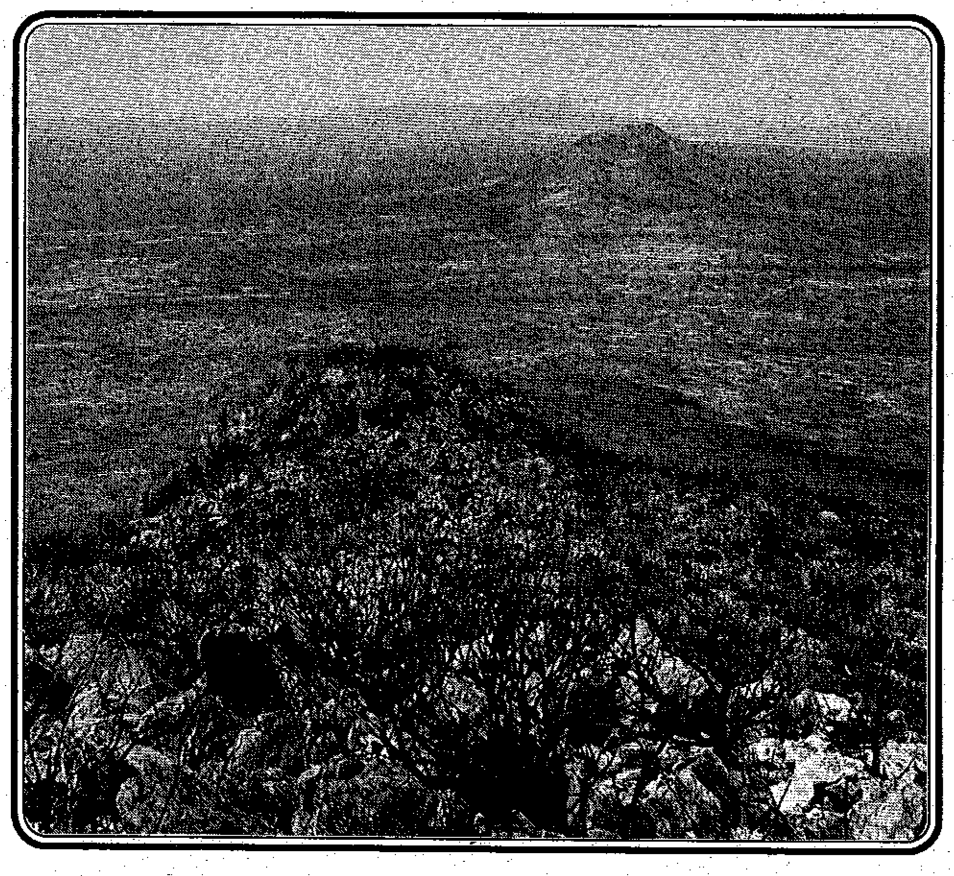
Wildfires in the Fitzgerald River National Park, Western Australia, December 1989

Lachlan McCaw, Terry Maher and Kelly Gillen



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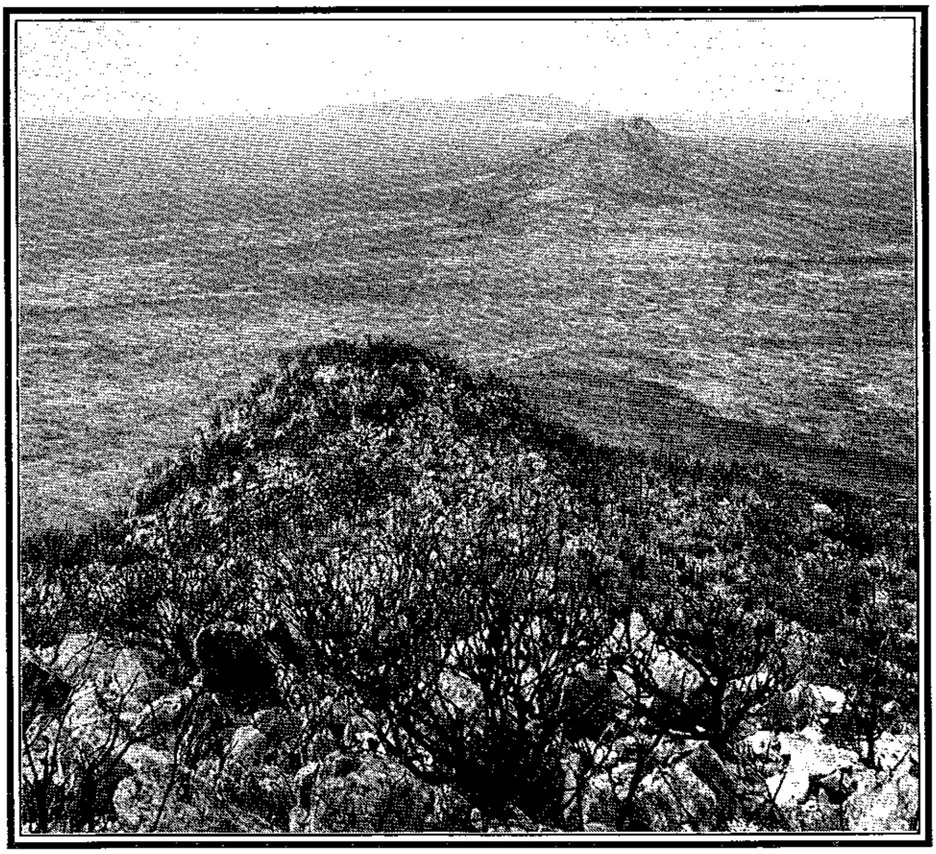

Frontispiece
View eastwards along the coastal strip of the Fitzgerald River National Park from the summit of West Mt. Barren, taken in September 1990 about nine months after the fire.

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Abstract

Wildfires started by lightning burnt 123 000 ha of shrubland, mallee and woodland in the Fitzgerald River National Park on the south coast of Western Australia during the latter half of December 1989. Most of this area was burnt on 21 December during a 10-hour period of severe fire weather conditions; several subsequent periods of severe fire weather caused fires to escape from the contained perimeter.

Fires in shrub and mallee fuel types behaved erratically and exhibited sudden changes in spread rate and intensity. These were related to fuel age and structure, fine fuel moisture content, and wind speed. Major fire runs were characterized by forward spread rates of up to 7.5 km h^{-1} and fire intensities of 20 000 to 40 000 kW m^{-1}. Fires spread extensively through 5-year-old fuels during conditions of Extreme fire danger.

This report describes fire weather conditions, fire behaviour and suppression action undertaken to protect life, property and areas of recognized ecological significance within the Park. The events of the 1989 season highlight the need for implementation of fire management programs that are compatible with conservation objectives, and at the same time reduce the likelihood of entire parks or reserves being burnt at the one time.

INTRODUCTION

Wildfires started by lightning burnt extensive areas of shrubland, mallee and woodland in the Fitzgerald River National Park (FRNP) during the latter half of December 1989. A total of 123 000 ha, representing some 37 per cent of the Park, was burnt as a result of the wildfires and associated suppression operations. The first of the fires started late on 15 December in rugged coastal ranges and burnt for several days before being contained. Three lightning strikes during the morning of 21 December 1989, a day of Extreme fire danger, developed into major fires that ran to the coast under the influence of strong northerly winds. South-westerly winds accompanying the passage of a dry cold front during the early afternoon resulted in further extensive runs by the eastern flanks of all three fires. The fires were eventually contained by joint suppression action involving volunteer Bush Fire Brigades and local authorities of the Jerramungup and Ravensthorpe Shires, and personnel from the Department of Conservation and Land Management (CALM), and the Bush Fires Board (BFB).

Management of fire on lands reserved for nature conservation is a complex, and at times controversial, subject both in Australia (Burrows *et al.* 1989) and in other countries with extensive parks and reserves containing fire-prone vegetation (Pyne 1982). Limited knowledge of past fire regimes, fire behaviour and biological responses to fire contribute to uncertainty about appropriate fire management. Formal research programs have been initiated to address important fire management issues but in the meantime there is a need for information on which to base interim plans, operational prescriptions and staff training programs. Local knowledge and experience have much to contribute in this role, as does information gathered opportunistically from operational burning and wildfires (Luke and McArthur 1978; Alexander and Lanoville 1987). This is particularly true for large and intense fires as these cannot readily be duplicated on an experimental scale.

The FRNP fires of December 1989 involved the largest and most prolonged suppression effort undertaken in a National Park in Western Australia to date, and highlighted the complexity of fire management on nature conservation lands. CALM personnel involved in the fire gained considerable experience of fire behaviour and suppression techniques in shrub, mallee and woodland fuel types. This report documents the sequence of lightning-caused wildfires in the Park during December 1989 and examines important aspects of the fire situation. Specific aims are :

- to examine available information on the behaviour of the fires and relate this to factors of fuel, weather and topography;

- to describe the strategies employed to suppress the fires and important factors that influenced the conduct of suppression operations;

- to draw general conclusions relevant to fire management in large parks and reserves in the South Coast Region of Western Australia.

GENERAL DESCRIPTION OF THE PARK

The FRNP occupies an area of 328 026 ha on the central south coast of Western Australia between the settlements of Bremer Bay and Hopetoun on the coast, and Jerramungup and Ravensthorpe inland (Fig. 1). Near the south-western corner of the Park there is a small enclave of private property on the Gairdner River at Quaalup.

The climate of the region is typically Mediterranean with cool humid winters and warm dry summers. Temperature extremes are moderated near the coast particularly during the summer months. Average annual rainfall is 500 mm to 600 mm in coastal areas of the Park but is less than 400 mm at the northern boundary. Rainfall tends towards a winter maximum but there may be very heavy falls during summer and early autumn in association with the passage of low pressure systems of cyclonic origin from the north-west.

The Stirling Fault runs east-west across the Park and separates the undulating northern uplands on granitic and gneissic rocks from the gently sloping marine plain composed of spongolite siltstone. Coastal sections of the Park are dominated by a chain of peaks and ridges of quartzitic and phyllitic schist rising to between 300 m and 450 m above sea level (ASL). Drainage follows a general north-west to south-east direction and is dominated by the Gairdner, Fitzgerald and Hamersley Rivers, which flow in narrow channels in broad flat-floored gorges. Spongolite cliffs and steep rubble slopes up to 50 m high occur along some sections of the gorges. All rivers are saline and flow only intermittently, terminating in shallow inlets. Geology, landforms and soils are discussed in detail by Chapman and Newbey[1] and summarized in the current management plan for the Park (Moore *et al.* 1991).

