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Regeneration after fire in King's Park, Perth, Western Australia

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Abstract

Fires, both devastating wildfires and controlled burns, have been frequent in King's Park over the past thirty years, and some changes in the vegetation over this period have been recorded. A major one has been the spread of the South African veld grass *Ehrharta calycina*, aided by fires and firebreaks. The native bush is fire adapted; none of the tree species and few of the shrubs are killed by fire. The undergrowth is rapidly built up again after a fire since most shrubs sprout vigorously from lignotubers or deep tap-root systems and monocotyledons make rapid recovery from undamaged underground apices. The few species killed by fire, with two exceptions, regenerate freely from seed. Nevertheless, too frequent fires have tended to reduce or eliminate certain species.

The regeneration in the first year differs with the season of the burn, spring burns favouring shrubs and autumn burns favouring the herbaceous species. Details are given for the progress of fire succession after particular burns at different seasons, and of the response to fire of some of the more important species.

It is concluded that in unmodified bush, control burning of small areas could be used effectively to maintain healthy undergrowth and a pleasing diversity. The problem of control of vegetation has been immensely complicated by the presence of veld grass and other weed species so much more aggressive than their native counterparts and apparently favoured by any programme of burning.

Introduction

Fires in eucalypt forests are of such vital importance that there is an extensive literature, most of it understandably concerned with forest trees and to a lesser extent major understorey species. The observations recorded in this paper have, as far as possible, included all species of the undergrowth, the vulnerability, type of regeneration and rate of recovery after fires at different seasons.

The area concerned is in King's Park, Perth, Western Australia, a reserve in which about 250 hectares is uncleared bush. An account of the park with a general description of the flora and fauna was given by Main and Serventy (1957). A more recent paper (Beard 1967) discussed the eucalypt woodlands comparing their present condition with the presumed original state.

The vegetation is a Eucalyptus-Banksia-Casuarina woodland with a dense low (30-100 cm) understorey of sclerophyllous shrubs and harsh monocotyledons (Fig. 1). It varies from an almost pure Banksia-Casuarina woodland through stands with Jarrah *(Eucalyptus marginata)* or Jarrah and Marri *(E. calophylla)* as an overstorey to the Banksia-Casuarina, to a more open woodland with tall Tuart *(E. gomphocephala)*.

Notes and photographs of the regeneration and some measurements of rates of growth following different fires have been made over many years. Some permanent quadrats laid down in 1936-40 have been remapped at intervals for more than 30 years. Observations have been mainly in the south-west half of the park and adjacent University land.

In a climate with a cool wet winter and long hot dry summer the fire hazard is very high, due both to the climate and the highly inflammable vegetation. Fires in the park have been frequent and have occurred in all seasons. They fall mainly into 2 groups: devastating wildfires in mid-summer (January-February), and mild burns covering smaller areas in spring and autumn.

The most extreme fires burn the foliage and may kill the upper branches of the trees; less intense ones do not burn but scorch and kill the leaves which fall later (Fig. 2A); the ideal control burn leaves the canopy even of the small trees unharmed (Figs. 2B and 11A.). In all fires except those over recently burned sections the shrub layer is burnt off to ground level, except for a few dead sticks of some of the stronger shrubs. In severe burns the ground surface is left as white sand with patches of ash and charcoal (Figs. 2-3). In a mild burn only the loose litter is burnt, leaving the older organic layer.


A
B
C

Course of regeneration during the first year

Regenerations after fires of December 1950, January 1958 and January 1973 in the same area and January 1970 in a different site are described as typical of mid-summer fires. However, it must be remembered that no two fires are exactly the same, nor are the following weather conditions. Damage to trees was severe in all these fires, most extreme in 1973. The state of the trees and the ground surface immediately after, or within a few weeks of the burn, are shown in Figures 3A-D.

Growth

The first plants to grow are the *Xanthorrhoeas* (Blackboys) (Fig. 3). The burnt off leaves continue basal growth and new leaves appear from the well protected apex. Sedges, particularly *Tetrariopsis*, grow almost as soon from underground basal extension of the burnt off leaves. New leaves of the cycad *Macrozamia* appear within a few weeks, grow extremely rapidly and reach full length in about 4 months (Fig. 3D).

Some of the deep-rooted shrubs sprout within 2-3 weeks of being burnt, e.g. *Persoonia*, *Jacksonia*, *Daviesia* (4 species), *Leucopogon*, *Stirlingia*, *Scaevola*, *Petrophile* and *Hardenbergia* (a climber) and some others, e.g. *Hibbertia*, *Oxylobium*, less vigorously. All these show as isolated tufts in the extensive areas of bare ground (Figs. 3 and 4). Figures 3A, B, C, D, all show the regeneration before the winter rains. The soil is exposed to the full heat of the summer sun to be followed by the battering and leaching of the heavy winter rain.

Shortly after the commencement of the effective winter rains there is a sudden flush of growth of herbaceous plants. First are the geophytes, *Burchardia umbellata*, *Sowerbaea*, *Caesia*, *Eryngium*, *Drosera* spp. and orchids. Annual weeds germinate quickly and are very conspicuous at this stage in disturbed areas, being more vigorous than the native annuals, which also germinate, but more slowly. Of these, *Calandrinia corrigioloides* and, to a lesser extent *C. liniflora*, are very abundant although rarely seen in unburnt areas.

The winter rain also increases the growth of the shrubs. New growth appears on plants which had started before rain. In many cases, particularly *Scaevola* and *Kennedia*, this winter growth has much larger leaves than those produced in the summer. New clusters of shoots appear above ground on plants which had made little or no growth before the rain. Those species which normally grow mainly in winter, e.g. *Phyllanthus*, *Hybanthus*, now grow rapidly, while others grow slowly until the spring warmth. Seedlings of trees and shrubs also appear soon after the rains. At this stage the 'patchiness' of the ground cover is very noticeable. Many species are very unevenly distributed, and the total shrub cover varies greatly from place to place.

Flowering

The flowering of herbaceous species follows the same progressive seasonal pattern after fire as in unburnt bush, e.g. *Drosera erythrorrhiza* in May, other species later; *Lomandra preissii* very soon after rain followed by *L. micrantha* and *L. endlicherana*. Orchids come into flower from May to November, each species having a short flowering period. *Caladenia flava*, one of the commonest, is illustrated (Fig. 4A). The greatest show of herbs is in spring and early summer, with *Burchardia*, the most widespread and abundant species (Fig. 5B) and other liliaceous species. Annuals on the average flower later than the geophytes but again there is a sequence of flowering, e.g. in the composites the order is *Podolepis*, *Podotheca* (Fig. 4C) and *Waitzia*.

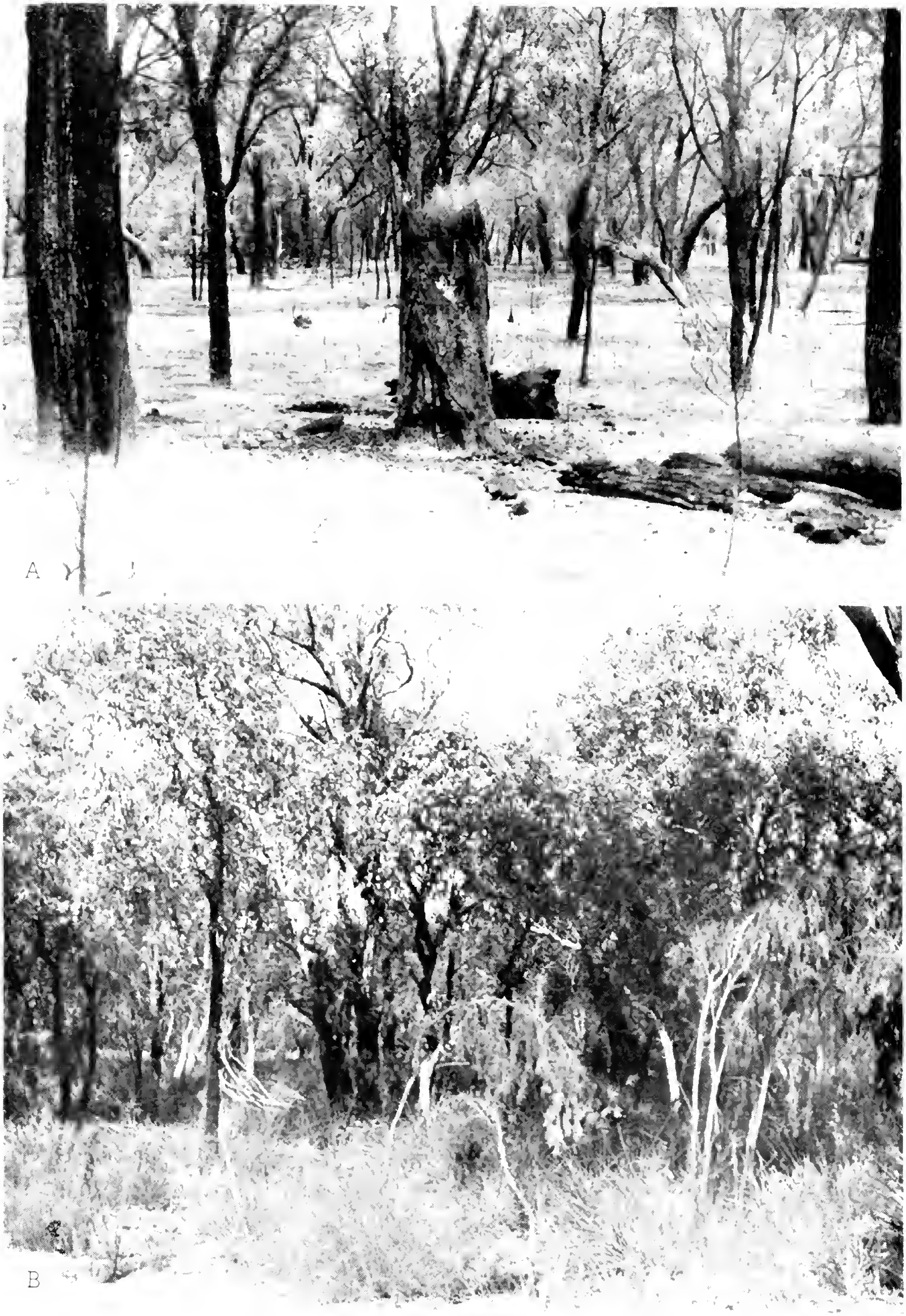
By far the most conspicuous species in October-November, is the annual grass *Stipa compressa* with its long golden awns (Fig. 4D). It dominates the burnt areas, obscuring the lower shrub regrowth. The tall white flowering spikes of *Xanthorrhoea* project above this sea of grass and the dark brown inflorescences of the two species of *Haemodorum* show up against the pale grass (Fig. 3F). Both *Xanthorrhoea* and *Haemodorum* flower profusely after fire but very rarely in unburnt bush.

Most of the common shrubs, e.g. *Daviesia*, *Hibbertia*, *Oxylobium*, *Hovea*, *Hypocalymma*, *Leucopogon* and *Stirlingia*, do not usually flower in the first season after a late or mid-summer burn. None were seen in flower in the sites burnt in 1973. However, some early-blooming species do flower in the first year—notably *Scaevola canescens* which flowers from May onwards, even on 5-7 cm of regrowth. In early spring the creepers *Hardenbergia* and *Kennedia*, and some of the small herbaceous perennials, e.g.*Hybanthus* and *Monotaxis*, are in flower.

In general, flowering for sprouting shrubs is particularly good in the second and third years after fire. In September to October 1974, flowering was spectacular in the less weedy parts of a January 1973 burn, after two above-average rainfall winters and a virtual absence of tree canopy. Kangaroo paws have many times been noted as particularly abundant in the third and fourth years when new seedlings from the fire are flowering. The surviving old plants bloom in their first season of regrowth.

In the Tuart areas the course of the regeneration is similar to that described above for Jarrah-Banksia communities, although there are some different species (see species list) and in general a more herbaceous undergrowth. The common *Daviesia* spp. are almost absent. *Macrozamia* is far more common. Of the species almost confined to the Tuart, *Clematis*, *Rhagodia*, *Scaevola holosericea* and the thoroughly naturalised South African *Pelargonium capitatum* all

Figure 1.—Types of vegetation. A.—Typical Banksia—Casuarina woodland with dense low shrub undergrowth; *Acacia pulchella* in flower; August 1960. B.—Tuart with *Grevillea vestita* in flower. C.—Tuart with veld grass; *Dryandra* in right hand corner.


A
B

make good regrowth. The tall shrubs *Conospermum triplinervium*, *Dryandra sessilis* and *Grevillea crithmifolia* are killed by fire whereas *Grevillea vestita* suckers freely from horizontal roots.

The fireweed distinctive of the Tuart association is the tall, semi-herbaceous *Anthocercis littorea* (Solanaceae). It is killed but seedlings are numerous and grow rapidly, reaching 1-2 m and flowering within a year of the fire.

