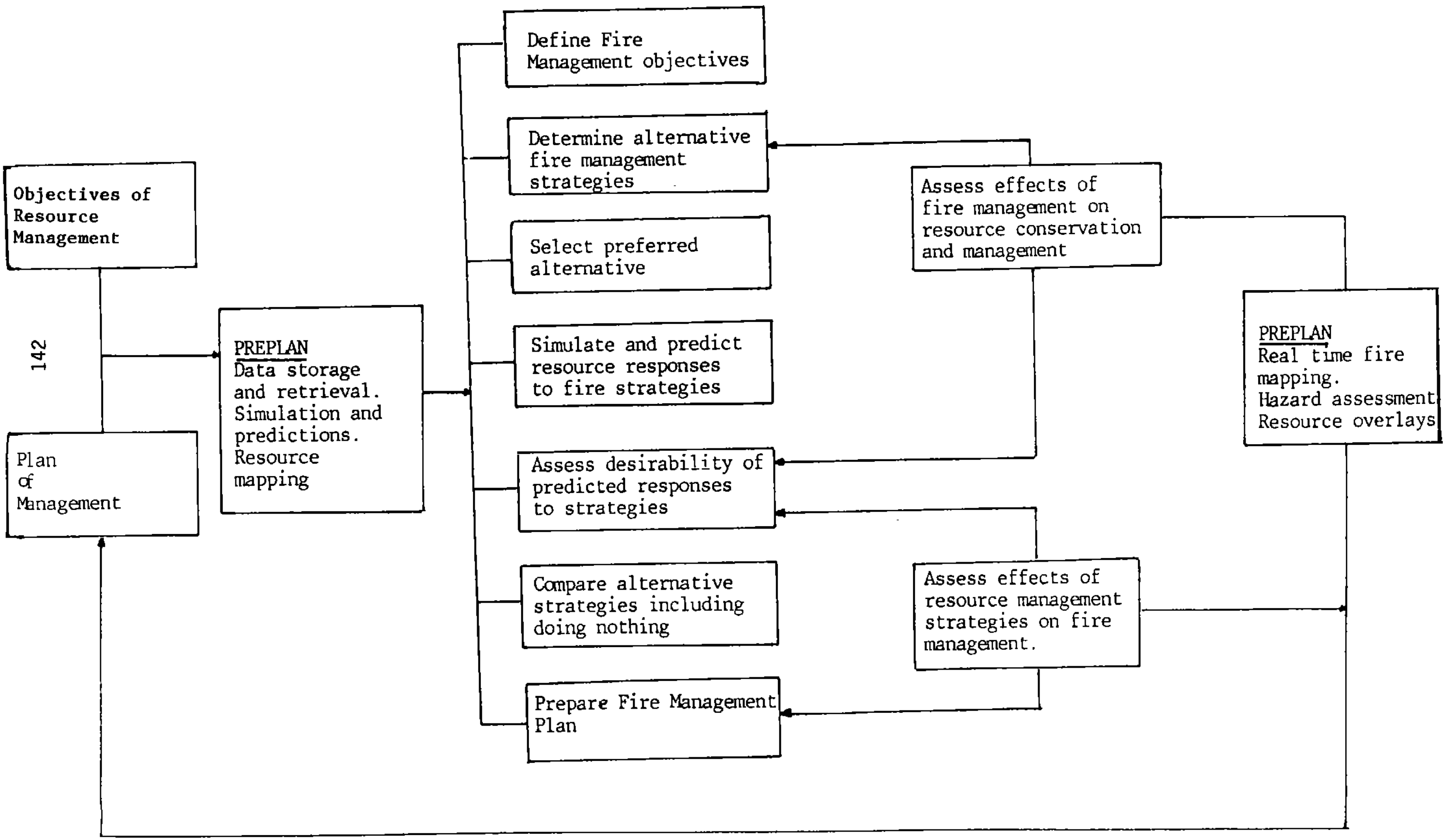

Figure 3. PREPLAN and its role in park management planning.

predictions into meaningful terms and hence define acceptable fire regimes for each fire management area or unit within a park or reserve. Having defined the fire regimes the strategies for the manipulation of the fuel complex to provide the regime(s) with respect to fire intensity can be formulated. These fuel strategies may in some units meet the requirements for hazard level fuel reduction where the hazardous nature of the fuels have been identified and reduction is considered necessary to provide for obligatory fire management issues.

Delineation of Core Fire Management Units

The zoning of areas of similar biophysical, biogeographical, recreational and resource values into management zones has been a traditional approach to park management planning. This approach to planning infers that once defined, the zones will retain the identified values and the management objectives and strategies will be retained in some future time frame.

Fire management on the other hand must recognise the dynamic nature of fire as a process and as a major driving force in most natural vegetation ecosystems. Approaches and techniques must be used which can provide for a dynamic plan.

A fire management unit must be considered as a concept area where a set of resources and values demand a range of fire regimes to meet management objectives and/or obligatory fire management requirements exist.

The core units are defined on vegetation types, biogeographical features, recreation potential, fire behaviour, park boundary and adjoining land tenure relationships. The core units are further defined by the resource values recognised in the park plan of management or as perceived by the fire management planners.

With the increasing complexity of issues, values, conflicts and concepts, there is an increasing demand for integrative and manipulative techniques to define the fire regime(s) which best meet management objectives. Computing techniques now provide this capability through the storage and retrieval of masses of resource data.

The PREPLAN suite of programs as developed by the N.S.W. National Parks and Wildlife Service encompasses a basic geographical information system linked with integrative mapping capabilities such that any data manipulations, simulations and predictions can be mapped as overlays. While the map overlaying technique identifies core units with similar fire management concepts and objectives, the units are considered as dimensionless as the implementation of strategies in one unit will influence the selection of alternative management strategies in adjacent core unit areas. This is particularly pertinent where planned burning is implemented as part of a defined fire regime and by necessity where unplanned wildfire occurs over two or more core unit areas. The management strategies and the planned fire regimes for each core unit must also be flexible to account for unplanned fire events and to the changing extent of each core management unit.

The ready access to computing facilities and the use of the PREPLAN programs has enabled both the prediction of fire behaviour under any set of weather conditions, vegetation and fuels, and the delineation of core fire management units using the same stored data base. An additional and probably the most significant capability provided by the PREPLAN programs is the quantification of hazard and risk concepts (Fig. 4).

Hazard and Risk Assessment

Hazard and risk are terms in common use in fire planning documents, hazard particularly being in the context of fuels of some specified level. In the eastern states hazard fuels are those in the order of 8-10 tonnes per hectare, the hazard presumably being the actual intensity of a fire originating from the fuels. The quantification of hazard requires the assessment of all other factors which contribute to fire behaviour and taking account of the location of values likely to be impacted by wildfire. A wildfire distant from a development for example, presents little threat to life and property so the hazardous nature of the fire irrespective of intensity must be low. PREPLAN enables the quantification of hazard at any point, location or area within a park or reserve, in the terms of intensity hazard, rate of spread hazard, flame length hazard or a combination of all by integrating all resource data.

The relative hazard levels are continually changing as a response to weather conditions, changes in vegetation, management strategies and so on, thus a dynamic approach to hazard assessment is necessary. In the past hazard has been considered as a static factor and only changing with a change in fuel load.

The quantification of fire hazard has in N.S.W. become a legal requirement where any development approval is sought from a determining authority (Anon. 1984). In many instances the authority is the National Parks and Wildlife Service thus the PREPLAN program has enabled the fire hazard to be assessed and quantified at any time for both the assessment of potential impact on natural resources as well as developments and proposed developments (Good 1984).

Summary

Fire management planning has changed from the simplistic fire control and suppression approach with prescribed burning for fuel reduction as the dominant strategy, to a scientific approach based on resource evaluation, an understanding or prediction of ecosystem responses and assessment of hazard and risk.

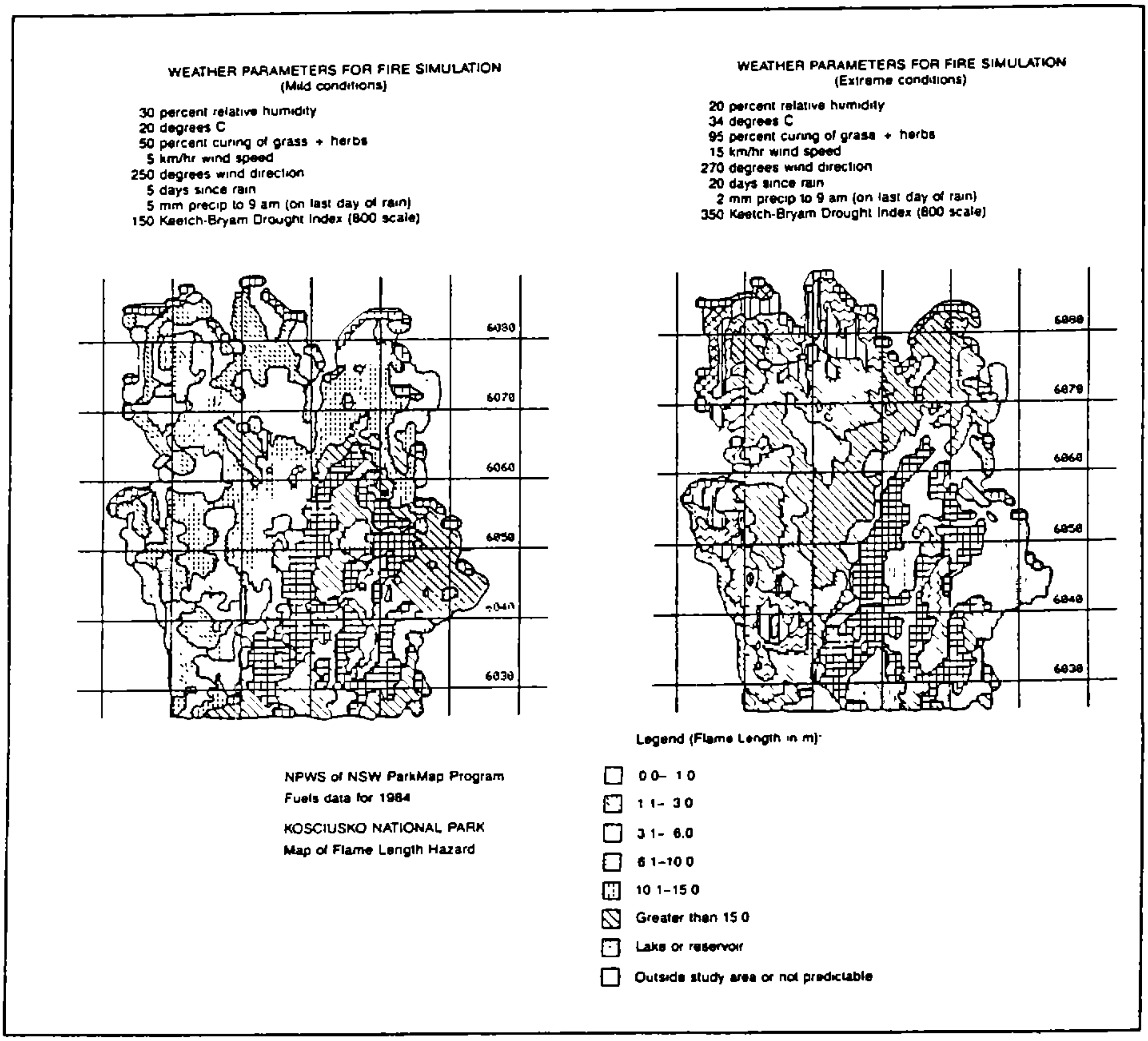

Figure 4. Hazard map under different weather conditions.

Any plan must recognise the dynamic nature of the ecosystem within which fire is a process and identify the role of planned and unplanned fire in the system.

In the implementation of fire management strategies all alternatives must be accounted for, particularly where a preferred strategy is singularly exclusive or irreversible. The alternative of not doing anything should always be considered as an acceptable alternative whenever a plan or decision to implement a strategy is based on little or no resource data.

Fire management is therefore the end result of sound planning based on a detailed knowledge of resources, the implications of having those resources to manage and the potential to effectively implement strategies.

While the capacity to appreciate the full complexity of issues, resources and conflicting philosophies on fire management will never be realised, the PREPLAN suite of programs has enabled the preparation of detailed and rational fire management plans formulated on the best available resource data. The integration, simulation and prediction of fire behaviour, and vegetation and fuel responses to fire regimes has also enabled many of the conflicting concepts to be resolved, particularly those related to hazard fuel reduction and 'protection' burning.

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THE PLANNED USE OF FIRE ON CONSERVATION LANDS - LESSONS FROM THE EASTERN STATES

R.B. Good

The implementation of prescribed burning for hazard fuel reduction has been a forestry management practice for many years and today dominates all forested land fire control and suppression strategies. The proliferation of prescribed burning practices in conservation reserves and national parks must be questioned but unfortunately after every major fire season there is a call for more and more hazard fuel reduction burning which in most cases would not assist fire suppression activities. Fires such as occurred on Ash Wednesday in the eastern states were fires which would have occurred under the prevailing weather conditions and burned through the countryside irrespective of any previous hazard fuel reduction. In many areas extensive prescribed burning had been previously carried out and while intensities were noted lower to some degree the rates of spread were such that control problems still existed. Where intensities were lower they were only marginally lower and when the upper intensities were in the order of 70-80,000 kwm and the lower intensities 10-20,000 kwm, it is obvious that prescribed burning had little impact upon the extreme fire situation. Fire management personnel must identify the 'manageable wildfire' they are considering and for which they are implementing a hazard reduction program.

It is increasingly obvious that many of our fire management practices in parks and reserves conflict with other natural resource management objectives due to the perceived need to be carrying out planned burning programs such as fuel hazard reduction, even when a quantified need for such has not been determined or identified. These burning programs have locked managers into inflexible and in many cases irreversible fire regimes and management practices which are detrimental to the very resources which other management plans and strategies aim to preserve or conserve.

Planned Use of Fire

In most parks and reserves the planned use of fire has only been for the reduction of hazardous fuel levels but this situation is changing and ecologically based fire practices are now being developed and implemented on a small scale.

Prescribed burning for fuel reduction in the eastern states follows the principles and concepts developed by Alan McArthur (1962) in the 1950s and 1960s, but unfortunately these principles and practices have been applied almost carte blanc over all forested lands with little or no background resource data and with only an overall perception of what constitutes hazardous fuels; these being considered singularly in terms of tonnes per hectare.

McArthur did state that the amount of fuel on the forest floor was the most significant variable and the only variable over which some control could be exerted. This is not entirely correct but irrespective McArthur considered only the fine fuels on the ground which contribute to fire behaviour, be it wildfire or prescribed burning. This has been found to be a dangerous basis on which to plan fire suppression and prescribed burning as most eastern state forests have an understorey of shrubs which influence fire behaviour often to a greater extent than the weight of fine fuel on the ground. The McArthur tables do provide for an input of shrubs to the total fine fuel load but only to the extent of 2.5 T/ha for every 25% increase in cover or a maximum of 10 T/ha. Generally in the shrub overstoreys of the forests the fine fuel component of the shrubs is far in excess of 10 T/ha hence the effect on fire behaviour is much greater than can be calculated for the tables.

The shrub component also changes fire behaviour through the structure of the fuel complex and the differential in moisture percentage and curing rates as compared with the fine fuels on the ground. In many prescribed burning programs the shrubs have been observed not to burn at the time when ignition in the fine fuels is first possible (early morning/late evening) but reach an ignition threshold during the day when the shrubs burn unpredictably. This unpredictable behaviour is due to the tall open aerated fuels and the burning of volatile oils particularly with species of the rutaceae and myrtaceae families. On the other hand the shrubs may also suppress the rate of spread of a fire when they are very dense and when they shade the ground litter layer, and change the wind profile.

The litter fuel structure similarly may influence the amount of ground fuel consumed by a fire and hence the amount of energy release to pre-heat the shrub component to ignition temperature. The depth and degree of fine fuel compaction (bulk density) influences the retention of moisture and hence the behaviour of a fire burning in such fuels. Heavy deep and compacted litter fuel beds are generally perceived as potential fire hazards based only on the fuel weight, but these are often a lesser potential hazard due to their lower flammability and relatively high moisture level than much lighter loosely packed fuels which dry out very rapidly after rain or on a diurnal cycle. This is particularly important in moist eucalypt forests. If prescribed burning was possible and carried out effectively in terms of meeting the prescription of burning, only the drier top 5-10 cm of fuel (5-8 T/ha) would be removed, thus exposing the lower moist levels of the fuel bed to drying out. This part of the fuel bed then carries the same hazardous fuel level as that which has been removed hence the 'hazard' has not been removed at all. This aspect of fuel management has now been recognised by fire managers as having contributed to their past dilemma of needing to burn on a very short rotation cycle (1-2 year intervals) to get the fuel levels below 8-10 T/ha or a level below which the hazard is perceived to be removed.

Due to prevailing weather conditions being either too wet or too dry burning on a 1-2 year cycle has seldom been found possible, so the hazard, so called is never removed by burning.

In dry forest types having 20-30 T/ha of fuel a similar dilemma exists for managers as short cycle burning is untenable in parks and reserves and a prescribed burn meeting all the prescriptions relating to flame height and canopy damage, would not reduce fuels below the 8-10 T/ha fuel level. If such a prescribed burn did reduce fuels to these levels wildfire intensities would be reached. The latter has occurred on numerous occasions with 22% of all wildfires in 1982-83 in N.S.W. being prescribed burns which reached wildfire intensities.

There is an obvious need to completely review both the objectives and practices associated with planned burning in parks and reserves to reduce the number of resulting wildfires. One objective in the past has been to provide a mosaic of age classes and to maintain species diversity although this has been more of a post-burning justification for prescribed burning, particularly where the prescriptions relating to canopy damage have not been met. A mosaic can be achieved but in the mountainous terrain of the forested areas of the eastern states the mosaic tends to become fixed through time as burnt or unburnt. This is a result of burning during autumn when only the drier ridges will burn under prescribed conditions. These generally are the areas which have the lowest fuels due to poor site conditions, while the sheltered slopes and gullies with heavier moist fuels remain unburnt retaining high fuel weights. During prolonged droughts which usually precede most severe wildfire seasons; these fuels dry out and become the real hazard i.e. the lower fuel areas are continually reduced and the heavy fuel sites may not be reduced at all until a wildfire actually occurs during a period of extreme fire weather. Prescribed burning thus has many problems associated with it in implementation and in meeting the prescriptions and the objectives of its use. Prescribed burning has, as a result, been found by hard experience not to be the panacea of fuel reduction and fuel management. Where it has been found to be effective in terms of fuel reduction, it has only been in very small areas and has been a result of luck as much as good management and planning.

Many other factors must now be considered in the planning of prescribed burning and any program must be based on detailed data and an appreciation of the resources which determine fire behaviour and those which are affected by any fire event. The days of the simplistic approach to planning a prescription burning program based on the tonnes per hectare of fine fuel concept are long gone. Even if the simple approach is perpetuated legal responsibilities under recent legislation will inforce a change in attitudes, approaches and strategies of implementation. Traditional approaches are therefore unsatisfactory and changes are not only desirable but will be mandatory.

Fire Management and Recent Legislation in N.S.W.

Prescribed burning has found support to date through obligations to life and property inferred in the various State Bushfire Acts. These make reference to taking all possible means of control in reducing the occurrence of fire and its spread from one land tenure to another.

Prescribed burning has enabled very large tracts of forested land to be 'treated' to meet this end and to provide protection of life and property.

Two aspects of the above must be questioned - the first being; as prescribed burning is the dominant strategy is it meeting the requirement for 'all means of control', and secondly is it providing protection. Fire managers so often now refer to prescribed burning for fuel reduction as protection burning. The inference from using such a term has already been challenged and no doubt will be again. Fuel reduction through any means does not provide protection to life and property; it only reduces the potential intensity of a wildfire. Through the continued use of the term protection burning, a public expectation has been generated for all fire management plans to now ensure protection from all wildfires. The wildfire events of Ash Wednesday are evidence that this can never be assured by any management authority.

In N.S.W. over the past five years additional legislation has been introduced which imposes further obligations on natural area managers particularly when planning a regime of prescribed burning. The Environmental Planning and Assessment Act now requires land management authorities to give detailed consideration to the environmental consequences of any management activity. The Act lists the factors to be taken into account when considering the likely impact of an activity. Those pertinent to prescribed burning or any planned strategy including the alternative to do nothing are:

* any environmental impact on a community
* any transformation of a locality
* any environmental impact on the ecosystem of a locality
* any diminuation of the aesthetic, recreational, scientific or other environmental quality or value
* any effect upon a locality having aesthetic, anthropological, archaeological, cultural, historical, scientific or social significance or special value for present or future generations
* any endangering of any species of flora and fauna
* any long term effects on the environment
* any degradation of the quality of the environment

* any risk to the safety of the environment

* any curtailing of the range of beneficial uses of the environment

* any pollution of the environment

* any cumulative environmental effects

It is obvious there are very few circumstances which from first principles it can be concluded that there is not likely to be any potential impact from any planned fire. The challenge then becomes one of assessing the significance of the impacts. The latter is a requirement of the Act, but this is not to say that an environmental impact statement will be necessary in all cases. What it does mean is that the significance of potential impacts is the minimum assessment. The range of potential impacts may be summarised as in Table 1 (Davey 1984). To be able to address these issues it is essential and necessary to have a detailed knowledge and appreciation of the basic natural resources; this knowledge not only being a fundamental requirement but now a legal requirement.

Summary

Sound and effective resource management including fire management cannot be based on limited data, biased information and planning. Managers must be self-critical and the only way to achieve this is through an understanding of the basic ecological principles that underlie effective resource management and planning.

Many lessons have been learnt in the past decade from attempts to implement fire management strategies based on the historic McArthur approach and little or no resource data. Changes in concepts and strategies are now taking place as detailed resource data surveys are carried out and as a response to a greater appreciation of environmental issues and demands expectations of resource management. New and dynamic resource and fire modelling techniques are also contributing to sound management decision making assisting in more accurate fire behaviour predictions and assessment of potential impacts.

Table 1. Potential impacts of fire.

POTENTIAL IMPACTS (Temporary, long-term or permanent)	AS A CONSEQUENCE OF			
	Wildfire	Fire Suppression Operations	Fire Protection	
			Fuel modification or reduction	Provision of permanent access and firebreaks
* exposure of people to fire: loss of life, physical injury, psychological disturbance	x	x		
* direct loss or damage by combustion during the fire of:	x			
. signs and park facilities				
. fences	x		x	
. dwellings and other buildings	x			
. vehicles	x			
. communications and utility services	x	x		
. community facilities	x			
. stock and crops	x	x		
. plan and equipment	x	x		
. shelter, shade, screen	x	x	x	
and amenity plantings	x			
. historic relics and structures	x		x	
. resident individuals of fauna species	x		x	
* temporary loss or reduction by combustion during the fire of:				
. plant cover	x		x	
. animal habitat	x		x	
. animal food resources	x		x	
. short-term grazing potential	x		x	
. weed infestations	x		x	

POTENTIAL IMPACTS (Temporary, long-term or permanent)	AS A CONSEQUENCE OF			
	Wildfire	Fire Suppression Operations	Fire Protection	
			Fuel modification or reduction	Provision of permanent access and firebreaks
* outright loss during and/or following the fire of:				
. rare and endangered species	x		x	
. soil	x		x	
* short and/or long-term change after fire in:				
. soil structure and chemistry	x			
. vegetation structure and floristics	x			
. primary production	x		x	
. habitat and animal communities	x	x	x	x
. discharge characteristics, water yield and chemistry of run-off	x		x	
. recreation settings	x	x	x	x
. landscape character	x	x	x	x
. weed infestations	x		x	
. grazing potential	x		x	
* heat damage to:				
. landforms	x		x	
. Aboriginal sites	x		x	
. historic sites	x		x	
* physical disturbance during construction of access, clearing and firebreaks, or cutting of helipads:		x		x
. loss of habitat continuity		x		x
. change in landscape character		x		x
. change in recreation settings		x		x
. disturbance or rare and endangered species		x		x
. mechanical damage to landforms		x		x
. mechanical damage to cultural sites		x		x
. erosion		x		x
* from introduction of fire retardant chemicals:				
. change in soil nutrients:		x		
distortion of vegetation				
. dynamics and possibly floristics		x		
. change in water chemistry of run-off		x		

(After Davey 1984)

It is to be hoped that the lessons from the past will continue to initiate changes in fire management before further 'catastrophic' events resulting from both planned and unplanned fires and legislation force change upon resource managers.

Richard Vogl (1977), a noted American ecologist, has recently echoed the same concern in the U.S.A.

"In spite of recent advances, aids and comprehensive plans, controlled burning programs will not be totally successful unless the manager is fully aware of the basic properties of the resources under consideration and the ways that these resources react with fire. These basic principles cannot be ignored, compromised or breached without serious ecological backlashes. They should be understood well enough to be included in all public relations and educational efforts. Part to the art of controlled burning is being able to extrapolate, synthesize and generalise in a holistic manner so that basic principles of the resources and the fire can be clearly indentified. Management guidelines are dictated by the inherent biological-environmental composition of the resources and not by any economic, sociological, technological or political expediencies".

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THE CONTRIBUTION OF PRESCRIBED BURNING TO FOREST FIRE CONTROL IN WESTERN AUSTRALIA: CASE STUDIES

R.J. Underwood, R.J. Sneeuwjagt and H.G. Styles

Introduction

The major eucalypt and pine forests of Western Australia occupy only two million hectares and are restricted to the southwest corner of the State. Two factors influence management in this area. Firstly, the forests are managed for a wide range of protective, productive, recreational and conservation values (Beggs 1982). Secondly, some 0.5 million people live near or within the forest region. Each year this region experiences a hot, dry summer, during which wildfires regularly start in the forest (Peet 1965; Luke & McArthur 1978).

For example, in the 30-year period 1954-1984, foresters dealt with 8533 fires burning in or threatening State forests (WAFD Annual Reports 1954-84). This represents an average of 284 fires each year.

Many of these fires occurred during severe or "blow-up" weather conditions (Burrows 1984). These conditions are characterised by high temperatures, dry fuels and hot, strong winds. Forest fires burning under such conditions can have catastrophic consequences: lives are lost and property is destroyed (Rodger 1961). They can also cause serious resource losses (Peet & Williamson 1968), erosion, siltation of streams, loss of wildlife and reduction of landscape values (Leitch et al. 1983) and disruption to forest based industry, including bee-keeping. Furthermore, the suppression of high intensity forest fire is highly dangerous and very costly. Nineteen firefighters lost their lives fighting forest fires in South Australia, and Victoria in 1983. The direct fire fighting costs of suppressing one fire in the Karri forest of W.A. in 1969 exceeded $100,000 (Peet 1969), equivalent to nearly half a million of today's dollars. This includes no allowance for loss and damage resulting from the fire, and for the value of volunteer fire fighters working on adjoining farmland.

Foresters in Western Australia have been concerned about the problem of wildfire since the beginnings of forest management in the 1920s (Kessell 1923). Since then there has been a steady evolution in fire policy as research and field experience led to improvements in technology and to a better understanding of fire behaviour and its role in forest ecosystems (Underwood & Christensen 1981).

The current approach is based on the premise that since fire occurrence is inevitable, the aim must be to minimise undesirable consequences. Stemming from this philosophy two complementary management systems have emerged.

The first involves maintenance of an efficient fire detection system, backed up by effective fire fighting forces stationed throughout the forest zone. This system has a proven capacity for rapid location and suppression of the fires which break out under mild to average summer weather conditions.

The second system involves the systematic reduction of inflammable fuel on the forest floor by a programme of rotational prescribed burning. The aim of this programme is to help fire fighters cope with fires starting under severe weather conditions or when many fires occur simultaneously. Under such circumstances the suppression task can rapidly exceed fire fighting resources, leading to large, intense forest fires, and consequent social and economic damage. Current estimates show that the organisation required to suppress a large forest fire burning under severe conditions can cost up to $40,000 per day. Such a fire may take 5 or more days to be fully contained.

Experience over a wide range of weather conditions has shown that direct attack on forest headfires is not likely to succeed when flame heights are more than three metres or where fires are moving faster than 100 metres per hour. Fire behaviour is directly affected by the amount of fuel, and so long as inflammable fuel weights are maintained at less than about 8 tonnes per ha in the Jarrah (**E. marginata**) forests or about 15 tonnes per ha in the Karri (E. **diversicolor**) forests, there is a good chance that direct attack on the flanks of a fire will succeed with eventual control of the headfire by pincer action from the flanks. This applies even under severe weather conditions. Furthermore, areas of light fuel throughout the forest provide anchor points for suppression lines, refuge areas for threatened fire crews or civilians, and improved access for men and equipment working on a fire edge or suppressing spot fires ahead of a main front.

There have been no major fires since 1961 in the Jarrah forest, where a prescribed burning programme commenced in 1954, or since 1969 in the Karri forest where the fuel reduction policy became effective in the late 1960s (Underwood & Christensen 1981). During this time no single firefighter has been burnt to death in a forest fire in W.A. - nor have there been any losses of life of civilians living in or near the forest zone. This contrasts with the "Ash Wednesday" fires in Victoria and South Australia in February 1983 which resulted in 70 deaths and hundreds of serious injuries.

Despite these results, both the effects and the effectiveness of prescribed burning are challenged. For example, Raison et al. (1983) suggest that a range of ecological problems may develop as a result of cyclic prescribed burning. They list alteration of ecosystem processes and components, accelerated soil erosion and depletion of nutrients. They also argue that since fuels re-accumulate after burning, the fire control advantages are shortlived and therefore dubious.

Though there is considerable literature on fire ecology, very little has been published on forest fire control in Australia on the contribution to control made by prescribed burning for fuel reduction, apart from Billings (1981) and Rawson (1983). However, there is a wealth of unpublished information and personal knowledge within the WAFD (W.A. Forest Dept).

Dating back over 50 years, records are available of nearly every fire which has occurred within State forests, together with detailed reports of investigations into serious and large fires. Departmental officers have also developed a reliable prediction system on forest fire behaviour and fuel accumulation for Jarrah, Karri and pine forests, (Sneeuwjagt & Peet 1979), which can be used to make projections on the behaviour of past fires.