Vegetation within the FRNP is closely linked to landform and soil factors (Beard 1972; Chapman and Newbey[1]). On the northern uplands and marine plain there are extensive communities of open and very open mallee with an understorey of low shrubs, together with low shrublands dominated by species of Proteaceae and Leguminosae; these correspond respectively to the mallee heath and scrub heath formations mapped by Beard (1972). Closed shrubland thickets characterized by species of Myrtaceae and Proteaceae are predominant on the coastal ranges. Woodlands of *Eucalyptus occidentalis* occur along watercourses and in swampy depressions on the marine plain, while low woodlands, often composed of *E. clivicola* and *E. platypus* occur along the slopes and rims of the major gorge systems. Other plant communities in the Park are associated with coastal dune systems, granitic outcrops and saline lakes.

These vegetation units provide a useful overall stratification of fuel types within the FRNP although detailed descriptions of fuel characteristics are not yet available for all types. In the open mallee and scrub heath communities live shrubs are the dominant component of the fuel. At maturity the shrub layer typically varies from 0.5 m to 1.5 m in height depending on soil type, rainfall and species composition and may contribute 3 to 5 t ha^{-1} of live material and 2 to 4 t ha^{-1} of dead material as fine fuel. The sparse layer of leaf litter, although contributing only a further 2 to 4 t ha^{-1} to the fine fuel quantity plays a crucial role in sustaining fire spread in these fuel types (McCaw 1991). Dry fuel conditions and wind speeds in excess of 10 km h^{-1} are required for sustained fire spread because of the discontinuous nature of the fuels.

Closed shrubland thickets on the ranges tend to be taller, more continuous and have a greater component of suspended dead foliage and ground litter than is the case for the mallee and scrub heath communities on the surrounding plains. For this reason fires are able to spread at low wind speeds and may backburn downslopes or against the wind; fires may also burn throughout the night if conditions are relatively dry. Available fuel loads are correspondingly higher and may approach 30 t ha^{-1}.

Woodland communities are distinguished by the presence of a more or less continuous layer of leaf litter and a closed canopy which reduces wind speed within the stand. Equilibrium litter fuel loadings of 8 to 12 t ha^{-1} are typical of these stands under most situations. An understorey of Myrtaceaous shrubs may also be present in some low woodlands. During mild burning conditions fires spread principally in the litterbed but under dry, windy conditions the entire crown stratum may be consumed. Accumulations of fallen logs and branch wood commonly present in woodlands provide a potential source of reignition.

Prior to December 1989 large areas of the Park had remained unburnt for more than twenty years (Moore *et al.* 1991). Escapes from fires lit for agricultural clearing burnt substantial areas of the northern uplands in the period between 1954 and 1969. Between 1969 and December 1989 most fires in the Park started from lightning strikes and burnt areas of less than 2000 ha; a notable exception to this was a 17 000-ha fire in the central coastal section of the Park near Mid Mt. Barren during the summer of 1985.

[1] A. Chapman and K. Newbey, unpublished manuscript 'Biological survey of the Fitzgerald River National Park'.

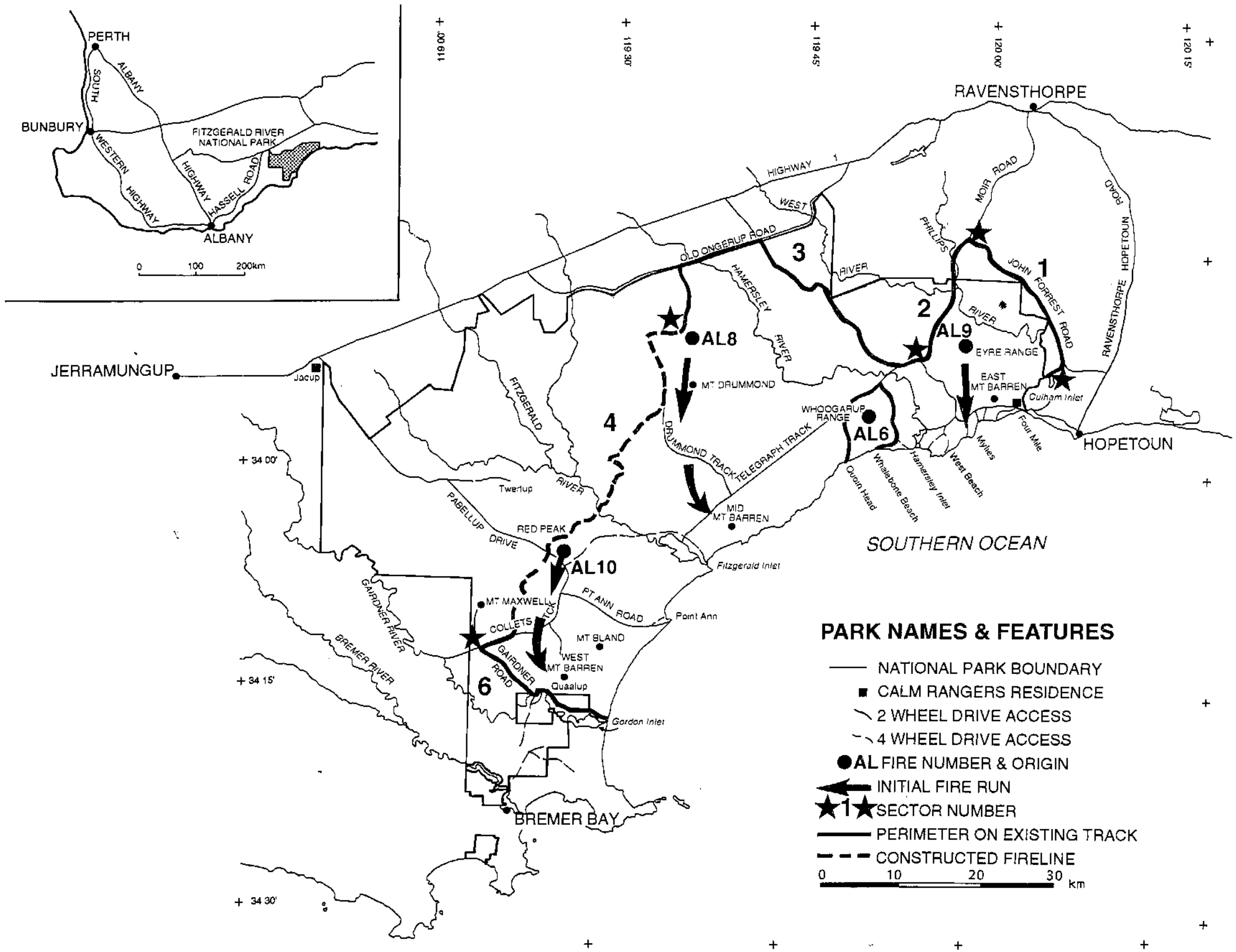


Figure 1

General layout and features of the Fitzgerald River National Park showing the origins of fires AL6, AL8, AL9 and AL10 and the final perimeter of the burnt area. Fire runs under northerly winds on 21 December 1989 are indicated. Sectors used during the suppression operations are numbered (1-4, 6).

Past fire protection strategies for the FRNP have placed priority on the construction of dual firelines around the Park boundary to establish a narrow buffer strip (100 to 200 m wide) in which fuel accumulation would be reduced by rotational burning. In the more discontinuous fuel types it has proven difficult to undertake satisfactory prescribed burning within the confines of these narrow buffer strips unless the structure of the vegetation has first been modified by scrub-rolling. A length of heavy chain dragged between two bulldozers has been employed for this operation. During 1988 and 1989 most of the perimeter buffer on the western and northern boundary of the Park was scrub-rolled and subsequently burnt. Wind-driven fires prescribed during dry spells in the winter have shown promise as a means for creating fuel-reduced strips without the need to construct additional firelines (Duxbury[2] personal communication). Fires lit during pre-frontal northerly winds in June or July have, on a number of occasions, burnt elongated strips before being extinguished by rain or the onset of moist overnight conditions. Further development of this technique is warranted, and would be assisted by the availability of reliable fire behaviour predictions for the major fuel types in the Park.

The FRNP is one of the most significant conservation reserves in south-western Australia and is one of only two areas in the State registered as an International Biosphere Reserve. The Park is floristically rich containing 75 endemic species and some 250 species that are rare or geographically restricted (Chapman and Newbey[1]). Declared Rare Flora are protected under the Wildlife Conservation Act and Ministerial approval is required before known populations can be disturbed. A number of species of rare fauna are present within the Park, being largely concentrated on northern uplands unburnt for more than 15 years. These species include the Dibbler (*Parantechinus apicalis*), the Red-tailed Wambenger (*Phascogale calura*), the Heath Rat (*Pseudomys shortridgei*) and the Ground Parrot (*Pezoporus wallicus flaviventris*). Relationships between fire regimes and habitat requirements of these species are not yet well understood.

The Park is used extensively by anglers, bushwalkers and visitors with an interest in natural history. Recreation activities tend to be concentrated at specific sites along the coast.

The FRNP is administered as part of the Albany District of CALM's South Coast Region. Three permanent ranger staff are located in the Park at Hopetoun, Quaalup and at the Jacup headquarters, some 20 km east of Jerramungup; technical and administrative support staff are located at Albany. A formal management plan has recently been approved for the Park (Moore *et al.* 1991) following an extensive program of public consultation.

Plant disease caused by soil-borne fungi of the genus *Phytophthora* has the potential to cause serious degradation in many of the plant communities along the south coast and prevention of disease spread is given paramount importance in the planning and implementation of activities within the Park.

FIRE CHRONOLOGY

Four major fires ignited by lightning strikes burnt in the FRNP during December 1989. The following section describes the chronology of major events during the fires and is based on the fire diary maintained at CALM's Albany District office. The alphanumeric code used in the diary to identify individual fires has been retained for this report. For convenience events have been grouped into five distinct phases; relevant weather and fire spread data are summarized in tables.

Phase 1

15 December - 20 December - Fire AL6

WEATHER

On 15 December coastal areas east of Albany experienced severe electrical storms in the wake of a hot, dry day with strong northerly winds (Table 1). These conditions were associated with the development of a heat trough over the lower south-west corner of Western Australia (Fig. 2). Temperatures moderated overnight and light drizzle fell in coastal sections of the Park the following day. A gradual warming trend established over the next four days as a new high pressure cell developed in the Great Australian Bight bringing a return to easterly winds.

FIRE ACTIVITY

Fire AL6 was ignited by a lightning strike on the crest of the Whoogarup Range (119° 50' E 35° 58' S) at about 2100 h (Western Standard Time - WST) on 15 December (Fig. 1). The fire burnt in dense shrub thickets on the range despite cool and drizzly conditions and by 1500 h on 17 December had burnt 2 km downslope to the base of the northern side of the range. Prevailing south-easterly winds then pushed the headfire towards the Telegraph Track in open mallee heath with an estimated rate of forward spread of 2 to 3 km h^{-1}. Suppression action along the Telegraph Track halted the run of this fire. No further major fire runs took place although inaccessible areas on the range continued to burn for some days afterwards. Substantial pockets within the perimeter of fire AL6 remained unburnt or were burnt at intensities insufficient to consume shrub foliage.