Where a fallen tree trunk has burnt to ash a small orange discomycete fungus appears in the first year followed by *Funaria hygrometrica* fruiting in the second year. Exuberant growth of *Funaria* on burnt ground is a well-known phenomenon in many moister climates, but it is interesting that it also occurs in this habitat not particularly favourable to mosses.

Season of burn

Early regrowth after fires differs markedly with the season of burns; in general spring burns favour shrubs and autumn burns favour herbaceous plants.

Burns in March 1952 (Fig. 5), and March 1956 and 1957, will serve as examples of autumn burns in Jarrah woodlands. As with any fire, blackboys and sedges were the first to grow, little else appearing before the first rains, which were followed by a flush of herbaceous shoots. There was also some sprouting of shrubs through May and June. These shoots mostly remained short until the warmer weather in spring, and did not flower until the following year. An exception was the winter growing *Phyllanthus*, which grew rapidly and reached flowering in August of the first year. Through winter the herbaceous geophytes, *Burchardia*, *Arthropodium*, *Caesia*, *Sowerbaea*, with the sedges and the smaller annuals, formed the bulk of the ground cover with the short shrub shoots more or less obscured. Figures 5A, B and C show the same site burnt in March 1952—A. 2 days after the fire, B. *Burchardia* in flower in September, and C. *Stipa* in flower in October. *Podotheca* (Fig. 4C) and other smaller annuals were also abundant. Equally spectacular displays of *Burchardia* and of annuals later, occurred after fires in other areas in March 1957.

Spring to early summer fires result in rapid and vigorous shrub growth which, with equally rapid growth of blackboys and other fibrous monocotyledons, goes far to restore the undergrowth before the late summer drought. The effects of several control burns in early November have been watched and measurements recorded of average rates of growth of several of the common sprouting species. In all sites regrowth was very good, shoots of shrubs showing within 3-6 weeks of the fire, growing rapidly and continuing later into the summer than is normal for unburnt plants. Shrub regrowth was advanced enough for flowering in following winter to spring of *Daviesia* spp., *Hibbertia* spp., *Oxylobium*, *Stirlingia* and others which do not flower until the second season after an autumn burn. Figure 5E shows the same site as Figure 5B and at the same time of year but after another fire in early summer. Figure 2B shows regrowth of shrubs in June after a November burn and also illustrates the trees with even low branches undamaged and tall shrubs (*Jacksonia*) unburnt. This was an ideal control burn although the fire hazard had been high; minimum damage was done and only the loose surface litter was consumed. This may be compared with conditions after the wildfire of 1973 (Fig. 3). Figure 11A shows regrowth after another mild early summer fire.

A spring burn followed by enough rain to germinate seeds may result in seedling death over summer as there is not time enough for the tap root to penetrate deeply before the dry season. An example of this was recorded in 1949 where of numerous seedlings of *Acacia pulchella*, which grew after an October fire, not one survived the summer. In an adjacent quadrat burnt in January seeds did not germinate until May and after growing through the winter and spring were safely established before summer. The increase of the *Acacia* here was from 3 plants before to 69 after the fire. For annuals a fire before the plants have set seed reduces the seed available for next season. Winter and early spring fires damage geophytes when foliage is burnt off after the new growth has depleted storage organs. One June burn resulted in very poor flowering of *Burchardia* compared to adjacent unburnt bush, and in marked contrast to the rich flowering after autumn burns.

It must be emphasised that although autumn burns undoubtedly favour herbaceous plants they are not necessarily unfavourable to shrubs. In fact, in the absence of competition from veld grass, the slower early leafy growth and delayed flowering may eventually result in a sturdier plant.

Continuing regrowth

For the first 2 or 3 years after a fire shrubs are erect and vigorous with a variable amount of bare ground between them. As lateral branching increases the plants spread and become straggly; the shrubs overlap each other and the associated spreading fibrous monocotyledons.

The general vegetation level is restored early and changes very little, but the density of cover increases as branches multiply and new shoots grow from ground level. Certainly tall shrub species regenerating from seed in the lower layers eventually grow tall and project above the general level, but as these shrubs tend to occur in thickets in restricted localities they do not invalidate the picture of a predominantly uniform low level of undergrowth.

Figure 2.—A.—Photo taken the day following a fire in February 1959. The fire did not go through the canopy but the leaves were scorched and fell later. The old tree in the centre was burnt through and was still smouldering, fresh white ash in foreground. This is part of the stand referred to in Table 1. B.—A mild control burn; even tall shrubs and lower branches of trees not burnt. Photo May 1953 six months after the fire in November 1952. Shrub regrowth well established.

Samples of bush at different intervals after fires are shown in Figures 6A-F.

With age the percentage of dead wood increases, and leaf and twig litter from trees accumulates and tends to cover the shrubs. After about 10 years, or sometimes less, *Daviesia* spp. in particular and also *Petrophile linearis* and *Conostephium pendulum* show definite signs of deterioration, and become infected with scale insects and sooty mould. *Stirlingia*, so strikingly vigorous in its growth and flowering after fire, becomes an inconspicuous component, non-flowering and with stem increments and leaf size steadily diminishing so that old plants have small tufts of leaves on long stems which tend to become prostrate. *Hibbertia* and *Oxylobium*, on the other hand, continue to grow and flower, although in somewhat tangled mats. *Acacia pulchella*, with its single main stem, continues to grow well and flower profusely for 8-10 years, but over subsequent years many plants begin to die. The smaller *Gompholobium* suffers a similar fate.

In stands not burnt for 20 years or more, there is a real suppression of the undergrowth and a heavy build-up of leaf and twig litter (Fig. 6D). Nevertheless, few plants are killed and some grow with only the tips of long trailing stems showing through the deep litter. The quite small plant, *Monotaxis*, is one of these. *Hibbertia*, *Hovea*, *Pimelea*, *Conostephium* and others continue to grow and flower unless totally smothered by *Casuarina* litter. The greenhood orchids, particularly the tall handsome *Pterostylis recurva*, are always at their best in long unburnt areas with deep organic matter. One small area which had escaped fire for at least 60 years and in which several fire-sensitive species were persisting has, unfortunately, been absorbed into a developed area.

Long term effects of repeated fires

These include progressive damage to trees, soil deterioration, reduction or elimination of weakly regenerating species and increase in weed species. Benefits of periodic burning include removal of senile and diseased branches, destruction of insect and fungus pests, rejuvenation of sprouting shrubs many of which seem to require periodic burning for healthy growth and flowering, and production of new crops of some short-lived shrubs which need fires for renewal from seed. The balance between good and bad effects depends on the extent, severity and frequency of fires, and because of the differing responses of different species there is no absolute optimum.

The greater damage by severe and extensive wildfires than by small mild burns needs no restatement. Irreparable damage to trees where fire has eaten into the heartwood or killed main branches is obviously more likely in wildfires, as is destruction of organic matter in the soil. In the park most of the common species survive the wildfires and make vigorous growth and flower profusely after mild or severe burns. The undergrowth may, in fact, benefit initially from the reduced transpiration and greater light where the tree canopy has been destroyed, but in the long term, with repeated fires, loss of organic matter and excessive leaching of the soil probably has a deleterious effect, particularly on the smaller species. Sampling in many sites has shown, as would be expected, a clear relationship between organic content of the sandy soil and its water holding capacity which, in the absence of organic matter (there is no true humus), is extremely low.

Fires every year, or as often as the bush will carry fire, are very detrimental to the undergrowth. This was seen in University land where deterioration was evident even before the veld grass overran the area. Regrowth of the sprouting shrubs became weaker with each succeeding fire and a number of the less vigorously regenerating shrubs died out, e.g. *Hovea* and *Pimelea* and *Phyllanthus*. The fire-sensitive species, *Acacia pulchella* and *Gompholobium tomentosum*, were eliminated. Deterioration of the soil was suggested by the abnormally small size of many annuals and herbaceous geophytes. This was very noticeable in *Drosera* species, in *Trachymene pilosa*, and in small annual grasses and composites. An orchid, *Lyperanthus nigricans*, recognised as one which flowers well after bush fires, had completely ceased to flower, although small leaves appeared annually for many years.

Response to fire of plants in relation to their life form

In an attempt to include most of the 230 species and make some generalizations—always dangerous as every species behaves differently—species are grouped and discussed under life forms.

Trees

None of the tree species is fire-sensitive, all are capable of sprouting from epicormic buds although some suffer more damage than others. A detailed survey after a severe fire in a dense Banksia-Casuarina stand showed that in this particular fire crowns of a few of the larger trees remained more or less undamaged but most mature trees had the leaves killed by heat although the fire did not run through the canopy (Fig. 2A). These sprouted up the upper branches, as in Figure 7E. Smaller trees had the upper branches killed and sprouted from epi-

Figure 3.—These photographs all show regrowth after a fire on 16 January, 1973. A.—Soon after the fire. B, C, D April 1973, three months after the fire. B.— *Xanthorrhoea* tufts, fallen leaves, bare sand. C.—Regrowth of *Daviesia divaricata* (centre and others with burnt old stems). *Stirlingia* (right), *Schoenus grandiflora* in front of bent stem. D.—*Macrozamia* and *Persoonia* regrowth. E.—Same site as A one year later, April 1974. Many Eucalypt coppice shoots, shrub regrowth partially obscured by dry grass (*Daviesia nudiflora* in front of bent tree trunk). F.—*Xanthorrhoea*, *Stipa compressa* and *Haemodorum* (2 spp); November 1973; approximately the same site as B. G.—Epicormic shoots starting on some burnt trees; *Xanthorrhoea* with blackened trunks; June. H.—Same site as G one year later; poor recovery of trees; veld grass on edge of firebreak.


A
B
C
D
E
F
G
H

cormies up the trunk as in Figure 5, while saplings under 2 m were mostly killed to ground level and produced coppice shoots. Many of the smallest saplings were completely killed. Actual figures recorded in part of this survey are given in Table 1. This is probably a common pattern in summer fires—and it has been noted in several others also. Damage was more severe in the January 1973 fire, examples of which are shown in Figures 3, 7 and 11.

Casuarina fraseriana is very badly damaged; the bark is thin and rough and easily burnt. Most trees of this species in the park have parts of the trunk dead and hollowed out by repeated