In this paper we present a selection of case studies drawn from this information. We attempt to illustrate the contribution of prescribed burning to forest fire control in W.A., and discuss the advantages and disadvantages involved.

Method

Forests Department records of forest fires in W.A. over the period 1969-1984 were consulted. From the numerous fires in which the beneficial effects of fuel reduction burning was evident, 9 were selected for detailed analysis (Table 1). In making the selection we tried to ensure that a range of forest and fuel types were represented, and that examples of major fire runs as well as smaller fires with high damage potential were included. The study has concentrated on fires occurring over the past 15 years to ensure comparability with current suppression methods. The locations of the study sites are shown in Figure 1.

For each study fire we examined the fire report, and record of subsequent investigation; meteorological data from the nearest station; archive fuel type and fuel age maps; and topographic and tenure plans. Fire behaviour projections were calculated using the WAFD Forest Fire Behavior Tables (Sneeuwjagt & Peet 1979).

These studies provided data on:

* Date and time of fire start.
* Cause of fire.
* Meteorological conditions leading up to, during and after the fire.
* Fuel types and ages.
* Actual and projected fire behaviour.
* Actual and projected fire size.
* Suppression measures.
* Values threatened.

Results: The Case Studies

1. The Orchid Road Fire of December 1969

The fire commenced in a farm paddock adjoining State forest at approximately 0930 hrs on 31 December 1969. It originated from smouldering logs within dry grass, fanned by strong easterly winds.

Table 1. The Study Fires.

Case Study No.	Fire Name	Date of Fire	Major Fuel Type	Eventual Size
1.	Orchid Road Fire	31.12.69	Jarrah/ti-tree/ pasture	40 ha
2.	Rocky Gully Fire	20.12.74	Jarrah/pasture	8000 ha
3.	Lake Muir Fire	28.02.77	Jarrah/swamp	7100 ha
4.	Brunswich Fire	04.04.78	Jarrah/pine/ pasture	3760 ha
5.	Gervasse Fire	04.04.78	Jarrah/pine/ pasture	2730 ha
6.	Maranup Ford Fire	04.04.78	Jarrah/pasture/ pines	5280 ha
7.	Colonel's Fire	31.01.84	Jarrah/marri	60 ha
8.	Nornalup Fire	24.02.84	Swamps/karri/ tingle	170 ha
9.	Grimwade Fire	02.03.84	Pine Plantation/ Jarrah	171 ha

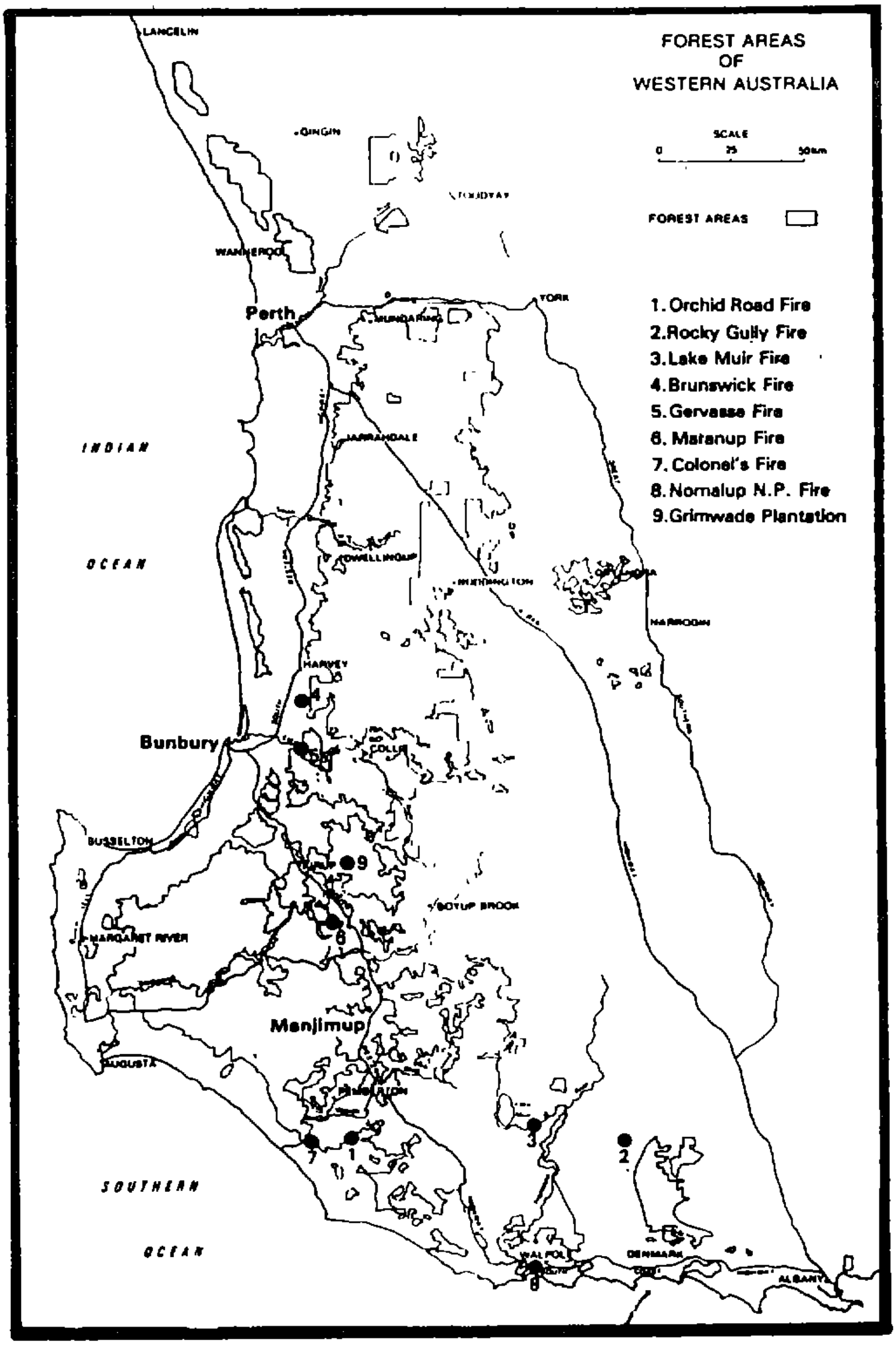

Figure 1. Locations of study fires.

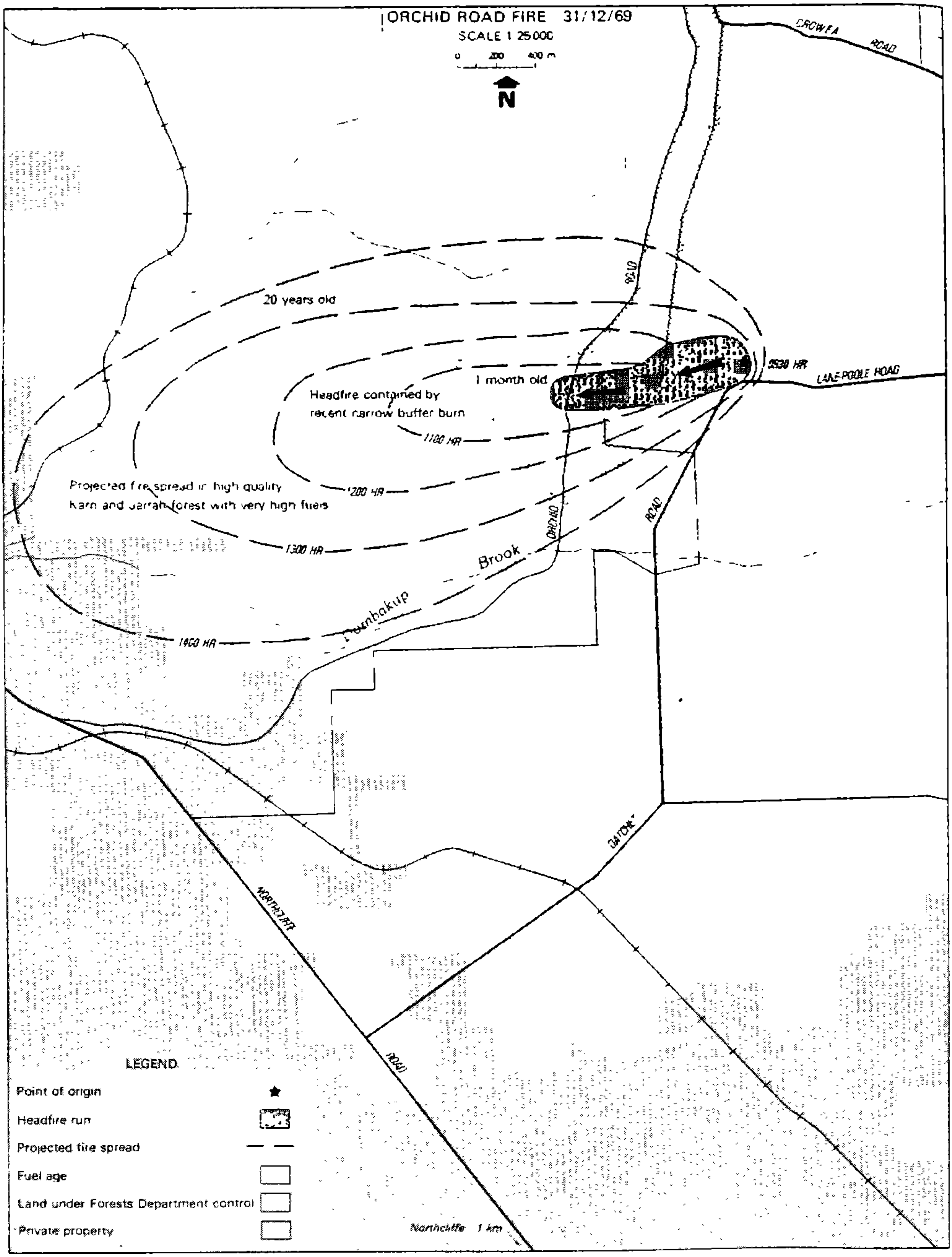

Figure 2. Orchid Road Fire.

Weather conditions in the southwest had been severe for the three previous days, and a number of fires were already running in the region. The conditions at Pemberton Headquarters (15 km from the fire) were 31°C temperature, 25% relative humidity and 45 km/hr winds with gusts to 60 km/hr. Under these conditions predicted rate of spread in heavy karri fuels ahead of the fire was approximately 600 m/hr. In this situation, flame heights would have exceeded 20 m, and direct attack would not have been possible.

The fire expanded rapidly in the pasture and quickly entered State forest. It ran immediately into a narrow strip of forest which had been prescribed burnt in the previous month. Fire behaviour was mild and the edges were attacked directly by forestry crews when they arrived at about 1000 hrs. Including the area of pasture burnt in the farmer's paddock, final fire size was 40 ha.

Suppression and mop-up was completed by 1430 hrs. The crews and machines then transferred to another fire elsewhere in the region.

The Projection: Beyond the narrow buffer within which the fire was contained, the forest carried 20 year old fuel loads. This area had been previously burnt by wildfire in 1950. The three major forest blocks in the path of the fire (Crowea, Dombakup and Warren) all comprised virgin Karri, Marri and Jarrah forest. These blocks are surrounded by private property and National Park.

Easterly winds and high temperatures persisted for approximately 24 hours following suppression of the fire. This was followed by a southwesterly change. (Headfire rates of spread of up to 1000 m/hr were measured on another fire in similar fuels on the same day.)

A projection of likely fire development over the first 5 hrs of 31 December 1969 is shown in Figure 2. This projection assumes success in controlling the tail of the fire in private property, and that no long distance spotting occurred. It was estimated that the fire would have attained a size of 12000 ha by mid-day of the following day (1 January 1970) and caused severe damage to forest and community values.

2. The Rocky Gully Fire of December 1974

The fire commenced from burning waste at a sawmill located 7 km southeast of Rocky Gully. The time was 1230 hrs on 20 December 1974. On this day, temperatures throughout the southwest exceeded 40°C and relative humidities were below 10%. Gale force northwesterly winds (60-70 km/hr, gusting to 90 km/hr) blew for most of the day until a southwesterly change came through in the evening. Departmental fire fighters were simultaneously dealing with 44 separate wildfires in State forest that day.

The fire escaped into Vacant Crown Lands and was attacked immediately by sawmill workers, but they could not contain it. The fuels were Jarrah forest and open ti-tree flats, unburnt for at least 10 years (actual fuel age not known).

Fire behaviour was intense. At a rate of spread of approximately 6400 m/hr, the fire ran 15 km in 2.5 hrs. Spotfires were numerous and developed up to 2000m ahead of the front.

No departmental firefighters forces were available to move to this fire due to commitments on other fires. In any case, fire intensity greatly exceeded that at which suppression could be attempted.

At 1500 hrs, the headfire and northeastern flank ran into forest prescribed burnt two and three years previously. The head fire stopped at this point. Control and mop-up was completed by a small team of volunteer bushfire brigade forces the following days. The actual fire size was 8000 ha. See Figure 3.

The Projection: Assuming the headfire continued to spread at 6400 m/hr in the forest it is calculated that the fire would have run for a further 26 km and reached a size of approximately 30,000 ha over the period 1500 hrs to 1900 hrs on 20 December. See Figure 3. Such a fire would have posed a direct threat to the town of Denmark (population 1000) and surrounding farming communities.

3. The Lake Muir Fire of January 1977

Two fires were lit by an arsonist, in a Flora and Fauna Reserve adjoining State forest, at 1710 hrs on 16 January 1977. Although fuels were estimated to be over 15 years old, conditions were cool and mild and fire fighters successfully extinguished both fires the same evening.

Eight days later at 1315 hrs on 24 January 1977, a new fire commenced in the same area, either an escape from one of the original fires or a third attempt by the incendiarist.

Conditions at the time were hot and dry (weather at Manjimup, 60 km from the fire, was 34°C, RH 24%) with northeast winds (20 km/hr) followed by northwesterlies in the afternoon. The fuels in the area were Jarrah, paperbark and swamp, unburnt for at least 15 years.

Under these conditions, suppression attempts failed. Flame heights were recorded up to 8m and the average head fire rate of spread was 1000 m/hr. Spotting was estimated at 200m. Suppression efforts were deferred until evening under cooler conditions. Early the following morning, bulldozers succeeded in surrounding the fire with earth breaks.

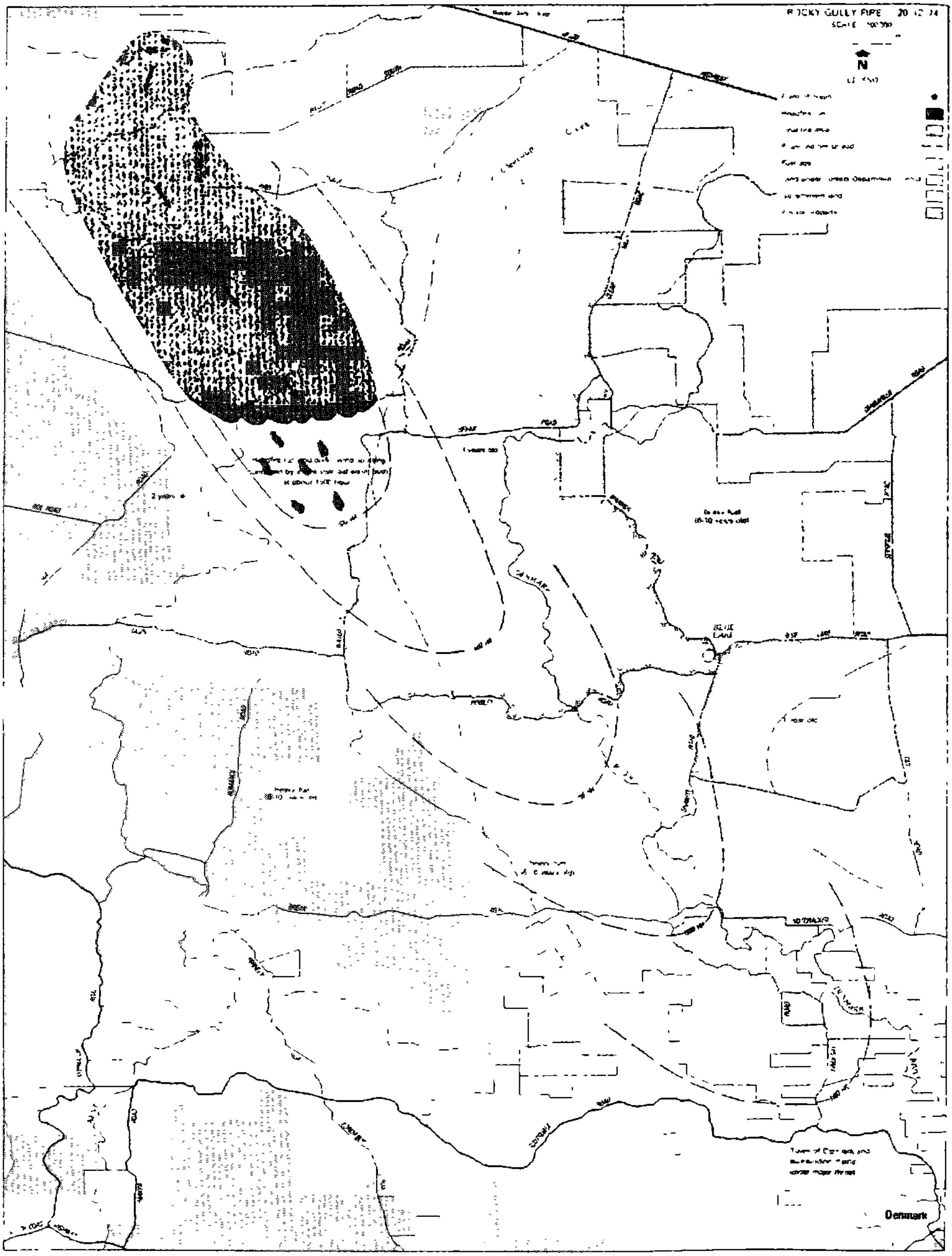

Figure 3. Rocky Gully Fire.

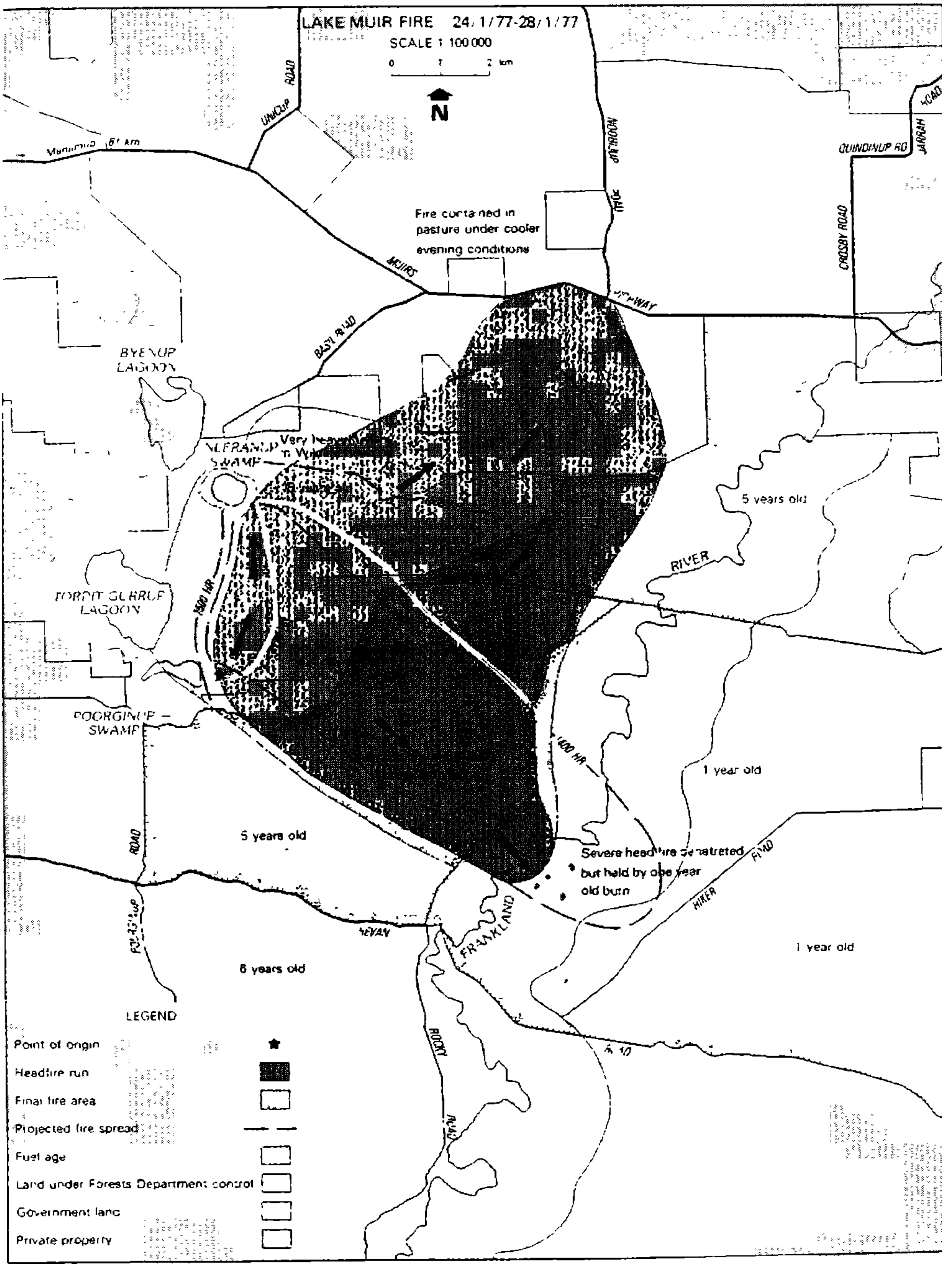

Figure 4. Lake Muir Fire.

The following day (25.1.79) was also hot and dry (temperature 37°C and RH 29%). Strong northwesterly winds up to 30 km/hr blew all morning, followed by a southwesterly change in the early afternoon. Numerous spot fires occurred across the eastern edge of the fire; these eventually overcame the efforts of suppression crews. A major fire developed driven by the northwesterly wind. Head-fire rate of spread reached 3000 m/hr. At 1400 hours the fire front ran into a one year old prescribed burn area. The head fire stopped at this point. However, before this situation could be capitalised, the wind swung from northwest to southwest and the whole northern flank of the fire broke away. A new fire developed with a 7 km front. Flame heights reached 35 m and the head fire rate of spread exceeded 6000 m/hr.

Late on the afternoon of 25 January the fire reached private property, comprising paddocks eaten bare by stock over previous months and a network of firelines prepared that day. A heavy concentration of Departmental and volunteer forces was able to contain the fire at this point. All edges were contained on the following day. Final fire size was 7100 ha. (See Fig. 5).

The Projection: Had not the head-fire driven by the northwesterly wind run into a one year old burn it is calculated that the southeasterly head-fire run up to 1400 hr on the 25th would have proceeded for a further 3.5 km before the southwesterly change came through. The subsequent breakout of the northern edge would have generated a fire size of approximately 10,000 ha, and caused a more difficult suppression problem on private property and on State forest and Wildlife Reserves.

Cyclone Alby Fires of April 1978

On 4 April 1978, Cyclone Alby passed through the southwest corner of Western Australia. High temperatures, dry north-west winds of up to 140 km/hr, and a prolonged period of drought, combined to produce one of the most serious fire emergencies in the south-west forest zone since records have been kept.

Ninety two separate wildfires developed within the region. These burnt out 54,000 ha of private forest, State forest and Crown lands, but the area of State forest burnt was confined to less than 7000 ha. In all cases where fires entered State forest from neighbouring properties, they were contained or retarded by light fuels. The following three wildfire case studies provide examples of this.

4. The Brunswick Fire

This fire occurred during the passage of Cyclone Alby on 4 April 1978. It started at 1440 hrs in pasture on private property as a spark from a rotary slasher.

The fire ran 12 km in 1.5 hr indicating a headfire rate of spread of 8000 m/hr. Fuels were mainly flats, Jarrah forest and privately owned pine plantations. No suppression could be attempted on head or flank fires at any stage of the main fire run.

The fire burned through private property and skirted along light (4 month-old) fuels in the adjoining State forest on the eastern flank before burning through some 50 ha of the Forests Department Brunswick pine plantation. The head fire was then halted by light fuels within a large private forest block that had been burnt 5 months and one year earlier by the Forest Department in a mutual aid agreement with the owner.

The fire was fully under control by evening and mopped-up on the following day. Total fire area was 3700 ha, of which only 320 ha was within State forest.

5. The Gervasse Fire

The fire commenced at about 1600 hrs on 4 April 1978. The cause is not known. Smoke and dust throughout the south-west obscured the fire detection system. It is probable that the fire commenced in grassland on private property as a spot fire thrown from the Brunswick fire burning directly to the north at that time.

No suppression activity could be attempted. Fire behaviour was not closely observed, but it appears that head fire rates of spread varied between 5000 and 10,000 m/hr through privately owned bush and pine plantation. The fire entered State forest at approximately 1700 hrs driven before winds of over 100 km/hr. Fuels in the forest were only 1, 2 and 3 years old as a result of prescribed burning operations. The fire front was halted and contained in these areas. Numerous small spot fires occurred up to 3 km ahead into these low fuel zones but failed to develop.

The tail of the fire was suppressed by farmers on the night of the 4th. No action was taken on the fire in State forest for another three days until fire fighters could be freed from more pressing tasks elsewhere. During those days the fire trickled about in the light fuels, and burnt only 500 ha of State forest. It was eventually made safe by burning out to existing roads and fire breaks on 7 April (see Fig. 6).

The Projection of both the Brunswick and Gervasse Fires: Northwesterly cyclonic winds continued unabated in the area until 2300 hrs. At this time, a southwesterly change came through. The projection of these fires up to 2300 hrs if forest fuels in the area had been 10 years old, would show that both fires would have joined up and burnt out a total of 33,000 ha. This would have involved total destruction of the Brunswick pine plantation, worth over a million dollars. More seriously, the spotting from a high intensity forest fire burning under cyclonic winds, would have generated impossible conditions for fire fighters and occupants on farms and townships downwind of the fire.