[2] G. Duxbury, previously Ranger, FRNP

Table 1

DAILY 1500 h (WST) WEATHER OBSERVATIONS FOR JERRAMUNGUP AND RAVENSTHORPE DURING THE LATTER HALF OF DECEMBER 1989.

Also shown are the Grassland Fire Danger Index for Jerramungup at 1500 h and the forecast Fire Danger for the Eastern South Coast weather district. Degree of grass curing is 100 per cent.

	Jerramungup [a]					*Ravensthorpe* [b]			
Date	*Temp (°C)*	*Rel Hum (%)*	*Winds km h⁻¹*	*Dir*	*Fire Danger Rating at 1500 h*	*Temp (C°)*	*Rel Hum (%)*	*Wind Dir*	*Forecast Grassland Fire Danger Rating*
15.12.89	30	19	38	NE	Extreme	22	72	NE	Extreme
16.12.89	16	57	30	S	High	25	n/a	n/a	High
17.12.89	22	24	15	S	High	20	45	NE	Moderate
18.12.89	27	20	15	SW	High	25	43	SE	Moderate
19.12.89	25	24	17	SE	High	22	48	SE	Moderate
20.12.89	28	20	30	SE	Very High	29	34	SE	Moderate
21.12.89	34	10	29	W	Very High	36	12	NW	Extreme
22.12.89	24	19	25	NW	Very High	27	28	NW	Moderate
23.12.89	22	25	32	NW	Very High	26	29	NW	High
24.12.89	25	20	34	W	Very High	27	37	NW	Moderate
25.12.89	26	16	15	SE	High	24	32	SE	Moderate
26.12.89	33	9	16	NE	High	30	28	SE	High
27.12.89	38	7	38	NW	Extreme	41	12	NW	Extreme
28.12.89	27	13	11	S	High	24	40	SE	High
29.12.89	29	15	12	N	High	28	32	NE	High
30.12.89	27	17	32	W	Very High	27	28	NW	High
31.12.89	31	12	9	NW	High	29	n/a	n/a	High

a Data from Department of Agriculture remote weather station. Wind speed recorded continuously at 10 m height in the open.
b Data from Ravensthorpe Post Office meteorological station.
n/a Data not available.

SUPPRESSION

The strategy employed to control Fire AL6 was to burn back from a perimeter defined by existing tracks which enclosed an area of some 4100 ha (Table 2). In open mallee fuel types strips 50 to 100 m wide were scrub-rolled inside the perimeter to improve the efficiency of backburning operations, but scrub-rolling was not required in areas of shrub thicket. The scrub-rolled strip along the Telegraph Track halted the headfire run on 17 December and allowed suppression crews equipped with heavy duty pumper units to contain the fire. Mop-up and patrol activities continued until 20 December.

Phase 2

21 December - Major runs by fires AL8, AL9, AL10.

WEATHER

The severe fire weather experienced along the south coast on 21 December resulted from the development of a heat trough over the south-west corner of the State (Fig. 2). As the trough intensified on 20 December strong north-westerly winds developed above 1500 m altitude, although at lower elevations winds remained predominantly easterly (Fig. 3). During the morning of 21 December surface wind direction shifted progressively from north-east to west-north-west and then swung abruptly south-west with the passage of a dry cold front. Wind speeds recorded at Jerramungup were at a maximum between 1100 h and 1200 h with an hourly average of 44 km h⁻¹ (Table 3); peaks of up to 56 km h⁻¹ were recorded over 1-min intervals. Grassland fire danger (McArthur 1973) at Jerramungup entered the Extreme range, defined by a Grassland Fire Danger Index (GFDI) > 50, by 0900 h and remained there till after 1400 h. For a period of about one-and-a-half hours during the middle of the day the GFDI exceeded the nominal upper limit of 100. Coastal areas at the western end of the Park experienced the southerly change at around 1400 h and by 1600 h it had reached East Mt. Barren. Cooler air associated with the change did not penetrate northern areas of the Park until between 1700 h and 1800 h. Weather conditions moderated overnight to a minimum temperature of about 13°C with light westerly winds.

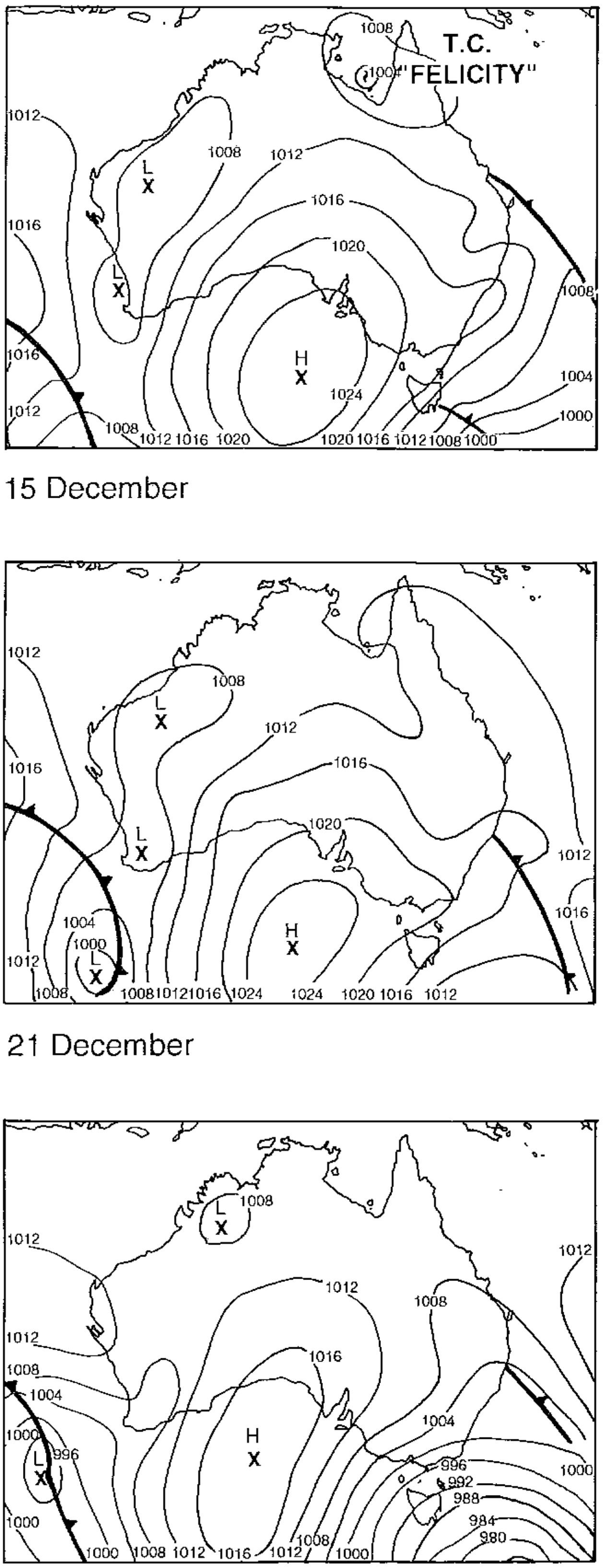


Figure 2
Surface synoptic charts for 0800 h (WST) on 15, 21, and 27 December 1989.

FIRE ACTIVITY

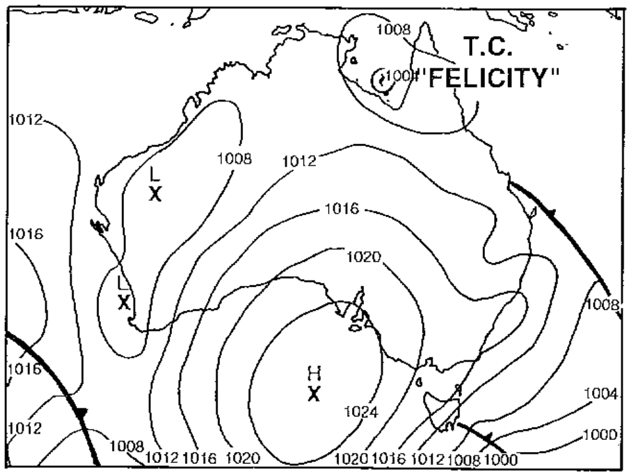
Separate lightning strikes during the morning ignited three fires in central and northern areas of the Park. Fires originated at the following points (Fig. 1):

- AL8, north of Mt. Drummond near Short Road (119°38'E, 33°50'S) at 0830 h;
- AL9, on Annies Peak in the Eyre Range (119°58'E, 33°50'S) at 0930 h;
- AL10, 2 km east of the junction of Pabelup Drive and Telegraph Track (119°26'E, 34°08'S) at 0900 h.

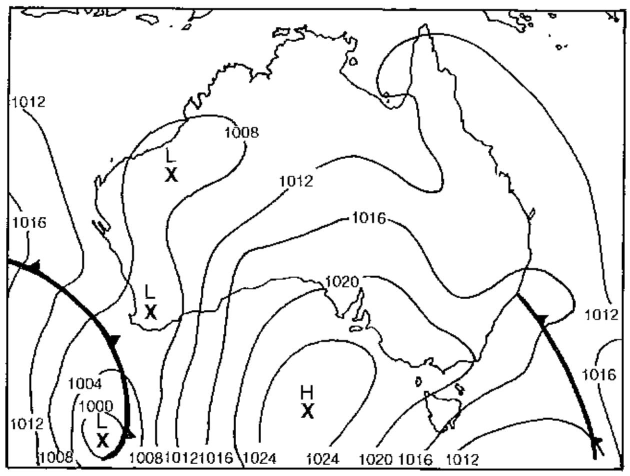
Fire AL8 initially ran in a southerly direction in open mallee heath that had been unburnt for at least twenty years (Fig. 4). During the 2 hours following ignition the fire travelled a distance of about 4 km (rate of spread 2 km h^{-1}). From 1040 h to 1125 h the fire spread a further 3 km to the south (rate of spread 4 km h^{-1}) passing to the west of Mt. Drummond (Table 4). The increased rate of spread during this period was probably a result of the more severe burning conditions, the gradual uphill slope and the fact that the fire had undergone initial acceleration. The fire continued spreading under the influence of northerly winds and was reported as having crossed the Drummond Track at around 1300 h. Likely reasons for the reduced rate of spread (2.7 km h^{-1}) between 1125 h and 1300 h include the downslope direction of spread and the fact that the fire encountered fuels burnt only 5 years previously (Table 5). Some 30 per cent of the area of younger fuel remained unburnt, mostly as patches of at least several hectares in size (Fig. 4).