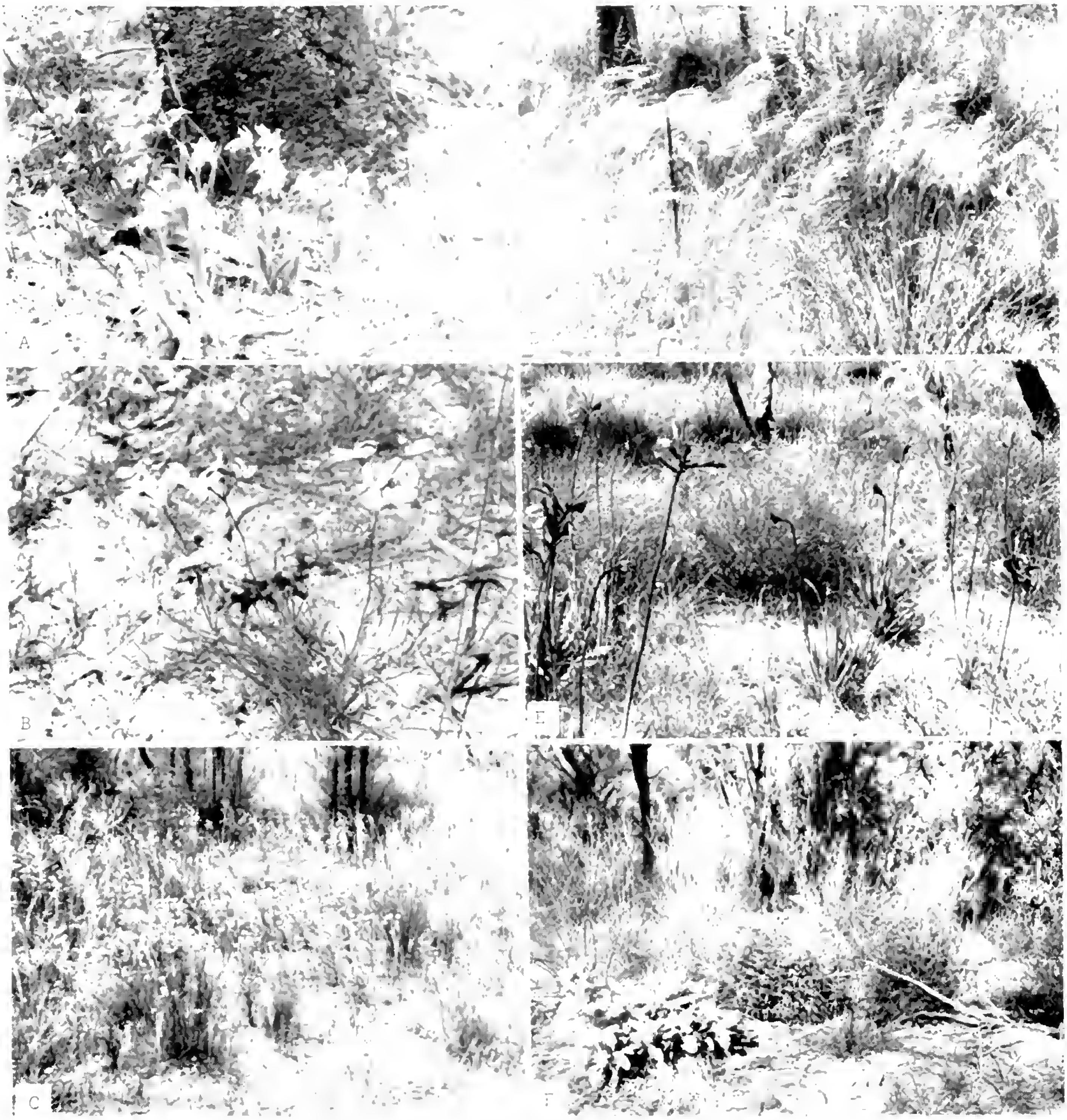


Figure 4.—A—D Herbaceous species in the first season after fire. A.—*Caladenia flava*. September 1958, after January fire. Note the hard undamaged bark of *Banksia menziesii* (leaves on ground). B.—*Stylidium schoenoides*. Note different positions of the column ("trigger"). September 1970 after a January fire. C.—*Podotheca chrysantha* and *Stipa*. October 1955, after a May fire. D.—*Stipa compressa* with long awns and sparse *Ehrharta* with taller panicles. October 1961 after a December fire. E. Regrowth in second year. *Anigozanthos manglesii* (Kangaroo paw) in flower and bud in foreground. *Daviesia juncea* (centre) and other shrubs. August 1974, after January 1973 fire. F.—Regrowth of various shrubs. Left to right: *Daviesia divaricata*, *Helichrysum cordatum*, *Stirlingia* (behind with tall inflorescences), *Oxylobium* (centre), *Leucopogon propinquus*; Monocotyledons in foreground. June 1974, after a November 1973 fire.

fires, and poor incomplete canopies. The trees, however, cling to life very persistently and will survive with only strips of living tissue up the trunk. This capacity to survive in a mutilated condition has undesirable consequences. The mass of shoots up the burnt trunks persists for very many years as there is no healthy crown to shade out lower branches and eliminate weak saplings, as would normally occur in overcrowded stands. Hence flowering undergrowth species and healthy seedling trees are suppressed and the mass of branches from the ground up

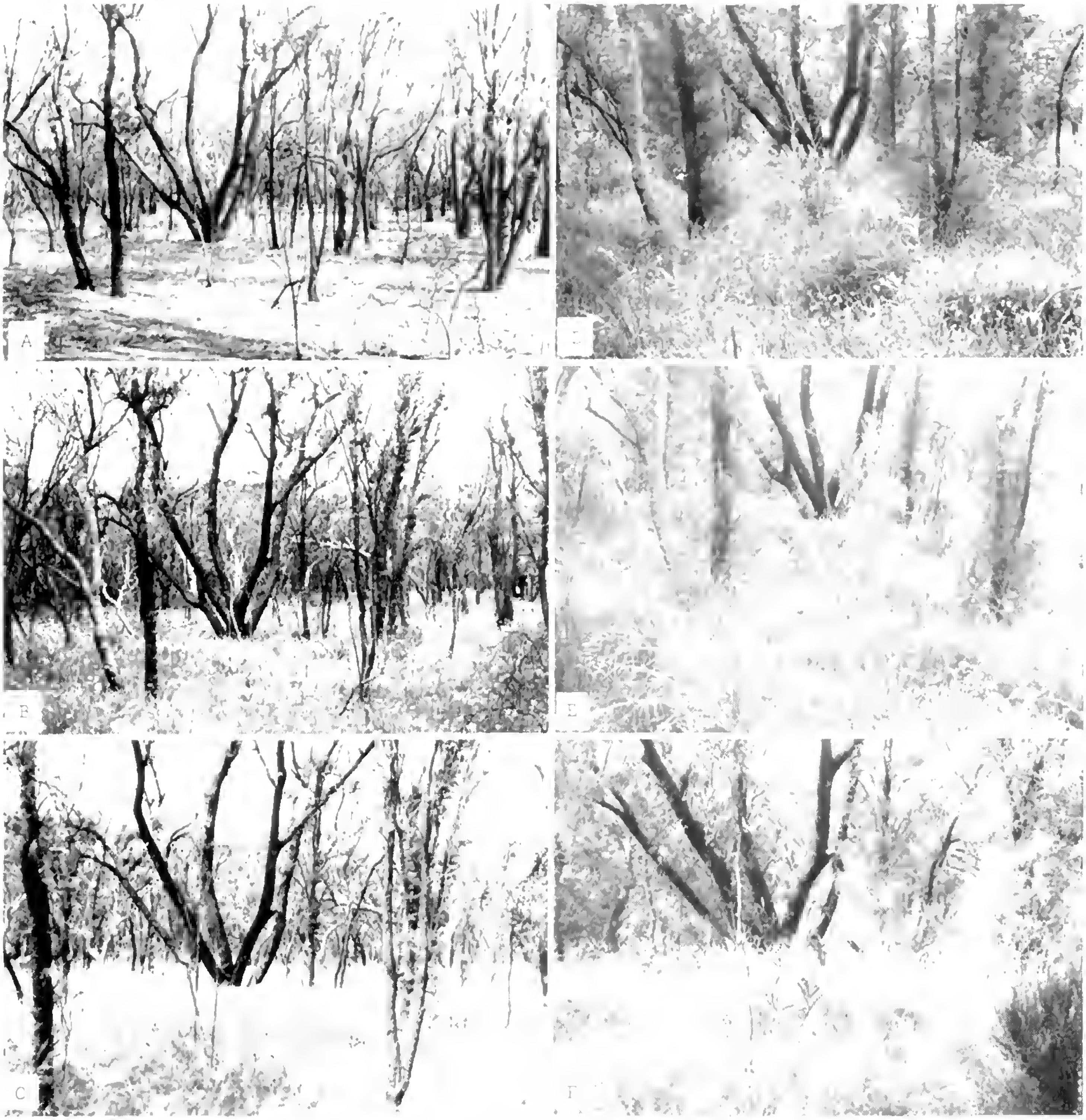


Figure 5.—Series taken to the same tree following a severe fire in March 1952. A.—March, 2 days after the fire. The section in the background was not burnt. B.—September, *Burchardia* in flower. C.—October *Stipa compressa* in flower dominating the ground cover. D.—A year later than C, November 1953. Note epicormic shoots on *Casuarina* trunks, a *Banksia* seedling plant just left of forked *Casuarina*, dead *Acacia pulchella* (non-sprouting) extreme right corner, *Briza maxima* against shadow left of this and absence of *Stipa compressa*. E.—September 1955, after a second fire in November 1954. Compare with (B) September 1952. *Burchardia* in flower as (B) but shrub regrowth much greater. *Hibbertia* in flower in foreground. The seedling *Banksia* in (D) has been killed but the coppice shoots of *Banksia* sapling centre have grown taller. F.—October 1959. Veld grass now well established.

creates a dangerous fire hazard.

Seedlings of *Casuarina* are found but their occurrence seems very irregular and probably depends on the right combination of ripe seed released, but not burnt, and suitable conditions for germination. After the March 1952 fire (illustrated) carpets of seedlings were found under several old female trees. The seedlings were first seen in early June when slender shoots were just appearing between the small cotyledons. By mid-August the still unbranched shoots averaged 7-8 cm in height, and in late September were about 10-15 cm with some branching. Two months later their height was mostly 16-20 cm with considerable increase in the growth of their branches. By December their growth had apparently ceased and some plants had yellowed. Over the summer a few plants

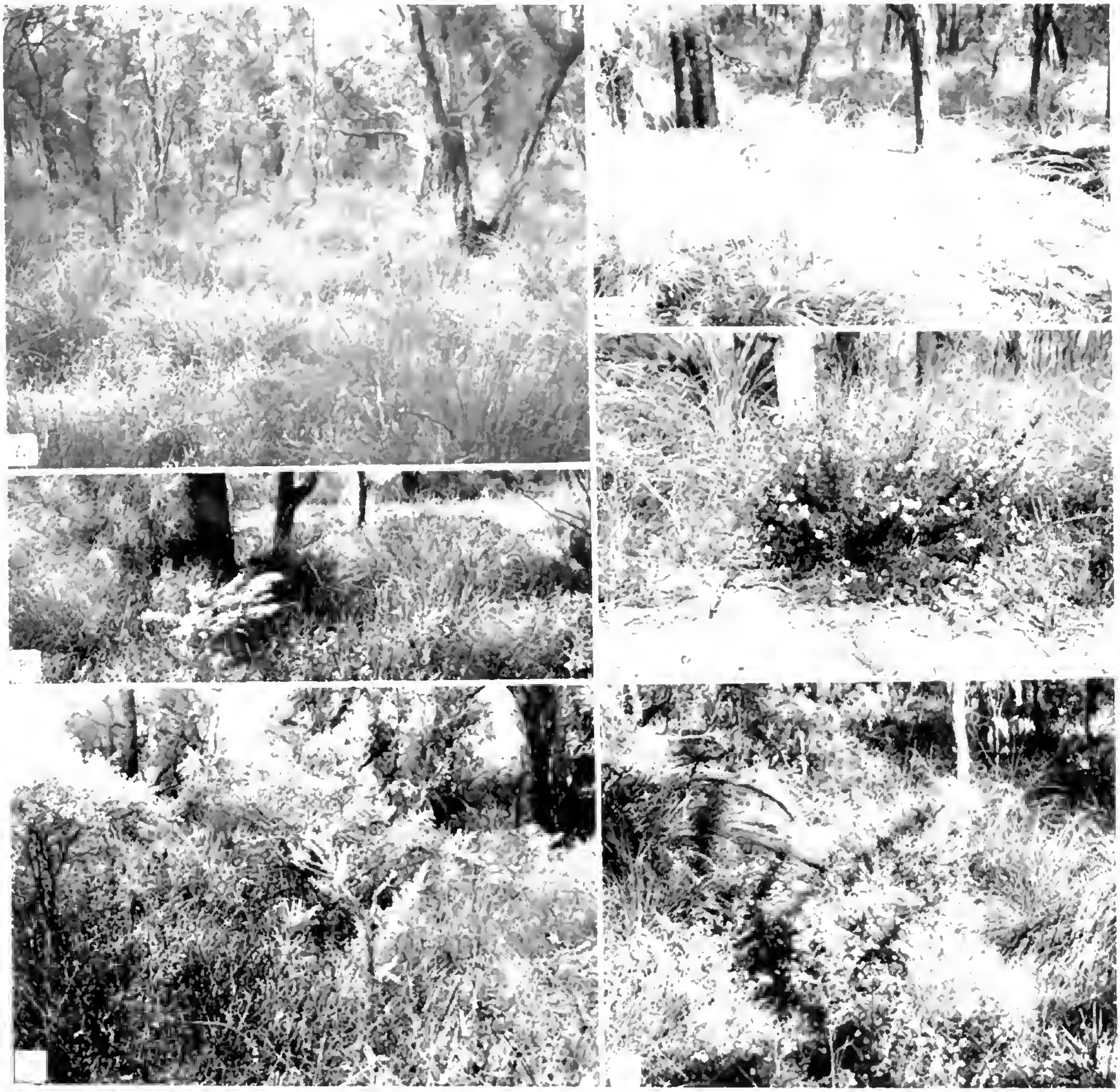


Figure 6. Examples of continuing regeneration. A. Two years after fire in December 1950, shrub layer re-established, tree canopy partially restored. (*Casuarina* right, *Banksia* left.) Shrub cover mainly *Daviesia* spp., *Oxylobium*, *Xanthorrhoea* with many smaller plants not recognisable in the photo. B. *Acacia pulchella* in flower. September 1953. Growth from seed after December 1950 fire. C. Same stand in the seventh year after fire; *Acacia pulchella* now well above general level, left and centre back. *Jacksonia furcellata* and *Banksia menziesii* both also grown from seed after the 1950 fire. D. Unburnt site under *Casuarina*, accumulated needles suppressing undergrowth. E. *Hibbertia* in flower in the second year after the January 1973 fire. F. Unburnt for probably 12 years, at least 10 years. *Hibbertia* in flower in a tangle of bushes. *Macrozamia* leaves on left.