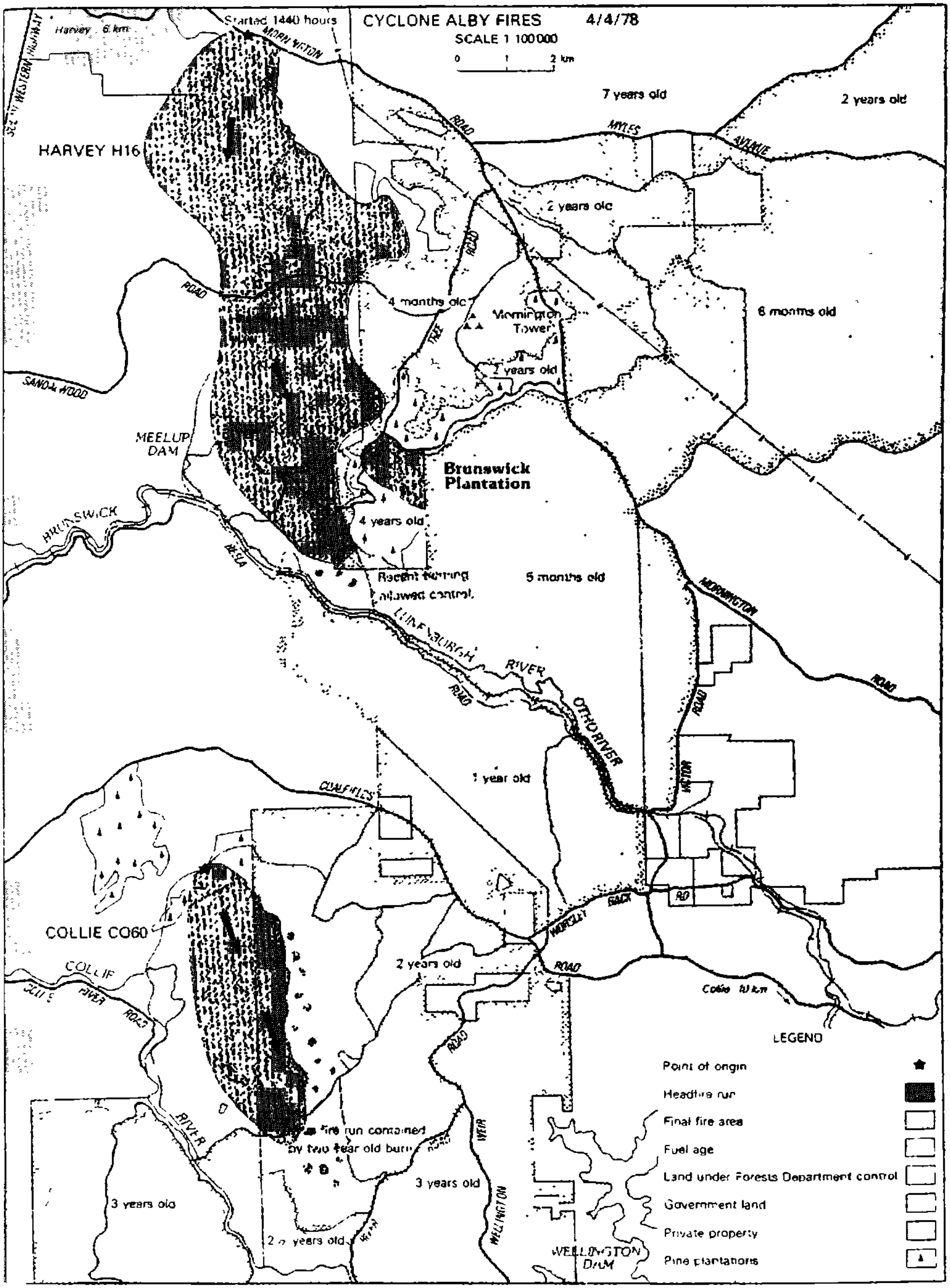

Figure 5. Cyclone Alby Fires

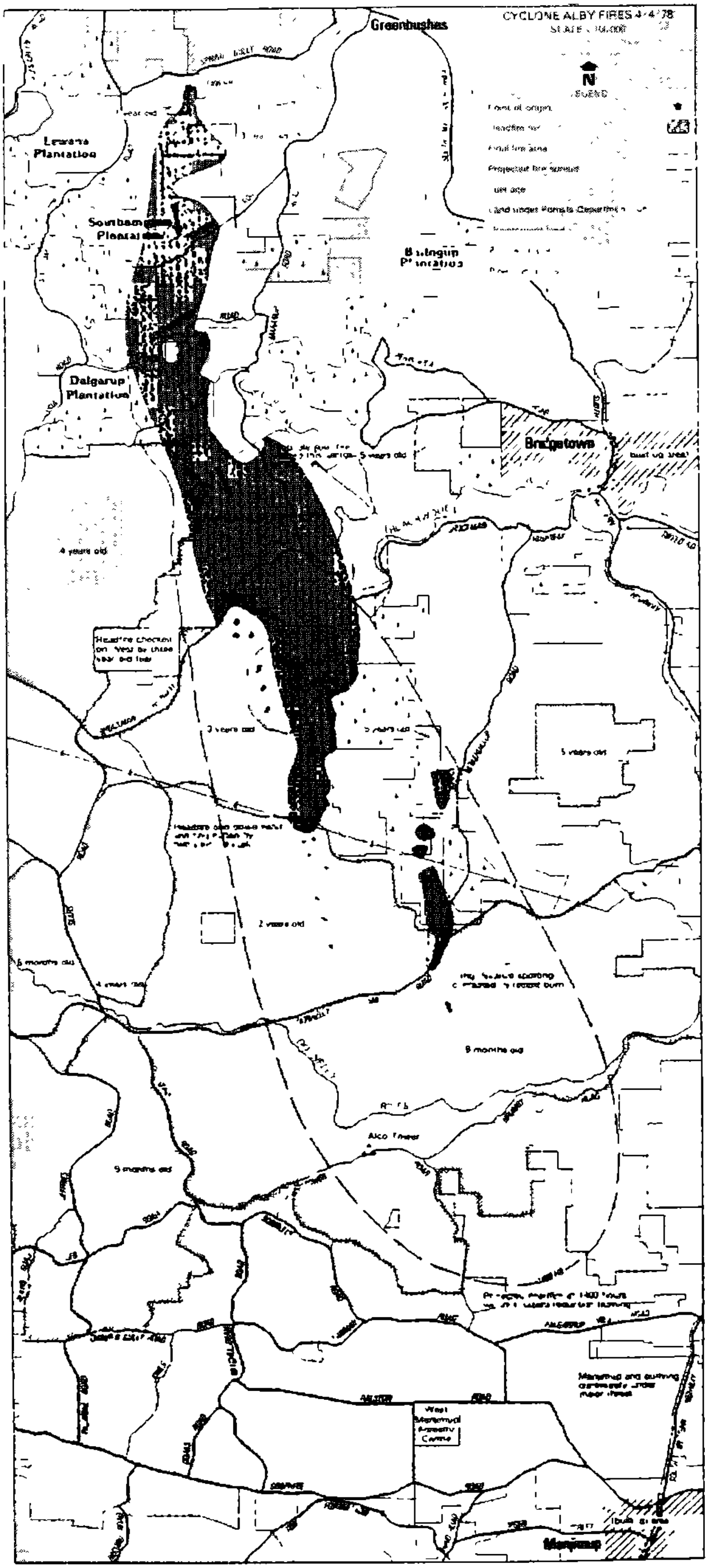

Figure 6 Cyclone Alby Fires

6. The Maranup Ford Fire

The Maranup Ford fire escaped from a clearing burn on private property 16 km northeast of Bridgetown. The fire started at 1100 hrs and rapidly burnt through pasture and bracken fuels on steep slopes. The wind was Northeast to North up to 40 km/hr. At about mid-day the fire was contained by bushfire brigade units at Huitson Road, within private property. However, at about 1500 hours the arrival of Cyclone Alby winds of 80 to 120 km/hr caused the fire to break away to the south. The head-fire reached rates of 5000 to 10,000 m/km. Spotting up to 10 km in front of the head-fire occurred when the fire crossed the Blackwood River and accelerated up the southern slopes of the valley. Many of these spots eventually became part of the main head fire, whilst others showed up as individual fires in State forest north of Manjimup townsite. The main fire eventually stretched 21 km, although 4 spotfires developed 3-6 km further downwind. During its run, the shape of the main fire was narrowed by the presence of 3 and 4 year old burns on the western flank. The head fire was effectively stopped on State forest when it reached a 2-year-old burn. The spotfires which would have threatened the Manjimup community also failed to develop because of light fuels within a 5-month-old burn located 15 km north of Manjimup.

No suppression was possible during the main run of the fire because of the intense fire behaviour, falling trees and flying debris.

Because of community problems elsewhere in the wake of the cyclone, suppression of the fire within State forest was given a low priority, and delayed for 2 days. During these days, the fire trickled about harmlessly in light fuels. Final containment of the fire on State forest was not completed until 4 days later and involved the locating and mopping-up of many spotfires that had not developed in the light fuel areas.

The total fire area was 5280 ha. This included 270 ha of Forest Department pine plantation and 1000 ha of native forest (see Fig. 7).

The Projection: If the forest fuels ahead of the fire had been 10 years old, it is predicted that the fire would have reached the outskirts of Manjimup town by 1930 hrs. The cyclonic winds continued at Manjimup until midnight. In the absence of prescribed burnt fuel reduced zones in State forest, this fire could well have spread for another 30 km by 2400 hrs on 4 April covering an area of 40,000 ha of farmland and State forest. The town of Manjimup (population 3500) and settlements of Palgarup (130), Deanmill (200) and Jardee (100) may have been engulfed by this fire (see Fig. 7).

7. The Colonel's Fire of January 1984

The fire commenced at 1330 hrs on 31 January 1984 when a smouldering log from a clearing burn on private property flared up and ignited dry pasture.

The conditions at the time were severe, with a temperature of 40°C and relative humidity of 16% recorded at Pemberton (20 km away). At the time of the escape winds were northwest at 25 km/hr. A strong (35 km/hr) southwesterly wind followed at about 1400 hrs.

There was no one on the farm on the day, and the fire was not immediately attacked. It entered thick scrub and burnt out into the neighbouring D'Entrecasteaux National Park. The forest type was mixed Jarrah and Marri and fuels were 10-year-old (i.e. approximately 18 tonnes per hectare). Two Departmental fire-fighting crews were unsuccessful in attempts to control the head-fire at this stage, and were withdrawn to work on the south eastern flank where fire intensity was less intense.

At approximately 1700 hrs the head-fire ran into a one-month-old burn on State forest. The burn protected an extensive area of young Karri regrowth, pine plantation, State forest and National Park. The head fire was halted in the burn and suppression crews were able to contain the flanks by direct attack. Fire area was 60 ha (see Fig. 8).

The Projection: Southwesterly winds, high temperatures and low humidity persisted for approximately 7 hours after the start of this fire. Given no protective fuel reduction burning in the area this fire would therefore have continued to spread at 400 m/hr fanned by the strong southwesterly wind. It is estimated that by midnight the fire area would have been about 500 ha. Such a fire had the potential to destroy large areas of highly valuable and fire sensitive Karri regrowth forest, pine plantation, National Park and private property.

8. The Nornalup National Park Fire of January 1984

This fire commenced in National Park, presumably from a fisherman's campfire at 0800 hrs on 24 February 1984. It immediately burned into an area of dense, impenetrable swamp where direct fire attack could not be mounted.

Conditions were mild, with the weather readings at Walpole (4 km away) at the time being temperature 24°C, relative humidity 54% and winds northeast at 5-10 km/hr.

The fire was attended by a small fire fighting force, who allowed it to burn slowly through the swampy country with the aim of tying it in later when it backburned out to access tracks.

At mid-day the wind veered to southeast and freshened to 25-30 km/hr. The flank fire became a head-fire, reaching a rate of spread of 500 m/hr within the dense ti-tree flats. At 1230 hrs the fire crossed the Southwest Highway and entered the dense mixed Karri and Red Tingle (*E. jacksonii*) forest in this area of the National Park. These stands had not been burnt for 25 years.

At this stage the head fire rate of spread exceeded 300 m/hr and direct attack failed.

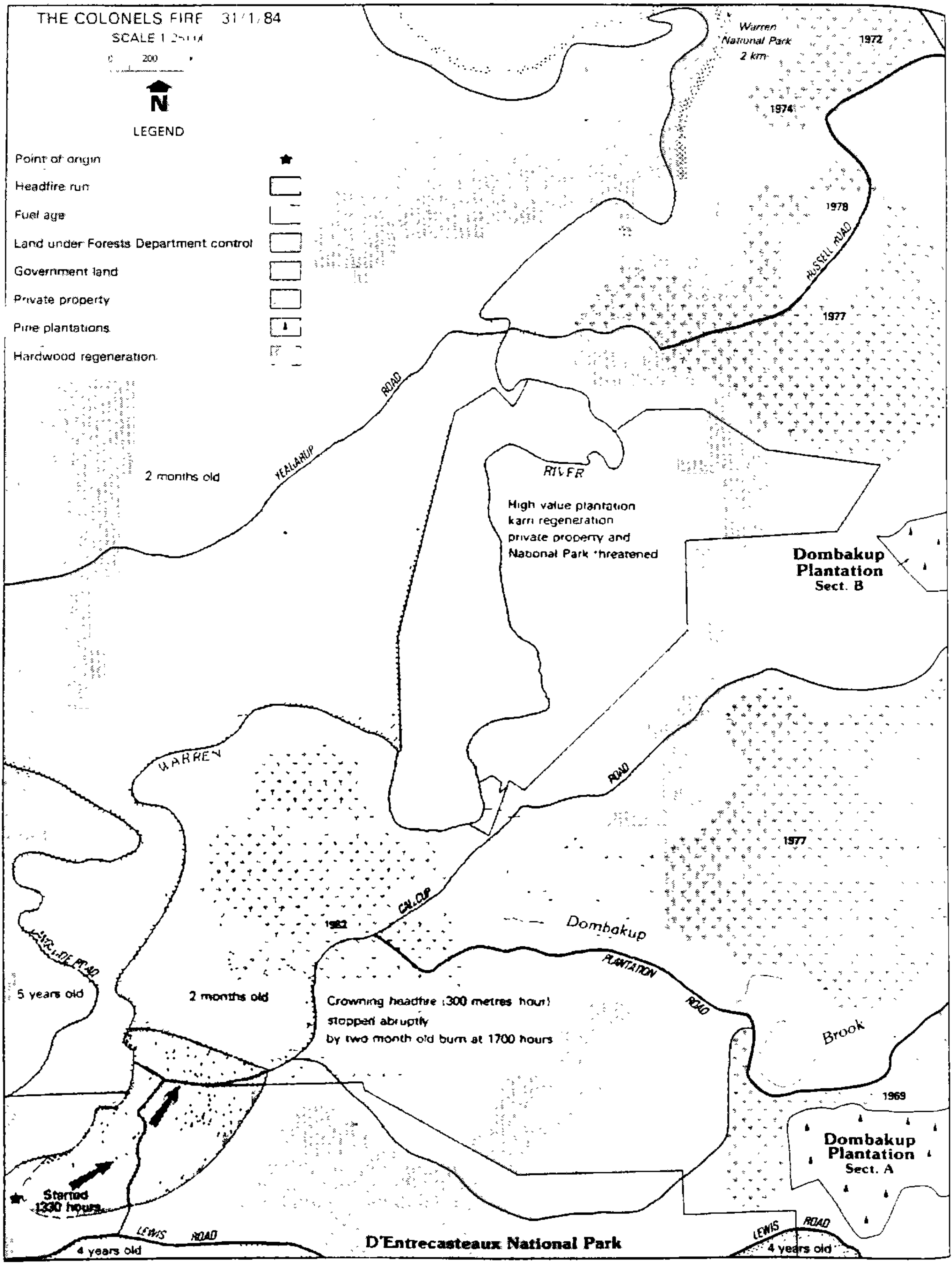

Figure 7. The Colonels' F

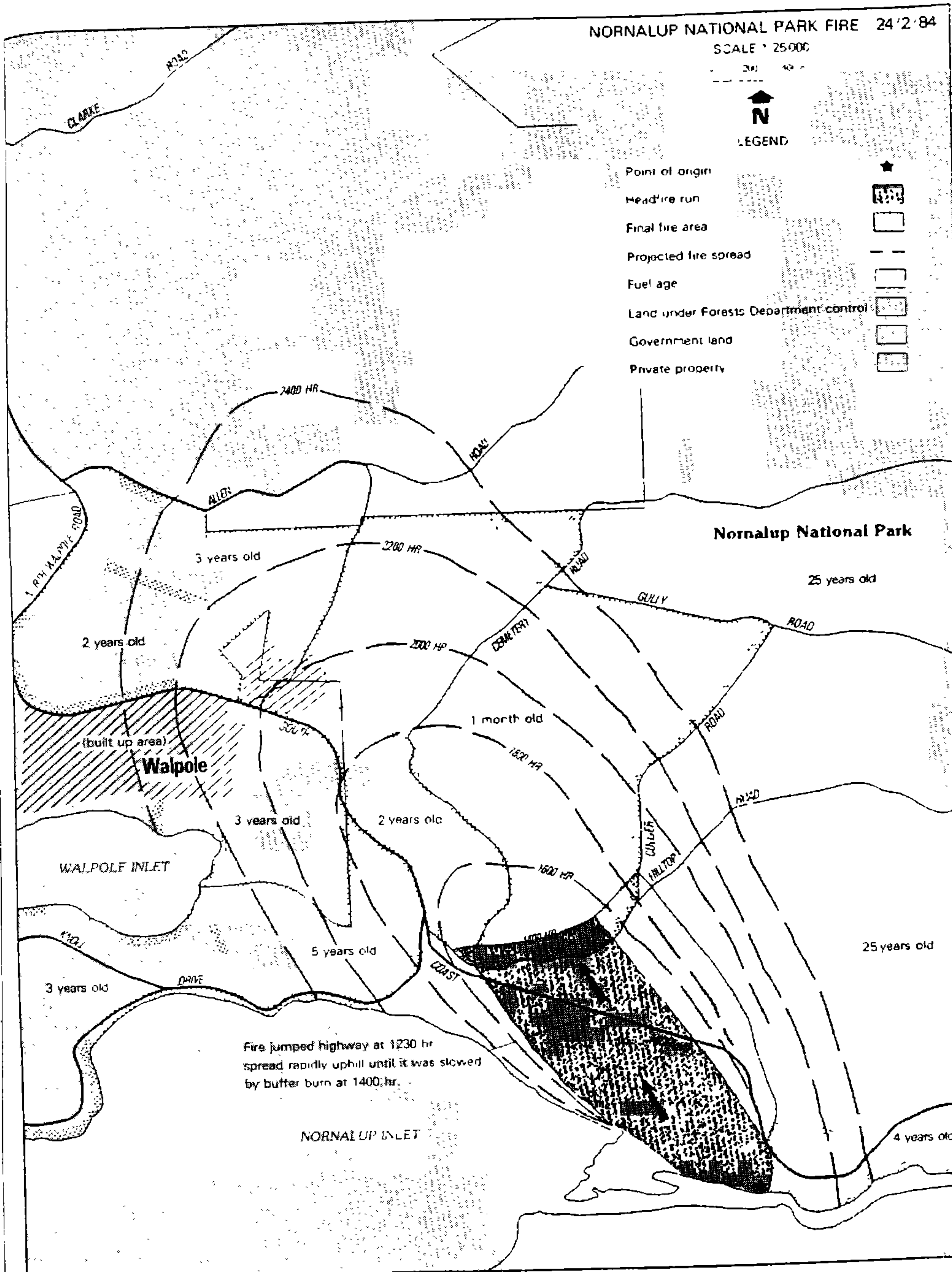

Figure 8. Nornalup National Park Fire.

The head-fire was abruptly halted when it reached a one-month-old prescribed burn at 1400 hrs. This burn had been carried out to protect the Walpole townsite and adjoining farms. The flanks of the fire were contained by direct attack leaving a final fire size of 170 ha.

The Projection: Assuming a head fire rate of spread of 300 m/hr in the forest over a ten hour period from 1400 to 2400 hrs, eventual fire size could have amounted to 900 ha from this fire. Apart from National Park, this area is likely to have included the eastern part of the Walpole township (population 800) and the surrounding farming community. Strong northeasterly winds occurred on the following day which would have driven any running fire into Walpole township, emphasising the value of containing this fire to a small size (see Fig. 9).

9. The Grimwade Plantation Fire of March 1984

The fire commenced at 1420 hrs on 2 March 1984 in 50-year-old Pinus radiata plantation at Grimwade. The cause of the fire was not established.

Conditions were hot (35°C) and dry (relative humidity 20%). When the first forces arrived, the fire was influenced by light northeasterly winds. Suppression was difficult due to the intensity of the fire and difficulties of access caused by logging debris. Before the fire could be contained a strong (35 km/hr) southwest wind change at 1730 hrs caused the fire to break away and expand rapidly. The rate of spread of the fire varied from 700 to 1000 m/hr, augmented by continuous spot fire development 200-500 m in advance of the head fire. Flame heights exceeded 30 m, and a crown fire developed.

At 1930 hrs the head-fire burnt out of the pine plantation and entered a strip of Jarrah forest separating the burning pine from another pine plantation 1.5 km away.

The Jarrah stand had been prescribed burnt 5 months previously. This burnt area was part of a system of buffers around the Grimwade pine plantation which have been systematically burnt every 4-5 years as protection against wildfires. Once it entered this buffer the head fire decreased in intensity and was successfully suppressed. This was followed by direct and successional attack on the flank fires still burning within the plantation.

The final fire size was 171 ha, including 18 ha of Jarrah forest. Approximately $400,000 worth of pine trees were killed in the fire.

The Projection: High temperatures and strong southwesterly winds persisted up to 2100 hrs. Allowing for a head fire rate of spread of 700 m/hr in the pine forest, and of 400 m/hr in the adjoining jarrah forest (assuming 10-year-old fuel), a fire of 500 ha was estimated for the period up to 2100 hr. By this time, the fire would have burnt an additional 80 ha of mature pine plantation and about 250 ha of high quality Jarrah pole forest. As strong northwesterly winds were experienced on the following day, the rest of the Grimwade plantation (2300 ha) and the Grimwade settlement (population 100) and sawmill could also have been under major threat as indicated in Figure 10.

Discussion

The presence of zones in the forest where fuels had been reduced by prescribed burning was an important factor in reducing fire size and improving the ease of control in the cases studied. The projections indicate that in every case a larger fire would have led to serious social and economic costs to the community.

Any theoretical projection of a fire can be debated. This is because the development of a forest fire is influenced by two sets of factors. The first are physical and environmental, i.e. weather, fuel and topography. These factors can be measured and their effects on fire rate of spread calculated with reasonable accuracy. The second set of factors are the suppression forces brought to bear on the fire perimeter by the firefighting agency. Firefighter effectiveness is highly variable: it is influenced by fire size and intensity, access, terrain and forest type, the equipment used and numbers of men and machines available. All of these factors can be roughly predicted, but not so the intangibles such as leadership, morale, fitness and organisation.

In the fires studied in this exercise, we tried to project a "most likely" result, based on known physical factors, knowledge of events prevailing at the time and our own firefighting experience. (The combined fire fighting experience of the authors in the Jarrah and Karri forest exceeds 70 years.)

The small sample of case studies does not, of course, represent a statistical or scientific support "for" the contribution of prescribed burning, in the sense that plot or laboratory studies on soil nutrients before and after fire are sometimes cited as proofs "against" (Raison et al. 1984).

Nevertheless, in the context of a record of no serious forest fires over more than two decades and the accumulated summer experiences of hundreds of Western Australian forest fire fighters, it is difficult not to acknowledge the positive contribution to forest fire control which the prescribed burning policy has made.

This view is further supported by comparative data on fire size between the south-west and other areas with similar climate, terrain and forest type but where no prescribed burning programme is in place. For example, Mount (1984) has presented data which indicate that the average fire size in comparable forests in Tasmania is 18 times larger than in W.A. The figure for Victoria is approximately 12 times and N.S.W. 13 times (W.A.F.D. 1980).

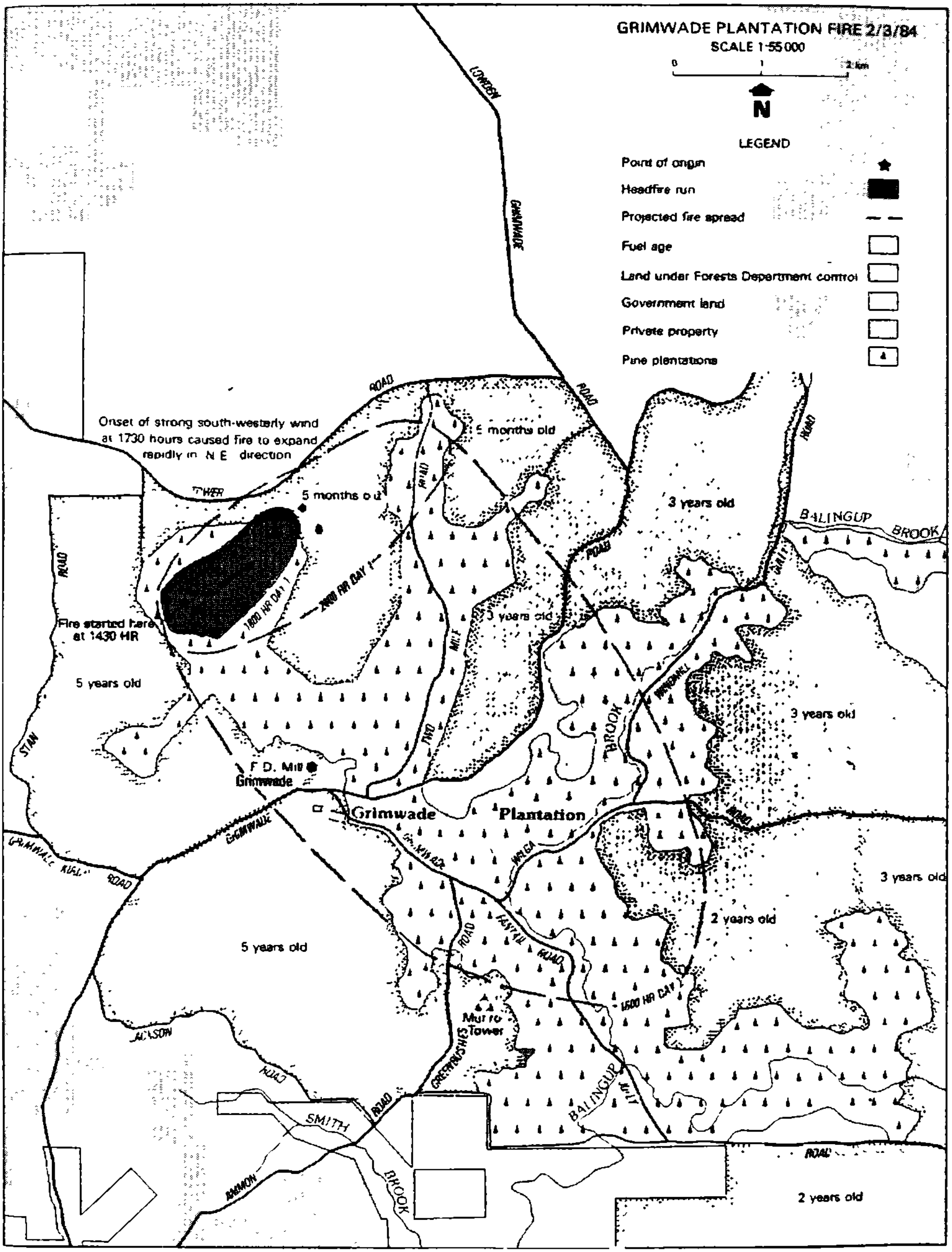

Figure 9. Grimwade Plantation Fire.

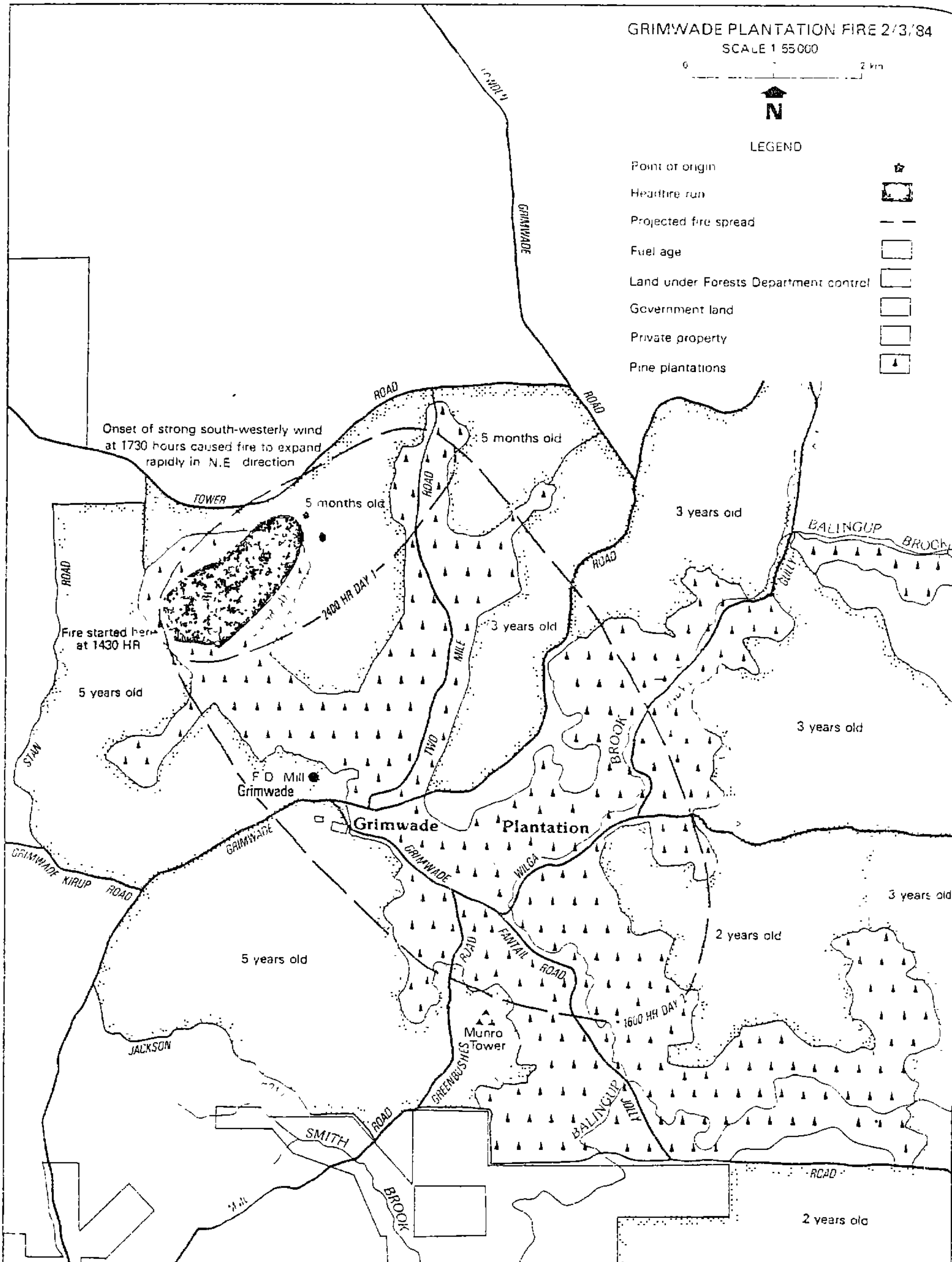

Figure 10. Grimwade Plantation Fire.

The case against prescribed burning is usually based on two factors: ecological damage and dubious fire control benefit (Considine 1984). The first question is contentious (Attiwill 1985); certainly not enough research has been done yet to fully elucidate the effects of the range of possible regimes (including fire exclusion) on the range of forest ecosystems in South-western Australia.

In our opinion, the question of fire control value is not contentious. Light fuels resulting from prescribed burning do reduce fire intensities and improve the ease of wildfire control. Of course fuels do re-accumulate. Therefore, there is a need for a cyclic programme of fuel reduction, where burns are repeated once a critical level of re-accumulation has been reached. In the south-west forests this critical level takes about 5-8 years in the jarrah and karri forests and 8-10 years in forests further east adjoining the main agricultural zone. In an 8-year rotational programme, approximately 50% of the forest fuels will be 4 years "old" or younger, providing excellent opportunities for wildfire control under difficult conditions.

Finally, five important points must be made.

1. A prescribed burning programme should not be embarked upon without solid data on fuel accumulation rates and fire behaviour. This is needed to allow rotation lengths to be tailored to site characteristics and vegetation factors, and to enable prediction of fire intensity on the day. Without these data, fires may be lit too frequently or too rarely, or may be difficult to control and lead to the sort of suppression costs and damages the burning programme is designed to minimise.

   Research into fuel accumulation and fire behaviour in W.A. forests is probably further advanced than for any other W.A. vegetation type, but is still incomplete and continuing.

2. A prescribed burning programme is not a fire control system by itself. It must be welded to an effective fire detection and suppression organisation.

   Fuel reduction does not prevent forest fires. In fact, numerically most forest fires start under relatively mild conditions and are easily suppressed by a quick moving and well trained firefighting force.

3. Managers asked to implement a prescribed burning programme must be thoroughly trained, possess a high level of technical expertise in fire behaviour and control and be provided with men, equipment and finance to implement the policy. The more complicated and diverse the prescriptions, the more costly they will be. This demands a high level of agency commitment, and Treasury support.