The fire spread a further 15 km south of Drummond Track and eventually burnt up a broad gully almost to the summit of Mid Mt. Barren. The forward rate of spread of the fire after 1300 h must have averaged 7.5 km h^{-1} for it to have travelled this far by the time the south-westerly change arrived at about 1500 h (Table 4). For the first 5 km south of Drummond Track the fire spread through mature open mallee and then subsequently through 5-year-old mallee and thicket fuels resulting from the 1985 wildfire. The younger fuels did not prevent the headfire from spreading, but unburnt pockets were larger and more common in the 5-year-old fuel than was the case in areas of older fuel.

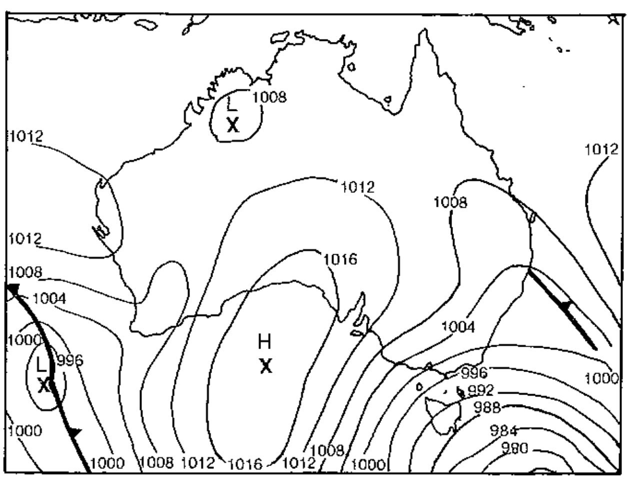
The extent of fire spread east of Mt. Drummond during the morning is unclear, but by the time the south-westerly change arrived in this section of the Park the eastern flank had travelled some 8 to 10 km and burnt into the 1985 wildfire area, in some cases for up to 1 km.



15 December



21 December



27 December

Figure 2

Surface synoptic charts for 0800 h (WST) on 15, 21, and 27 December 1989.

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Table 2

SUMMARY OF SUPPRESSION ACTION ON SECTORS DURING EACH PHASE OF THE LARGE FIRE ORGANIZATION.

Refer to Figure 1 for sector locations.

Phase	*Date*	*Sector No.*	*Suppression Action*
1	16-17.12.89	Fire AL 6	Scrubroll and burn back from existing tracks to establish perimeter from Whalebone Beach along Telegraph Track to Quoin Head.
2	21.12.89	1	Scrubroll and burn back to contain fire west of John Forrest Road.
		2	Scrubroll 50-100 m wide strip along northern park buffer and Moir Road.
		3	Scrubroll 50-100 m wide strip along Hamersley Drive, Old Ongerup Road and northern section of Drummond Track.
		6	Burn back from Gairdner Road and Collets Track, and along track on north side of Gordon Inlet.
3	22-24.12.89	1	Patrol and mop up along burnt edge.
		2	Burn back from scrubrolled edge then mop up and patrol.
		3	Burn back from scrubrolled edge then mop up and patrol.
		4	Construct fireline along northern perimeter of Fire AL10. Burn back to consolidate edge where required then mop up and patrol.
		6	Contain hopovers along northern bank of Gairdner River.
4	25.12.89	All Sectors	a.m. Patrol with light units. p.m. Construct fireline to contain hopover in Red Peak area of Fitzgerald River valley.
	26.12.89	4	Consolidate Red Peak hopover. Patrol other sectors.
	27.12.89	1	Protect life and property. Contain escaped fire in pasture fuels.
		4	Let fire run until conditions moderated in the evening, then construct further fireline to contain hopover.
5	28.12.89	All Sectors	Mop up and patrol.
		3	Burn back south of Telegraph Track from Hamersley Drive to Whalebone Track to contain fire activity around Hamersley Inlet.
	29.12.89 - 10.1.90	All Sectors	Mop up and patrol. Conduct scrubrolling along strategic tracks within park to provide buffers to protect remaining unburnt sections.

The change resulted in a major extension of Fire AL8 to the north during the remainder of the afternoon, mostly through mature open mallee fuel types. By early evening the fire had crossed the Hamersley River and extended northward towards the Old Ongerup Road where it stopped after encountering areas already back-burnt as part of the suppression operations that had commenced during the late afternoon. North-easterly spread of the fire towards Hamersley Drive was prevented by a 2-km wide strip of 5-year-old fuel resulting from a 1985 prescribed burn; the fire burnt into this buffer for only a few hundred metres before stopping (Table 5).

Fire AL9 initially spread downslope in a southerly direction from Annies Peak in the Eyre Range (450 m ASL) to the coast near West Beach, a distance of about 11 km (Fig. 1). Slopes immediately beneath the peak are steep (30 - 45^{0}) and there is an average slope of 8^{0} over the 2 km to the south. In the 2 hours following ignition the fire travelled about 6 km through shrub thickets (rate of spread 3 km h^{-1}) (Table 4); no reliable estimates of spread rates are available for later stages of the fire. The south-westerly change reached the eastern end of the Park at between 1545 h and 1600 h and drove the fire north-east across the top of East Mt. Barren, passing within a few metres of the

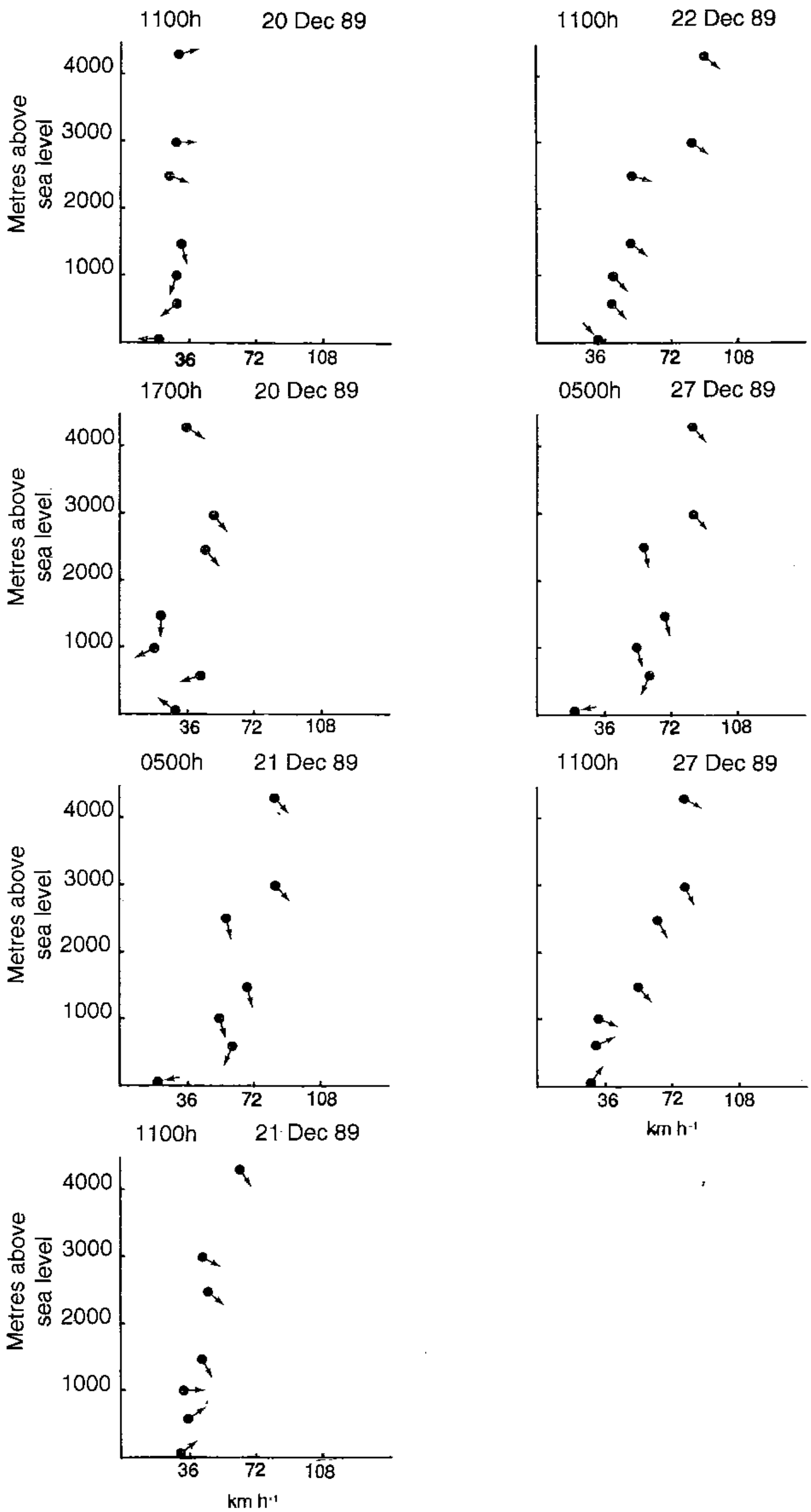


Figure 3
Upper level wind speed (•) and direction (↑ = north) at Albany for various times on 20, 21, 22 and 27 December 1989.

Table 3
HOURLY MEAN WEATHER OBSERVATIONS AND CALCULATED GRASSLAND FIRE DANGER INDEX (MARK 4) FOR JERRAMUNGUP ON 21 AND 27 DECEMBER 1989.
Data from Department of Agriculture remote weather station.

Time	*21 December 1989*					*27 December 1989*				
(WST)	*Temp (°C)*	*Rel Hum (%)*	*Wind (km h⁻¹)*	*Dir*	*Fire Danger Index*	*Temp (°C)*	*Rel Hum (%)*	*Wind (km h⁻¹)*	*Dir*	*Fire Danger Index*
0600	22	31	28	NNE	18	21	33	22	NNE	11
0700	23	31	24	NE	14	25	20	30	NNE	28
0800	27	20	34	NNE	37	29	14	32	N	41
0900	31	14	42	NNE	73	33	12	32	N	49
1000	33	11	41	N	81	36	10	34	N	64
1100	35	9	43	N	>100	38	8	32	NNW	65
1200	36	9	44	NNW	>100	39	8	34	NW	75
1300	35	9	40	NW	88	39	7	35	NW	82
1400	35	9	32	WNW	58	39	8	37	NW	88
1500	34	10	29	WNW	45	38	8	38	NW	90
1600	34	10	27	WNW	40	36	9	38	WNW	82
1700	32	10	26	W	36	33	10	36	WNW	65
1800	25	26	26	S	19	31	11	32	WNW	48
1900	21	34	26	S	14	28	12	33	WNW	45
2000	19	41	21	S	9	25	15	29	W	30
2100	17	55	21	S	6	23	28	29	W	20
2200	17	59	21	S	6	22	36	20	W	10
2300	17	57	20	S	6	22	46	20	W	9
2400	16	58	14	S	3	17	63	26	SW	7

Table 4
SUMMARY OF FIRE SPREAD OBSERVATIONS DURING THE MAIN FIRE RUNS ON 21 DECEMBER 1989 (based on the fire diary maintained at the CALM Albany District Office).