Table 1

Part of an assessment of damage and recovery of trees in Banksia-Casuarina *woodland, burnt 1st February, 1959, as surveyed by students in July, 1959. All the trees in the transects, which were 1 chain wide, were counted and classified: saplings were counted separately from mature trees.*

Transect	Species	Killed		Killed to ground level		Canopy stripped		Canopy intact	
		over 2m	under 2m	over 2m	under 2m	over 2m	under 2m	over 2m	under 2m
Transect 1 (7 sq. chains)	*Casuarina fraseriana*	9	22	3	139	261	7		....
	Banksia attenuata	4	1	4	14	21	7	11	....
Transect 2 (12 sq. chains)	*Casuarina fraseriana*	4	34	4	83	168	11	9	....
	Banksia attenuata	3		10	24	103	3	2	
	Banksia menziesii	2	1	1	3	29		1	
A severe burn	Totals	22	58	22	263	482	28	23	
Transect 3 (5 sq. chains)	*Casuarina fraseriana*	3			24	9	3	77	....
	Banksia attentuata				12	3		29	....
A mild burn	Totals	3			36	12	3	106	....

died but most of them survived. In February the root-stocks of some of them had a slight swelling of the hypocotyl. Two years later a small lignotuber, 8-10 mm in diameter had developed. By October 1960 surviving plants were still under 60 cm tall and lignotubers of two dug up were only 2.5 cm long and 1.5 cm diameter. Unfortunately a second fire in November 1954 had destroyed all except a few isolated plants near the fire edges so there was no chance to see what would have happened to such a dense stand of young plants. I have not seen an equivalent mass of seedlings since but similar mass germinations from early fires may explain thickets of *Casuarina* which occur in the park.

Banksia trees, with their very thick, very hard bark, suffer minimum damage to trunks of mature trees (Fig. 4A), though saplings are killed to ground level. Most trees sprout along the upper branches (Fig. 7E). Healthy shoots grow from the lignotubers of burnt-off saplings and seedling regeneration is good and well able to compensate for deaths of trees. After the severe fire in January 1973, a very large number of Banksia trees did not recover, but it is uncertain how many were dead or dying as a result of a long drought increasing the usual summer deaths. Another factor which could account for the high mortality in this extremely hot fire is destruction of the dense mat of proteoid roots which occurs close to the surface in the organic layer of the soil. Roots have been seen exposed on badly burnt sites.

The Eucalypts, *E. marginata* (Jarrah) and *E. calophylla* (Marri), both have rough bark which readily carries fire into the crown. Most of the Jarrah trees have scars at the base of the trunk which are burnt out more deeply with each successive fire. This is particularly bad where the trees are coppice from early cutting and debris collects between close trunks. Marri often does not show the extent of the damage until 3-4 years after the fire, when sheets of bark are pushed off by healing and growth at the side of the wound. This exposure shows how much of the living cambium had been killed at the time of the fire, although the bark had not been burnt through (Fig 7G). In all the Eucalypts reduction of the crown through fire damage makes recovery from insect attack more difficult. Where upper limbs are killed they remain for many years projecting above the slowly growing branches from epicormics lower on the trunk. Figures 7A, B and C show a Jarrah tree before and after a bad fire in 1973 and Figure 7D one similarly damaged in a fire in February 1942, and photographed 18 years later. Few really healthy Jarrah trees remain.

The even more marked deterioration of Tuart trees in the park is due to a complex of factors of which fire is only one and perhaps a minor one. This has been discussed by Beard (1967).

Cycad

Macrozamia, with its large store of food in the underground (here) tuberous trunk, shows very rapid growth of the leafy crown which may be restored in one year. Cones are found, in plants old enough to reproduce, in the second year after a fire, but with slow development to seed-shed (about February-March) and a further year on the ground required to ripen the seed, seedlings will not appear until the fourth winter. Although the large seeds germinate on the surface of the ground, the tap root is strongly contractile so that the growing point of young plants is well buried and protected from fire.

Shrubs

As already reported, almost all of the shrubby undergrowth species are capable of sprouting when burnt off to ground level (Fig. 9). Of those few which are killed, several are tall shrubs which may reach small tree dimensions, e.g. *Dryandra sessilis*, *Conospermum triplinervium*, *Adenanthos cygnorum* (a few colonies only in King's Park—favoured habitat is very poor white sand), *Dodonea hackettiana* (confined to very small area). When old enough these may survive some fires though younger plants are killed as are the smaller species, *Acacia pulchella*, *Leuco-*

pogon racemulosum, *Calytrix fraseri*, *Pimelea rosea* and *Gompholobium tomentosum*. Seedling regeneration is good for all of these except *Leucopogon* and *Calytrix* where very few seedlings survive and the species are tending to become extinct, at least in the southern half of the park. All have the same habit characteristic of fire-sensitive species; a single main stem which continues into a tap root without enlargement below ground. Also each of these species continues to grow taller year by year and does not sucker from the ground as do many of the sprouting species, even when not burnt.

The sprouting shrubs which, with the shrubby monocotyledons, make up the great bulk of the undergrowth, mostly have deep and massive woody tap roots, e.g. *Daviesia nudiflora*, *Oxylobium capitatum* (Fig. 8), in some cases enlarged into a true lignotuber, e.g. *Persoonia saccata*. Many others have somewhat similar but more irregular and less deep and massive woody root

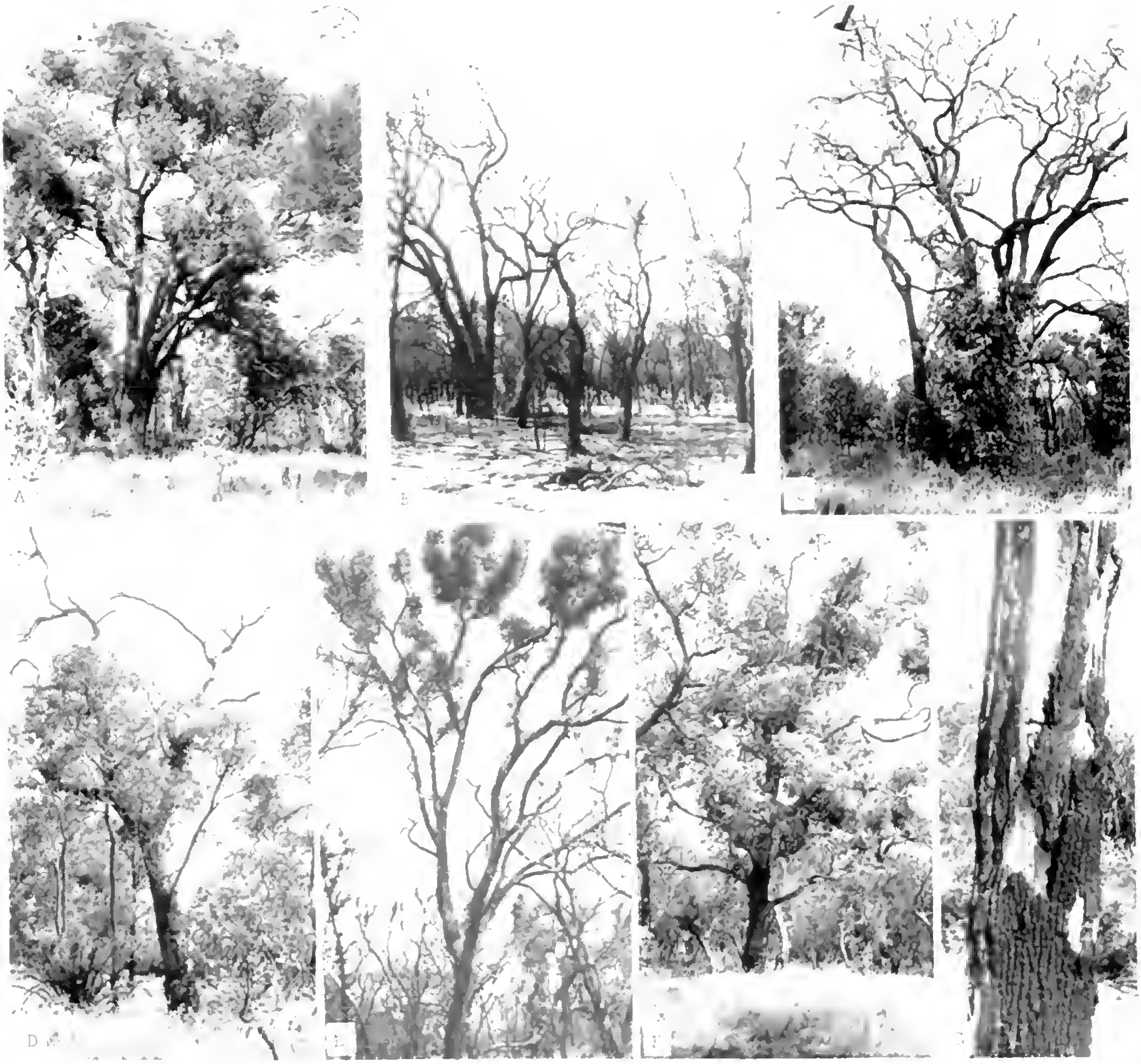
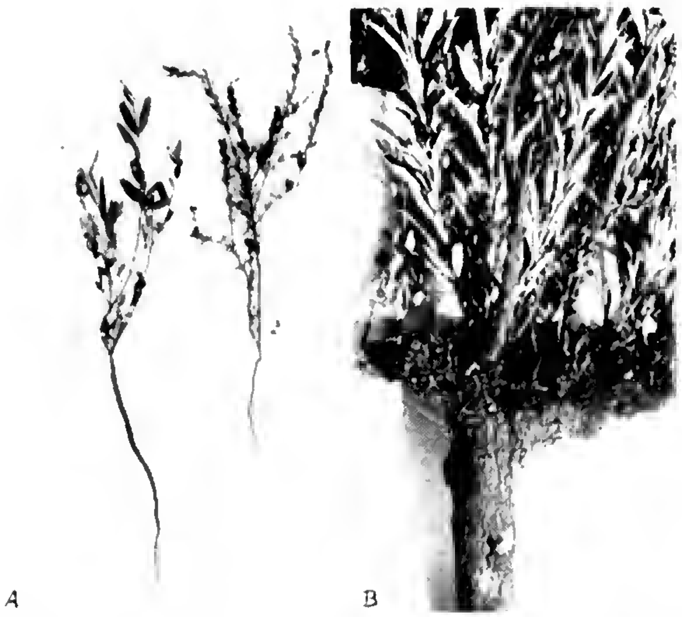


Figure 7.—Trees. A, B and C show the same jarrah tree. A.—Photographed in 1960. B.—Soon after the severe fire in January 1973. C.—More than a year later April 1974. The upper part of the tree had not recovered, the base of the trunks were clothed with epicormic shoots. D.—A jarrah similarly damaged by a fire in February 1942, and photographed November 1959. Two of the now 18 year old branches can be seen on the right side of the tree, those on the left fork are obscured by the better foliage of a sapling in front. E.—A less severely burnt jarrah tree in which the canopy is recovering. The smaller Banksias in the background show similar sprouting in the upper branches. Burnt January 1970, photo April 1970. F.—A marri which was a fine shapely tree before a fire from which it has not fully recovered; veld grass became established after the same fire. G.—The scarred trunk of a marri tree burnt 3 years earlier and photographed when the killed bark had just fallen exposing the damage and growth at the edge of the scar.



A B

Figure 8.—Root system. A.—Young plants of a species capable of sprouting (*Oxylobium capitatum*) and one which is killed by fire (*Gompholobium tomentosum*). *Oxylobium*, even at this early stage, has a much thicker and longer (broken off in specimen) root in proportion to its top than *Gompholobium*. B.—Rootstock of an old plant of *Daviesia nudiflora* which has been repeatedly burnt.

systems, e.g. *Bossiaea*, *Hibbertia*, *Astroloma*, or somewhat fleshy ones, as *Scaevola* spp., *Helichrysum cordatum*. *Hardenbergia*, a climber with particularly deep thick tap roots, regenerates extremely rapidly and grows through the summer. Suckering from horizontal roots is not uncommon and results in concentrations of plants in species with this habit, e.g. *Stirlingia*, *Grevillea vestita*, *Acacia stenoptera*, *Macarthuria* and others.

Many of these plants are undoubtedly very long-lived. Unfortunately there are no conspicuous annual rings by which to date them, but some indication has been given in quadrats kept under observation since 1936 or 1940 (Appendix 1). In one quadrat laid down in 1936, the same plants of *Daviesia nudiflora*, *D. juncea* (1 died) *Hibbertia hypericoides*, *Hypocalymma robusta*, are still there in 1973 (37 years), and not very different in size. One of the observed characteristics of unburnt shrub species is the relatively small annual growth increments and the death of some branches over the summer. In other long-term quadrats the same plants of *Leucopogon propinquus*, *Petrophile macrostachya*, *Mesomelaena stygia* and *Stirlingia* are still surviving. All these quadrats have been burnt several times during the 30 or more years since they were first mapped. Although *Persoonia* was not in any of these quadrats, the size of some lignotubers suggests that it is very long-lived. It would be interesting to know whether the life span of some of these shrubs equals or exceeds that of some of the trees.