4. To be successful and effective, a prescribed burning programme must be thoroughly planned at three separate levels of implementation. First, there needs to be a regional burning plan which indicates the most suitable burn boundary location, burn frequency (rotation), season of burning for each forest area and highlights areas which are not to be burnt, both regionally and within daily "jobs". Such a plan should be reviewed and updated each year for the following 5 year period.

   Secondly, burning prescriptions must be prepared months in advance. These involve detailed inspection and fuel sampling, and indicate the most suitable weather conditions and ignition procedures required to meet burn objectives. In preparation for the burn such tasks as perimeter track maintenance and notifications to neighbours and forest users must be planned.

   Finally, on the day of the burn, the wide range of tasks involved with the ignition and containment of the fire within the burning block must be planned in detail and be well co-ordinated. To be effective, burns should cover at least 60% of the area; patchy, light burns will not provide useful fuel reduction. All burns must be thoroughly mopped up and subsequently patrolled to ensure the edges are safe.

   These three levels of planning and control are crucial to the success of a prescribed burning policy.

5. A prescribed burning policy, like any system of forest ecosystem management, must be accompanied by an active research programme. This should be focused on fire regime effects (including the study of unburnt controls) and on the development of improved fire detection and suppression systems, so that any change in one part of the fire management approach can allow a calculated adjustment to be made somewhere else. Research into social factors and community attitudes is also needed (Underwood 1985).

The current fire management policy in W.A. forests is not regarded as an end-point. Adjustments are continually being made in the light of changing community attitudes and improved science and technology stemming from research and management experience. In the meantime, the current policy, which includes the regular, cyclic prescribed burning of about 70% of the southwestern forests (excluding areas set aside for scientific study or specific species conservation programmes), provides a high level of community security from the ravages of intense fire, improved safety for firefighters and an opportunity to develop and test a range of alternative fire management systems.

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WATER CATCHMENTS AND FIRE MANAGEMENT IN THE NORTHERN JARRAH FOREST

B.J. Fleay

Introduction

A unique combination of topography, upland lateritic gravels, deep soil profiles and of vegetation types give Northern Jarrah Forest Catchments their distinctive hydrology - a near absence of overland flow even in heavy rain. Streamflow is generated almost entirely from near surface groundwater discharges. This is in contrast with other parts of Australia and the World with similar rainfall, for example mountain ash forested catchments in Victoria.

In the absence of overland flow, fire in Northern Jarrah Forest water catchments has at the most marginal direct impact on both the quantity and quality of water resources.

Longer term indirect impacts can occur as a consequence of different fire management regimes that, together with other forest management practices, affect the density and structure of vegetation on catchments. Generally a reduction in forest evapotranspiration will increase streamflow volume. In this context, however, other forest management practices may be more important than fire management.

Catchments of the Northern Jarrah Forest

Figure 1 shows the location of water catchments in the Northern Jarrah Forest.

The jarrah forest has frequently been described as unique and fragile. Botanically the region is quite unusual. In comparison to other areas of Mediterranean climate, the overstorey (mainly jarrah) is of exceptional height. This enhanced tree growth appears to arise from greater water availability due to an unusual combination of favourable attributes of its environment, i.e. high rainfall, flat topography and a deep water retaining soil profile. No other Mediterranean area combines all these favourable attributes (Di Castri & Mooney 1973).

These Jarrah Forest catchments occupy the western region of the Darling Range. The Darling Range is a consequence of marginal upwarping of the Yilgarn Block, a part of the stable shield area that constitutes a major part of the Great Plateau of Western Australia.

Short westward flowing rivers have dissected the western edge of the Plateau which is more elevated than the region to the east. These rivers occupy valleys that are generally sharply incised, progressing from V-shaped to flat floored from west to east. They are the major source of surface water for public supply and irrigation in the South West of WA.

The bedrock is principally granite with some minor belts of metamorphosed sedimentary and volcanic rocks.

The soils of the jarrah forest are dominated by upland laterites which typically consist of ironstone gravels in a sandy matrix overlying concreted or unconsolidated laterite of 2-10 metres thickness. This in turn is underlain by a deep pallid clay horizon which is succeeded by weathered parent material above the bedrock. In general, the gravels tend to become finer and less permeable downslope, sometimes grading into sandy yellow earths in the lowest positions. In the more incised valleys, erosion has led to the exposure of various weathered and unweathered materials, movement and sorting of detritus, and cementation. As a result, the ridges and remnant plateau elements are extensively occupied by the laterite mantle and the valleys show morphology and soils dependent on the amount of local relief, the colluvium on slopes, the degree of stripping of the weathered mantle and the geological nature of the substrate. The range of soils occurring here include red and yellow podsolics and red and yellow earths.

The soil profiles are generally shallower in the west than in the east where there can be areas of strongly leached sands. Likewise the depth to the permanent water table is generally shallower in the west than in the east.

The soils and the lateritic profile in particular are extremely deficient in plant nutrients. Dr Frank Hingston's paper (Fire in Northern Jarrah Forest) outlined some aspects of nutrient cycling.

The climate is typically Mediterranean with mild, wet winters and hot, dry summers. Figure 2 shows rainfall isohyets. About 80% of rainfall occurs in the period May to October while 80% of pan evaporation occurs from November to April. Average monthly rainfall only exceeds average monthly pan evaporation for five months of the year in the high rainfall zone (above 1100 mm) and for four months of the year in the low rainfall zone (below 900mm).

These comments on the Northern Jarrah Forest catchments would be broadly applicable to southern forested catchments as well. Dr Per Christensen in his paper (Fire in Southern Tall Forest) outlines some areas where minor differences may apply.

Hydrology

It is necessary to understand the principal hydrological characteristics of these catchments in order to assess the impact of fire on water resources. What follows is a brief summary more extensively described in the first two references.

Figure 3 illustrates the jarrah forest hydrological cycle and soil characteristic morphological zones.

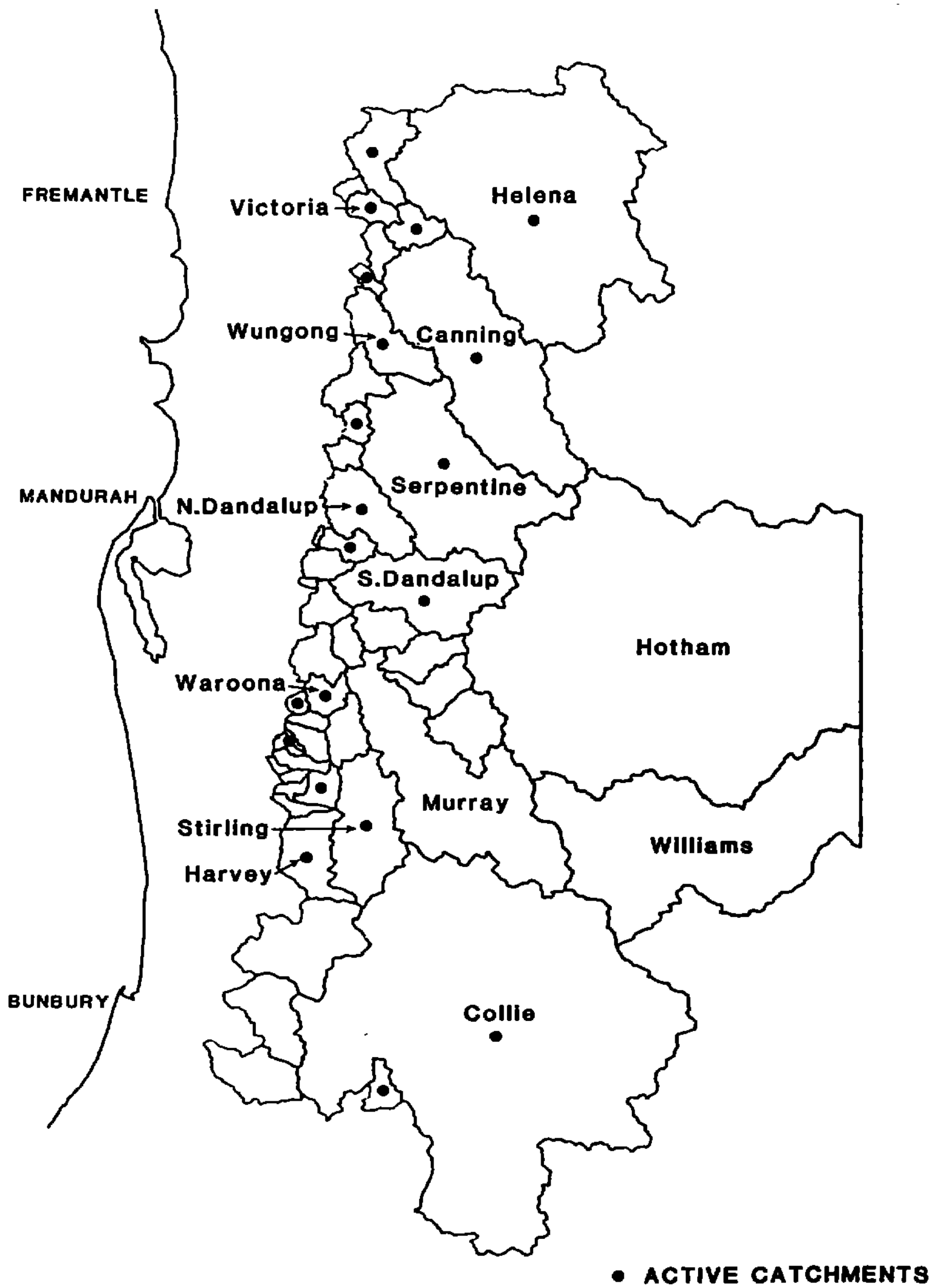


Figure 1. Catchments in the Northern Jarrah Forest.

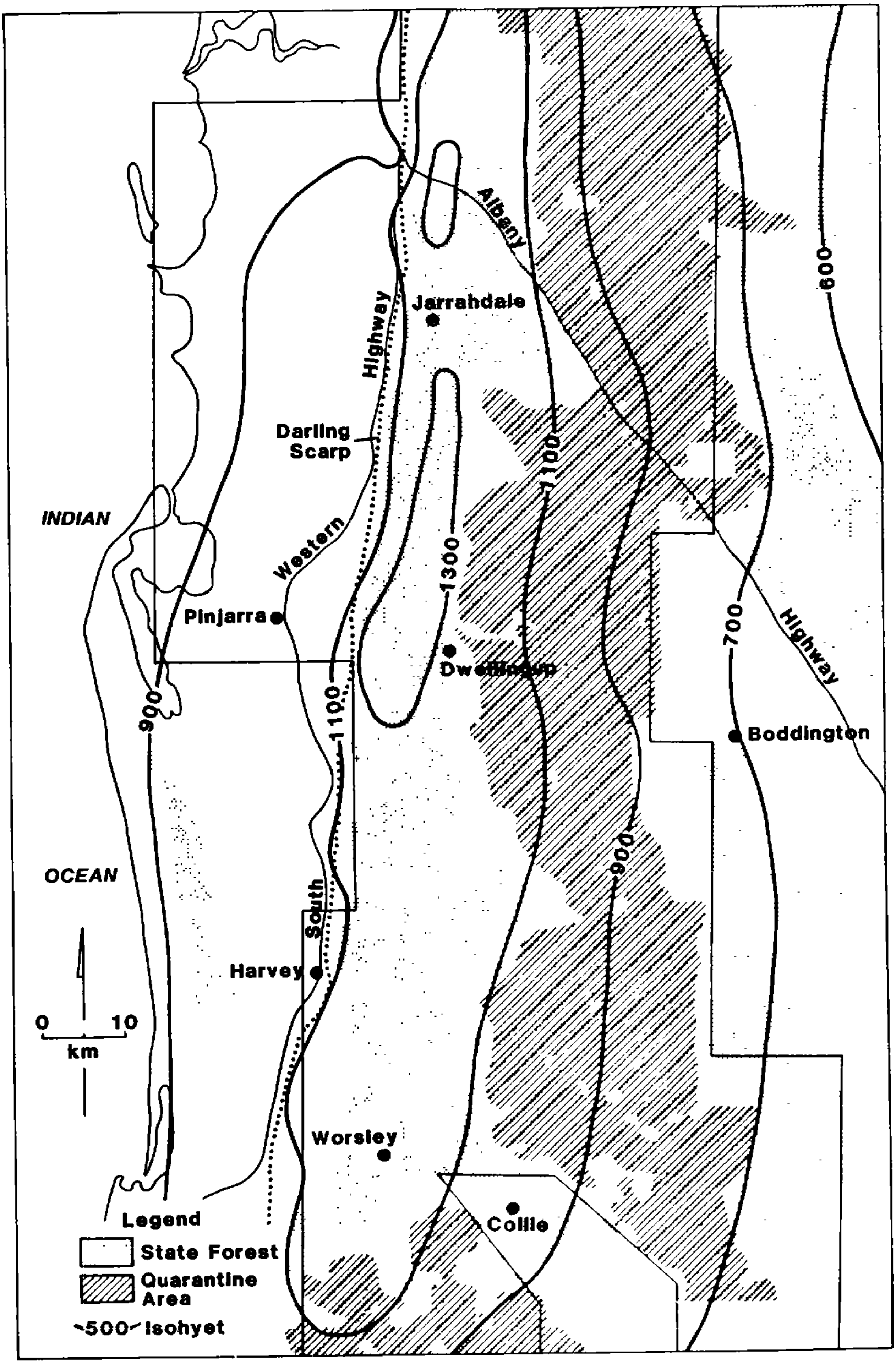


Figure 2. Average annual rainfall isohyets across the northern jarrah forest.

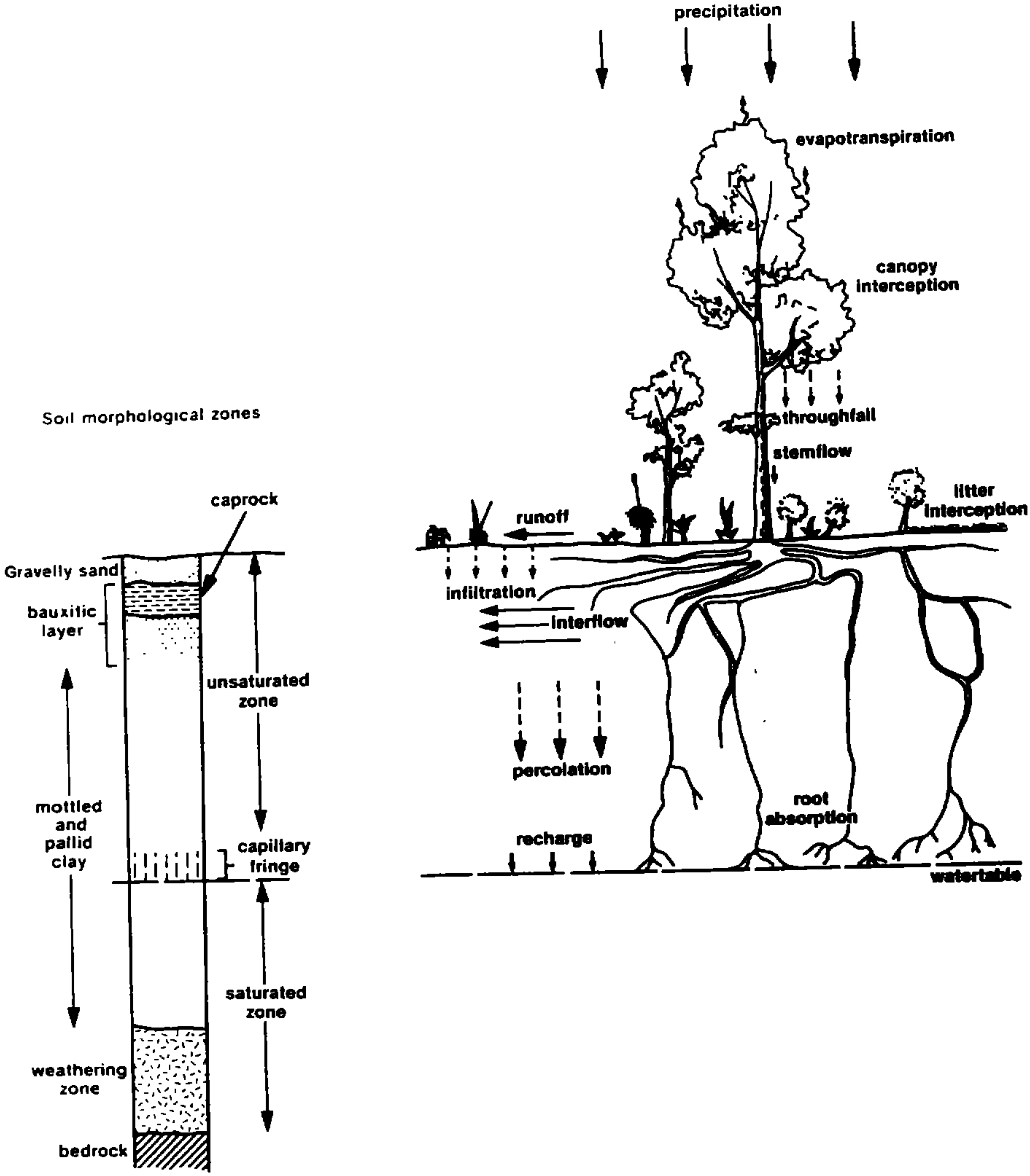


Figure 3. The jarrah forest hydrological cycle and soil morphological zones (not to scale).

Rainfall is intercepted by the vegetation canopy where it is either held and subsequently evaporated or drips from the canopy as throughfall. Some rainfall is intercepted by the stem and branches and is either absorbed or runs down the trunk as stemflow. The remaining rainfall falls directly to the ground surface, either as litter interception or as infiltration to the soil surface. In heavier storms most rainfall infiltrates, some may run off.

Interception losses in the jarrah forest are not well understood but can be almost 30% of rainfall based on the few measurements made. Evapotranspiration from understorey and ground layer (groundflora, litter and soil) can comprise about half of rainfall, at least in the higher rainfall zone. In addition the freely transpiring characteristics of jarrah itself are well known. By far the major portion of rainfall is lost to evapotranspiration, especially in the drier eastern region.

Infiltration capacities of Darling Range soils are highly variable, with greater than a hundred fold variation in hydraulic conductivity, but are generally of such magnitude that they are rarely exceeded by rainfall intensities. Even heavy rain will soak into the sandy gravel surface soils.

Unlike many parts of the world the overland flow contribution to streamflow is almost insignificant in the jarrah forest catchments. The ability of the upper soil horizon to absorb rainfall and rapidly transmit the water as near surface lateral flow is considered to be the major source of streamflow. Only low in the landscape, adjacent to watercourses do lower infiltration capacities give rise to the possibility of overland flow during high rainfall events.

Permeability variations in the soil profile lead to the development of perched water tables with delayed drainage. These sustain streamflow between storm events.

These near ground surface processes generate fresh water streamflow in both high and low rainfall zones in forested catchments.

Groundwater recharge to the water table is small, with water for the most part reaching the water table at depth in the pallid clay zone via preferred pathways such as old root channels and other fissures. Recharge is probably in the order of 1-3% of rainfall with higher infiltration on lower slopes in the high rainfall zone, where depth to water table is low. The deeper the water table the less water will percolate to the groundwater table.

Figure 4 illustrates in simplified form these stream generation phenomena for the high rainfall zone. In the low rainfall zone soil profiles are generally deeper, the permanent aquifer is saline and well below stream bed level and does not normally contribute to streamflow.

The Mediterranean climate and these hydrological characteristics are responsible for evapotranspiration water losses dominating over streamflow. consequently only in the high rainfall zone does a significant proportion of rainfall appear as run-off. Within the 1300 mm rainfall isohyet, for small catchments, 20-25% of rainfall contributes to streamflow. In the drier eastern portions of forested catchments only 1-2% of rainfall contributes to streamflow, and not all in dry years. Figure 5 illustrates some of these features.

As a consequence stream flow from jarrah forest catchments has the following unique characteristics:

(a) An absence of extreme flood events.

(b) A low proportion of rainfall becoming streamflow.

(c) A lack of overland flow, hence absence of erosion with streamflow consequently of low turbidity.

(d) Low nutrient levels both due to nutrient deficient soils and the absence of erosion - nutrients are commonly transported to water storage on particulate matter.

Water from these catchments is of exceptional clarity.

The impact of bushfires on water resources can now be considered.

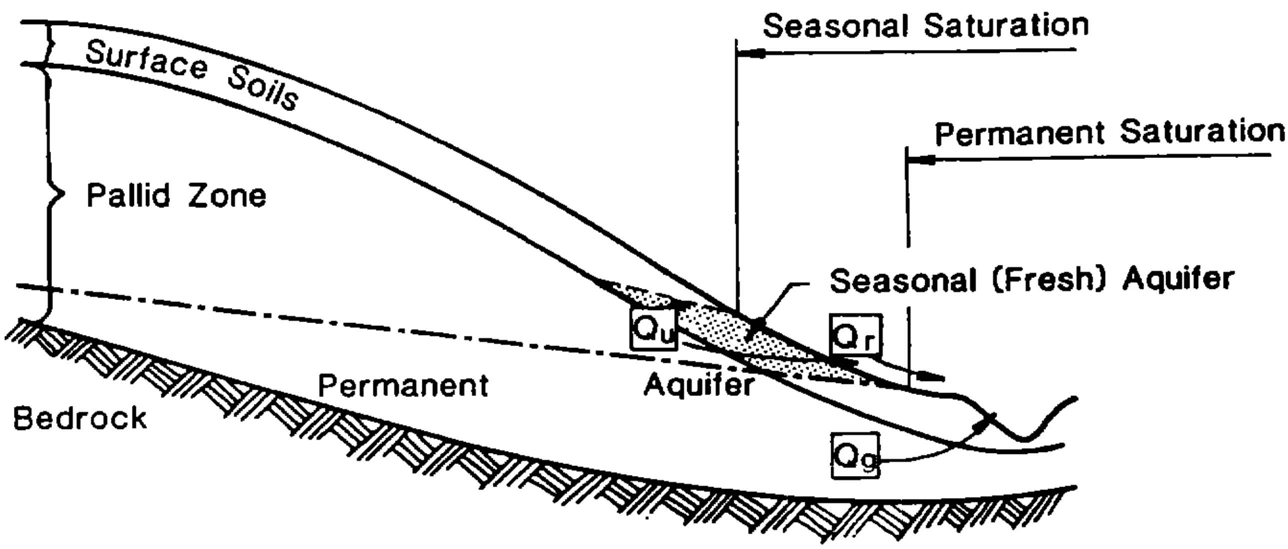
Fire and Water Resources

Direct Impact

The immediate impact of fire is to reduce understorey, ground cover and litter, and sometimes overstorey leaf density. The extent will depend on fire intensity. The ground will be covered with ash and dry fine soil. In the next winter rains interception losses will be reduced and a greater proportion of rain will reach the soil surface and infiltrate. The seasonal saturation zone near streams may expand slightly. It can be expected in undisturbed forest therefore that an increased proportion of rainfall will appear as streamflow and perhaps reach the deeper groundwater profile via preferred pathway infiltration. However, this impact has not to this author's knowledge ever been measured.

Under these conditions there is still minimal overland flow - the near surface soil layer is still mostly capable of absorbing even intense rainfall. Only adjacent to streams is there an opportunity for a marginal increase in erosion and mobilisation of ash to streams by overland flow.

It is rare with present fire management policies for extensive areas of forest to be severely burnt, rather a mosaic pattern prevails.



Legend

—·— Piezometric surface of permanent aquifer

Q_u Shallow subsurface flow

Q_g Groundwater flow

Q_r Surface runoff

Figure 4. Hydrology, high rainfall zone.

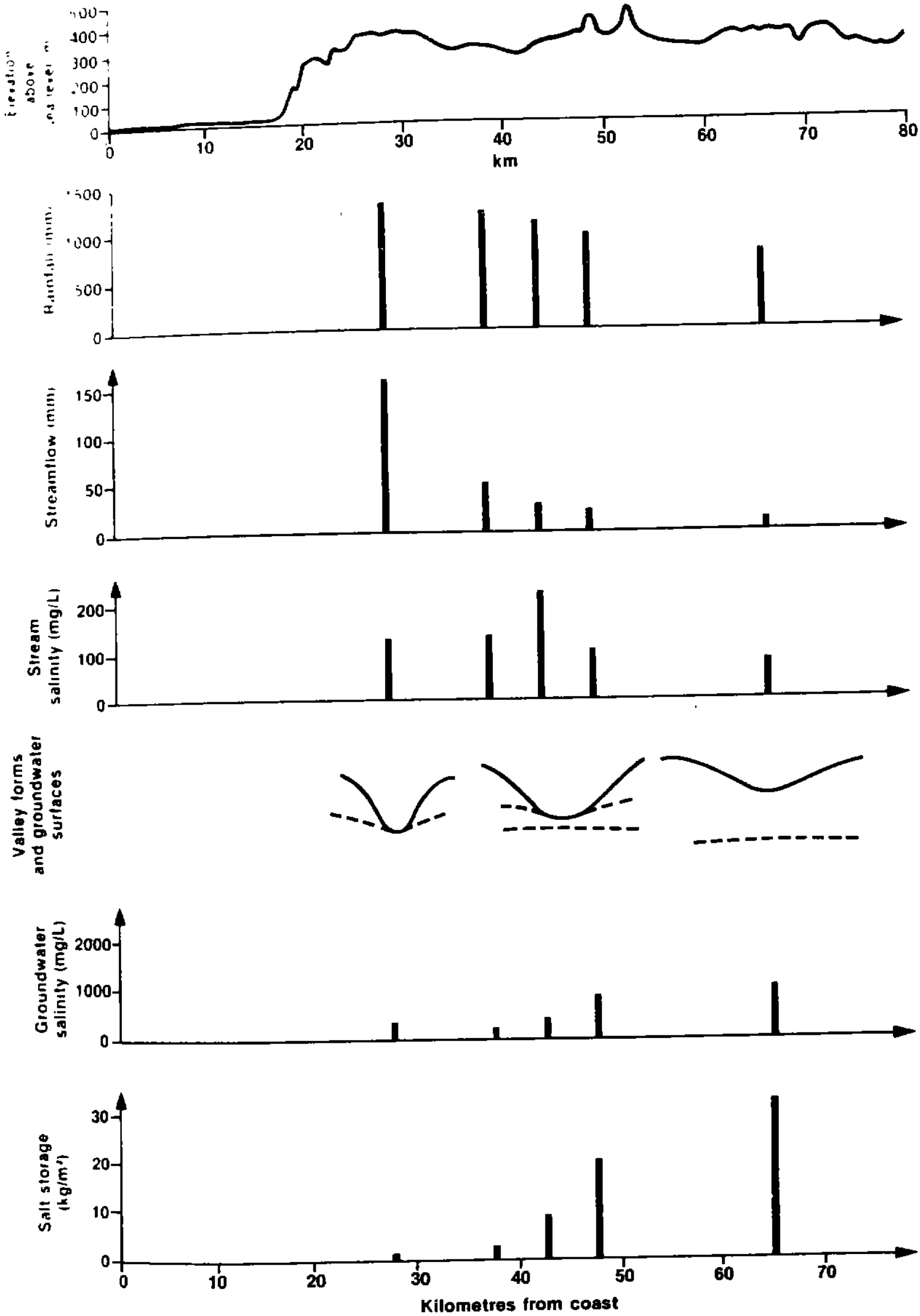


Figure 5. Variation in hydrosalinity parameters on a west-east transect across the northern jarrah forest.

The Jarrah Forest ecosystem has a good capacity to regenerate after fire and the pre-fire hydrological regime is rapidly restored. Only intense wildfire will damage or kill the larger trees. Other papers in the symposium describe this capability in more detail.

By contrast in many Victorian rivers affected by the 'Ash Wednesday' fires, for example, stream flow from first post fire rains was black with ash and produced severe water quality problems to some public supplies. Further the Mountain Ash forest is severely damaged by wildfire and takes years and even decades to regenerate with a correspondingly long impact on catchment hydrology.

The larger reservoirs in the Jarrah Forest have a substantial capacity to buffer any local poor quality inflow that does arise from fire.

The direct impact of fire on water resources in undisturbed Jarrah Forest catchments is therefore at the best marginal.

Indirect Impact

From the discussion above on hydrological processes it is clear that forest management practices that reduce both interception of rainfall and evapotranspiration by both overstorey and understorey as well as by ground cover and litter should increase water yield. Provided these practices do not increase the risk of mobilising saline groundwaters in the low and intermediate rainfall salt risk zones adverse impact on water quality is unlikely to occur. Fire is only one among many management tools available in this regard.

Caution is needed in pursuing too far management strategies to increase water yield in this unique ecosystem due to the fragile nature of many of its components.

Rehabilitated Bauxite Mines

Bauxite mining alters significantly the unique soil profile of the Jarrah forest. In the high rainfall zone where present mining occurs bauxite is mined in discrete pits generally in the middle to upper part of the landscape. After rehabilitation the landscape is a mosaic of unmined forest and rehabilitated pits.

In particular the shallow sandy-gravelly upland lateritic layer is removed in mining, generally down to the mottled and pallid clay horizons. It is this lateritic layer with its high infiltration capacity and ability for near surface lateral transmission of water that gives the undisturbed forest its distinctive hydrological character, viz. a minimum of overland flow as described earlier. Immediately after mining the compacted pallid clay zone has low infiltration capacity, a high potential for surface run-off and severe erosion. A major objective of rehabilitation practices is to avoid this happening in the short and long term.

Deep ripping on the contour is a standard part of the current rehabilitation prescription for the high rainfall zone and aims to:

(a) Provide an 'anchor' for the subsequently returned top soil by controlling the overland flow of water.

(b) Promote direct infiltration and near surface lateral water movement as in the original soil profile.

(c) Reactivate 'preferred pathways' to the deep water table.

(d) Break up compacted pit floors to permit root penetration of replanted understorey and overstorey species.

Figure 6 illustrates these features before and after mining. Further engineering measures are employed to manage overland flow, either by contour banks and pit bottom sumps or by a system of grade discharge banks directing overland flow to predetermined sump areas within the pit.