Fire No.	*Burning Period*	*Distance travelled (km)*	*Rate of Spread (km h^{-1})*	*Fuel type and age*	*Terrain*
AL 8	0830-1040	4	2	Mature open mallee	Mostly flat
	1040-1125	3	4	Mature open mallee	Average up-slope 3° but steeper (20°) near Mt. Drummond.
	1125-1300	4	2.7	Mature open mallee	Average downslope 3° except near Mt. Drummond.
	1300-1500	15	7.5	a) Mature open mallee (5 km) b) 5 yr old open mallee (7 km) c) 5 yr old thicket (3 km)	Flat Flat Average slope 4° but steeper (30°) on Mid Mt. Barren.
	1500-1800	(approx only) 12	4	a) Mature open mallee b) fire stopped in 5yr old mallee	(a) and (b) mostly flat
AL 9	0930-1130	6	3	Mature thicket	Average downslope 8° but steeper (30-45°) close to Annies Peak.
AL 10	0900-1000	0.2	0.2	*E. occidentalis* swamp	Flat
	1000-1250	12	4	Mature open mallee	Flat
	1250-1400	(no reliable estimate available)			
	1400-1900	25	5	Mature open mallee	Flat

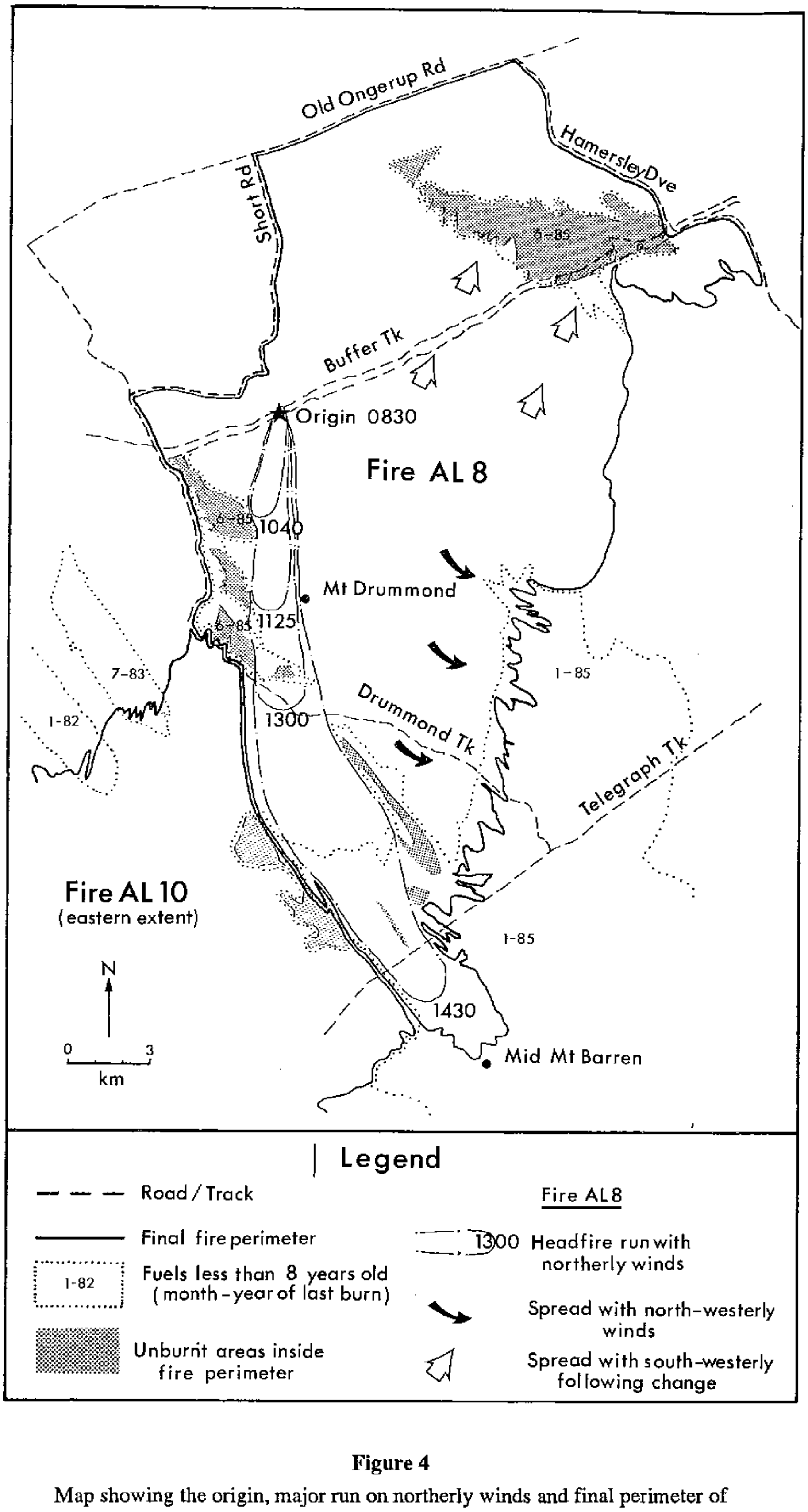


Figure 4

Map showing the origin, major run on northerly winds and final perimeter of Fire AL8. The eastern extent of fire AL10 is also shown. Dotted lines indicate the boundary of fires within the previous 8 years.

Table 5
ANALYSIS OF FIRE SPREAD IN FUELS UP TO 8-YEARS-OLD BASED
ON FIELD OBSERVATIONS AND INTERPRETATION OF SATELLITE IMAGERY.

Vegetation type is open mallee and scrub heath in all cases except some shrub thicket on Mid Mt. Barren which is asterisked.
Grassland fire danger at the time when the fire encountered the younger fuel is indicated.
Areas of fuel less than 8 years old burnt by fire in December 1989 are shown in Figure 4.

Fire Number	*Location*	*Last Burnt*	*Direction of fire spread*	*Grassland fire danger*	*Extent to which younger fuel reburnt*
AL8	Drummond Track	June 1985	S	Extreme	Burnt across a 1.5 km wide strip, but some 30% of area remained unburnt.
	Mid Mt. Barren	Jan 1985	SE	Extreme	Burnt across 7 km leaving only narrow remnants unburnt.
	Mid Mt. Barren *	Jan 1985	SE	Extreme	Burnt a further 3 km in shrub thickets and up steep slopes during the final stages of run.
	Mid Mt. Barren	Jan 1985	ESE	Very high/ Extreme	Tongues of fire spread up to 1 km into younger fuels along most of the edge.
	Northern buffer track	June 1985	NE	High/ Very High	Tongues of fire spread up to 0.5 km into younger fuels along most of the edge.
AL9	North of Phillips River	June 1985	NE	High/ Very high	Majority of area remains unburnt, with occasional tongues of fire penetrating up to 0.7 km.
AL10	East of Mt. Maxwell	April 1982	SW	Extreme	Entirely reburnt.
	West of Drummond Track	Jan 1982	NE	High/ Very high	Entirely reburnt across 1.5 km wide strip.
	West of Drummond Track	July 1983	NE	High/ Very high	Mostly reburnt across 1.5 km wide strip.
	East of Drummond Track	June 1985	NE	High/ Very high	Majority of area remains unburnt, with occasional tongues of fire penetrating to 0.3 km.

Ranger's residence. Subsequently, the fire spread up the western side of Culham Inlet. A 2-km wide strip of 5-year-old fuel contained the fire north of the Phillips River as conditions moderated (Table 5) but the fire continued to spread to the north-east through long-unburnt mallee until early evening when it was contained on John Forrest Road. Post-fire inspection near Fourmile Beach revealed several spotfires that had ignited some 300 m outside the fire edge but failed to develop.

Fire AL10 was first detected soon after 0900 h but appears to have developed slowly for about an hour within an *E. occidentalis* swamp, probably because wind speeds were lower beneath the tree canopy. Between 1000 h and 1250 h the headfire travelled 12 km (rate of spread 4 km h^{-1}) across flat terrain in open mallee vegetation, mostly unburnt for at least twenty years (Table 4). A 1-km wide strip of 8-year-old fuel in the path of the headfire was completely reburnt. The progressive shift in wind direction to the west-north-west resulted in the headfire following a gradual arc to eventually spread along the northern side of the Gairdner River, thus fortunately skirting the private property enclave at Quaalup. The southern edge of this arc was clearly evident on post-fire satellite imagery (Fig. 5) probably because fuel consumption was more complete in areas burnt by the headfire than in areas burnt by flankfires prior to the change, or in later back-burning operations. The south-westerly change, which arrived at Quaalup at about 1400 h drove the eastern flank of the fire on an extensive front across West Mt. Barren and Mt. Bland, and subsequently across the Fitzgerald River. The run of this fire was checked by areas burnt earlier in the day during the initial run of Fire AL8, and by areas of 5-year-old fuel associated with the 1985 Mid Mt. Barren wildfire. At the northern extremity the fire also reburnt across successive 1.5-km wide strips of 7 and 8-year-old open mallee on the broad uplands to the west of Drummond Track; the fire eventually halted after crossing Drummond Track and burning to a distance of 200 to 300 m into 5-year-old fuel. The fire spread about 25 km on a broad front after the south-westerly change and must therefore have maintained an average rate of spread of 5 km h^{-1} to cover this distance before the onset of cooler evening conditions.

SUPPRESSION

Active fire suppression efforts did not commence until the evening. Earlier in the day, uncertainty as to the location and extent of fires within the Park, and the extreme behaviour of the fires prevented crews from attempting suppression work. The small number of CALM personnel at the scene were also committed to the immediate protection of life and property. Forces available for initial attack consisted of volunteer Bush Fire Brigades from the Shires of Jerramungup and Ravensthorpe and 15 CALM personnel already in the Park. Additional CALM fire suppression crews and equipment were despatched to the FRNP during the afternoon from Esperance, Albany and from the Wheatbelt, Central and Southern Forest Regions. Because of the considerable travel involved most incoming crews were rested after arrival and deployed on the fireline early on 22 December.