The pattern of regrowth for these shrubs is rapid growth of erect multiple shoots from a few cm below ground level so that the plants are almost back to their pre-fire size in 2 or 3 years or less. Thereafter, growth becomes slower and slower and flowering is reduced.

Stirlingia is rather distinctive. The vigorous growth and abundant production of tall flowering panicles makes this the dominant shrub (in stands where it occurs) for its first flowering after a burn (Fig. 11). In the following year 2 lateral branches grow from below the old fruiting panicle and in subsequent years these continue to grow without flowering and with decreasing stem increments and decreasing leaf size.

Some of the smaller semi-herbaceous perennials, e.g. *Macarthuria*, *Hybanthus calycinus*, *Monotaxis grandiflora* and *Opercularia*, also able to shoot from below ground level, have survived repeated fires well although lacking massive rootstocks. There is a zone of soft corky tissue about ground level on the slender stems or roots which may give some insulation against fire as well as against summer soil heat.

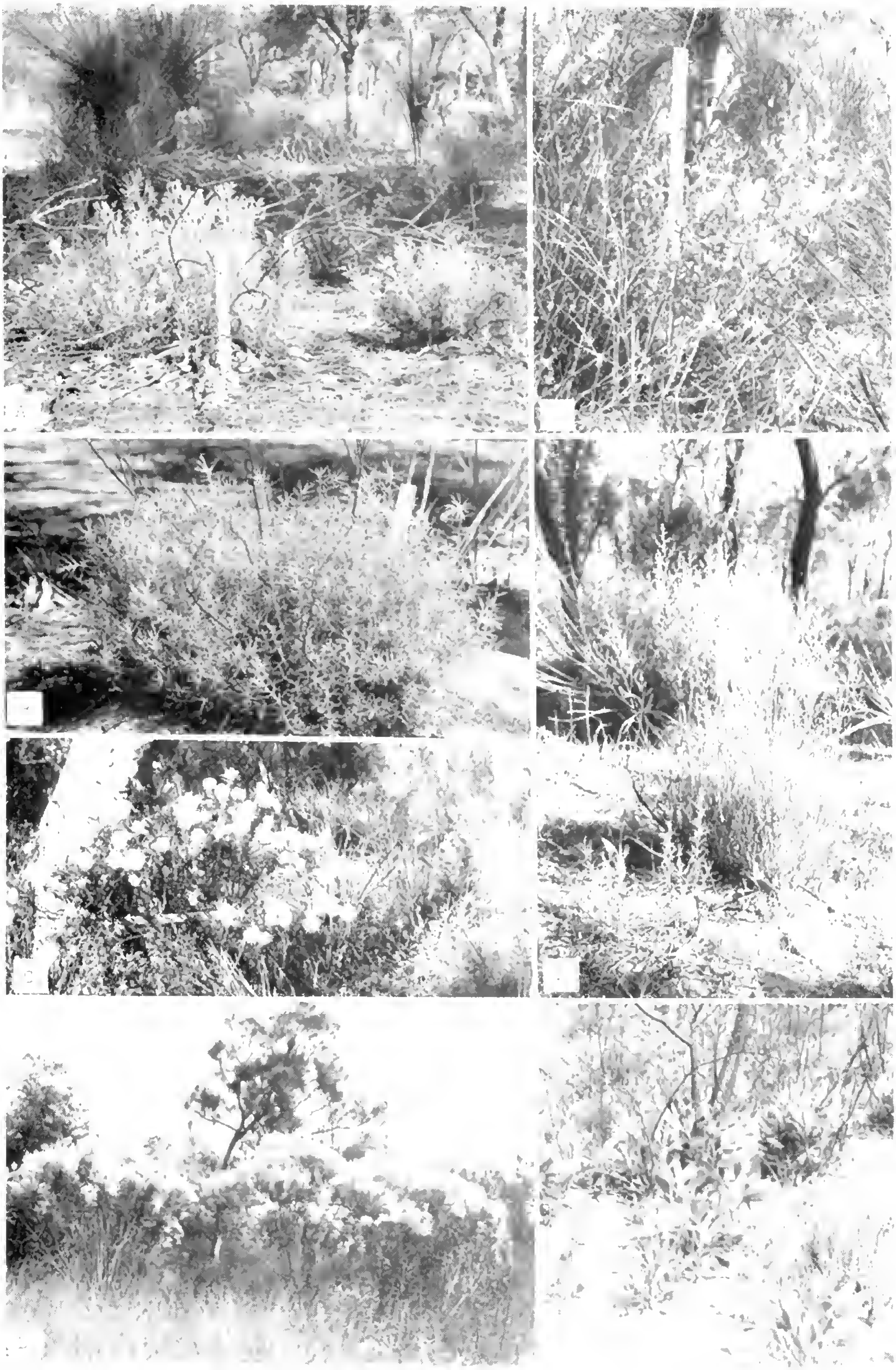
Species which have disappeared from or have been greatly reduced in some frequently burnt areas are *Pimelea leucantha*, *Calytrix flavescens* and *Cryptandra arbutiflora*. These sprout weakly but succumb to repeated fires. *Phyllanthus* and *Hovea* have decreased in abundance in frequently burnt areas, although both regenerate after fire from sprouting and from seedlings. *Hovea* has gone from 2 permanent quadrats. Numerous seedlings had become established after fires before, but not since the quadrats were overgrown by veld grass. Competition from veld grass may be a factor in the decline of these two probably not particularly long-lived species.

Seedling regeneration of long-lived species need not be frequent but is still necessary. Seedlings of *Oxylobium*, *Hovea*, *Daviesia nudiflora*, *Jacksonia* spp., *Hardenbergia* and *Phyllanthus* are frequent and not only after fires. *Hibbertia hypericoides*, one of the commonest species in the park, produces very few seeds and seedlings are extremely rare. In *Stirlingia latifolia*, which has prolific seeding after fire, seedlings are also very rare, but in this species there is highly efficient vegetative multiplication.

Persistent evergreen geophytes

The harsh sedges and some of the Xanthorrhoeaceae with massive underground parts and buried and well-sheathed growing apices are probably the most fire-resistant plants in the community. They are the first to show recovery after fire and the most persistent in repeatedly burnt areas.

Xanthorrhoea preissii is generally accepted to be a very slow-growing long-lived species though there is little factual record. In the repeatedly burnt Banksia woodland the plants are mostly tufts of leaves from the ground with little, if any, stem above ground level. Fire damage seems to produce multiple growing apices. How much of the absence of tall specimens here is due to conditions, or how much is due to cutting for



kindling before the park was reserved—100 years ago—is largely speculation. There are some specimens with trunks up to about 2 m in the Tuart and limestone sections. An undisputed fact is that burning induces profuse flowering (Fig. 3F) the first year after a burn. The dry fruiting spikes persist for another year or more.

The sedges, *Tetrariopsis octandrus*, *Mesomelaena stygia*, *Lepidosperma* spp., *Schoenus grandiflora*, form massive clumps (particularly below ground) with well-sheathed and buried growing apices. Plants of these have persisted in quadrats observed for 30 years or more but no doubt live very much longer than this. Plants vary in size from single tufts to clumps covering circular areas up to 60 cm diameter. *Amphipogon turbinatus* is a grass with a similar harsh bushy habit and underground rhizomes. Rhizomatous species of *Restio* and *Loxocarya* are widespread and also extremely fire-tolerant. *Lomandra* species have underground growing points well sheathed by persistent leaf bases, and *Thysanotus sparteus*, a leafless inconspicuous plant above ground, has a short thick rhizome buried up to 6-10 cm below ground level.

Herbaceous geophytes and other perennial species which die down over summer

These are very different; mostly small plants; orchids, sundews (*Drosera* spp.), trigger plants (*Stylidium* species) and small liliaceous species. Although over 40 have been recorded, many are rare and inconspicuous. All are active only from the period of the first effective rains until the upper layers of the soil dry out in early summer. They tolerate fires well as they have usually died down to the dormant subterranean stage before the fire. As stated earlier, they benefit particularly from autumn fires when the shrub competition is most reduced. The common and widespread species, *Burchardia umbellata*, flowers in unburnt bush, but flowers are more abundant and more conspicuous in burnt areas. *Haemodorum* (2 species) produces tall robust spikes (Fig. 3F) from deep, massive, well-sheathed growing points. The trigger plant, *Stylidium carnossum*, and the orchid, *Prasophyllum elatum*, also produce tall spikes rarely seen except after fire. Neither is common. Many of the orchids flower better but not exclusively after fires. This is true of the most common species of orchids, *Caladenia flava* and *Diuris longifolia*, and also of *Eryngium pinnatifida* (Umbelliferae). The rosette *Stylidium brunonianum* and *S. piliferum* deserve a special mention as they have no underground perennating organs but survive both fire and summer drought with the small dry leaves closed over the growing point. There is only one minor grass, *Microlaena stipoides*, in the herbaceous rhizome geophyte category.

Annuals

Most of the park annuals appear to be larger and more floriferous after fires. *Podotheca chrysantha* showed this markedly after several late summer fires. The small umbelliferous species, *Trachymene pilosa* and *Homalosciadium homalocarpum* increase in abundance, although always present, but *Calandrinia corrigioloides* and *C. liniflora* are rarely seen except after fires when the former particularly is extremely abundant. The occurrence of all of these annuals is uneven at any time and no doubt their presence and abundance in any particular place after fire is related to the amount of seed in the ground. A fire occurring before annuals had set seed could be detrimental. The only spectacular true 'fireweed' among the annuals is *Stipa compressa*. This species, flowering in October and striking with its long golden awns, is normally abundant and widespread in the first year after a fire and completely absent the following year, although there has been little change in the habitat, and there must be seed in the ground as the grass appears again in abundance after another fire.

Introduced species

Veld grass

The tremendous spread and increase of veld grass (*Ehrharta calycina*) over the past 20-30 years has been reasonably well documented. Its increase after fires has been noted repeatedly. A photographic record of a first appearance after a fire is shown in Figure 10. Several of the permanent quadrats were put down either before or shortly after veld grass invaded them and show its history in each quadrat. Increase after fire is shown in quadrat A3 (Appendix 1, Fig. 13). In all quadrats very numerous seedlings were noted after fires although sometimes old moribund clumps were killed. These quadrat samples are small and lately near widening road verges. All remaining plots have been for many years overgrown with veld grass.

The relation to fire is partly an indirect one, since the edges of annually ploughed firebreaks provide a particularly favourable habitat for the establishment of veld grass. The spread along and into the bush from firebreaks was shown in an extensive survey by Watson and Meagher in 1949. A re-survey by them of part of the area 8 years later confirmed the relation to firebreaks and showed a further spread and increase in density of the grass. However, another section remapped in 1961, and which had been free from fire since 5 years before the earlier mapping, showed a very significant decrease in contrast to an adjacent portion which had been burnt and showed an increase. In one quadrat, unburnt for 15 years, there had been a gradual decrease from 115 clumps to 6 clumps in the

Figure 9.—Examples of shrub regrowth. A, B, F, G in the first year. C, D, E after several years. A.—*Petrophile macrostachya*—regrowth in March after a December burn. B.—*Leucopogon propinquus* regrowth 6 months after a July burn. C.—Unburnt *Pimelea* a species which regenerates weakly and is tending to disappear. D.—*Conospermum triplinervium*. Young plants which grew from seed after a fire which killed the parents, flowering for the first time in their seventh year. E.—An unburnt *Petrophile macrostachya* in flower. F.—*Stirlingia latifolia* 6 months after a December burn, in bud on short regrowth. G.—*Scaevola canescens* regrowth 6 months after a March burn

$36\ m^2$. On the western edge of the park, where Banksia-Casuarina canopy was dense, there was negligible penetration of the veld grass into unburnt bush, in spite of its occurrence along the cleared boundary. In a different site, where shrub undergrowth was dense but tree canopy poor, as a result of severe but infrequent fires, there was also very little veld grass. These examples and other general observations show that undisturbed dense bush can resist the advance of veld grass and even suppress it. As a contrast, in a section of University land burnt almost annually from 1950, veld grass spread from a cleared section and by 1960 most of the site was becoming a veld grass savannah woodland. In general, veld grass has increased more rapidly in the open Tuart woodlands than in the dense Jarrah-Banksia-Casuarina communities.

Figure 10.—Veld grass. A. Veld grass well established having spread after fire in 1958 from the firebreak in the foreground. November 1960. B & C. The same site: B in October 1956 with dense shrub cover and C in October 1960 after a fire in January 1958 in which one of the 4 marri trunks was burnt through and fell (lying across right of photograph); veld grass established and flowering; marri coppice from base of trees.