The long term success of these measures to control water movement and erosion in rehabilitated pits depends on speedy revegetation to increase leaf and groundcover interception of rain and to help stabilise soils against erosion. The current rehabilitation prescription provides for early establishment of groundcover and understorey species.

This approach to pit rehabilitation rapidly produces a large understorey biomass. As it reaches old age after 5-8 years the understorey will present a major fire hazard to the trees which will then be at a very sensitive stage of growth. It is likely that understorey tree density will decrease as overstorey species grow to maturity. While fire tolerance is an important factor in selection of tree species for planting the vulnerability of these new ecosystems to wildfire has yet to be ascertained. It is unlikely that the rehabilitated pit vegetation will be as tolerant of fire as the Jarrah Forest it replaces. The first ten to twenty years will be the most critical and require a substantial increase in fire control measures and costs for this period.

If fire severely damaged vegetation in rehabilitated pits replanting would be necessary to quickly restore protective ground cover to control erosion. Provided this is done the impact of fire on water resources will be marginal, but of course at increased cost.

Fire control is a major medium term problem for rehabilitated pits. Both the Department of Conservation and Land Management and the mining companies recognise the problem and are taking action to avoid fire reaching or breaking out in rehabilitated pits.

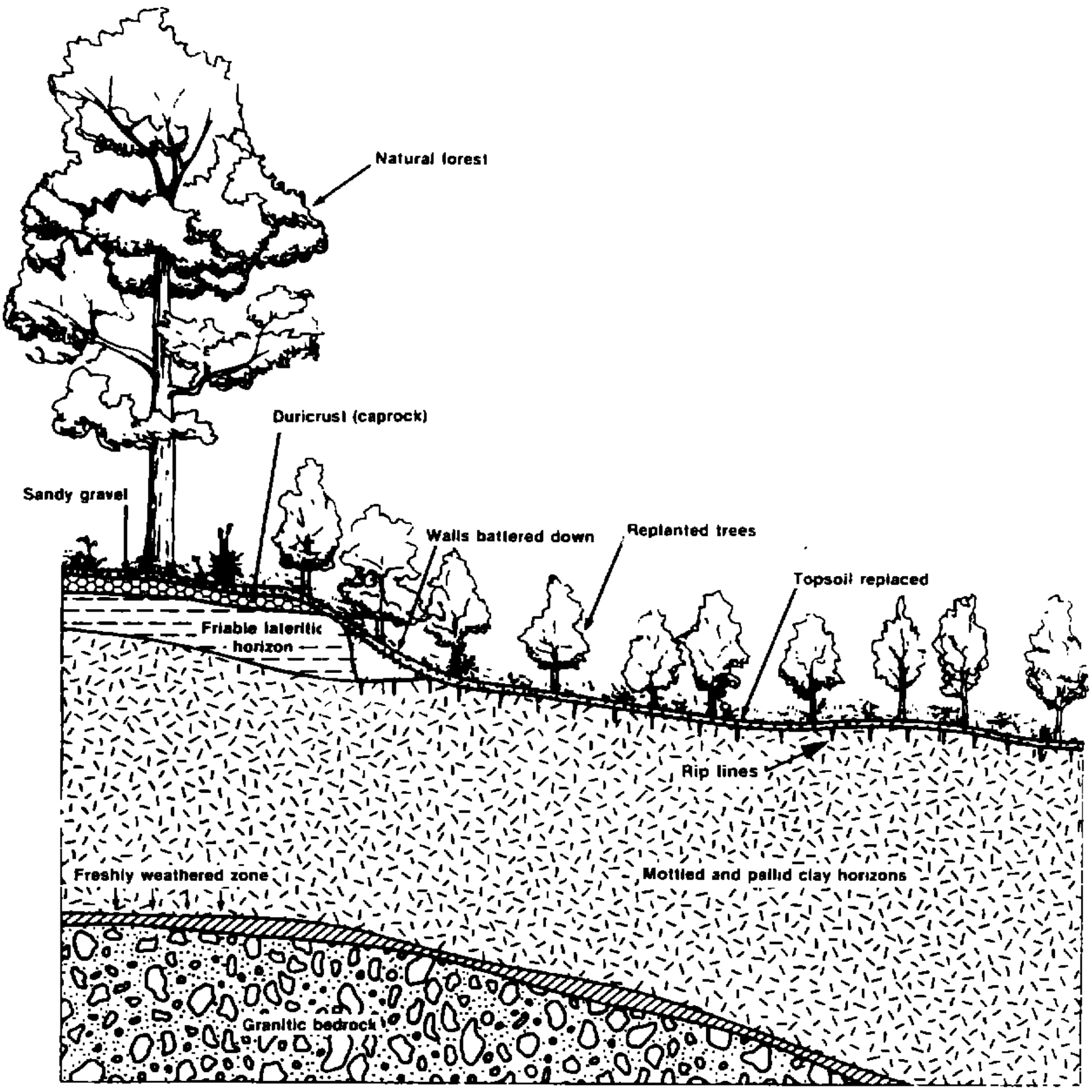


Figure 6. Rehabilitated minepit showing the soil profile before and after mining.

Conclusion

The physiography and soil profiles together with their vegetation systems give water catchments in the Northern Jarrah Forest their unique hydrological characteristics. Overland flow makes a minor contribution to streamflow and then only from land adjacent to streams. Shallow groundwater flow is the major source of streamflow. The forest recovers quickly from fire to restore the pre-fire hydrological regime. All these factors together result in fire having at the most a short term marginal impact on the quantity and quality of water yield in the undisturbed forest environment.

The potential for water erosion from bauxite mines is greater than in the undisturbed forest. Current rehabilitation prescriptions, viz. ripping on the contour, grade and contour banks, sumps and revegetation with early groundcover and understorey development have so far provided effective management of erosion. In their early years these replantings are fire vulnerable and will possibly in the long term be more sensitive to fire than the original forest they replace. With effective management practices nevertheless the impact of fire in such rehabilitated pits on water yield and quality should still be marginal.

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PLANNING AND MANAGEMENT OF FIRE IN METROPOLITAN CONSERVATION AREAS

Susan A. Moore and Gordon Graham

This paper is divided into six sections. The first section (A) introduces the Perth metropolitan region and its conservation areas. This leads into the second section (B), which outlines the values of the metropolitan conservation areas. An introduction to planning follows (Section C). The fourth section (D) covers one of the major planning and management considerations on metropolitan reserves - the problems of fire and weeds. Section E introduces the management of the metropolitan conservation areas with a discussion of their history. Section F uses management for fire control as an example of on-the-ground management. Two case studies are used - Thomsons Lake Nature Reserve and Ellen Brook and Twin Swamps Nature Reserves.

A. Introduction: Metropolitan Conservation Areas

It is fortunate that the Perth metropolitan area, unlike many other metropolitan regions, has large portions set aside under planning and wildlife legislation for open space purposes. This is evident from the Metropolitan Region Scheme and Local Authority town planning schemes. In addition, there are a great many small bush areas on private freehold land (e.g. backyard gardens and uncleared rural land), vacant Crown land and other uncleared reserves dedicated to other purposes (Briggs 1984). Throughout the following discussion, the term "metropolitan region" refers to the region as defined by the Department of Conservation and Land Management (Fig. 1).

The metropolitan conservation areas represent much of the diversity of the Perth region. Islands are well represented (e.g. Carnac, Shoalwater Bay Islands), as are the Swan coastal plain wetlands (e.g. Lake Joondalup, Forrestdale Lake). Further to the east, Ellen Brook and Twin Swamps Nature Reserves include areas representative of the upper reaches of the Swan.

The term "metropolitan conservation area" also requires definition. The term covers areas of bush in the Perth metropolitan region which have some nature conservation value. They are covered by a range of tenures and purposes, from nature reserves vested in the National Parks and Nature Conservation Authority, to reserves set aside as "Parkland" and vested in the Local Authority. These areas are similarly variable in size, ranging from negligible (offshore islands) to Thomsons Lake Nature Reserve with an area of 509 ha.

Although there is a large number of conservation reserves in the Perth metropolitan region only a small number of these are managed under formal management plans or programs. Those formally set aside for the purpose of protecting the natural environment usually lack comprehensive planning and management because of a deficiency in funds for staff, research and equipment. The remaining areas on freehold land and other reserves also lack comprehensive planning and management because there is no legislation to encourage or enforce their protection.

B. Values of the Metropolitan Conservation Areas

Nature conservation areas in the metropolitan region are vitally important in terms of wildlife conservation. This importance is based on five functions:

1. habitat availability,
2. linkage,
3. scientific reference,
4. education, and
5. rare species.

1. Habitat Availability

One of the most important aims of wildlife conservation in Western Australia is the setting aside of representative areas of natural vegetation, plus the wildlife it supports. The metropolitan region is no exception, and the diversity of habitats contained necessitates a comprehensive system of reservation. Metropolitan conservation reserves are particularly important in terms of providing habitat for bird species, both nomadic and sedentary.

2. Linkage

The linkage function is particularly important for numerous bird species. Nomadic birds require frequently occurring sites which provide refuge and food. For these birds it is necessary to have a "stepping stone" or linkage system connecting these sites.

Thus, the presence of bird species in Perth is dependent to some degree on the quality of the linkage system provided. This quality is determined by the distance between sites, the size and type of the site (e.g. large or small water body, dense understorey, open woodland) and the quality of the site's environment (e.g. degree of human disturbance, amount of food, number of feral cats).

The linkage function is also important for the maintenance of floral genetic diversity which is essential for the survival of viable populations. Many of the metropolitan conservation reserves are too small to ensure the survival of certain floral species. Some small areas may not contain large enough populations of certain species for them to be self-sustaining, and thus must rely on the importation of seeds and pollen from more productive surrounds.

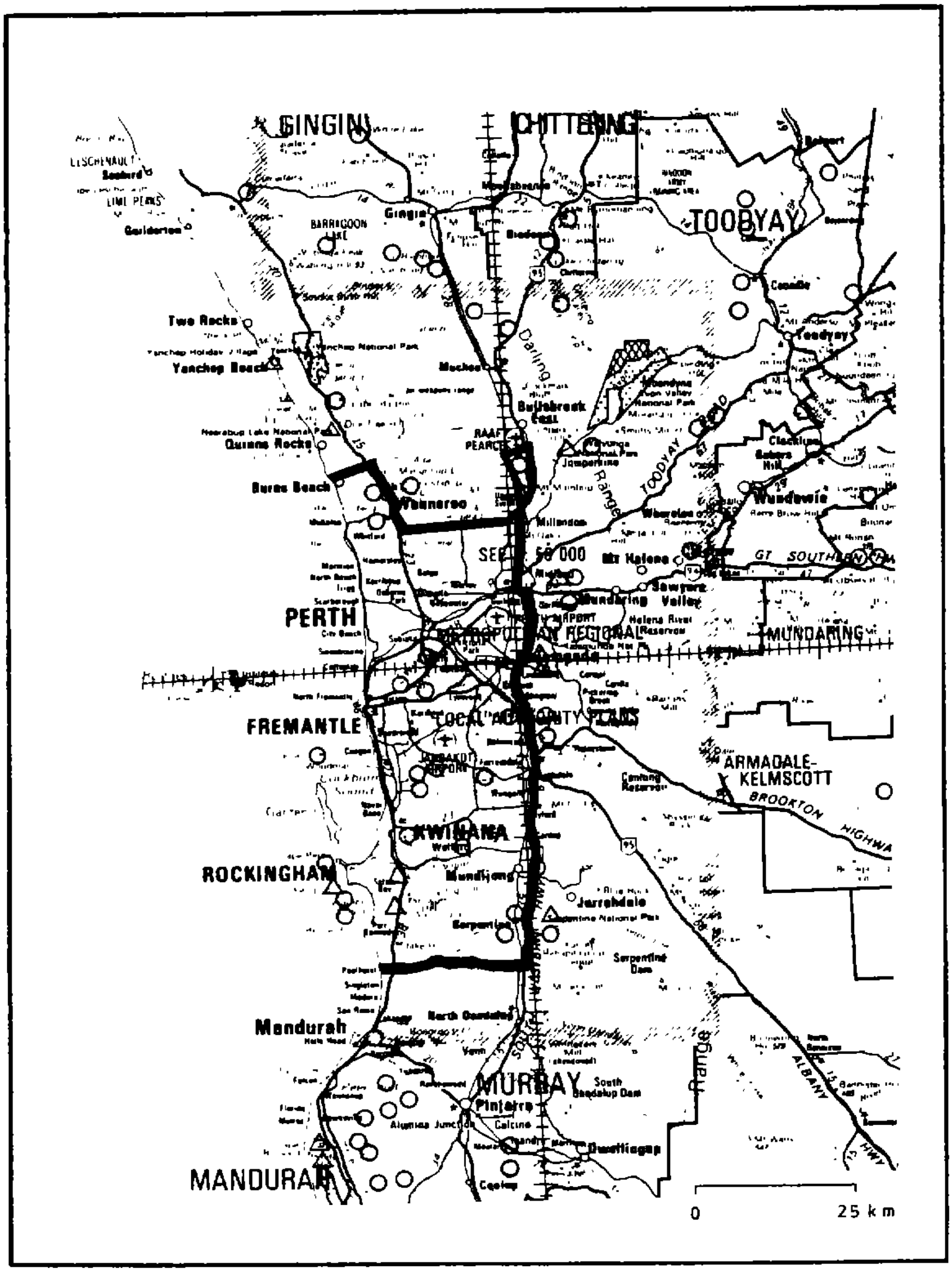

Figure 1. The metropolitan region, as defined by the Department of Conservation and Land Management (1985).

Linkage is also an important consideration in terms of fire planning and management. Without it, small areas completely burnt by fire will not be recolonised by local native species. Similarly, these links are necessary to encourage birds and reptiles to recolonise after fire.

3. Scientific Reference

Although most of the conservation reserves in the Perth metropolitan region are not in a pristine state, they do indicate aspects of the natural environment, especially flora and landscape, prior to European settlement. Having such a system with a significant level of duplication is vitally important in terms of fire management. Then, if a reserve is completely burnt, hopefully another similar reserve remains unburnt, providing a reference area.

4. Education

Metropolitan conservation reserves are an easily accessible education resource. They provide opportunities for nature study, whether it be wildflower appreciation, bird-watching, bushwalking or photography. These areas also give children first-hand experience of the bush and encourage them to feel that it is part of their total environment.

5. Rare Species

Similarly to many conservation reserves State-wide, the metropolitan conservation areas represent the remnants of locally restricted, as well as once extensively distributed species, particularly plants. As such, most rare plant species in the metropolitan region are found only on conservation areas.

C. Planning

Planning is a fundamental concept in natural land management. The practical problems of providing biological as well as people management are enough in themselves to require careful planning for all conservation areas. There are, however, several further reasons for doing so, some of which are fundamental to the principles and philosophies of management for conservation. These are:

1. Time Scale of Management

The natural processes which management guides and emulates operate over long time scales - the growth and decay of plants, the succession of vegetation types, changes in animal populations, changes in community composition and the evolution of new species. Some types of management action, such as the removal and translocation of a species, occur at one point in time and are completed very quickly - their effects are felt until the system adjusts to the new regime. Other kinds of management, such as prescriptions for fire regimes and animal and plant control measures are applied over a period of time, for as long as their effects are required.

Because of the time scales involved, both kinds of management are best applied within the framework of a previously prepared management plan. Approaches to management change, but a well-recorded plan for management stands as a statement of objective and methods which outlive changes in operational staff and help the management process to weather changing opinions.

2. Public Participation

Management plans provide an opportunity for all sections of the community to play a part in the future of conservation reserves. Also, the public should be involved, as a matter of principle, as most of the metropolitan conservation areas are part of the public estate. Lastly, public participation is one avenue for increasing community support for conservation.

3. System Planning

All conservation areas in the State are part of a single system, and one which can be variously subdivided to group areas according to the biological features, management objectives or for purely administrative purposes. In this way the metropolitan conservation areas can be regarded as a discrete subsystem.

The use of system planning enables a management plan to identify complementary areas and detail complementary management, particularly in terms of fire. Thus a variety of fire regimes and protection measures can be implemented, depending on the conservation and protection needs of a particular area.

Over the last 5-6 years management plans for conservation areas in W.A. have aimed to integrate all relevant management strategies. Thus, fire is not considered in isolation - it is considered as part of a group of management strategies including public use, rehabilitation of degraded areas, dieback protection and weed control. Thus, a fire protection strategy such as firebreak construction must take into consideration the effects of such an action on populations of rare species, weed invasion, increased public access and the introduction of dieback.

Planning for the management of conservation areas has been necessarily conservative, considering the lack of information available on the responses of the biotic community to fire. As such, fire should be excluded from a community until the slowest growing obligate-seed-regenerating species has produced its first crop of viable seed. Even a single fire in the interim could cause localised extinctions.

In past management plans for conservation areas in W.A. the approach towards fire has been conservative. The following objectives summarise this approach.

"To protect the natural values of the conservation area, and at the same time protect the assets of adjacent landholders."

"To minimise the risk of occurrence of wildfires on the conservation area, and to suppress such wildfires as may occur."

D. Fire and Weeds

The problems of fire and weeds are closely related. Frequent burning encourages invasion by weeds, such as veldt grass, which regenerate rapidly after fire outcompeting the slower growing native species. Weeds thickly colonise the bare ground left after fire. Since most weed species dry out over the summer months, further fires can start easily and burn fiercely.

Frequent fires damage the tree canopy and destroy tree seedlings and shrubs. Consequently, more light penetrates both vertically and laterally encouraging strong weed growth, and competition for moisture and nutrients, so depressing the rate of restoration of the canopy. Long term success in weed control and associated fire frequency will not be achieved until the tree and shrub cover can be restored and maintained.

Of a total 2,010 plant species in the Perth region 546, or 27%, are naturalised aliens (Marchant 1984). Obviously, disturbances to the metropolitan conservation areas through plant and timber removal, gravel and sand mining, rubbish dumping and frequent fires have made these areas highly susceptible to weed invasion.

The problem is exacerbated by people; the following question posed by Dr P. Wycherley (Director, Kings Park and Botanic Garden) summarises the problem - "people, fire and weeds: can the vicious spiral be broken?" People, as far as can be determined, have been the only cause of fire in Kings Park over the last 40 years. These fires increase veldt grass competition and dominance through the destruction of the tree canopy and suppression of tree and shrub regeneration. People who light fires either deliberately or accidentally complete the "vicious" cycle.

E. History of the Metropolitan Conservation Areas

In order to understand how fire is planned for and managed on metropolitan conservation areas we must look at the historical pattern of use and management.

Generally speaking, there has been a history of neglect. As development has taken place around the bush areas there has been an increase in a variety of detrimental pressures, particularly an increase in the incidence of wildfires. Most of these have been caused by the escape of fires associated with the clearing of land or by deliberate lighting. As the bushland has become increasingly neglected the values attributed to them, by the community, have markedly decreased and regular burning has become common-place.

The legacy of this process is conservation reserves where the vegetation structure is in many cases fire-prone. The most obvious changes have occurred in the understorey. Two general changes are noticeable. In many situations, the trend is for the gradual introduction of annual weeds which creates a yearly fire control problem. In other places there may be the growth of fire-stimulated indigenous-woody species. Of particular note is **Acacia saligna.** This species regenerates in dense bushy stands which, as they mature, pose a severe fire risk. Fires in these areas tend to be very intense with high flame heights, making them difficult to control.

Other less obvious results are the loss of large trees and the removal of some fauna species. The loss of fauna species is not well documented and reasons for their disappearance may be a result of a number of pressures - not just fire.

F. Management for Fire Control

The overall situation of redressing the neglect has usually only come about after community pressure has been brought to bear on the authority responsible for management.

Restoration of these degraded areas requires expensive management input, not the least of which is fire control. In the past all management inputs have been severely restrained by a lack of resources.

Fire management in the metropolitan region, and through-out the State, is complicated by the need to liaise with a number of groups. A number of organisations must be considered, not only during the planning of fire control measures but also in the event of fire. Bodies involved include the Bush Fires Board, Local Government Authorities, West Australian Fire Brigade and local volunteer fire brigades.

The people in these organisations may have very different perceptions of the use of fire and the techniques required for the suppression of wildfires, in comparison to the views of the authority responsible for the management of a conservation area. Subjects which may be perceived very differently by different groups include: the adequacy of fire protection measures and the threat to adjoining lands; the need for, and impact of fuel reduction burning on small bush areas; frequency, size, season and intensity of fuel reduction burning; and the best methods of attack in the event of a wildfire. Most of the problems created by the differing outlooks can be resolved through close liaison.

The general aim of fire management on metropolitan conservation reserves is one of fire exclusion or at least a marked reduction in the frequency of fires.

The following two examples are used to illustrate the approach adopted:

1. Thomsons Lake Nature Reserve, and

2. Twin Swamps and Ellen Brook Nature Reserves.

Firstly, however, it should be noted that the fire control measures presented are by no means the one and only solution, as the measures may change with changes in:

1. the condition of the reserve as a function of time,

2. the resources available to the managing organisation,

3. the level of research and monitoring work available which provides data to modify and/or change the measures, and

4. the effect of further wildfires whilst the measures are in place necessitating re-assessment.

Therefore, a manager must maintain a flexible approach to fire control and its interaction with other management concerns.

Now to the examples.

1. Thomsons Lake Nature Reserve

This reserve is approximately 34 km, by road, south-west of Perth (Fig. 2). It includes Thomsons Lake, which is part of the north-south chain of wetlands known as the Cockburn wetlands, and 300 ha of mainly woodland and open forest in a 100-400 m buffer around the lake. This 509 ha reserve is the largest nature reserve in the Perth metropolitan region. It is vested in the National Parks and Nature Conservation Authority (NPNCA) and as such the Department of Conservation and Land Management is responsible for its management.

The management plan for this nature reserve was approved by the Minister for Fisheries and Wildlife in early 1981. This plan details broad management objectives, including fire protection, for the reserve. These broad management objectives have enabled operations staff to develop, and continue to develop, detailed management programs. In terms of fire protection these are based on the prevention and immediate suppression of all fires.

A 20 m clear-earth firebreak is maintained around the perimeter of the Thomsons Lake Nature Reserve. Most of the numerous narrow tracks through-out the reserve have been closed off, as they served no useful purpose as firebreaks. These tracks also detracted from the aesthetic and conservation values of the area and provided little in the way of fire protection. Four radial firebreaks complement the perimeter firebreak (Fig. 3). These radial breaks, which run from the perimeter to the lake margin, consist of a central 3 m clear-earth firebreak and slashed break 6-8 m either side. A similar break follows the lake margin.

In the event of fire occurring on the reserve the choice exists between two main suppression strategies.

If the fire is relatively mild and is associated with light fuels in a readily accessible area, direct attack methods are used. This involves using fire-fighting units and personnel. Earth-moving equipment may be used, taking due account of the environmental impact.

In a severe wildfire situation direct attack methods would endanger personnel; thus, the radial firebreaks are used in an indirect approach. Fire crews instigate back-burning from the radial and lake-margin firebreaks, both of which have slashed edges.

There are several advantages of the clear earth, plus slashed margin, firebreak.

1. Back-burning is safer for fire crews because of the absence of elevated flash fuels adjacent to the point of action. Also, the back-burn has an increased margin of safety before it builds in intensity.

2. The risk of a back-burn crossing the firebreak is significantly reduced. Moreover, any hopovers that occur are more easily suppressed.

3. There is a greater probability of fire crews being able to stop a head-fire when it strikes this type of firebreak.

All experienced firefighters are aware that the successful suppression of wildfires is, to a certain degree, based on probabilities and the rapid assessment of acceptable risk. This also holds true for the level of fire control works that are instituted in a particular area.

2. Ellen Brook and Twin Swamps Nature Reserves

These two small reserves, Ellen Brook with an area of 67 ha and Twin Swamps with an area of 155 ha, are located approximately 24 km north-east of Perth (Fig. 4). Ellen Brook is adjacent to the Great Northern Highway, and Twin Swamps lies some 4 km to the north. As with the Thomsons Lake Nature Reserve, both reserves are vested in the NPNCA.

While the vegetation differs markedly between the two reserves, the two areas are managed for the same purpose - the maintenance and enhancement of suitable habitat for the rare and endangered Western Short-necked Tortoise. This has necessitated an extremely cautious approach to the use of fire and its control.

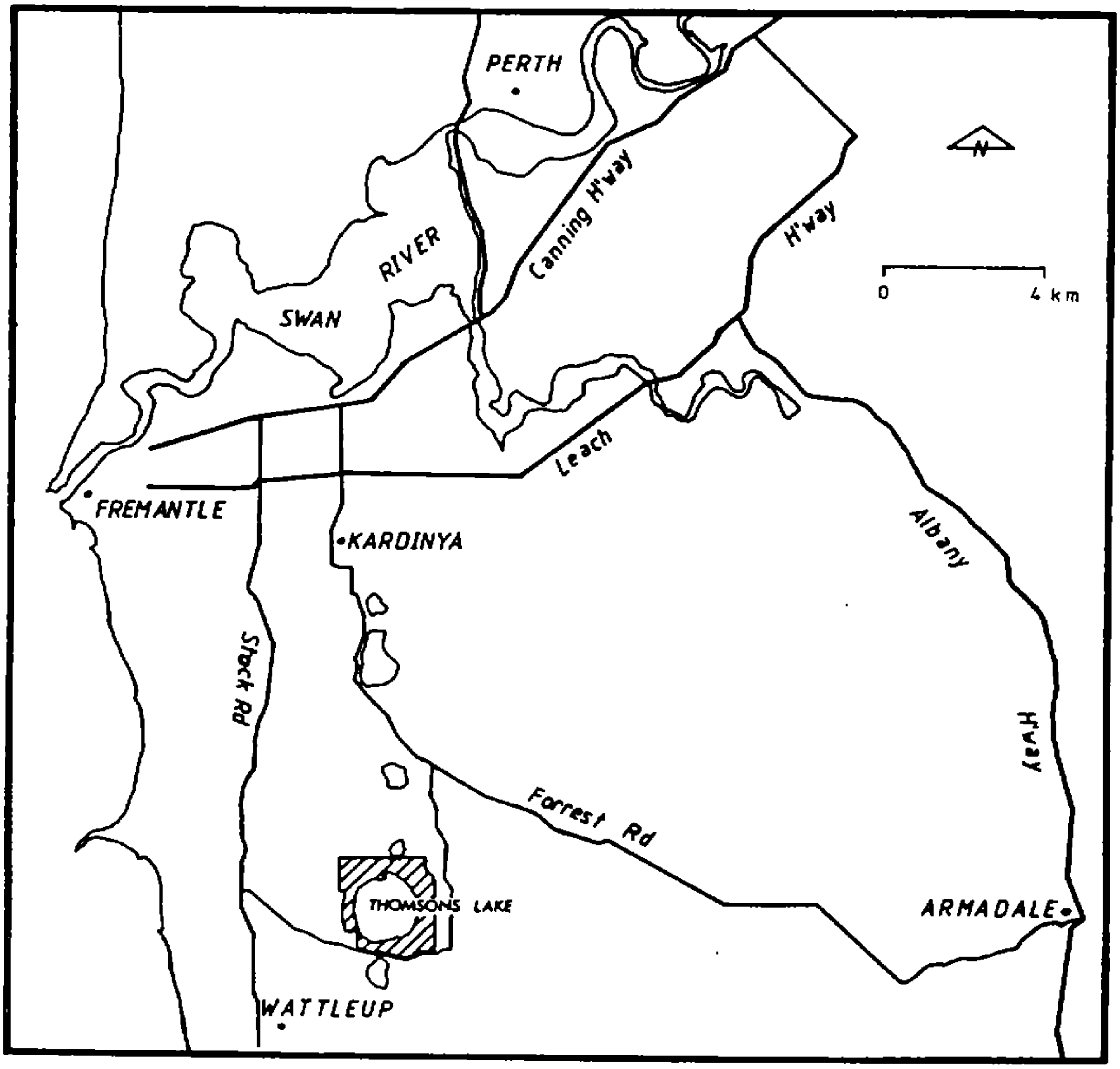

Figure 2. Location of Thomsons Lake Nature Reserve.

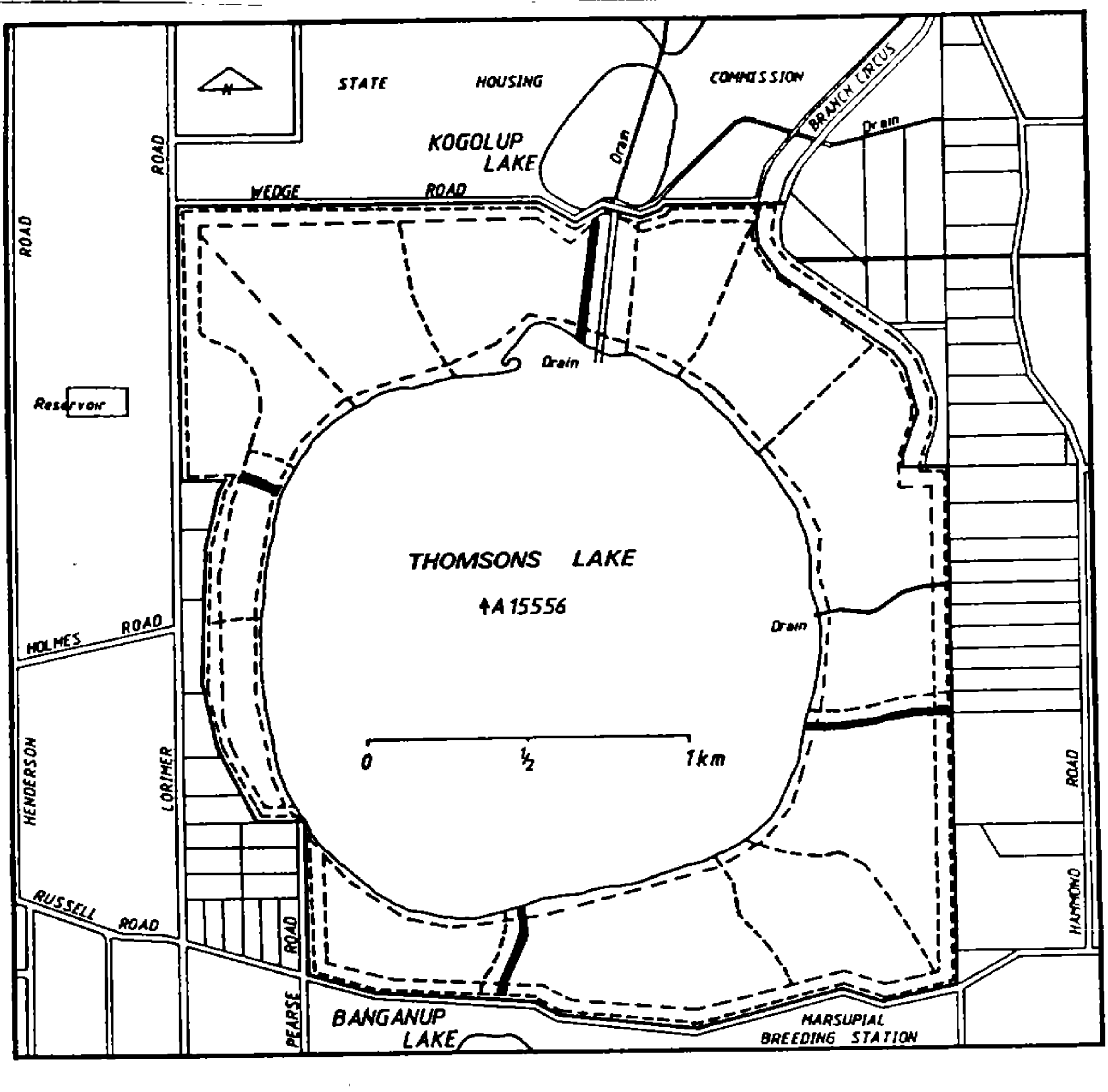

Figure 3. Thomsons Lake Nature Reserve, showing firebreaks.