By evening field reports indicated that fires AL8 and AL10 had linked, and that an almost continuous swathe had been burnt across the southern and central sections of the Park (Fig. 1). The immediate objective for suppression was to halt northward spread of fires and in particular to protect the townships of Ravensthorpe, potentially threatened if south-west winds persisted, and Jerramungup, potentially threatened by a shift to south-easterly winds. The strategy adopted to contain fires was to employ indirect attack from existing roads and tracks where possible and, where necessary, to construct firelines along the fire edge. The overall fire suppression plan developed for the Park utilized 5 sectors, numbered 1-4 and 6, that were retained for the duration of operations with little alteration (Fig. 1). The need for an additional sector (number 5) extending along the entire north-west boundary of the park was envisaged during the initial planning phase but subsequent developments rendered it unnecessary.

Figure 5

Satellite image of the FRNP showing the extent of area burnt by the fires of December 1989. Previous fire scars are distinguishable in some areas by pale tones.

Overnight work on Sectors 1 and 2 at the eastern end of the Park concentrated on scrub-rolling of strips adjacent to existing roads and tracks in preparation for burning back the next day. Areas of dense *Banksia* heath fuel were burnt to secure the fire perimeter on Sector 6 near Quaalup. Work commenced on a bulldozed fireline to contain the western and northern flanks of fire AL10.

Phase 3

22 December - 24 December - Consolidation and mop up.

WEATHER

Weather conditions moderated on 22 December. Winds were predominantly from the north-west during the daytime and tended to shift southerly overnight in coastal areas. On 22 and 23 December daytime temperatures in the Park were mild and nights were cool and dry (Table 1). Light coastal drizzle extended across the southern half of the Park on the morning of 24 December.

An intriguing aspect of fire behaviour during this period was the failure of the southern flank of Fire AL8 between the Hamersley River and Hamersley Drive to spread southwards under the influence of the prevailing north-westerly winds (Fig. 5) despite the mature condition of the surrounding vegetation. Presumably, the absence of further spread reflects a negligible amount of reignition along this section of the fire edge.

SUPPRESSION

A thorough reconnaissance of the Park was undertaken from a light aircraft during the morning of 22 December to establish the location of the fire perimeter, assess the extent of the burnt area and examine possible routes for fireline construction across the inaccessible Fitzgerald River valley. Extensive use was made of the aircraft for reconnaissance purposes during subsequent phases of the fire. Backburning of scrub-rolled strips continued on Sectors 1 and 2 and further progress was made with fireline construction across the valley of the Fitzgerald River from both the Pabelup Drive and Drummond Track ends. Steep breakaway slopes, and the difficulty of following the burnt edge at night in mallee fuel types posed problems for fireline construction. Firelines were completed during the morning of 23 December and backburning and mop up operations continued until the afternoon of the following day. No running fire was evident by this time and most CALM crews were released to return home in time for Christmas Day, with only a skeleton staff retained for patrolling.

Phase 4

25 December - 28 December - Fire activity at Red Peak, Gordon Inlet and Hopetoun.

WEATHER

Winds turned south-easterly on 25 December for the first time since 21 December placing the northern and western sections of the fire perimeter under threat of escapes caused by reignition of woody fuels. Dry north-easterly winds raised temperatures across much of the Park on 26 December and a day of Extreme fire danger followed on 27 December (Table 1). Grassland fire danger at Jerramungup was in the Extreme range for 8 hours with a peak GFDI of 90 at 1500 h (Table 3). As on 21 December strong north-westerly winds, high temperatures and low humidity accompanied the development of a heat trough (Fig. 2). Cooler weather returned on 28 December.

FIRE ACTIVITY

Fire escaped across the newly constructed fireline in the Red Peak area (Fig. 1) of the Fitzgerald River valley during the early afternoon of 25 December fanned by the south-easterly winds and burnt an area of about 5 ha of *E. platypus* low woodland. Moderate fire behaviour overnight and on the following day allowed this escape to be contained.

On the afternoon of 27 December the hot, windy conditions caused fires to escape at a number of places in the Park. Escapes from several points around the Red Peak hopover rapidly developed into intense fire runs spreading at up to 5 km h^{-1} with flame lengths up to 10 m and associated spotfire development. At the eastern end of the Park, fire escaped into pasture and spread in an easterly direction across the Hopetoun-Ravensthorpe Road exhibiting severe fire behaviour in light grass fuels. Fires from an unknown origin were also active south of the Gordon Inlet at Quaalup, although there are no details of fire behaviour. Fires were active near the Hamersley Inlet but did not require suppression as surrounding fuels had previously been burnt by Fires AL6 and AL9.

SUPPRESSION

The Red Peak hopover was initially contained overnight on 25 December within a bulldozed fireline and patrolled on the following day. During the afternoon of 27 December the priority for suppression crews was to protect life and property on Sectors 1 and 6, with crews on Sector 4 being temporarily unable to attempt any control measures until fire behaviour became less severe. All fires were contained during the later stages of the afternoon as winds moderated.

Phase 5

29 December - 10 January - Consolidation and mop up.

WEATHER

For much of this period weather conditions were mild with maximum temperatures in the mid 20s, minimum relative humidities of 40 to 50 per cent and predominantly south-easterly winds; Grassland fire danger remained High. Hotter conditions associated with northerly winds resulted in Very High fire danger on 5 and 8 January, and Extreme fire danger on 9 January.

FIRE ACTIVITY

There was no further significant fire activity within the Park during this period.

SUPPRESSION

Crews continued to consolidate and mop up around areas burnt on 27 December with periodic patrols along the entire perimeter of the fire. Further strips were scrub-rolled along strategic tracks in western and northern sections of the Park to establish a system of buffers to protect remaining unburnt areas.

FIRE ANALYSIS

Weather

RAINFALL

Rainfall in the Fitzgerald River area was slightly above average during 1989 with annual totals of 408 mm for Jerramungup (annual average 392 mm) and 465 mm for Ravensthorpe (annual average 422 mm) (Bureau of Meteorology 1989). Above-average falls continued until the beginning of December when a distinct dry spell commenced; during the remainder of 1989 no further rainfall was recorded at Jerramungup and only 3 mm was recorded at Ravensthorpe. Light showers on 16 December and 24 December were confined to coastal areas of the Park and there was no widespread rain across the fire area until the end of January 1990. These heavy falls were associated with an intense tropical low pressure system which brought widespread rain to the Wheatbelt and South Coast regions of the State. At Ravensthorpe, rainfall for January 1990 (108 mm) was more than five times the normal monthly average of 21 mm.

Antecedent rainfall conditions during 1989 are unlikely to have contributed significantly to the extent or intensity of the December fires in the FRNP. The major fuel types in the Park are dominated by perennial trees and shrubs which do not exhibit any pronounced curing or desiccation of foliage during the typical 'summer' dry period of 5 to 6 months. Furthermore, unlike some mallee communities in south-eastern Australia (Noble *et al.* 1980) annual grasses are not a significant fuel component in most vegetation types in the FRNP.

The light rain that fell during the main period of suppression operations had little impact on the extent or intensity of fires. In open mallee and shrubland fuel types fine fuels dried rapidly and were capable of burning within 1 to 2 days of rain; light falls were also insufficient to cause any substantial increase in the moisture content of litter and woody debris in the woodland fuel types. Rainfall in fact hindered suppression operations by delaying backburning in open mallee where dry fuels were needed to ensure continuous fire spread.

SYNOPTIC SITUATION

During the month of December the synoptic situation in the southern half of Western Australia is typically dominated by the presence of anticyclones in the Great Australian Bight with resultant easterly winds. Heat lows develop in the northern half of the State and progressively extend down the west coast as a trough of low pressure. Strong north-east to north-west winds and high temperatures are common at this stage of the cycle and thunderstorms may be associated with passage of the low pressure trough. Easterly movement of a cold front brings cooler southerly winds and the re-establishment of the anticyclonic pattern.

The three critical days during the FRNP wildfires (December 15, 21 and 27) were associated with presence of heat troughs over the south-west corner of the State (Fig. 2). This weather pattern may be expected to bring severe fire weather to the south coast and adjoining areas on a number of occasions during each summer. In addition, heat troughs are often accompanied by dry lightning storms which provide a ready source of fire ignition. Weather experienced in the Park and adjacent areas on these three days was characterized by extended periods with temperatures in excess of 30°C, relative humidities below 20 per cent and northerly winds 30 km h^{-1} or greater in strength (Table 1). Forecasts for the Eastern South Coast District, which covers the eastern half of the FRNP, correctly predicted the occurrence of severe fire weather in the Park on the 15, 21 and 27 December. Over recent fire seasons the number of forecast days of Extreme Grassland Fire Danger for the Eastern South Coast Weather District has ranged from 3 to 9, with a mean of 7; corresponding figures for the number of days in the Very High range are 12 to 35 with a mean of 20 (Table 6). The 1989/90 fire season was not therefore unusual in terms of the number of days when serious fires could be expected.

Table 6

FREQUENCY OF FORECAST DAILY GRASSLAND FIRE DANGER FOR THE EASTERN SOUTH COAST WEATHER DISTRICT FOR SIX RECENT FIRE SEASONS.

Source: Bureau of Meteorology, Perth.

Season	*No. of days in category*		
	High	*Very High*	*Extreme*
1982/83	90	35	3
1983/84	75	21	7
1984/85	96	16	9
1985/86	62	19	8
1988/89	81	19	8
1989/90	69	12	4
Mean	79	20	7

Large fires started by lightning occur regularly in bushland and agricultural areas along the south coast of Western Australia. Extensive tracts of vacant crown land north-east of Ravensthorpe burnt in 1979, and much of the Cape Arid National Park (approximately 300 km east of FRNP) burnt in 1981 and 1983. Further lightning-caused fires burnt an area of around 600 000 ha of mallee and woodland communities in the south-coastal hinterland during the summer of 1990/91.

Fire Behaviour

The major fire runs on 21 December and 27 December were a direct result of severe fire weather, with fire danger remaining in the Extreme range on these days for 6 and 8 hours respectively. The severity of fire weather on 21 December approached that experienced in South Australia during the Ash Wednesday fires on 16 February 1983 (Keeves and Douglas 1983) and exceeded that reported at Lismore during the fires of 12 February 1977 in the Western District of Victoria (McArthur *et al.* 1982). Historically, most major bushfires in Australia have made extensive runs during periods of severe weather conditions lasting less than 12 hours (Cheney 1976). This was the case in the FRNP where an area of about 113 000 ha was burnt by the three fires on 21 December, the largest of which was Fire AL10 (Table 7). The major fire runs were responsible for more than 90 per cent of the area burnt, with the remainder burnt out in association with suppression operations.