Other introduced species

Introduced bulbs, e.g. Gladiolus and Cape Tulip, so much more massive than the native herbaceous geophytes and with enormously greater seed production, have also been spreading through the park in recent years, particularly in areas burnt or mown, and are likely to constitute another hazard for the indigenous vegetation. Figure 3A-C shows how much bare sand is open to colonisation by weeds after a summer fire.

It should be mentioned that there are annual weeds which have been long established throughout the bush, e.g. *Ursinea anthemoidess, Heliophila pusilla, Kohlrauchia prolifera, Briza maxima* and some other grasses and medics. In the poor sandy soil these plants remain very small and constitute no threat to the indigenous vegetation. There is often a temporary increase in size after fire but the effect is not lasting. In disturbed areas numerous species of weeds are flourishing.

In the south west corner of the park there has been a gradual spread, a short distance into the bush, of *Agonis flexuosa* from trees planted along a road near the beginning of the century. This is a species native to the Perth coastal plain, though not naturally present in this area. Fires may have aided this spread but no records have been kept.

Discussion

It has been shown that few plants are killed by fire. In the Jarrah-Banksia-Casuarina woodland none of the persistent monocotyledons are fire-sensitive and only 8 of the 90 species of the dicotyledon trees, shrubs and undershrubs. When the woody species more or less confined to the Tuart and limestone sites are included, another 8 fire-sensitive shrubs can be added. Fire-sensitive shrubs are marked (F) in the species list (Appendix 2).

A striking feature is the speed of the recovery of the undergrowth. The rapid growth of long, sturdy multiple shoots of the sprouting shrubs contrasts with the relatively small annual growth increments in unburnt bush. In the early stages of regrowth after fire the still intact deep and extensive root systems are supplying small shoots, and the greatly reduced total transpiration of the vegetation means more water remaining in the soil. Thus growth of the new shoots can be faster and continue longer into the summer than growth of the same species in unburnt bush. This advantage applies only to the deep rooted plants. For shallow rooted species conditions on burnt areas are more severe in early summer because of earlier drying out of the exposed surface soil.

The rapid growth of shoots from old root systems is in contrast with the very slow growth of seedlings of the same species. In some sites observed, seedlings of *Phyllanthus, Bossiaea, Daviesia nudiflora, Oxylobium* were mostly only 10 cm or less in the first year, and a few up to 30 cm but most less than 20 cm in the second year. The tap roots were very much longer than the shoots and most seedlings showed a corky thickening in the surface layer of soil. The very small top no doubt enables the plant to survive the summer until the root is well established. Under favourable conditions, as under cultivation, growth is very much faster.

These observations confirm the adaptation to fire of this vegetation and both its inherent stability and its vulnerability to disturbance.

The stability is shown in the periodic rejuvenation and long survival of individual plants through repeated fires; the abundant renewal from seed of some of the fire-sensitive species and in the resistance of healthy undisturbed bush to aliens. The fact that most species in the undergrowth are long lived, slow growing but sprouting vigorously from ground level after fire makes for a stable population with the same major species occupying the same sites. The relatively few perennial species killed, but regenerating freely from seed after fire, show much more variable and fluctuating populations as seeds and seedlings are more susceptible to hazards of weather and to destruction by insects.

The vulnerability is exhibited in the general deterioration of the bush, the deformed and stagheaded trees, the reduction of many of the attractive species, and the over-running of the area by veld grass and to a lesser extent by other aliens. Too frequent and too severe fires are undoubtedly contributing but not the only factors responsible. It seems clear that the effect of introduction of a perennnial grass such as *Ehrharta calycina* has been to change the whole cycle of regeneration after fires. Herbaceous species with extensive root systems are more or less lacking in the undisturbed bush; annuals are small and short-lived and are dried off before any severe water stress for perennials; herbaceous geophytes are small and non-aggressive. Both categories probably contribute a little easily decomposed organic matter to the surface layers of soil but are neither large enough nor numerous enough to offer any serious competition even to the seedlings of woody shrubs and certainly not to the adult plants. It is very different with *Ehrharta* which so thoroughly exploits the soil with roots which penetrate deeply as well as ramifying through the upper levels.

Although mature shrubs have persisted in dense veld grass and have even been able to suppress it, survival of seedlings is much more difficult. There is some evidence for this suggestion from permanent quadrats (see Appendix 1). For example, in H3 (Fig. 12) after the fire in summer 1936-37, there were very numerous seedlings of the fire-sensitive *Gompholobium* and *Acacia pulchella*, also several of the regenerating *Hovea* and *Helichrysum cordatum*. None of these have been recorded since the quadrat has been covered with veld grass. In A3 (Fig. 13), in 1947, a group of young *Daviesia nudiflora* plants established from seedlings after fire in 1944 were reduced in 1951 to a single plant which had gone by 1954. Veld grass was well established before 1951. Seedlings of *Daviesia nudiflora* have not been recorded in this quadrat since. Another quadrat free of veld grass had, until 1954, numerous young plants, many originating after a fire in 1942; unfortunately, it was destroyed in 1954 soon after the first entrance of veld grass.

No records have been kept of numbers of annuals but general observation is of reduction where veld grass is dense. However, annuals are suppressed also by the native shrubs and are only abundant after fire and in more or less open spaces.

Deliberate use of fire

Records of regeneration after fires in different seasons and at different intervals give some guidance to possible management by controlled burning.

Given a healthy stand without veld grass or South African bulbs, a good tree canopy with predominantly herbaceous undergrowth could be maintained by frequent mild autumn burns, perhaps every 4 or 5 years. Towards the end of the dry season herbaceous geophytes are dormant with their perennating parts fully mature, annuals are dead with seeds dry and hard. A light autumn burn provides a good seed bed, with increased minerals and increased spaces free from smothering shrubs and leaf litter, so that conditions are ideal when the rains start.

On the other hand, the common flowering shrubs such as *Hibbertia, Daviesia, Oxylobium* and *Hypocalymma* may be encouraged by spring or early summer burns which give them a good start before the next winter rains bring up the herbs which then have to face strong competition from the shrubs. Seeding of the previous season's annuals may have been prevented by early fire. As mentioned earlier many of the sprouting shrubs require periodic burning to keep them in healthy flowering condition. Periodic burning also maintains young and vigorous colonies of the freely seeding fire-sensitive species, *Acacia pulchella, Gompholobium tomentosum* and *Pimelea rosea* but for these it is essential that enough time elapses between fires for the new plants to produce seed. Stands burnt at intervals of about 8-10 years have maintained good shrub cover. Shorter intervals favour some species, longer others. For successful establishment of trees and long lived shrubs, it is probably the intensity of the fire which determines the age necessary for survival, certainly many small saplings have been killed in summer fires; another argument for mild control burns. Figure 11A-B contrasts the damage resulting from a successful control burn and a severe wildfire.

Where Banksia-Casuarina canopy is dense, complete or long term protection of some small areas would preserve some of the more vulnerable species and produce a type of woodland in which the shrub layer is suppressed so that the space between ground and tree canopy is more open.

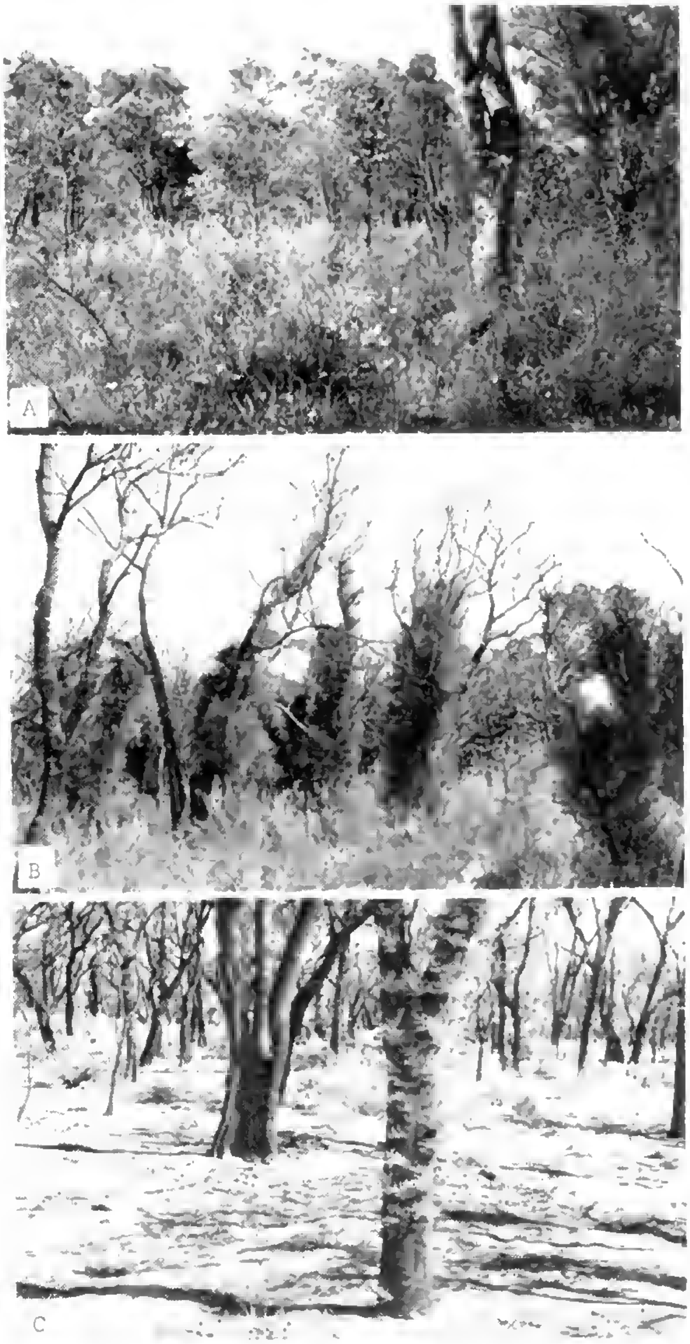


Figure 11.—Contrasting results of control burning and wildfire. A.—Nine months after a successful control burn; young trees undamaged, good shrub cover re-established. B.—Eighteen months after a wildfire in January 1973; no recovery of tops of trees; *Casuarina* trunks clothed in epicormics; *Stirlingia* flowering in both photographs. C.—Early stage of epicormic growth on *Casuarina* trunk; another tree scarred by a previous fire with growth at the edge of the old wound showing.

By burning small areas at a time, stands of the above types in different stages of regeneration could be maintained to give a pleasing variety as well as some protection against wild fires. Unfortunately the present condition of poor trees and veld grass through most of the undergrowth makes the position much more difficult. Nevertheless, the known facts of the effects of fire allow some measure of control at least in the areas less badly infested with weed species.

Further research

There is a big field of research in understanding the differing responses of different species to burning. In other parts of the world, e.g. the Californian chaparral (as well as Australia) abundance of particular species after fires has been related to different causes, some inherent in the morphology of plant or seed, others response to the changed environment. Some indications which could be followed up in species from King's Park are given.

Species of *Daviesia* and *Stirlingia latifolia* grow and flower after fire as do plants in the undisturbed bush cut to ground level. The pruning effect of fire seems to be the main influence here as the habitat is unchanged. Fasciated shoots have been found on fire regrowth, most commonly in the legumes, *Daviesia* spp., and *Jacksonia* spp. Is this a response to wounding or to unbalanced nutrition? With *Persoonia saccata* the particularly strong regrowth is understandable as it has the most massive lignotuber of any shrub species in the park. The regrowth apparently flowers only when it has reached a certain size level or maturity irrespective of season. If unburnt, it flowers only in December. It is apparently indifferent to day length and temperature. By contrast *Stirlingia latifolia* flowers in September whenever it is burnt, although the vegetative shoots are very much taller where the interval between fire and flowering is longer. This does suggest a day length control. Why doesn't it flower unburnt? *Kennedia prostrata*, both regrowth and seedlings, always grows better on or near ashbeds; extra potassium in the soil may be a factor.

Among the monocotyledons very striking flowering of the *Xanthorrhoea* occurs in the first year after a fire. Flowering is very rare in unburnt bush, but does occur in gardens receiving extra water and fertiliser. Similarly, in the cycad *Macrozamia*, coning occurs more frequently in gardens.

Examples of 2 sedges with different responses are *Tetrariopsis octandrus* which produces stiff erect flowering shoots very quickly after a burn; thereafter the leaves continue to grow on with no flowering until, in long-unburnt bush, mats of long trailing leaves spread over the ground. In *Lepidosperma* species, on the other hand, new flowering stems are produced from the base each year, burnt or unburnt.

How is it that the seed of *Stipa compressa* can be in the ground through so many wet winters without germinating and then grow so luxuriantly after a fire? The stand of Figure 3 had not been burnt for 13 years. Seeds of other species of *Stipa* in the arid inland survive drought, and germinate following good rains.