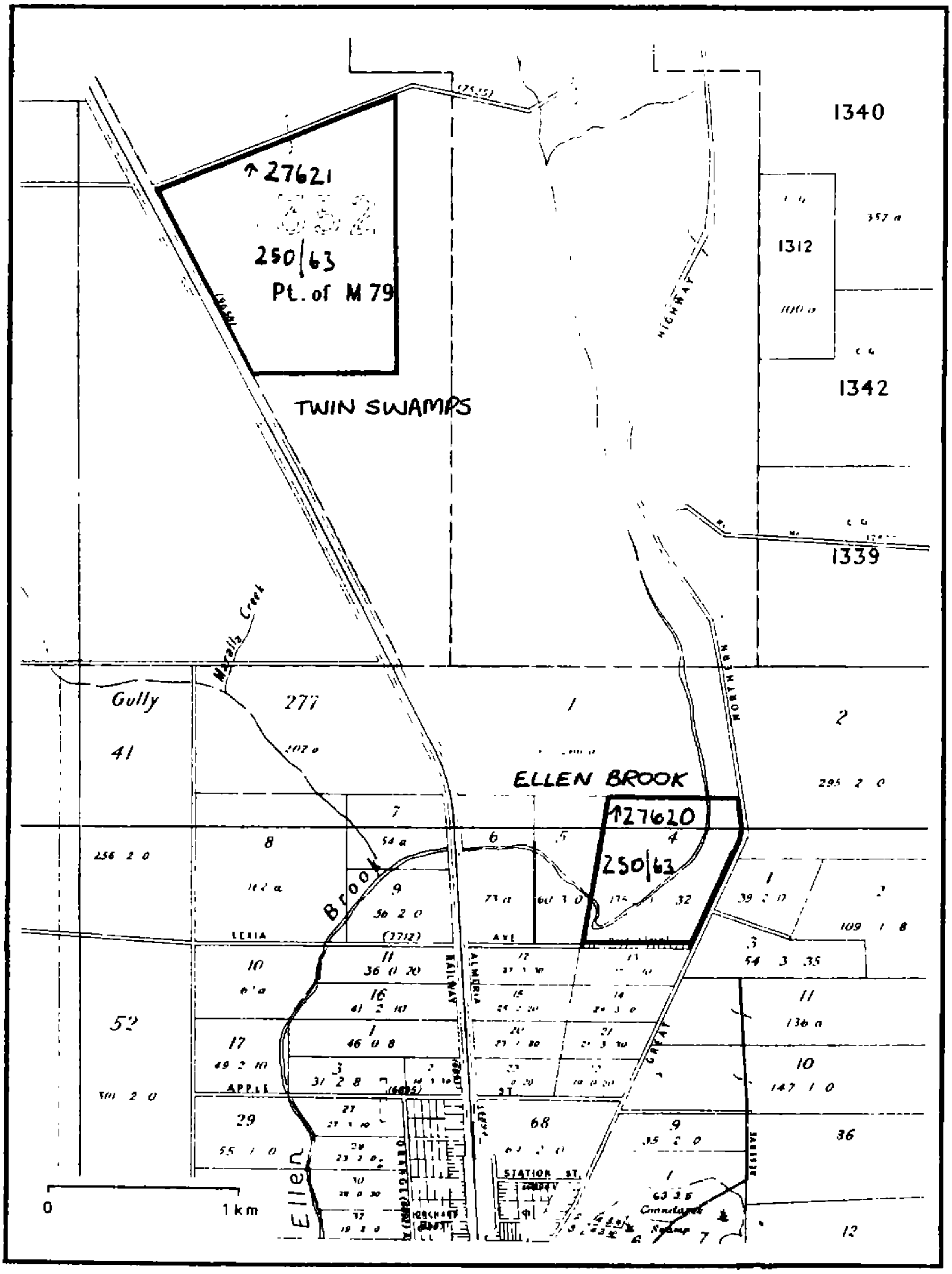

Figure 4. Location of Ellen Brook and Twin Swamps Nature Reserves.

Protective burning is used in fire management on the two areas, however only after close consultation with research staff based at the Wildlife Research Centre. Protective burning has largely been a response to requests from local fire brigades and neighbours who feel that the reserves are a fire threat.

Although the objectives of fire management on the two reserves are similar, the approach differs.

First, Ellen Brook Nature Reserve (Fig. 5).

1. A system of 3-4 m clear-earth firebreaks divides the reserve into blocks.

2. A 20 m buffer strip on the west side of the reserve, where the reserve abuts private property, is occasionally burnt at the request of the local Shire. This strip is dominated by annual grasses.

3. To protect both the tortoises, which take refuge during summer in holes created by the drying out of the clay soils, and regenerating tree seedlings, close contact is maintained between the Department, local fire brigades and the Shire. This has alleviated local fire management concerns before they have become major issues.

Secondly, fire management on Twin Swamps Nature Reserve (Fig. 6).

1. Similarly to Ellen Brook a system of 3-4 m clear-earth firebreaks divides this 155 ha nature reserve into blocks.

2. Within 10 m of the perimeter firebreak, on the eastern and southern sides adjacent to private property, all logs, dead trees, dead branches and dozer heaps are burnt. This aims to reduce the risk of hopovers, as well as the number of "hot spots" adjacent to the firebreak.

3. Consideration is being given to burning blocks adjacent to Warbrook Road.

4. An undeveloped road reserve which follows the western edge of the reserve will be maintained, with the assistance of the Shire, in a low fuel condition.

These two examples emphasise that each conservation area within the metropolitan region must be managed for its individual conservation values.

In conclusion, there are a number of conservation areas in the new Perth metropolitan region which have yet to be assessed in terms of fire management requirements. However, it is hoped that with the creation of the Department of Conservation and Land Management more resources and expertise will become available in the metropolitan area - an area which, in reality, is the general public's window to conservation and land management practices state-wide.

Answers to Questions

1. Watsonia occurs in various concentrations in conservation reserves in the Perth metropolitan region. This species appears to be more common in highly disturbed environs.

2. The boundaries of the Perth metropolitan region (as defined by the Department of Conservation and Land Management, 1985) were drawn to include a manageable area of existing conservation reserves and areas recommended for reservation (System 6 recommendations).

3. Fires outside the metropolitan region will be attended by district and regional crews. The area surrounding Perth lies within the Northern Forest region and as such fires on land under the control of the Department of Conservation and Land Management will be attended by crews from this region and its associated districts.

4. No generalised figure can be given for the frequency of fires on metropolitan conservation areas. However, the frequency has increased over the last 10-15 years with many areas experiencing fire every 2-3 years.

5. Many of these small bush areas are cut by numerous firebreaks. A strategic firebreak system should be selected and all other tracks closed and encouraged to regenerate.

6. Most, if not all, fires on metropolitan bush areas are deliberately started by people.

7. Veldt grass may be controlled by the exclusion of fire. Fire exclusion encourages regeneration of native understorey species, and allows the tree canopy to develop. At Thomsons Lake fire has been excluded from most parts of the reserve for at least 4 years, and good regeneration of both the overstorey and understorey is occurring. However, it will be at least 10-15 years before any definitive conclusions can be drawn.

8. Lupin drives are a successful technique for removing lupins. Children can easily be provided with an incentive, and numerous lupins removed!

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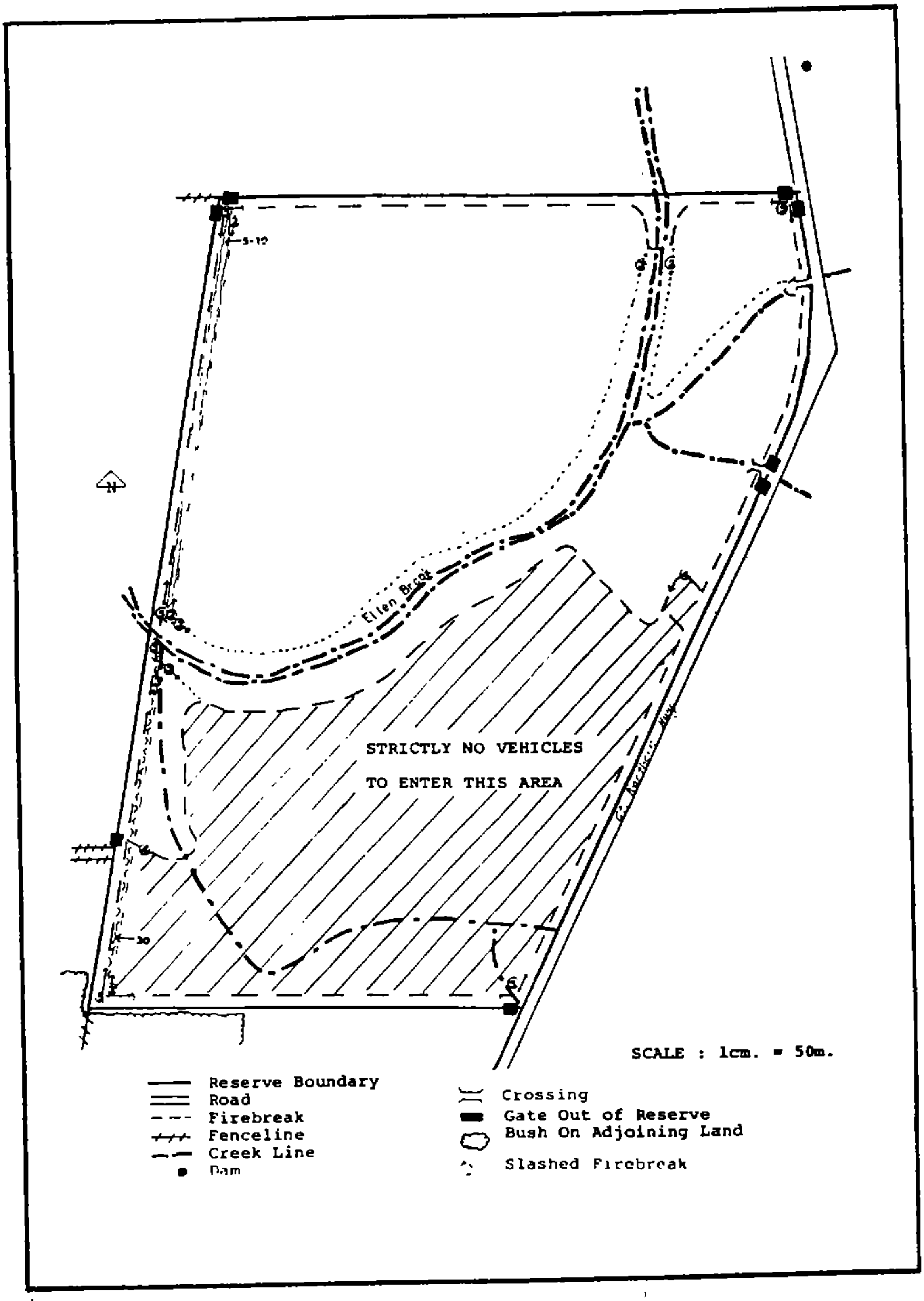

Figure 5. Ellen Brook Nature Reserve, showing firebreaks.

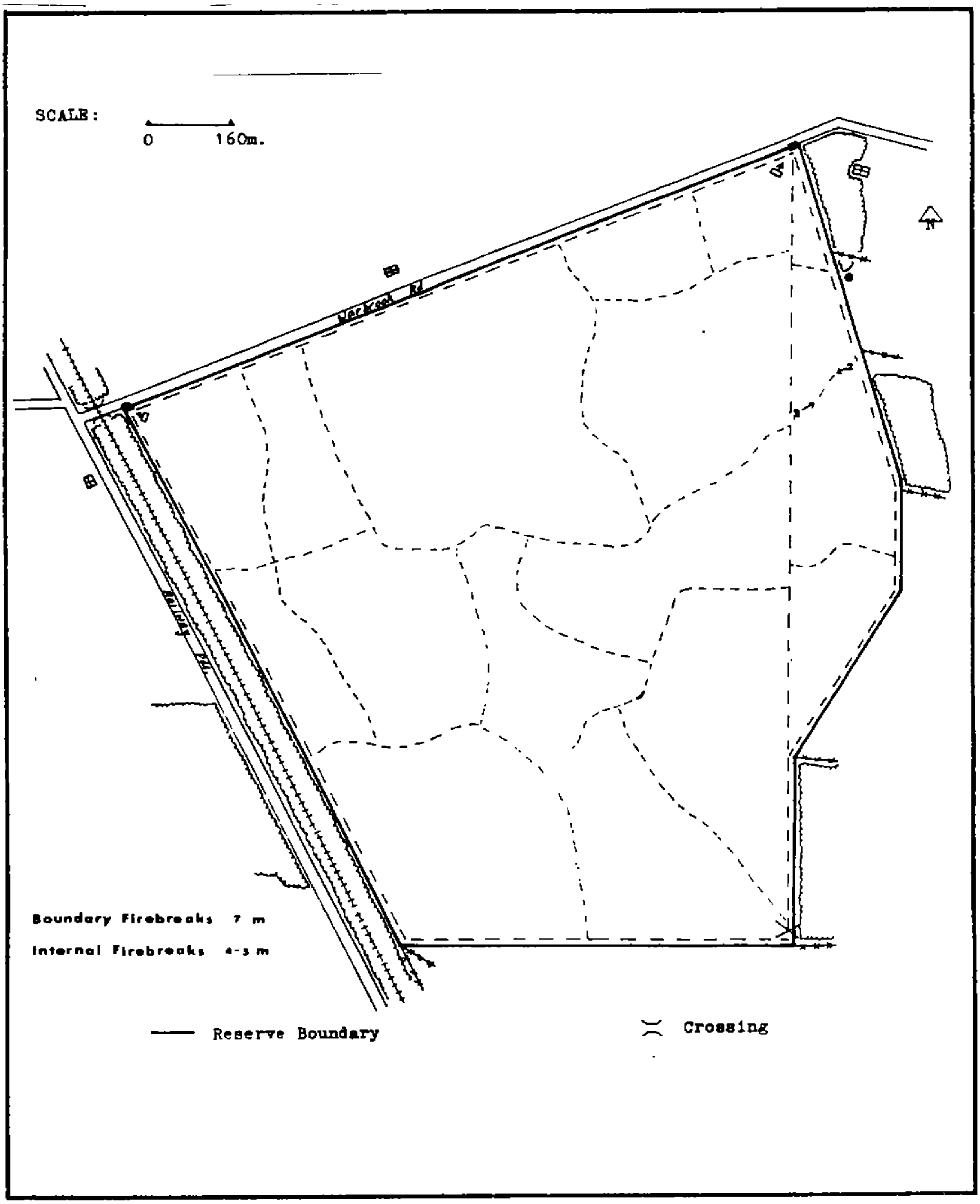

Figure 6. Twin Swamps Nature Reserve, showing firebreaks.

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A FRAMEWORK FOR FIRE MANAGEMENT PLANNING IN THE PROPOSED SHANNON FOREST AND D'ENTRECASTEAUX NATIONAL PARK

Paul Llewellyn

1. Introduction

The Shannon Forest and D'Entrecasteaux National Park are two large adjoining areas of approximately 177,000 hectares. The Shannon Forest composes the entire drainage basin (60,000 ha) of the Shannon River which drains the southern portion of the Karri forest belt. The D'Entrecasteaux National Park comprises most of the coastal belt adjoining the Karri forest (approx. 117,000 ha) (CTRC 1984) (Map I).

The priority land use in the Shannon before 1983 was timber production, although it did contain two Conservation Management Priority Areas (Forests Dept 1982). The area has had limited recreational use in the past. The D'Entrecasteaux National Park was formerly almost exclusively Crown land which had been used extensively for pastoral grazing. Some pastoral leases still operate in the area. This part of the coast is widely used for recreation, centred on the beaches and inlets, particularly by people living in the region. There are 26 freehold locations inside the boundary of the proposed Park. These past and present uses have a bearing on the future management of the various areas in the Park for the conservation of their natural environments.

This paper deals with the problem of changing land-use priorities from those mentioned above to those with a conservation emphasis. Although proposed as "national parks", to date only parts of the D'Entrecasteaux have been declared as such. Land management agencies have been briefed to manage (and to plan for) the areas as though they are National Parks.

The areas were proposed for reservation as National Parks in order to preserve a broadly defined set of conservation values (see Conservation Through Reserves Committee 1974; Bradshaw et al. 1975; Campaign to Save Native Forests et al. 1982). In the Shannon forest the principal values include tall Karri forest associations, other forest types and vegetation associations, landforms and drainages; and in the D'Entrecasteaux they include expansive coastal landscapes, a rugged coastline, estuaries, inlets, sand-dune systems and beaches. Both parks are of value because of their sheer size, being many times larger than other National Parks in the Karri forest areas (Map I).

Given this wide range of identified values and the scale of reserves, the design of park management aims to protect the overall or general conservation values (Good 1981). Thus, the broad objective for the management of the parks' natural resources is in accord with the view that: management should provide for the conservation of ecosystems represented in the parks.

2. Development of Fire Management Plans

In the development of the framework for fire management, it is recognised that fire is a major factor in the park ecosystems. The many apparent adaptations of the Australian flora to fire and the different fire regimes are well documented (Gill 1975; Ashton 1981; Christensen et al. 1975; etc). Such adaptations are widespread in the plant communities represented in the park. Although the effects of fire on the wildlife communities are evident, the overall range of frequencies, intensities, season and scale of burn to which they have become adapted is not always obvious. Furthermore, while wildlife communities might be fire tolerant, this does not mean that they are necessarily dependent on fire for their long term maintenance.

Notwithstanding these uncertainties, fire is considered as a key park management tool to be used to achieve conservation objectives and the protection of cultural values.

It is not possible, or sensible, to attempt to achieve a "natural fire regime" - if that could be defined - in 177,000 hectares surrounded by and containing settlements, private property, roads and regenerating logged-forest areas. However, operational fire management plans are needed for the parks. Managers must therefore make full use of the presently available skills and technologies to develop a fire management framework which provides for:

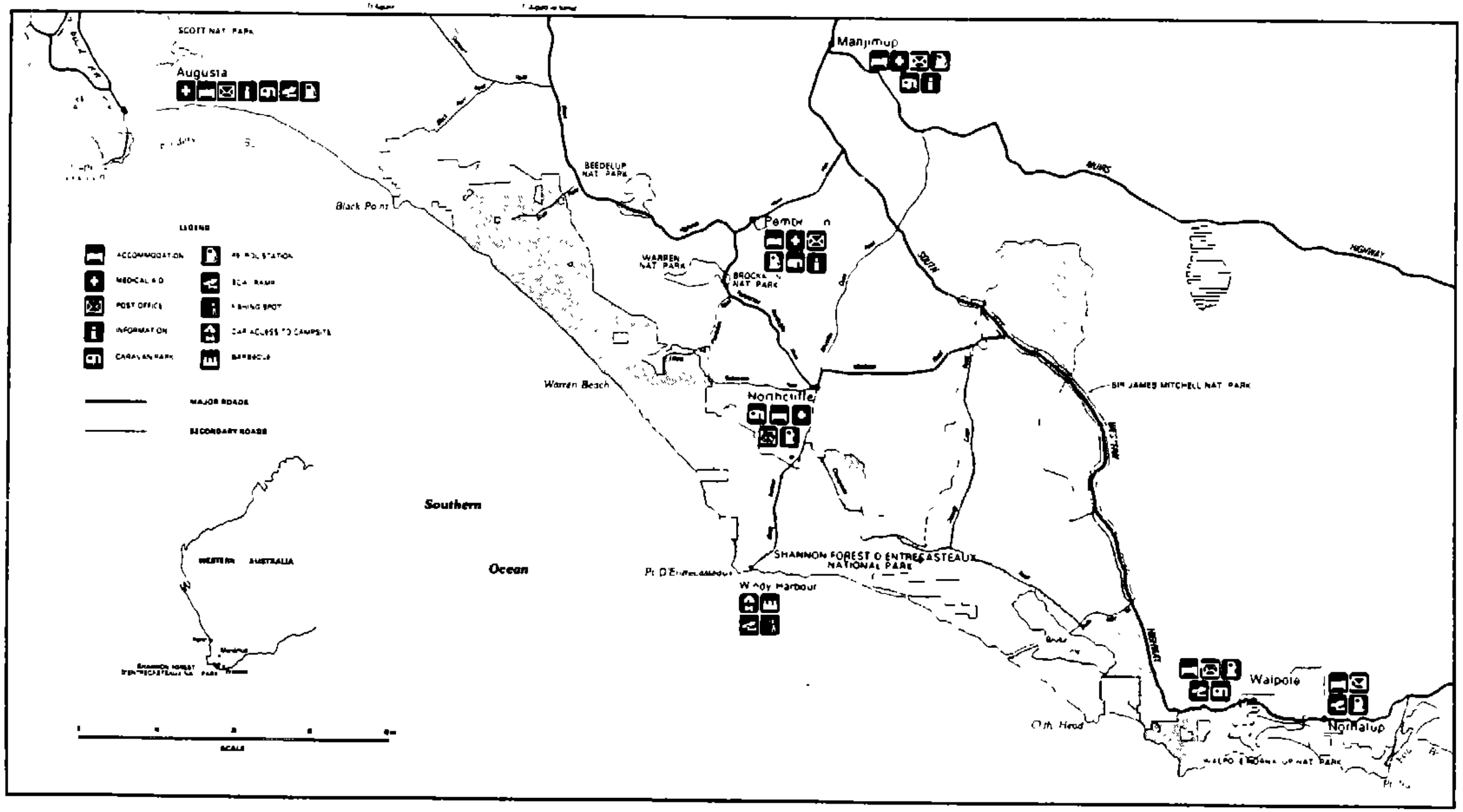
* the preservation of the physical landscape and the conservation of all species of plant and animal in the parks (i.e. the conservation component of National Park management objective).

* a sensible basis for increasing our understanding of the relationship of representative wildlife communities to fire.

To do this a framework is developed which attempts to deal with the wildlife resource in **time** - through the concept of succession, and in **space** - using the concept of ecosystems.

2.1 The Successional Model

It is convenient to consider a basic model of the effects of fire disturbance on wildlife communities. Although, as Noble & Slatyer (1981) point out, "the classical model of ecological succession is of limited value in communities subject to recurrent disturbance", the concept is nevertheless useful. Models of secondary succession which emphasise the initial floristic composition of sites (Egler 1954) and the competitive hierarchy of species (Horn 1976) have redefined the processes of change after fire disturbance. However the progressive changes in structure, composition and relative abundance of communities as they recover from fire disturbance is reiterated (Noble & Slatyer **ibid.**). These changes contribute to the overall richness and diversity of resources in space and **time**. It is assumed that such qualities are essential ingredients for the long term maintenance of viability of the park ecosystems.



Map I. The proposed Shannon Forest and D'Entrecasteaux National Park are considerably larger than the surrounding parks and reserves.

In the absence of detailed information about fire effects and "requirements" for natural areas, many National Park managers opt for maximum diversity of composition and structure of wildlife communities. The conservation fire management objective in that case would be: **To maintain a wide range of 'successional stages' in each of the major wildlife communities.**

Good (1981) points out that it is desirable to have a major portion of the park communities in a late stage of succession. This is the only way to maintain flexibility in the management of community succession. If the bulk of the resource is in the early stages of succession, there will be few short term options for manipulating the structure and composition of wildlife communities. Conversely, reserves with large portions in later stages of succession can be readily manipulated with many management options. Areas can be selectively burned to achieve the desired level of structural diversity. Wildfires from both natural and human sources will inevitably contribute to the overall diversity.

In the development of fire management plans for these parks it is assumed that successional diversity is a sensible objective. It is also assumed that managers should attempt to maintain a wide range of options for management of the parks' biophysical resources. Given these guidelines, strategies for implementation are needed. In many parks, diversity is achieved by burning a random patchwork of areas. To avoid this style of management, it was necessary to develop a more formal framework for fire management. This gave rise to a broadscale ecosystem approach to planning.

2.2 Towards an Appropriate Land Management Unit

Much fire ecology research is specific to a particular vegetation type, species or even site. As a consequence fire management plans for conservation areas are often based on scanty information from a few post-wildfire studies or species specific studies which are not necessarily applicable to the particular area. This research information is important in itself, but not always immediately useful in the development of management plans where there are complex distributions of different vegetation types, and where similar vegetation types occur in quite different sites and topographic locations.

Both of these conditions apply to different degrees throughout the Shannon Forest and D'Entrecasteaux Park. It is therefore not sensible to treat individual vegetation types in plans of this scale. Land management units must be defined which reflect:

* a scale appropriate for planning fire management in these extensive reserves, and

* the intended conservation management objective.

If an individual vegetation type is not an appropriate unit, then what is an appropriate scale?

It was possible to delineate broadscale natural land units in the parks on the basis of landforms, the distribution of key vegetation types, drainage and erosional processes. Areas with repeated patterns of landform and vegetation occurrence were delineated.

Each identified land unit therefore represents an assemblage of vegetation-community types related by soils, site, nutrient cycling and other biophysical characteristics. This fits Kreb's (1972) textbook definition of an 'ecosystem'. Thus, for example, the plant and animal communities of the plateaux elements of the Shannon Basin are distinguished from those of the lower flood plains and transitional wetlands on the coastal belt, and so on.

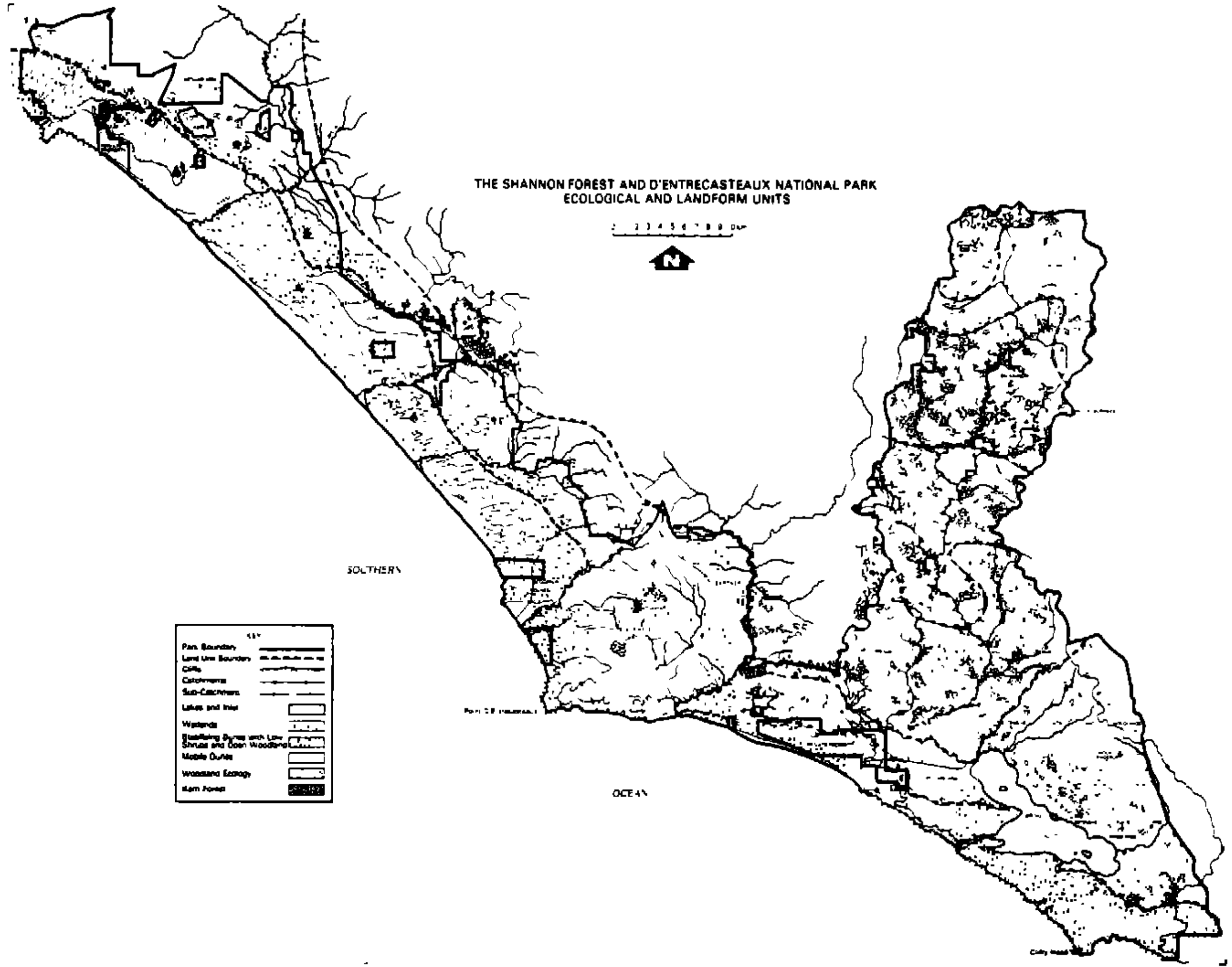
The land units highlight the changing sets of relational circumstances between the various plant and therefore animal communities. In many instances the land units also represent distinctly different circumstances for different vegetation types from the fire point of view. For example Karri forest, which occurs in extensive contiguous stands in steep incised valleys (central Shannon) would be prone to a very different fire regime to the islands of Karri which occur on low erosional hillocks surrounded by extensive heath and sedgeland flats (lower Shannon). Similar comparisons can be made for most other vegetation types in different land units.