Under Extreme conditions, fires in open mallee vegetation on flat terrain maintained average forward spread rates of 4 to 7.5 km h^{-1} for extended periods. Rates of spread were almost certainly much higher over shorter intervals when localized interactions between fuel conditions, slope and wind were favourable for fire spread. Spread rates in dense shrub thickets burnt during the initial southerly run of Fire AL9 appear to have been slightly less than in mature mallee fuel types during the same period. However, the effect on fire spread of the steep downslopes and modified wind flow in the lee of Annies Peak must be taken into consideration.

Table 7

AREA BURNT IN THE FITZGERALD RIVER NATIONAL PARK DURING DECEMBER 1989

(based on ground reconnaisance and interpretation of post-fire satellite imagery).

Fire No.	*Date*	*Fire Activity*	*Final burnt area (ha)*
AL 6	16-20 December	Whooganup Range	4 100
AL 8	21 December	Main run	34 000[a]
AL 9	21 December	Main run	22 000
	27 December	Hamersley Inlet	4 000[b]
AL 10	21 December	Main run	57 000
	26 December	Red Peak escape	5
	27 December	Red Peak escape	900
	" "	Gordon Inlet escape	600
Total area of Park burnt -			122 605[c]

a Includes areas scrubrolled and burnt along Hamersley Drive.

b Estimate of area burnt around Hamersley Inlet on 27 December is only approximate as fire run took place within contained perimeter.

c This figure is substantially less than the preliminary estimate of the area burnt (157 000 ha), which was made prior to the availability of satellite imagery. The preliminary figure has been quoted in several publications e.g. Hopper (1991), Moore *et al.* (1991).

Flankfire spread and fire shape were not accurately documented during the major fire runs because the massive smoke plumes prevented effective aerial reconnaissance. However, in view of the extent of the area burnt following the southerly change on 21 December it is clear that fire activity must have been sustained around most, if not all of the perimeter of each fire. This is in contrast to experience of wind-driven fires in the FRNP under less severe conditions when flanks have not extended following wind changes and the fires have consequently retained a long and narrow shape. No doubt the extreme dryness of the fine fuels played a critical role in the sustained activity of flank and back fires on 21 December.

Fire intensity (Byram 1959) is dependent on the rate of spread of a fire and the quantity of fuel consumed. Typically, about 10 t ha^{-1} of fine fuel is consumed in the flaming zone of a fire in mature mallee heath (McCaw, unpublished data). Based on this figure, intensities of 20 000 and 40 000 kW m^{-1} would be generated by fires spreading at 4 and 8 km h^{-1} respectively. Much of the area burnt on 21 December would have experienced intensities in this range, which are regarded as very high (Cheney 1981). Combustion of litter and shrub foliage was complete (Fig. 6a). In forest fuels direct or parallel attack is rarely successful on fires exceeding 3000 kW m^{-1} although this depends to some degree on the nature of the fuel type and the suppression techniques employed (Loane and Gould 1985). In shrub and mallee fuels the limit may be somewhat higher as there is less potential for propagation by spotting because of the lower canopy height and the smaller quantity of fibrous or pendulous bark on the trees. Intense headfires spotted for several hundred metres but spot-fires did not play an important role in fire spread as they were quickly overrun by the main fire front.

Fires in mallee and shrub fuels spread principally by direct flame contact. These fuel types have distinct threshold conditions of fuel moisture content and wind speed required for continuous fire spread (McCaw 1991). Slight changes in weather or fuel conditions may therefore result in dramatic alteration of fire behaviour. Thresholds vary between vegetation types according to the species composition and density of the shrub layer, and the amount and continuity of ground litter layer; both of these factors are strongly linked to the time since last fire. Sudden transitions from mild to violent fire behaviour were common, particularly during mid-morning as fuels dried out. In mallee fuel types fires typically ceased spreading overnight but reignited from smouldering mallee rootstocks and grass trees (*Xanthorrhoea* sp.) the following morning. At night, backburning operations were not effective in mallee fuel types and the perimeter of the fire could not easily be distinguished because there was no distinct flame front. However, because fire behaviour escalated rapidly each morning only a short period was available in which backburning operations could be undertaken safely and effectively before fires became so intense as to be uncontrollable.

Night-time conditions were relatively dry during the period of the fires except in the immediate coastal zone; overnight relative humidity rarely exceeded 70 per cent at Jerramungup. As a result fires sustained overnight in dense shrub thickets and in the continuous litterbeds of the woodlands, although intensity and rate of spread were much reduced and consumption of elevåted fuel tended to be incomplete. There were a number of instances where areas that had been burnt under mild, overnight conditions subsequently reburnt under more severe daytime conditions with the fire spreading principally through scorched or partially burnt shrubs.

Most of the area burnt in the Park had been at least twenty years without fire, and in some cases much longer. Fine fuel accumulations in shrublands tend to stabilize at an equilibrium level within 15 to 20 years after fire, and in some cases within shorter periods (Burrows and McCaw 1990). However, the flammability of some woodland and mallee types may continue to increase because of the accumulation of litter and twigs beneath mallee clumps, the build-up of fibrous bark on stems, and changes in the structure of the fuel complex. Mallee and shrub fuels as young as 5-years-old reburnt during conditions of Extreme fire danger (Table 5). However, it is likely that the younger fuels contributed to the reduced spread rate of fire AL8 between 1125 h and 1300 h, and retarded the spread of flankfires. Also, the proportion of 5-year-old fuels remaining unburnt was greater than in older fuels. Fire spread was retarded by 5-year-old fuels during the late afternoon on 21 December once the GFDI fell below 50. Fuels that were 8 years or older reburnt completely and did not appear to have significantly modified the pattern of fire spread.

Suppression

CALM's principal fire management goal is to protect community assets and environmental values from damage or destruction by wildfire. In the event of fire threatening these values an appropriate response is determined according to the following order of priorities:

- protection of human life;
- protection of community assets, property and special values;
- cost of suppression in relation to the values threatened.

In the case of the FRNP important factors that influenced the planning and implementation of fire suppression operations included the large size and remote location of the Park, the likelihood of further severe fire weather during the remainder of the summer, and the potential threat that uncontrolled fires posed to surrounding agricultural communities and significant environmental values within the Park.

The major fire runs on 21 December posed a direct threat to the settlements at Quaalup and East Mt. Barren and to the safety of visitors at coastal recreation sites within the Park, some of which are only accessible by four-wheel-drive vehicle. As the potential of the fires became clear during the morning of 21 December a Large Fire Organization was established to coordinate the suppression operations within the Park; this operated for the next 27 days until 10 January 1990. Close liaison was maintained between CALM, BFB and Shire Fire Control Officers throughout the period of the fires. The immediate priority on 21 December was the safety of visitors in the Park. Ground patrols, assisted by light aircraft, located visitors and escorted them to safe areas outside the Park. The Park remained closed until mid February 1990.

Following the southerly change on 21 December the principal concern became the threat posed to Ravensthorpe and Hopetoun, and the private property adjoining the eastern end of the Park. Consequently, the joint suppression effort between volunteer Bush Fire Brigades and CALM crews concentrated on containing the fire on Sectors 1 and 2 as conditions moderated in the evening. This strategy proved to be effective.

In the longer term the anticipated return to south-east winds posed a potentially serious threat to remaining unburnt areas in the north-western part of the Park and to private property adjoining the northern boundary. Protection of remaining unburnt areas of the northern uplands was considered a high priority in view of the known importance of these sites as habitat for species of rare fauna.

Fire controllers were faced with three broad options for containing the fire in the western half of the FRNP:

- take no immediate action but monitor the spread of the fire and undertake further control measures if important values came under direct threat;
- confine the fire within existing tracks by scrub-rolling and backburning;
- construct bulldozed firelines along the existing fire perimeter.

The option of doing nothing was not acceptable in view of the extensive length of uncontained fire perimeter, the likelihood of further severe fire weather during the summer and the important assets and values at risk. Fires continued to be active in inaccessible terrain along the Fitzgerald River valley and had the entire perimeter been left uncontained the extent of fire spread on subsequent days of severe fire weather would have been much greater. The security of the Park boundary would have remained doubtful under this strategy, and the lives of firefighters may have been jeopardized in attempting to contain any major fire runs that erupted during the remainder of the fire season.

The second option of confining the fire within existing tracks was considered, but the major disadvantage with this strategy was that there were few suitable tracks between the fire perimeter, as it existed at the completion of the major runs on 21 December, and the Park boundary. Withdrawing to the Park boundary would have extended the fire perimeter substantially with an estimated length of some 150 km necessary to link Fire AL10 at Gairdner Road to Fire AL8 at the northern end of Drummond Track. Most of this perimeter would have required scrub-rolling and commitment of considerable resources to backburning operations. This strategy would also have resulted in much of the remainder of the Park being burnt out, an undesirable result from an ecological standpoint given that western and northern areas of the FRNP are known to be important habitat for rare fauna. The agricultural lands adjoining this section of the FRNP contain few remnants of native vegetation and the scope for recolonization by less mobile species of fauna may therefore have been quite limited.

The third option was in fact adopted; that was to construct firelines along the existing fire perimeter. This strategy was favoured because it minimized the length of perimeter to be patrolled and allowed retention of unburnt areas in the north of the Park. It was not, however, a straightforward task. Much of the fireline had to be constructed in rugged, inaccessible terrain that included steep breakaway country along the river valleys. Light aircraft were used to assist ground crews in following the irregular fire edge and finding routes around obstacles. Fireline construction continued overnight despite the additional problems resulting from lack of visibility. Prompt containment of this sector of the fire was essential because of the anticipated return to south-easterly winds.

Ecological Considerations

Survival and spread of *Phytophthora cinnamomi* is minimal when soils are dry (Shea 1975) and fortunately most of the roads and tracks in the Park remained dry throughout the period of fire suppression operations. Following heavy rains in late January 1990 access to the Park was restricted in order to minimize the opportunity for movement of infected soil on vehicles and machinery. From the outset of suppression operations steps were taken to minimize the risk of spreading *Phytophthora* and bulldozers and chains employed for fireline construction or scrub-rolling were thoroughly washed down to remove accumulated mud and dust prior to entering the Park. Track construction and scrubrolling operations avoided known *Phytophthora* infections.

Scalping and heaping of topsoil, and disturbance of rootstocks was avoided where possible during fireline construction to minimize the potential for subsequent erosion. Damage to sandy and gravelly soils was generally minor but some problems were experienced where trafficable lines had to be constructed in steep breakaway country. Rehabilitation work to restore topsoil and prevent rainscouring was completed in late January 1990 in disturbed areas.