The ecology and physiology of species in this environment where fires are frequent offer scope for interesting research. It is, however, important that the normal growth habits, which are very varied, and responses to differing annual weather patterns, are known before detailed study is undertaken on responses to fire.

Acknowledgments.—Acknowledgments are difficult as so many workers have been interested in King's Park for many years and have talked with me about it. Quantitative work was initiated by Dr. J. I. Armstrong in 1936 as student exercises and has been continued since by successive generations of students and staff. A considerable body of information has been built up on the distribution and abundance of species. I have used a few samples of old quadrats as related to fire history and part of a student survey of tree damage by fire.

Permission to work in the park, and helpful interest, has been given by successive directors and superintendents. I wish to thank Mr. J. E. Watson particularly, for records of burning and of the invasion of veld grass in the park during his term of office. I have included repetition of notes on fires which I provided for the paper by Main and Serventy (1957) already referred to.

A species list has been in use in the Botany Department of the University of Western Australia for many years and from time to time has been updated with the help of the staff of the Western Australian Herbarium. Specimens from King's Park held in the Botany Department, University of Western Australia, go back as far as 1917.

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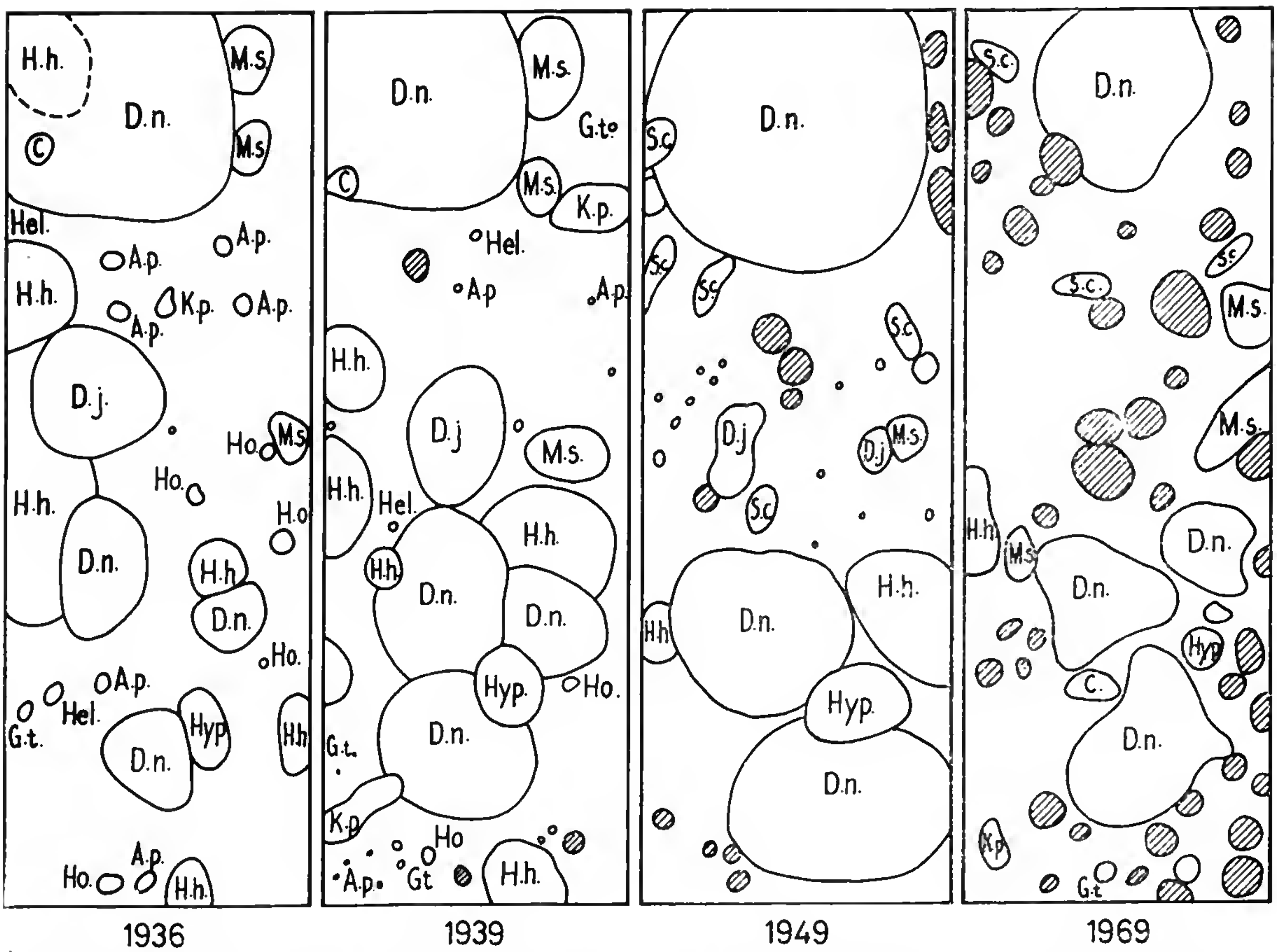

Figure 12.—Quadrat H3. First mapped in 1936, burnt in November 1936, November 1944, grazed by cows in 1951, burnt again in December 1960, and mown in 1966. First appearance of veld grass 1939 with large numbers of seedlings after the 1944 fire and after grazing. In 1953 old plants were waning in vigour but were abundant again 2 years after the 1960 fire. The same plants of *Daviesia nudiflora, D. juncea, Hibbertia hypericoides, Hypocalymma robusta,* and *Mesomelaena* have persisted more or less unchanged for over 30 years. There has been some loss in total shrub numbers. Seedlings of *Acacia pulchella Gompholobium, Hovea* and *Helichrysum* were abundant after the 1936 fire but surviving seedlings have been few since the veld grass overran the quadrat.

APPENDIX 1

Quadrats

Examples are given of a few of the chartings of two of the long standing quadrats H3 (Fig. 12) and A3 (Fig 13), both in predominantly Banksia-Casuarina woodland although there was an old tuart stump in A3 (not in the strip shown). The quadrats were 6 yards x 6 yards (approx. 6 x 6 m) but for simplicity only one 6 x 2 m strip is reproduced. Shrubs and woody monocotyledons only were recorded of the native species, but because of the interest of the invading veld grass that was recorded, the outlines representing the basal area of the clump, not the trailing foliage which spreads over most of the quadrat in later stages of its invasion.

Symbols used for species in quadrat charts

A.p.—*Acacia pulchella;* C.p.—*Conostephium pendulum;* C.pr.—*C. preissii;* C.c.—*Conostylis candicans;* C.s.—*C. setigera;* D.j.—*Daviesia juncea;* D.n.—*D. nudiflora;* D.i.—*Dianella revoluta;* G.t.—*Gompholobium tomentosum;* Hel.—*Helichrysum cordatum;* H.h.—*Hibbertia hypericoides;* H.H.—*H. huegelii;* H.r.—*H. racemosa;* Ho.—*Hovea trisperma;* Hyp.—*Hypocalymma robusta;* H.c.—*Hardenbergia comptoniana;* J.g.—*Jacksonia gracilis;* K.p.—*Kennedia prostrata;* L.p.—*Leucopogon propinquus;* Le.—*Lepidosperma* sp.; M.S.—*Mesomelaena stygia;* O.c.—*Oxylobium capitatum;* P.c.—*Phyllanthus calycinus;* R.—*Restio nitens;* S.c.—*Scaevola canescens;* S.p.—*S. paludosa;* St.—*Stirlingia latifolia;* Syn.—*Synaphaea polymorpha;* Tri.—*Trichoryne elatior;* X.—*Xanthorrhoea preissii;* / / / / *Ehrharta calycina* (veld grass), outline shows basal area of clump.

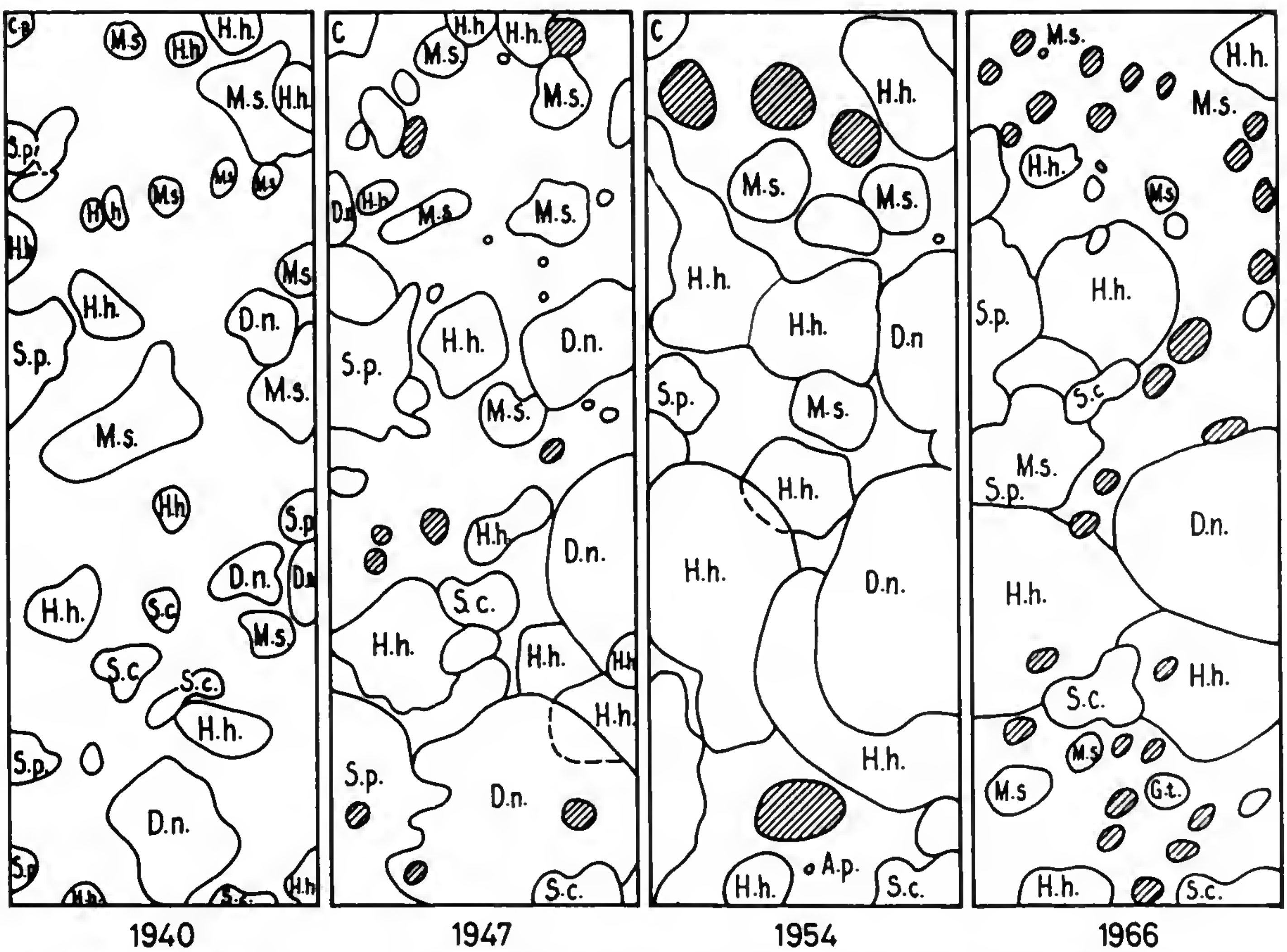

Figure 13.—Quadrat A3. Burnt in April 1939 and first mapped in August 1940. It was burnt again in April 1942, November 1944, November 1954, December 1958, mown December 1963. Three fires in close succession then a 10 year interval. Veld grass first appeared in 1945 and was well established by 1947. The same plants of *Daviesia nudiflora, D. juncea, Hibbertia hypericoides, Leucopogon propinquus, Stirlingia latifolia, Scaevola canescens, Mesomeloena stygia* have persisted throughout the period.

APPENDIX 2

King's Park species list

Species marked (L) are more or less confined to soils with limestone underlying or outcropping. Species marked (a) are annuals. (F) denotes species which are killed by fire, all others are capable of sprouting from burnt stems or roots.

Cycadaceae

Macrozamia riedlei (Gaud.) C. A. Gardn.

DICOTYLEDONS

Aizoaceae

Macarthuria australis Hueg.

Amarantaceae

Ptilotus polystachyus (Gaud.) F. Muell.
P. drummondii (Moq.) F. Muell.

Casuarinaceae

Casuarina fraseriana Miq.
C. humilis Otto & Dietr.

Chenopodiaceae

L *Rhagodia baccata* (Labill.) Moq.