Five key land units can be distinguished in the forest areas of the Shannon. In the coastal areas, six key land units are defined by sand-dune formations and wetlands, although vegetation associations are equally important (Map II).

For the purpose of planning, the broadscale natural land units are treated as land management units. All aspects of park management - especially fire management - can then be designed to conserve the specific ecological and landform characteristics of each unit. This means that characteristics of each unit must be clearly described, mapped, and eventually quantified. Given this rationale, the operational fire management objective would be: **To maintain a range of burn ages (i.e. successional stages) in each of the identified natural land units.** It follows therefore, that some areas, those designated as reference areas, must not be deliberately burned, while other areas should remain unburned for long periods. There will be areas in early successional stages as a result of wildfires and the need for some protection burning.

3. Fire Management Design

Having defined an operational objective, it is then necessary to systematically deal with the planning issues which arise out of re-orienting fire management objectives in the parks. Land management agencies have many obligations when designing fire management plans. To mention only some they must:



Map II. A series of natural land units has been delineated on the basis of landforms, drainage systems and the distribution key vegetation types. Each land unit is treated as a 'management unit' for the purpose of planning.

* ensure the safety of park visitors, neighbours and staff

* minimise the risk of damage to private property and public values in and adjacent to the parks

* prevent soil erosion and catchment degradation

* reduce the spread of exotic weed species and diseases

* retain some "fire induced" landscapes which form the basis of a park attraction.

The resolution of these issues often involves the use of some form of overlay mapping to highlight the key features in the parks. In this regard, an information data bank for fire management in the parks will be needed which identifies high-value areas and which provides guidelines for both planned and wildfire management (Good 1981; Claus, undated). The type of information required could include the location or distribution of:

* towns

* settlements

* private property and assets

* public assets

* young, fire sensitive Karri forest (< 20 years)

* recreational facilities, roads, bridges

* public recreational use patterns

* surrounding conservation values

* surrounding timber/forest values

* current and future timber cutting operations

* fire induced landscapes

* fire sensitive areas (e.g. fragile coastal dunes)

* rare or endangered species

* prime conservation value areas (e.g. pristine Karri forest, coastal heath landscapes).

Other information could include:

* fuel accumulation data

* fire behaviour data

* availability of suppression forces

* climatic data

The design of the plan to meet the conservation objective must make full use of the available roads and tracks and natural fire management boundaries.

Several design constraints were considered in the planning for the parks. They included:

* no further road or track development unless absolutely necessary

* minimal physical impact

* budgetary limitations similar to existing fire management programme

* legislative constraints.

3.1 Where Are We Coming From?

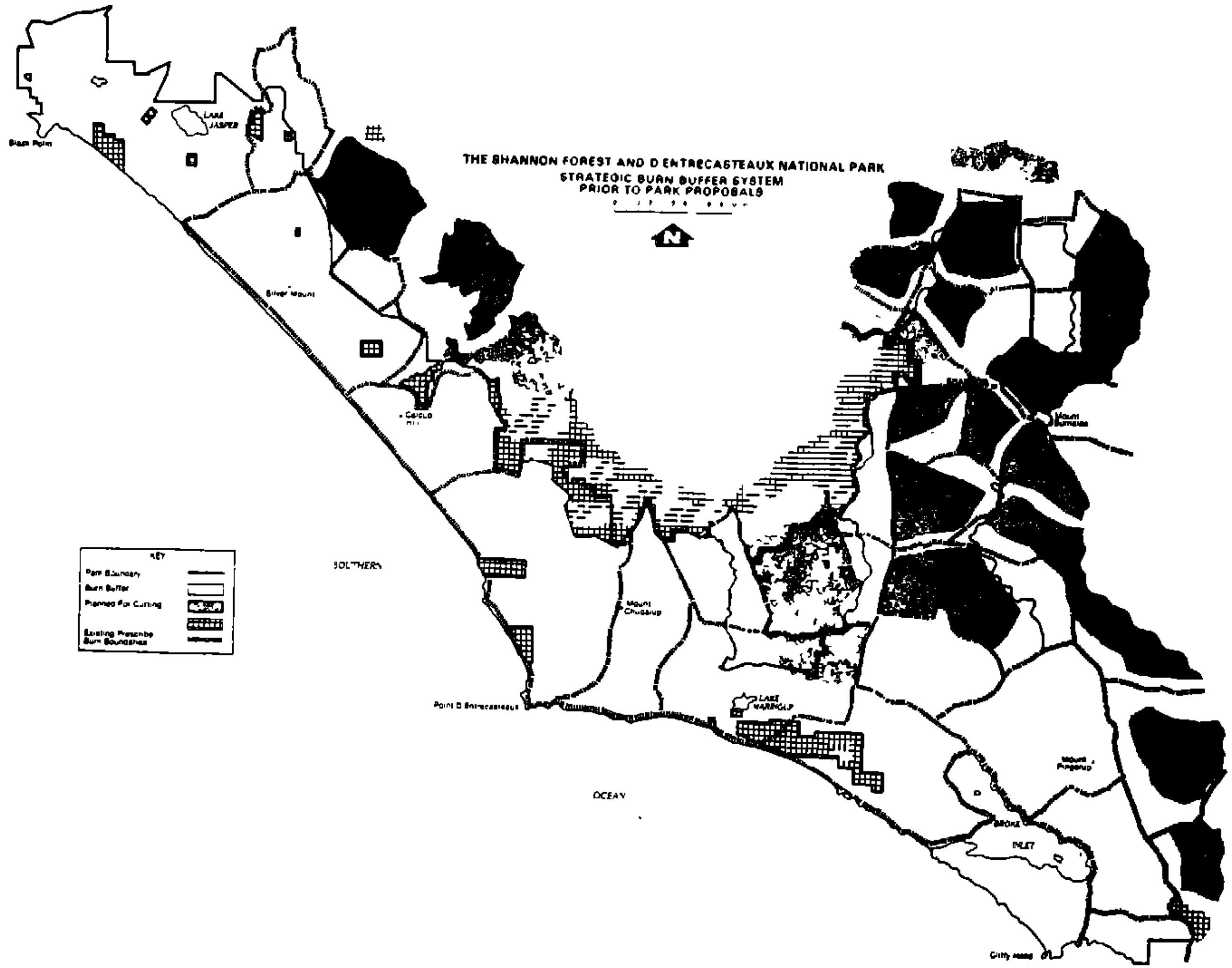
The current "fire protection" system covering the parks is summarised in Map II. A strategic buffer system divides the Southern Region forest estate into areas in which cutting and regeneration will take place in phase one. After these core areas are fully cut over, regenerated, and available for rotational burning, the buffers are cut and the process reversed. In addition to this long term strategy, year-to-year prescribed protection burns are carried out on a rotational basis to keep fuels below designated levels (Jarrah 8 tonnes/ha, Karri 18 tonnes/ha; no clear objective is set for non-forest areas). In practice most areas are burned on a 5-7 year rotation.

3.2 Where Are We Going To?

The design of this plan involved a process of compromise and adjustment to accommodate the conservation and protection objectives discussed above. The plan provides a reasonable combination of long rotation between fires in areas allocated specifically for conservation, and short-term rotation burning in buffer zones. The plan offers an opportunity to investigate the long-term ecological effects of a wide variety of fire regimes without compromising "protection" objectives (Map III).

The overall strategy aims at providing safe areas of flexible fire management within each of the key land units. Natural fire boundaries (sand-dunes, open water, main rivers) and fuel-reduced areas are utilised to divide each key unit into "cells". The risk of a major wildfire burning through large areas is reduced by breaking the park up into such cells.

The existing protection (by fuel reduction in forests outside the parks) have been considered in the park-management plan. Burn-boundaries between the parks and State forest have been allowed to overlap where necessary. The protective value of surrounding forest areas must be evaluated in terms of the presence of regenerating fire-sensitive Karri, and logging operations. It is proposed that the park management agency should co-operate with neighbouring landholders to ensure mutual satisfaction in fire management issues. The success or failure of the plans will depend to a large extent on good relations between the park managers and neighbouring land users.



Map III. Prior to their management as National Parks, these areas were incorporated into the strategic burn-buffer-system for protection of State Forest values (see section 3.1). The existing prescribed burn boundaries indicate that all areas were burned on a rotational basis, nominally 5-7 years.

All settlements and facility areas are given special protection by surrounding them with fuel-reduced buffers. The future protection of specific high-value or high-risk areas should entail careful assessment of the actual fire risks, and investigation of the options for reducing those risks to acceptable levels.

3.3 What is a Flexible Fire Management Cell?

Each cell usually comprises two to three fire management compartments that are bounded by roads, though on the coast this is often not possible and so individual blocks are isolated. One compartment is designated as a 'no planned burn area' and the other compartments are managed as 'long rotation areas'. In this way, a range of successional stages will be represented in each cell.

It is proposed that the long rotation areas be reviewed after 15 years at which time they can be assessed to see if the periodicity of burning is ecologically desirable. Criteria used in the assessment of areas must be specified quantitatively if possible. They could include the following:

* species composition and diversity (flora and fauna)

* structural characteristics

* litter characteristics

If at the time of assessment there are clearly discernible differences in the structure and composition of the communities in areas of different ages in the same land unit, this could constitute a case to defer burning.

The decision to burn or not to burn must also take into account the effects of past wildfires and/or the probable effects of future wildfires on both internal and external park values. If the area is not burned then it should be up for reassessment within a specified period of time, for example at age 25 years.

3.4 Fire Frequency: A Key Consideration

Fire frequency is emphasised as a key consideration in the long term management of park ecosystems. Apart from those already discussed the reasons for this emphasis include:

* most other factors, i.e. intensity, season of burn, size of burn, etc., can be readily manipulated from year to year

* many authors recognise the overriding importance of fire frequency and species life cycles in relation to secondary succession (Gill 1975; Noble & Slatyer 1981; Ashton 1981)

* variation in fire frequency is the missing ingredient in current fire regimes.

A proposal to allow areas in the parks to remain unburned requires very careful design and planning. The problems which arise out of the proposal must be confronted and resolved to the satisfaction of all parties concerned. If hazards exist they must be evaluated in terms of who, what, when, where and which are at risk, and all available options must be investigated to solve the problem. This will require formalisation of the decision-making processes in National Park management so that conservation criteria in fire management complement other considerations.

3.5 Wildfire Control

Wildfires are inevitable in National Parks and hence involve a key aspect of park management.

The retention of large areas of unburned parkland may create an environment prove to the development of largescale wildfires. While these issues are beyond the scope of this report, it must be stressed that park managers require a clear set of guidelines and policies for field management. The strategies for wildfire control, the pre-suppression and detection requirements, and the land use priorities in each area must be updated and reviewed regularly. In addition management staff must be well trained and aware of their responsibilities in dealing with National Park lands.

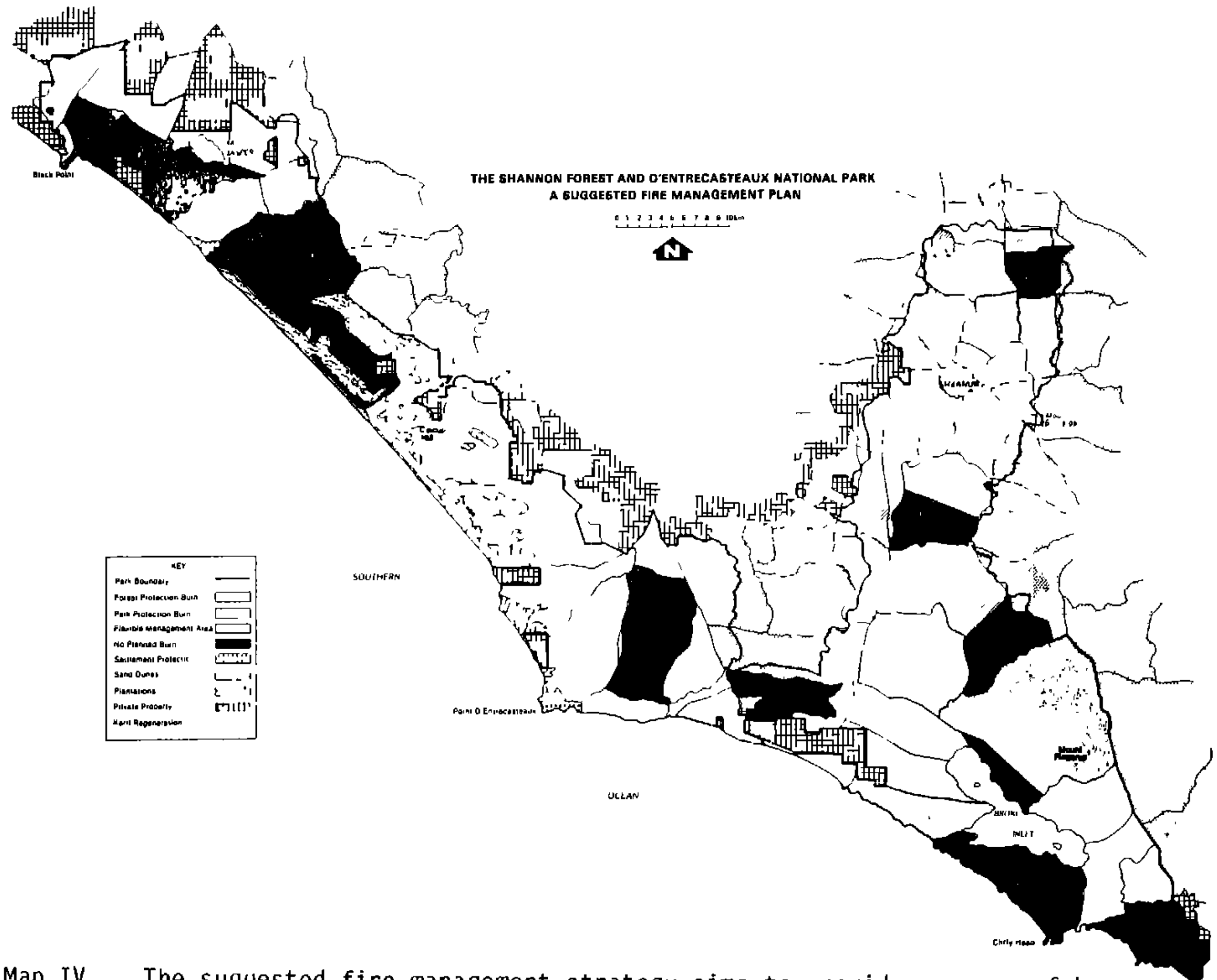
4. Conclusions

The fire management plan which has been presented here is based on the best available data. It is assumed for a number of reasons that a complete fire exclusion policy is not a viable management option. Similarly a strategy involving short rotational burns for protection is equally undesirable for National Park management.

The plan has been based on land units rather than on vegetation types, for this is considered to be the most practical and sensible approach. The concept of safe flexible fire management is in principle similar to the approach adopted for the Perup Fauna Priority Management Area (Christensen 1982). The Perup Fire Plan, however, focuses on specific faunal habitat, and has been operating for some time.

The idea of having flexible management-areas needs more careful consideration. The parameters, which should be measured to provide data on whether to burn or not, have not been ascertained. Until they are, it is suggested that simple parameters, such as species diversity, litter accumulation and minimum flowering-age of species, be used.

Because these plans are essentially experimental in nature, monitoring and research must be considered as a key component of the management programme. It is unlikely however that the financial resources will be available to



Map IV. The suggested fire management strategy aims to provide a range of burn ages (secondary successional stages) in each of the identified land units. Where possible, planned non-burn areas and flexibly managed long-rotation areas are isolated into cells by natural fire boundaries and broadscale fuel reduced buffers. Surrounding private property, pine plantations and regenerating Karri forest have been considered in the design of the plan. Rotational protection burns in forests outside the parks have been dovetailed with the fire management programme within the parks.

consider fire effects in any detail. Research priorities must therefore be carefully defined and monitoring programmes must be designed which suit the scale of the parks and the available management skills and resources. Extrapolation of at least some information from other areas is inevitable within the foreseeable future. As better information becomes available, changes and modification to the plans can be made where necessary.
In the design of these plans, duplication of a 'natural' fire regime has not been attempted. However, there is a need for research into the way in which fire has affected the wildlife communities in the parks. This may require some investigation into the use of fire by local Aboriginal populations before white settlement, and documentation of the use of fire by early settlers and pastoralists in the areas.

Fire is a little understood subject, and one which is of concern to many people. The fire management scenario presented here has attempted to provide a basis for improving the general understanding of fire ecology in the park environment. The successful implementation of the plan will require that park users and neighbours appreciate the intention of the proposed management. This will require public education to develop awareness and a general understanding of the principles and problems of fire management in national parks. Conversely, it will be the responsibility of management agencies to undertake social and economic research so that they fully understand public needs and expectations with respect to fire management (Stankey 1976).

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PLANNING THE USE OF FIRE ON CONSERVATION LANDS IN SOUTH-WESTERN AUSTRALIA

A.J.M. Hopkins

Introduction

A number of papers in these proceedings provide a summary of much of what is known about the effects of fire on the biota in Western Australia. Obviously there is much more to learn; indeed we are never going to be in a position of complete knowledge and understanding. Management programmes that make best use of existing knowledge and, at the same time, allow for additional information to be collected must thus be developed for it is through an iterative process that management will be refined.

The planning process is the major vehicle for interpreting knowledge and having it applied. But the process needs to be structured in order to deal effectively with conflicting objectives. In this paper I outline a planning process suitable for use in developing fire management plans for nature conservation lands.

Table 1. Management objectives for conservation lands as they might translate into actual fire management strategies.

Overall Management Objectives	Fire Management Objectives	Fire Management Strategies
1. Conservation of indigenous biota.	a) Protection to ensure whole reserve not burnt by a single fire. b) Fire exclusion from selected areas.	Mosaic burning. Construction of strategic fuel reduced zones. Fire suppression.
	c) Maintenance of process.	Ecological burning.
2. Protection of neighbouring property.	a) Fire protection. b) Fire suppression.	Construction of firebreaks. Fuel reduction burning. Fire fighting.
(3, 4, 5 ... Education, Research, Recreation ....)		

Fire Management Objectives

The planning and management process is generally structured in a heirarchical way starting with overall aims and objectives and working through specific objectives and strategies to tactics and actions. Table 1 illustrates a part of this heirarchy as it relates to the use of fire on conservation lands. For example, for conservation, it is important to avoid having any isolated reserve completely burnt out by a single fire event because local extinction of wildlife species could ensue; immigration and subsequent recolonisation would be restrictd by the reserve's isolation. Strategies for achieving this objective involve dividing the reserve up in some way that incorporates low-fuel areas and application of fire suppression measures where necessary.

The concept of maintenance of process requires special explanation. Basically, all plant and animal communities have evolved under a regime of various disturbance types (volcanoes, rockfalls, landslips, fires, floods, ... frequent to rare, intensive to mild, extreme to small, etc.). These disturbances trigger off regenerative processes that contribute to the character of the communities. Thus the conservation of the communities may involve ensuring that the disturbance regimes are continued. Likewise, it may be necessary to ensure that a new regime is not put in place. This is maintenance of process.

Fire was one of the disturbance types affecting Western Australian plant and animal communities during their evolutionary histories. Some of the fires were of natural origin; others were lit by Aboriginal people. But for most conservation lands the regimes of fire now prevailing differ from those of pre-European times. Thus management of those conservation lands may involve deliberate application of the previous regime over certain areas to conserve the biota through maintenance of the processes associated with that type of fire.

In the event that it becomes necessary to impose a fire for the purpose of maintenance of process, then the prescription is likely to differ from that for a fuel reduction burn for the same area. This is because the two management objectives invariably involve quite different fire regimes. The point is exemplified in Table 2. Note in this table that I have added a spatial consideration to the list of factors indentified by Gill (1975) as being necessary to characterise a fire regime. Spatial factors (areal extent and patterning or mosaic) have a major bearing on post-fire changes such as invasion, recolonisation and grazing.

As indicated above, one input into the fire behaviour model is information on the fuel array. This can either be sampled directly in the field or modelled. The models are calibrated using empirically derived data and incorporate estimates of litter fall rates, decomposition rates and proportions of fuel reduction resulting from any prescribed fires or wildfires. Some such models are available for wheatbelt vegetation types at Tutanning Nature Reserve (Fig. 1) but more will be required to complement any new fire models.

Table 2. Summary of typical fire regime characteristics for fuel reduction burns and ecological burns for a semi-arid woodland site in south-western Australia.

	Fire Management Objective	
	Protection	Maintenance of Process
Type of Prescribed Burn:	Fuel Reduction Burn	Ecological Burns
Regime characteristics:		
frequency	regular & frequent	irregular, infrequent (pseudo-random)
intensity	cool	hot
season	spring	late summer-autumn
spatial factors	patchy, often of limited areal extent	more uniform, often extensive

Fire Prescriptions

Once the objective for any management fire has been clearly defined then it is necessary to develop a prescription for achieving that objective. This necessitates the use of a fire behaviour model by which the dynamic properties of the fire (rate of spread, intensity, energy profile) might be predicted for the particular fuel array, terrain configuration and meteorological conditions. Models that are available for use in Western Australia at present are contained in the Modified McArthur Grasslands Meter (McArthur 1966) and the Forests Department Red Book (Sneeuwjagt & Peet 1979). Without doubt these models can provide some useful guidelines for fire management in some natural grasslands and non-forest vegetation types, but their general applicability to the many fuel and vegetation types occurring on conservation lands throughout the State is limited. There is an urgent need to develop new fire behaviour models that are appropriate for these conservation lands. The 3-strata Rothermel model, as adapted for Australian conditions and being used in New South Wales (Kessell 1985), warrants examination for its suitability for use in Western Australia.

Two features of the fuel accumulation curves given in Figure 1 deserve special mention. Firstly, the maximum standing crop of fire fuels in Wandoo communities at Tutanning is unusually low at around 9 tonnes/ha. It is possible this may reflect the high level of termite activity in this community. Secondly, the shapes of the curves for communities dominated by **Allocasuarina huegeliana** suggest that effective fuel reduction is difficult to achieve. **A. huegeliana** is extremely fire sensitive - trees are killed by even very mild fires - but they are rarely consumed. The dead trees begin to topple over after 3-5 years and then contribute to available fuels for a further 10-15 years. These two features, the naturally low fuel loading in Wandoo communities and the high post-fire fuel loadings in Allocasuarina communities, have important implications for the development of a fire management plan for Tutanning.

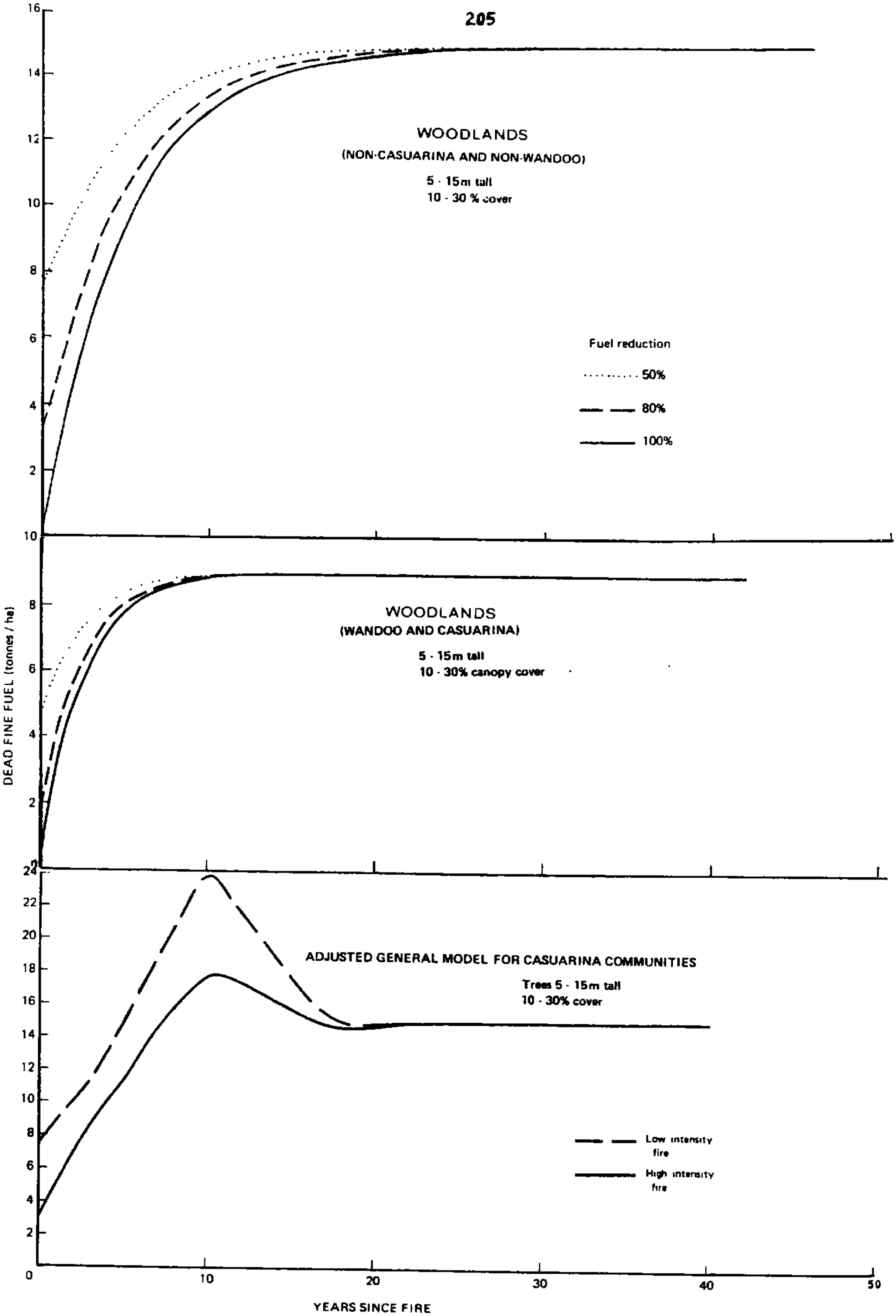


Figure 1. Fire fuels accumulation curves for some vegetation types at Tutanning Nature Reserve (Kessell et al. 1984).

A Systematic Approach to Planning the Use of Fire on Conservation Lands

There will inevitably be conflicts to be resolved in the development of fire management plans for conservation lands. Perhaps the most fundamental conflict is between fire protection for neighbouring lands and conservation: complete protection can require fuel reduction over much of the reserved area but the principal components of the fire fuels, the litter and shrub layers, are also important components of the biota and provide important faunal habitat and nutritional resources. Litter and shrub foliage invertebrates are major dietary items for vertebrates.

To facilitate resolution of conflicts such as this, I have developed a step-by-step process for planning the use of fire on conservation lands (Table 3). I illustrate this process using the fire management plan drawn up in 1976 for the Two Peoples Bay Nature Reserve, some 30 km east of Albany. The reserve is described in Hopkins (1985).

Table 3. A systematic procedure in planning for fire management on nature conservation lands in Western Australia.

1. Define aims/objectives for area.
2. Identify sources, risks.
3. Collate fire history data in conjuction with climatic data.
4. Examine ways to manage sources/risks without impact on biota.
5. Survey area for vegetation, fuels, natural low-fuel areas, important biota requiring special attention.
6. Redefine objectives if necessary.
7. Assess management capability for both planned and unplanned fire.
8. Examine simple methods for isolating sources from risk areas (strategic).
9. Plan other essential fire control measures.
10. Plan ecological burning requirements.
11. Undertake modelling where possible.
12. Plan and implement monitoring programmes.
13. Reassess plan regularly.