Most of the vegetation in sections of the Park burnt by the 1989 fires was in a mature condition and had been unburnt for more than twenty years. Many plants released abundant seed from woody capsules within 24 hours of fire, notably species of *Banksia*, *Dryandra*, *Isopogon* and *Hakea* (Fig. 6b). By the end of February 1990 rootstock species had resprouted over most of the burnt area, but seedling regeneration at this stage was limited to occasional individuals of *Acacia* and other species with hard, soil-stored seed. A survey of flora in burnt areas of the Park was undertaken in spring 1990 (Hopper 1991); there was extensive flowering of many species of orchids, and several plant species were recorded for the first time in the Park, including the branched catspaw (*Anigozanthus onycis*). The heavy rainfall of January 1990 is likely to have a profound impact on post-fire regeneration in some plant communities, and no doubt contributed to the early flush of growth apparent from many of the species with subterranean corms and rootstocks. Large amounts of seed were redistributed by water flow, mostly being deposited in localized depressions and along roadside drains (Fig. 6c). By September 1990 seedlings had germinated in distinct clumps in these sites (Fig. 6d).

In the limited areas of the Park burnt twice within 5 years (1985 and then again in 1989) some slower-growing species of obligate seed regenerators may have had insufficient time to mature and set seed in the intervening period. In this circumstance populations of these species may have declined substantially as a result of the 1989 fires or even suffered localized extinction

A number of populations of Declared Rare Flora were within the area burnt in December 1989. Known populations were avoided during scrub-rolling and backburning operations, although some species could not be readily located in the field because populations were very scattered and plants were not flowering at the time.

A preliminary survey in spring 1990 indicated that there had been excellent seed germination by a number of species of rare flora (Hopper 1991).

A large number of animals of many species certainly perished during the intense fire runs on 21 and 27 December. Carcasses of fire-killed kangaroos were found at a number of sites over the days immediately following the fires, but there was little evidence of smaller animals, probably because many were completely incinerated. At the Fitzgerald Inlet K. Gillen observed the remains of a large number of small birds on the ground in an area of woodland burnt at relatively low intensity, presumably having died from asphixiation and exhaustion.

Extensive flocks of birds were observed foraging for seed in burnt areas many kilometres inside the fire perimeter from the morning of 22 December onwards. A study of recolonization by vertebrate fauna following the 1985 Mid Mt. Barren fire highlighted the importance of unburnt remnants in providing refuges for less mobile species and habitat for recolonizing individuals (Chapman and Newbey[3]). Much of the area burnt in 1989 contained few, if any, such remnants and as a result the remaining unburnt areas in the north and west of the Park will play a key role in the post-fire survival and dispersal of many species of fauna.

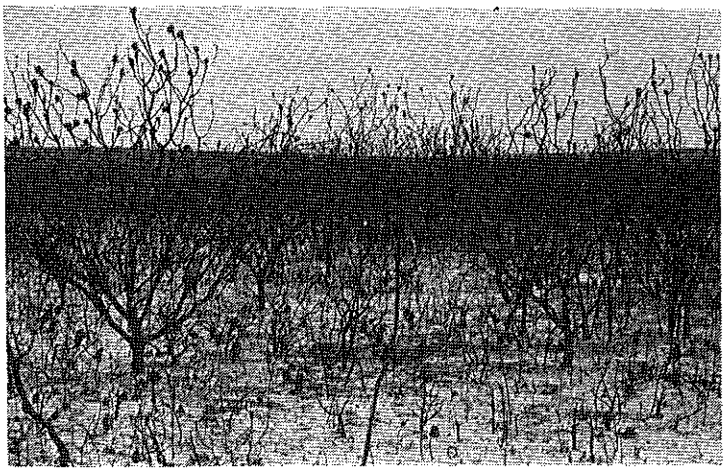
CONCLUSION

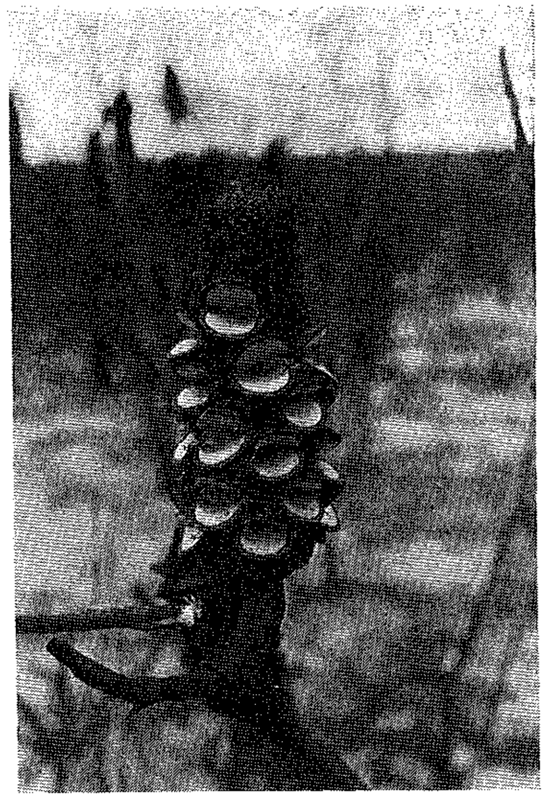
Extensive wildfires have been a relatively common event in the shrublands of south-western Australia during this century and fire scar patterns recorded on air photographs and satellite imagery reveal that some areas have burnt a number of times. Escaped agricultural clearing burns and deliberate ignition of the bush have caused some of these fires but many others have started from lightning strikes. Historically, the coincidence of lightning, severe fire weather and flammable vegetation would have ensured that fire was a periodic factor in the shrubland environment.

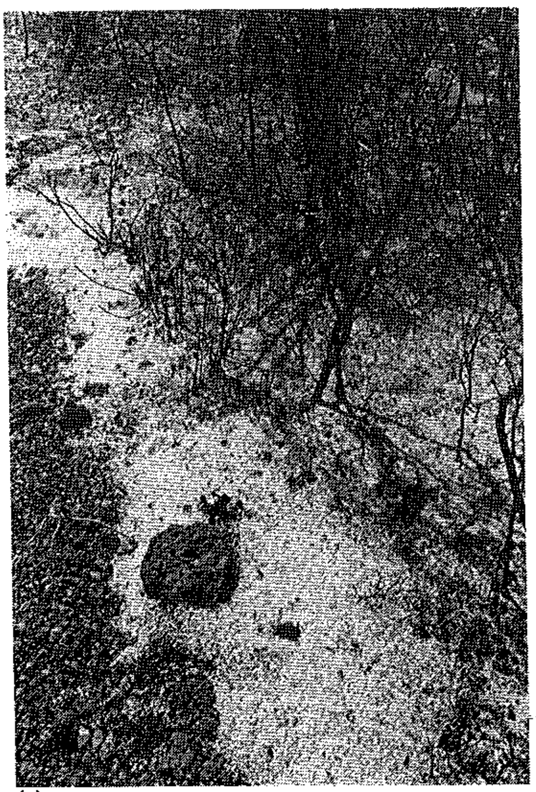
The lightning-caused wildfires of December 1989 in the FRNP represent a continuation of this fire regime. Weather conditions during 1989 were not unusual in terms of the drought conditions prior to the fire season, the frequency of days of severe fire weather, or the incidence of lightning. From the management perspective the occurrence of three widely dispersed lightning strikes in the Park on a day of Extreme fire danger could be regarded as an unlucky, but not improbable event. Whether or not the existence of extensive tracts of mature vegetation represents a situation uncommon prior to European settlement and development of the south coast is now impossible to say with any degree of certainty. Aboriginal people are known to have deliberately used fire for hunting and cooking (Hallam 1975), and may also have maintained a mosaic of burnt and unburnt areas as has been documented for the hummock grasslands of the arid zone (Burrows and Christensen, in press). Under the circumstances of December 1989 large and intense fires would almost certainly still have occurred even had a greater proportion of vegetation in the Park been in younger seral stages. However, the presence of tracts of young fuels would have tended to reduce the probability of ignition from lightning strikes and inhibited the initial development of fires. The existence of a mosaic of fuels of different ages may also have reduced the final extent of the burnt area and resulted in a more diverse pattern of burnt and unburnt patches.

Many of the parks and reserves in south-western Australia are now remnants in a predominantly agricultural landscape. This has two important implications for fire

[3] A. Chapman and K. Newbey, unpublished manuscript 'A study of flora and fauna response following the 1985 fire in Fitzgerald River National Park'.


(a)


(b)


(c)

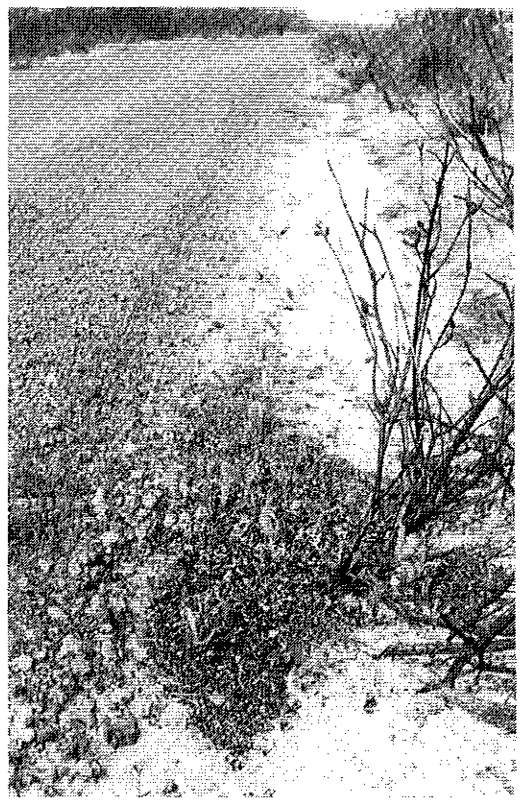

(d)

Figure 6

(a) *Banksia* thickets near Pabelup Drive defoliated by fire AL10.
(b) *Banksia* cone with open follicles and all seed released.
(c) Seed, mostly of *Isopogon* species, washed into roadside drain by heavy rains (February 1990).
(d) Seedlings of *Banksia* and *Isopogon* clumped in leaf litter along Pabelup Drive (September 1990).

management: firstly, fire management on CALM lands must be integrated with that on adjacent lands, giving due consideration to protection of life and property; secondly, fire management programs compatible with conservation objectives should be implemented to reduce the likelihood of entire reserves being burnt at one time. In large reserves fire management plans should aim to provide a diversity of seral stages to meet the habitat requirements of a wide range of native fauna, taking into account those species that are restricted in distribution or vulnerable to inappropriate disturbance regimes (Wardell-Johnson *et al.* 1989). Options may be quite limited in smaller reserves. On-going research is required to develop appropriate techniques for implementing fire management prescriptions in parks and reserves dominated by shrub, mallee and woodland communities.

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