1. Aims and Objectives for the Management of the Reserve include:

   1.1 Conservation of the Noisy Scrub-bird.

   1.2 Conservation of other rare speces of wildlife including the Western Whip-bird and the Western Bristle-bird.

   1.3 Conservation of the plant and animal communities represented on the reserve.

   1.4 Public education.

   1.5 Research

   1.6 Public recreation (there is an established picnic area and fishing is very popular).

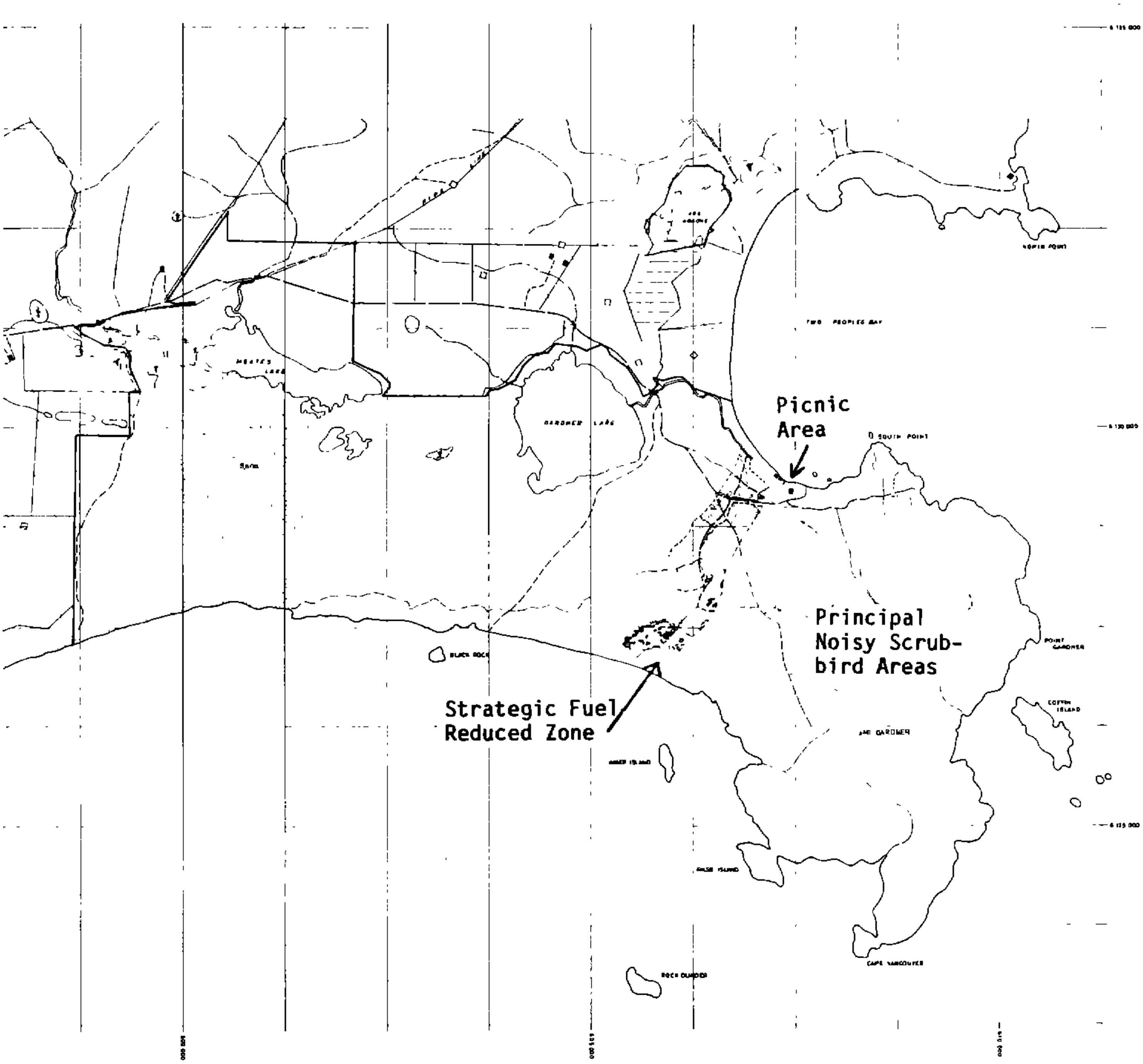
   1.7 Protection of human life and property values (reserve users and neighbours).

2. Sources of fire include the barbeques in the picnic area, marron fishing areas around Moates Lagoon, other public use areas, roads, and farming areas to the north and west of the Reserve.

   The population of Noisy Scrub-birds, at that time concentrated around Mt Gardner was the greatest risk. Next was the public, particularly those members concentrated in the picnic area.

3. Fire history data indicated that major fires in the previous 15 years had come from the west and northwest.

4. An important initiative was to replace the wood-fired barbeques in the picnic areas with gas-fired ones and ban fires from elsewhere in the reserve.



gure 2. Map of Two Peoples Bay Nature Reserve illustrating features of the 1976 Fire nagement Plan.

5. Natural firebreaks include the two lakes and the sand dunes at the western end of the reserve, and the large expanses of bare granite around Mt Gardner. There were no species other than the rare birds that were known at that time to require special attention.

6. Objectives were maintained.

7. There was a resident Ranger on the reserve equipped with two mobile units. Fire fighting assistance was available from the local Bush Fire Brigade and from departmental staff throughout the south-west.

8. A strategic, fuel reduced zone was designed through the isthmus with the objective of isolating major Noisy Scrub-bird habitat areas from the major sources of fire to the west (Fig. 2). This buffer was divided into 12 manageable blocks to be fuel reduced.

9. All boundary and internal firebreaks were maintained and/or upgraded. A programme of fuel reduction burning along road verges was instituted.

10. No burning for maintenance of process was planned.

11. A version of PREPLAN (Kessell et al. 1984) is being developed.

12. A detailed study of effects of fire and subsequent regeneration was initiated in September 1976. This is continuing.

13. The plan is due for re-evaluation in 1986. All research and monitoring are being collated at present.

The resulting Fire Management Programme satisfied the needs for internal and external protection, it enables large areas to be left unburnt for conserving the rare birds without causing undue danger and it has provided opportunities for research so that the next plan in 1986 will be substantially better than the 1976 one.

Concluding Remarks

In this paper I have focussed on concepts and decision making processes: concepts that I regard as being central to planning the use of fire on conservation lands and processes that may be used to translate these concepts into management actions. For example, it is an essential discipline to define objectives for a particular fire before developing the prescription - it leads to better decisions and elevates the level of debate should one ensue.

I have also drawn attention to some deficiencies in knowledge about the use of fire on conservation lands. The major deficiency is the lack of appropriate fire behaviour models. Many aspects of information on fire effects are lacking, and most of these will not be addressed by research in the foreseeable future. In the absence of this information it is highly desirable that managers keep good records of the fires they deal with and monitor results of those fires systematically. It is only through such a reporting - monitoring - re-evaluation process that management will improve in the long-term.

Finally, I want to raise the issue of public attitudes to fire. Much has been done in recent years to make people aware of fire safety. A major thrust has been towards fire prevention by fuel reduction burning. This has generated some rather casual attitudes towards fire, including the view that it is a tool that has been completely mastered. I believe that a little more circumspection is justified and warranted; public education programmes should now focus more on the environmental effects of deliberate or accidental incendiarism in order to develop a more thoughtful attitude to the use of fire.

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Plate 1. Heathland, mainly of Dryandra sessilis, after the fire of January 1984.

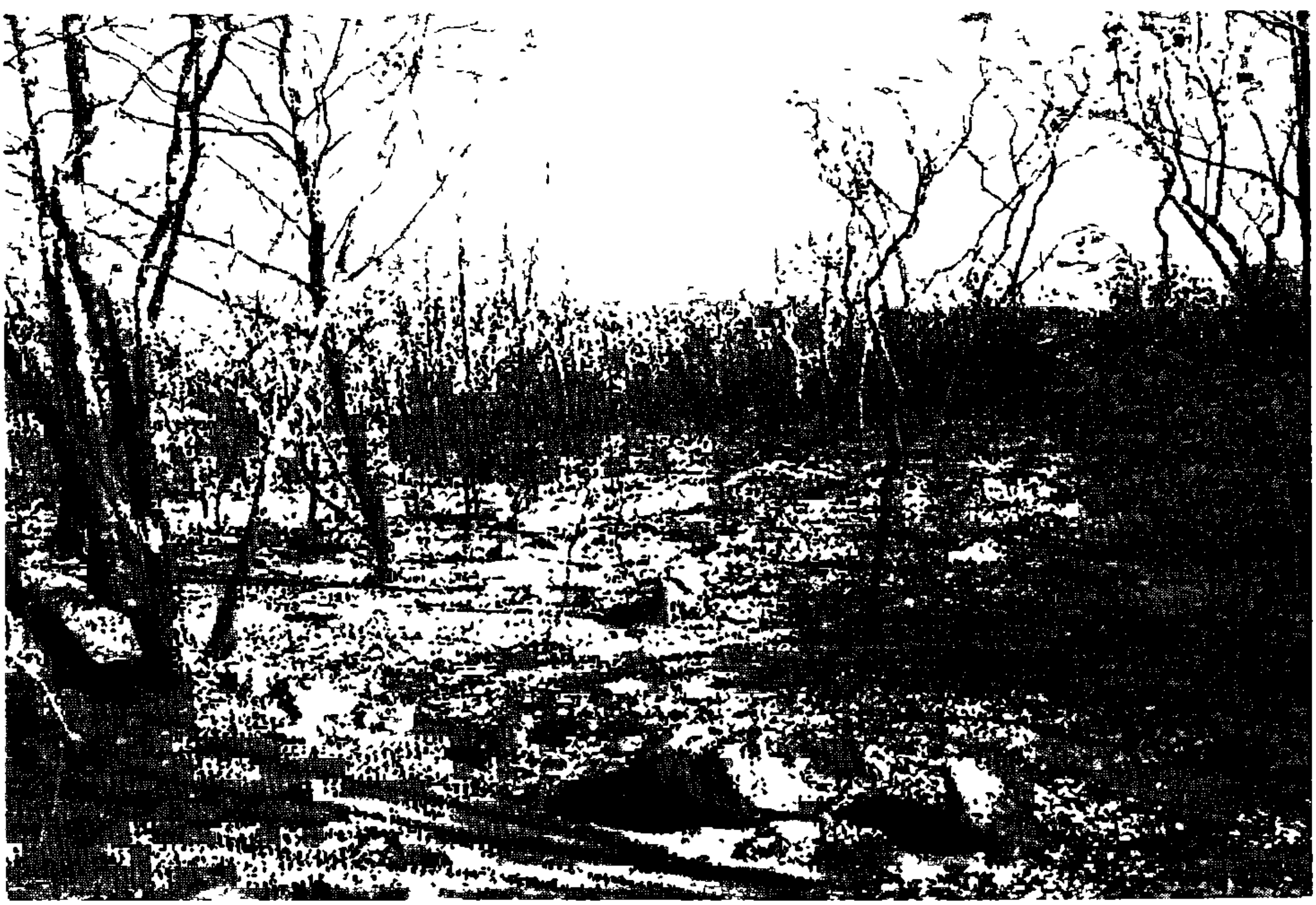

Plate 2. Blackened scene in limestone country on the west coast after the fire of January 1984.

Plate 3. Mixed mallee and wattle scrub destroyed by the fire of January 1984.

Plate 4. Mixed mallee and wattle scrub that escaped the fire.

From the apiarist's point of view, burns carried out after the trees have finished flowering would be the ideal programme. This we believe would not affect the trees natural flowering cycle and would create an ash bed for the seed set which has occurred. Apiarists believe that greater consideration should be given to this aspect, especially in respect to Wandoo and Karri forests.

The four main eucalypts utilised by apiarists in the forest are Jarrah, Marri, Wandoo and Karri. Marri has a short budding period of only two months (December-January) and hence autumn or spring burns have little effect. Jarrah has a 12-month budding period and usually buds every second year. Burning could be done in the autumn or spring after flowering. Wandoo and Karri have a budding period of two years, but usually set buds at intervals four to five years apart. It should be possible to program most burning away from the period of bud set.

The depletion of many species of understorey caused by the frequency of control burning is also of some concern to apiarists. Bees often get nectar and pollen from the many species of understorey that grow in forest areas. We would suggest that some consideration be given to occasionally extending the period between burns to allow the understorey to re-establish.

Conclusion

The W.A. Beekeeping Industry is a small rural industry. It does not have the manpower or the resources to cope with fire on its own. Apiarists have contributed to fire management in the past and will continue to do so in the future. With a more dedicated approach to fire management by all concerned including apiarists, I am sure that many of the adverse effects of fire can be overcome.

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CONTEMPORARY VIEWS OF THE VOLUNTARY CONSERVATION MOVEMENT ON THE USE OF FUEL REDUCTION BURNS AS A LAND MANAGEMENT TECHNIQUE

Alan Tingay

1. Introduction

The intention in this paper is to briefly present the current and evolving attitudes of the conservation movement towards the use of fuel reduction fires as a land management tool. That presentation is followed by a critical assessment of traditional arguments that are used by the advocates of fuel reduction burning, an assessment which is fundamental to conservationists' attitudes. Finally I will outline a prescription for improving the official approach to the use of fire which, if adopted, would confer a high degree of sophistication to this area of land management and would minimise public controversy that is growing over this issue.

2. Policies of the Conservation Movement

The use of fuel reduction fires in land management has not been a central environmental issue of the voluntary conservation movement until recently. However, with the increasingly widespread use of fire in the management of National Parks, conservation reserves, forest areas and urban bushland in south-eastern Australia, critical appraisal of the technique is growing.

In Western Australia, fuel reduction burning has arguably occurred over a longer period and has been applied more comprehensively than anywhere else in Australia. Here misgivings over current applications are also increasing in the conservation movement and there is a growing awareness that this 'sacred cow' of the land management arsenal does not have a solid basis in ecological theory or fact. As a consequence, there is mounting concern that fuel reduction burning as it is currently practised in W.A. may have the potential to cause widespread environmental damage by alterations to ecosystem processes, to vegetation structure and resilience, and by loss of fauna habitats. This seminar is testimony to these concerns.

To my knowledge at this time only one conservation group in Australia, the Nature Conservation Council of N.S.W., has a specific policy on fuel reduction burning. However that group is large and represents 75 affiliated scientific, conservation and environment groups in N.S.W. In addition the Australian Conservation Foundation (ACF) has circulated a draft policy for discussion and it is expected that a final document will be endorsed by the ACF council later this year.

Essentially these two policies are very similar and it can be anticipated that they will provide models for future policies of other State Conservation Councils.

In summary the policies state that the voluntary conservation movement is not opposed to fuel reduction burning per se but that it is opposed to burning being used in certain areas, at too frequent intervals, without adequate controls and with little thought to ecological and aesthetic consequences. They advocate the development of management plans which consider alternatives to the use of fire in attaining management objectives.

It would appear from these policies that there is definite possibility that a new dimension may be added to the classical controversies that have surrounded the management of Australian eucalypt forests. These controversies are of course, clearfelling, production of woodchips and pulp, the clearing of indigenous forests for pine plantations and the priority given to intensive production over conservation. To prevent fuel reduction burning being added to this list it will be necessary for land management authorities to modify existing practices substantially.

In order to understand why this situation is developing it is necessary to consider attitudes within the conservation movement to the priorities of, and justifications for, current practices.

3. An Analysis of Current Priorities and Supporting Arguments

3.1 Priorities

The concern of conservationists largely stems from the fact that in many contexts of natural land management and particularly in Australian forests the use of fire has a single or at least a predominant objective. This is to remove vegetation for the protection of human life and property and resources such as tree species utilised for timber. The objective is therefore socio-economic.

There has been very little consideration of ecological management objectives and a singular dearth of knowledge of environmental consequences either at the species, community or ecosystem level. Unfortunately there has been a tendency among management authorities to play down these matters and a reluctance to admit that problems may exist. This attitude is often based on generalisations regarding the natural role of fire in Australian forested ecosystems. These generalisations lie at the heart of the increasingly intense debate of fire and require careful scrutiny.

3.2 Natural versus Deliberate Burning

It is generally accepted that many Australian ecosystems have been influenced by fire in an evolutionary time scale. From this, it is often argued by managers, that fire, being a natural agent, is an essential requirement for the maintenance of ecosystem vigour. The argument may be supported by "evidence" of large scale seed fall and germination of various plant species after fire.

An alternative view may be put; namely that fire is a negative ecological factor which has necessitated the evolution of protective adaptive responses by flora and fauna. Large scale germination in this context may be interpreted as a response to ecosystem stress and damage.

Resolution of this argument is of course, fundamental to the evaluation of fire as a management option. A satisfactory answer will depend on extensive and long-term research in plant ecology to establish what are the necessary conditions for recruitment.

3.3 Aboriginal Use of Fire

There have been claims that modern hazard reduction burning is a continuation of Aboriginal land and game management practices. As such it constitutes no threat to natural ecosystems.

This argument is certainly a simplification for Australian eucalypt forests and should not be seriously entertained by managers. The basic facts about historical Aboriginal use of fire are unknown in most areas; there are few reliable scientific data and historical accounts are difficult to interpret precisely.

There is also the possibility that use of fire by Aboriginal peoples may not have constituted an optimal management technique for the ecosystems to which it was applied. The objectives of these previous land managers obviously differed from those which have priority today. Contemporary management applications should be based on rigorous scientific investigations of ecological consequences rather than on historical interpretation.

3.4 Frequency, Intensity and Timing

Independently of the above arguments, it can be safely assumed that the present use of fire differs substantially from natural fire regimes in frequency, intensity and timing. To produce manageable fires, control burns are generally applied with relatively short periodicity, moderate intensity and uniform season (usually Spring). Natural fires at any specific location were likely to have been variable in each of these respects. It follows that the ecological effects of hazard reduction burns may differ from those of natural fires. Again there is the possibility that these effects may be negative.

4. The Development of Management Plans

4.1 Research

The brief analysis of arguments used to justify current burning practice stresses the need for substantial research into possible ecological effects. Our argument is that any land management technique that is applied extensively should be evaluated first and foremost in terms of its ecological impact. The overall priority of management authorities should be to endeavour to maintain ecosystems in a natural state.

It can be assumed that ecosystems generally have tolerance limits to both natural and management events and that if these limits are exceeded deterioration is likely. The direction of research should be to try to define those limits in terms of fire tolerance.

Strategies used to achieve other priorities such as the protection of human life and property should always be required not to exceed the natural tolerance limit in their effects on the environment. If the strategy does not meet this requirement then the potential of manipulating other variables should be considered in detail.

For example, relocating or redesigning human settlements may be warranted in extreme cases. More practically, intensive management designed to protect a settlement may be appropriate in its immediate vicinity. The environmental damage which may occur in this context is preferable to broad scale application of fuel reduction burning to whole ecosystems ostensibly to achieve the same result.

A limitation of this approach is the fact that research is a slow process even when resources are committed to it. As there is a need for active management now, the problem becomes to ensure that present management has minimum potential to cause unforeseen consequences. This problem can be solved with the development of regional management plans which are conservative in terms of direct environmental impact.

4.2 Management Plans

4.2.1 Current Management Plans

At present there is a tendency in Western Australia for management plans to be little more than burning schedules for fuel reduction. They simply specify what parts of the management area will be burnt at what time. An example is the management plan produced for the Walpole-Nornalup National Park.

This tendency reflects an attitude of management authorities such as the Bushfires Board and Conservation and Land Management Department that fuel reduction burning is the only option which will achieve their priorities.

4.2.2 Regional Fire Management Plans

The present crude approach to management needs to be replaced by a sophisticated assessment of regional land use and land management objectives and of wildfire potential, behaviour and consequences. This analysis would then provide the data base for the development of wildfire prevention and control strategies designed to achieve multiple objectives.

In my view, seven steps are necessary to achieve each regional plan:

(1) Description: a comprehensive description of the region in terms of climate, topography, land use, vegetation, fuel loads, town planning etc.

(2) Analysis of these variables to provide a prediction of probabilities of wildfire in terms of generation and behaviour. This process could be greatly assisted by:

(3) Simulation: computer models of fire behaviour in complex environments are currently available and are being used in some parts of Australia. An example is the use of PREPLAN in the Blue Mountains National Park of N.S.W. In area this national park approximates the State Forests of W.A. but it has a much more complex topography and presents more difficulties in terms of wildfire control (see paper by Roger Good in this publication).

(4) Strategy development to prevent and control wildfires based on the above analysis. The strategy would be designed to achieve multiple objectives including the protection (non-manipulation) of bushland areas as far as possible.

(5) The Regional Plan would then be evaluated in terms of environmental impact in the same way that land management proposals by the private sector are evaluated. This process would feature a:

(6) Public review period to enable interested and affected parties to comment.

(7) Final adoption in a similar manner to a Town Planning Scheme.

Such Regional Plans would of course be dynamic and subject to formal procedures of review consequent to changing land uses and research findings.

4.2.3 An Example

Shortly after Easter 1985 the Brockman National Park outside Pemberton was burnt by a wildfire. This park is small but has great tourist value due to the beauty of the Karri forest it contains. Unfortunately these aesthetic qualities were severely damaged by the fire and will take some time to recover.

Enquiries at the regional office of the Conservation and Land Management Department revealed that the fire started as a result of a farmer burning off land adjacent to the park. The official comment was that the National Park was carrying high fuel loads and if fuel reduction burns had been applied more frequently the fire would not have occurred.

This example epitomises the points that I have developed regarding the present attitude of management authorities. The bush must be burnt in order to protect it from accidental or deliberate damage. No options for manipulating other variables are considered.

With a Regional Management Plan such as I have advocated the possibilities of accidents of this nature would be remote. In the present example, the regional description would have emphasised the proximity of farmland to the National Park.

Similarly the analysis would have revealed that there was a need for periodic burning of the farm paddocks for pasture development purposes and that this posed a major threat to the National Park. The strategy could maintain the differing objectives of farm and National Park management by ensuring that firebreaks were adequate, that pasture burns occurred at specified times and with suitable prescriptions and resources to prevent escape.

5. Conclusion

The voluntary conservation movement is concerned about the current use of fire in land management. It believes that a more sophisticated approach could establish conservation as a management priority without compromising socio-economic priorities.

Regional Management Plans would not only enable this but would confer benefits in terms of public relations, the image of management authorities and the efficient use of management resources.

FIRE PLANNING AND MANAGEMENT: AN OVERVIEW

M. McGrath

There seems to be general support for a change in fire management strategies in Western Australia although there is clearly some disagreement as to the desirable rate and eventual extent of that change. Change is being made possible by increased knowledge of the effects of fire on the natural environment, and made necessary by public pressures and political and legal changes.

Thus Burrows has noted that it is not acceptable for a managing authority to either:

1. Do nothing, and justify the inaction by saying that nature is being permitted to take its course (the course of action which some rural landholders and some managers responsible for fire protection in the forest would claim has been adopted in Western Australian nature reserves), or

2. Burn the forest black and justify it by saying that the flora and fauna are adapted to fire (which some conservationists and some rural landholders would claim was the policy of the former Forests Department).

Burrows, Hopkins and Good have clearly set out the potentially adverse impact on natural ecosystems of excessively frequent, unseasonal low intensity fires. Although obligate seed regenerators which do not reach maturity for some years are perhaps the most obviously affected, Burrows noted that persistent fires can have unforseen effects on the growth of resprouters.

Two different approaches to the problem of fire management in natural environments were evident. These were:

1. Fire should only be used for the mitigation of defined threats to life or property or, where adequate information is available on ecosystem response to fire and management objectives are clearly established, for the manipulation of ecosystems.

2. The need to minimise the incidence and extent of wildfires in the heavily settled South-west mandates the continuance of fuel reduction burning throughout the majority of the main forest belt, although the eastern low-rainfall margins of the forest provide the opportunity for a more ecologically based approach.

Detailed criticism of existing fire management practices was offered by Good and Tingay. Good charged that the practice of repeated high frequency burning for hazard reduction was simplistic, inflexible and environmentally damaging, and may be ineffective. Good's clear view is that inadequacies in the McArthur hazard assessment principles and in their interpretation, and in what he referred to as 'biased data and biased planning', have created a need to completely review both the objectives and practices associated with planned burning of parks and reserves in the Eastern States.

Rejecting the claim that hazard reduction burning creates a mosaic of vegetation age classes as a post-burning justification, he focussed on the effectiveness of the practice. In his experience, hazard reduction burning has only been effective in very small areas and as a result of luck as much as good management and planning. As a result, in the Eastern States at least, the days of "the simplistic approach to planning a prescription burning programme based on the tonnes per hectare of fire fuel concept" have apparently passed.

Underwood **et al.** presented nine case studies to support the contention that fuel reduction burning can be useful in controlling the rate of spread and intensity of wildfires. In each case it was claimed that economic damage would have been significant if the fire had not run into an area of forest which had only recently been burned.

No one would argue with the contention that fuel reduction burning has a place in fire management. However, the information presented by Underwood **et al.** does not provide support for the view that fuel reduction is always effective in all environments, nor does it prove that measures other than fuel reduction burning have no place in fire management. Furthermore, it does not address one of the major criticisms of current fire management planning practice, viz. that it is based upon the assumption that all vegetation poses a possible hazard which must be abated.

Three very significant points emerged from the data provided by Underwood **et al.** viz.:

1. In the first case study, a narrow buffer strip (only 200-600 m wide) was effective in halting a fire with an estimated rate of spread of 600 m/hr and a flame height of 20 m, despite the fact that the forest beyond had not been burned for 20 years.

2. In four out of the nine examples, the flame front was halted by fuels burned no more than three months beforehand. In six out of the nine examples the fuel age was one year or less, and in all examples it was three years or less in age. In view of the unacceptably high environmental costs which would be incurred if burning occurred at three-year or less intervals, it is difficult to understand what these examples contribute to the development of an ecologically sound fire management policy for Western Australian natural lands.

3. None of the nine fires was known to have been due to natural causes. Indeed, two were the result of burning-off on private property under severe fire-danger conditions, one was from sawmill waste and one was from a fisherman's campfire. This provides support for the suggestion that greater emphasis should be placed on preventing fire ignition.

Underwood **et al.** also made the important point that if the community demands a more sophisticated fire management system, it must accept the inevitability of higher costs, at least initially.

There seemed to be broad agreement as to the need for greater research into the responses of ecosystems and species to a range of alternative fire regimes. However, perhaps because on-the-ground managers were not represented amongst the speakers, there was no expression of the need for better communication of the results of research findings to managers. Efficient dissemination of such information is a high priority, and the general public as well as those directly involved in land management should be the subject of any such information drive.

However, we cannot afford to sit back and wait for the research results to pour in. Although the goal of professional fire management should be to have a detailed ecological resource inventory and a clear knowledge of the role of fire in every park and reserve, a number of measures are valuable in the interim:

1. Fire management plans must be based on at least a basic biological survey and fact finding mission, covering at least flora, fauna, fuel loadings and management objectives.

2. Area-specific fuel accumulation rates and measures of the patchiness of fuel buildup should be obtained.

3. Hazard or risk assessments should be undertaken, not merely on the basis of tonnes of fine fuel per hectare, but incorporating likely sources of fire ignition, fuel bed composition and structure, shrub fuels, weather data, historical fire patterns and natural fire barriers, and the number and location of properties which fire would be likely to threaten.

4. Computer modelling should be utilised to predict the rate of spread and intensity of fires and the impact of alternative fire regimes on vegetation succession. This methodology is of value both in fire management planning and in wildfire suppression operations.

Llewellyn showed that fire management planning for the Shannon and D'Entrecasteaux National Parks is proceeding in accordance with sound ecological principles. A broad ecological survey, based on interpretation of existing data and limited field checking, has been used to provide a basis for the development of fire management strategies. Although very considerable emphasis continues to be placed on the need to reduce fuels over much of the area, areas of special significance have been identified and incorporated in the planning process. Most importantly, the fire management plan is being developed with a view to the ongoing monitoring of the impact of the chosen strategy.

Any changes in the fire planning and management process, while directed primarily at the maintenance of conservation values consistent with the provision of an appropriate level of protection for human life and property, must also take into account subsidiary uses of natural environments. Fleay's paper indicated that changes in fire regimes are unlikely to lead to dramatic changes in water quality. This situation is quite different from the experience in the Eastern States where the steeper slopes and lower soil permeability mean that increased fire frequencies can lead to unacceptable levels of turbidity and reservoir siltation.

Beekeeping is one of the major rural industries whose requirements are often ignored in the development of fire management plans. Others include the cut-flower industry, the wildflower-seed industry, and the tourist industry. Davies has presented two major concerns of apiarists:

1. The failure of any Government body to take responsibility for the development and implementation of an ecologically based fire plan for the Northern Sand Plains which takes into account the needs of all land users.

2. The need in forested areas to extend the length of rotations of prescribed burns to prevent the loss of economically valuable understorey species; and the desirability of timing such prescribed burns to minimise the impact on honey flow.

Conservation reserves within or closely adjacent to urban areas obviously present particular difficulties for fire managers. Thus Chris Pratten of the New South Wales Conservation Council, at a similar seminar at Monash University in late 1983, criticised the New South Wales Board of Fire Commissioners over their efforts to apply hazard reduction burning practices, developed for broad areas such as State Forests, to small inner-suburban bushland reserves.

Fortunately the situation in Western Australia is not so grim. Moore and Graham explained that the problem in metropolitan nature conservation areas is not that pressures are being applied for the mitigation of the hazard posed to adjacent property by means of frequent 'prescribed burning', but that excessively frequent unplanned fires lead to environmental degradation of the nature reserve. In particular, they highlighted the potential for weed invasion as a result of excessively frequent fire. Moore and Graham explained that the general aim of fire management in metropolitan nature conservation areas is towards fire exclusion, or at least a marked reduction in fire frequency.

Two other significant points arose out of the seminar. These were:

1. Though most fires in south-western Australia have human rather than natural causes, the focus has been mainly on the medium by which the fire is spread rather than on the cause of the fires. For example, four out of five of the fires which led to the burning of 40,000 ha of the Northern Sand Plains in the summer of 1984 were caused by either arson or carelessness, and were thus at least notionally preventable.

2. The formulation of fire policy involves the assessment of the impact of planned and unplanned fires on the natural environment, timber values, private property and human safety. However, social factors have often been ignored. The reason for the blanket application of hazard reduction burning being the favoured method of using fire in the management of natural lands has as much to do with the psychological scars left by the Dwellingup and Karridale fires on the inhabitants of the small milling settlements then located in the forest, and on the politicians and bureaucrats then in power, as it has to do with ensuring the protection of human life and private property.

Where do we go from here? The Conservation Council believes that the Western Australian Government should, at the very least, implement the policy endorsed by the all-party Legislative Assembly Select Committee on Bushfires. The Select Committee, recognising the conflict in evidence presented to it on the effectiveness and ecological impact of hazard reduction burning, called for two changes:

1. The funding by Government of an independent investigation of the environmental impact of hazard reduction burning to be carried out by a tertiary institution within Western Australia.

2. The amendment of the Bushfires Act to ensure that a wider range of viewpoints is represented on the Bushfires Board. The Select Committee believed that there was a need for a change to the existing legal requirement that only farmers who are members of a local bushfires brigade may serve on the Board as representatives of the public interest. The Committee proposed that conservationists and other rural residents should also be eligible for membership of the Bushfires Board.

The Conservation Council will be pressing for the adoption of these policies.