Compositae (Asteraceae)

a *Angianthus humifusus* (Labill.) Benth.
a *Athrixia pulverenta* (Lindl.) Druce.
Helichrysum cordatum DC.
Lagenifera huegelii Benth.
a *Millotia tenuifolia* Cass.
L *Olearia axillaris* (DC.) F. Muell.
a *Podosperma angustifolium* Labill.
a *P. chrysanthum* (Steetz) F. Muell.
a *Podolepis nutans* Steetz.
a *Quinctia urvillei* Cass.
Senecio lautus Forst. f. ex Willd.
a *Waitzia citrina* (Benth.) Steetz.
a *W. suaveolens* (Benth.) Druce.

Crassulaceae

a *Crassula colorata* (Nees) Ostenf.

Dilleniaceae

Hibbertia huegelii (Endl.) F. Muell.
H. hypericoides (DC.) Benth.
H. racemosa (Endl.) Gilg.

Droseraceae

Drosera erythorrhiza Lndl.
D. glanduligera Lehm.
D. menziesii R. Br.
D. stolonifera Endl.

Epacridaceae

Astroloma ciliatum (Lindl.) Druce.
A. macrocalyx Sond.
A. pallidum R. Br.
Conostephium pendulum Benth.
C. preissii Sond.
L *Leucopogon parviflorus* (Andr.) Lindl.
L. propinquus R. Br.
F *L. racemulosus* DC.

Euphorbiaceae

Monotaxis grandiflora Endl.
Phyllanthus calycinus Labill.
Ricinocarpus glaucus Endl.
a *Poranthera microphylla* Brongn.

Geraniaceae

Pelargonium capitatum (L.) Ait.

Goodeniaceae

Dampiera linearis R. Br.
Lechenaultia floribunda Benth.
Scaevola canescens Benth.
S. holosericea De Vriese.
L F *S. nitida* R. Br.
S. paludosa R. Br.
L *S. thesioides* Benth.

Haloragaceae

Glischrocaryon aureum (Lindl.) Orchard.
Haloragis pithyoides (Nees) Benth.

Labiatae (Lamiaceae)

Hemiandra pungens R. Br.

Lauraceae

L *Cassytha racemosa* Nees.

Mimosaceae

Acacia cyclops A. Cunn. ex G. Don.
A. diptera Lindl.
A. heteroclita Meisn.
A. huegelii Benth.
F *A. pulchella* R. Br.
A. saligna (Labill.) H. Wendl.

Papilionaceae (Fabaceae)

Bossoaea eriocarpa Benth.
Daviesia divaricata Benth.
D. juncea Sm.
D. nudiflora Meisn.
D. pectinata Lindl.
L *Gompholobium aristatum* Benth.
F *G. tomentosum* Labill.
Hardenbergia comptoniana Benth.
Hovea trisperma Benth.
Isotropis cuneifolia (Sm.) Domin.
Jacksonia furcellata (Bonpl.) DC.
J. gracilis Meisn.
J. sternbergiana Hueg.
Kennedia prostrata R. Br.
Oxylobium capitatum Benth.
L *Templetonia retusa* (Vent.) R. Br.

Lobeliaceae

a *Lobelia tenuior* R. Br.

Loranthaceae

L *Amyema miquelii* (Lehm. ex Miq.) Tiegh.
Nuytsia floribunda (Labill.) R.Br.

Myoporaceae

L *Eremophila glabra* (R.Br.) Ostf.
L *Myoporum insulare* R.Br.

Myrtaceae

Agonis flexuosa (Spreng.) Schau.
Calytrix angulata Lindl.
C. flavescens A. Cunn.
F *C. fraseri* A. Cunn.
L *Calothamnus quadrifidus* R.Br.
Eremaea pauciflora (Endl.) Druce.
Eucalyptus calophylla R.Br.—Marri.
L *E. gomphocephala* D.C.—Tuart.
E. marginata Sm.—Jarrah.
Hypocalymma robusta Endl.
Kunzea ericifolia Reichb.
L *Melaleuca acerosa* Schau.
L *M. huegelii* Endl.

Phytolaccaceae

Tersonia brevipes Moq.

Pittosporaceae

L *Sollya heterophylla* Lindl.

Polygalaceae

Comesperma calymega Labill.
L *C. confertum* Labill.

Portulacaceae

a *Calandrinia corrigioloides* F. Muell. ex Benth.
a *C. liniflora* Fenzl.

Proteaceae

F *Adenanthos cygnorum* Diels.
Banksia attenuata R.Br.
B. grandis Willd.
B. ilicifolia R.Br.
B. menziesii R.Br.
B. prionotes Lindl.
Conospermum stoechadis Endl.
L F *C. triplinervium* R.Br.
Dryandra nivea R.Br.
D. sessilis (R.Br.) Druce.
L F *Grevillea crithmifolia* R.Br.
L *G. thelemanniana* Hueg.

L *G. vestita* (Endl.) Meisn.
L F *Hakea lissocarpha* R.Br.
H. prostrata R.Br.
L F *H. trifurcata* (Sm.) R.Br.
Persoonia saccata R.Br.
Petrophile linearis R.Br.
P. macrostachya R.Br.
L *P. serruriae* R.Br.
Stirlingia latifolia (R.Br.) Steud.
Synaphaea spinulosa (Burm. f.) Merrill.

Ranunculaceae

L *Clematis microphylla* DC.

Rhamnaceae

L *Cryptandra arbutiflora* Fenzl.
L F *Spyridium globulosum* (Labill.) Benth.
S. tridentatum (Steud.) Benth.
L F *Trymalium ledifolium* Fenzl.

Rubiaceae

Opercularia vaginata Labill.

Rutaceae

L *Boronia ramosa* (Lindl.) Benth.
Eriostemon spicatus A. Rich.

Solanaceae

L F *Anthocercis littorea* Labill.

Stackhousiaceae

Stackhousia brunonis Benth.

Sapindaceae

F *Dodonaea hackettiana* W. V. Fitzg.

Sterculiaceae

L *Thomasia cognata* Steud.

Stylidiaceae

Stylidium brunonianum Benth.
a *S. calcaratum* R.Br.
S. carnosum Benth.
S. piliferum R.Br.
S. repens R.Br.
S. schoenoides DC.

Thymelaeaceae

F *Pimelea rosea* R.Br.
P. sulphurea Meisn.
P. leucantha Diels.

Umbelliferae (Apiaceae)

Eryngium pinnatifidum Bunge.
a *Homalosciadium homalocarpum* (F. Muell.) Hj. Eichler.
a *Trachymene pilosa* Sm.
Xanthosia huegelii (Benth.) Steud.

Violaceae

Hybanthus calycinus (DC. ex Ging.) F. Muell.

MONOCOTYLEDONS

Centrolepidaceae

a *Centrolepis drummondii* (Nees) Hieron.

Cyperaceae

Lepidosperma angustatum R.Br.
L *L. gladiatum* Labill.
L. resinosum (Nees) Benth.
L. scabrum Nees.
Mesomelaena stygia (R.Br.) Nees.
Schoenus curvifolius (R.Br.) Benth.
S. grandiflorus (Nees) F. Muell.
a *Scirpus antarcticus* L.
S. arenarius Benth.
Tetrariopsis octandra (Nees) C. B. Clarke.

Gramineae (Poaceae)

Amphipogon turbinatus R.Br.
Danthonia semiannularis (Labill.) R.Br.
L *Dichelachne crinita* Hook.
Microlaena stipoides (Labill.) R.Br.
Neurachne alopecuroides R.Br.
a *Stipa compressa* R.Br.
L *S. elegantissima* Labill.
S. hemipogon Benth.
S. variabilis Hughes.

Haemodoraceae

Anigozanthos humilis Lindl.
A. manglesii D. Don.
Conostylis aculeata R.Br.
C. candicans Endl.
C. setigera R.Br.
Haemodorum paniculatum Lindl.
H. spicatum R.Br.
Phlebocarya ciliata R.Br.

Iridaceae

Orthrosanthus laxus (Endl.) Benth.
Patersonia occidentalis R.Br.

Juncaceae

Luzula meridionalis Nord.

Liliaceae

Agrostocrinum scabrum (R.Br.) Bail.
Arnocrinum preissii Lehm.
Arthropodium preissii Endl.
Burchardia umbellata R.Br.
Caesia parviflora R.Br.
Corynotheca micrantha (Lindl.) Macbride.
Dianella revoluta R.Br.
Laxmannia squarrosa Lindl.
Sowerbaea laxiflora Lindl.
Tricoryne elatior R.Br.
Thysanotus arenarius N.Br.
T. patersonii R.Br.
T. sparteus R.Br.
T. thyrsoideus Baker.
T. triandrus (Labill.) R.Br.

Orchidaceae

Caladenia deformis R.Br.
C. flava R.Br.
C. hirta Lindl.
C. huegelii Reichb. f.
C. latifolia R.Br.
C. menziesii R.Br.
C. reptans Lindl.
Caleana nigrita Lindl.
Diuris longifolia R.Br.
Elythranthera brunonis (Endl.) A. S. George.
Leporella fimbriata (Lindl.) A. S. George.
Lyperanthus nigricans R.Br.
Prasophyllum elatum R.Br.
Pterostylis nana R.Br.
P. recurva Benth.
P. vittata Lindl.
Thelymitra fuscolutea R.Br.
T. nuda R.Br.
Microtis unifolia (Forst. f.) Reichb. f.

Restionaceae

Lyginia barbata R.Br.
Loxocarya fasciculata (R.Br.) Benth.
L. flexuosa (R.Br.) Benth.
Hypolaena exsulca R.Br.
Restio nitens Nees.

Xanthorrhoeaceae

Acanthocarpus preissii Lehm.
Calectasea cyanea R.Br.
Dasypogon bromeliaefolius R.Br.
Lomandra caespitosa (Benth.) Ewart.
L. endlicheri (F. Muell.) Ewart.
L. micrantha (Lindl.) Ewart.
L. preissii (Endl.) Ewart.
L. suaveolens (Endl.) Ewart.
L *L.* sp. (undescribed).
Xanthorrhoea preissii Endl.—Blackboy.

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Ancient grooved stone axes from an alluvial terrace on Stonewall Creek, Kimberley, Western Australia

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Abstract

Stone artifact assemblages probably relating to two successive stone industrial phases identified in other regional sites have been found at an alluvial terrace on Stonewall Creek, a tributary of the Ord River, Kimberley, Western Australia. Two of three grooved stone axes from the surface of a truncated soil at the terrace site are carbonate and iron encrusted, the source of the carbonate encrustations being an eroding younger soil unconformably overlying the truncated soil. The encrusted axes are older than a typical Ord valley late-phase stone artifact assemblage found on the surface of the younger soil. Correlations with similar grooved axes from Miriwun, a local rock shelter, and from Arnhem Land, where a similar two-phase stone industrial succession is known, suggest that the Stonewall Creek axes belong to the early Ord valley stone industrial phase, and are possibly early Holocene or late Pleistocene in age. Various data show that hunter-gatherer adaptation in the Ord valley may have been relatively stable since the late Pleistocene.

Introduction

In 1972, while engaged in a programme of archaeological salvage and survey, I recorded a number of archaeological sites on alluvial terraces in the Ord valley, Kimberley, Western Australia. This account describes the depositional sequence of stone artifact assemblages recovered from an alluvial terrace on Stonewall Creek, one of the tributaries of the Ord River and notes several significant artifacts from there. This site and its artifact assemblages have been briefly noted by Dortch (1977) and Mulvaney (1975, p. 194).

Stonewall Creek drains a 300 km^2 catchment area of barren ranges, rocky outcrops and semi-arid structural plateaus east of the Ord River (Fig. 1). This small stream system flows only during the summer wet season when the typically intensive rains often cause heavy flooding. During floods the system is capable of carrying relatively very large amounts of sediment, with the result that the shallow, braided middle reaches of Stonewall Creek are marked by massive alluvial terraces composed of gravel, sand and clay.

The Stonewall Creek terrace site

Numerous scatters of stone artifaots, presumably the remains of old campsites, occur on the surface of the terraces on Stonewall Creek. The largest and most important of these known at present is located on a weathered, partly eroded terrace situated within the fork of Stonewall Creek and one of its tributaries 19 km east of the Ord River (16° 01′ S, 128° 52′ E; Fig. 1). The terrace, extending over 2 ha, has been used extensively as a campsite during the past, its chief attraction perhaps having been a series of semi-permanent pools in the granite bed of the main channel (Fig. 1). Much of the terrace is heavily eroded, and other parts have been badly damaged by gravel quarrying and other activities related to the construction of the adjacent paved road.

The alluvial terrace consists of two sedimentary units (Fig. 2). The upper or younger is a reddish sandy soil containing varying amounts of gravel; it unconformably overlies a light-coloured deposit which interfingers with thick pebble beds resting on the granite bedrock. This sequence of sediments ranges in thickness from 1-3 m, and always there is a clear interface between the reddish and light-coloured units. Two similar units extend in a terrace along the north bank of Stonewall Creek for several hundred metres downstream, and similar depositional sequences are exposed in other terraces several kilometres downstream. Gravel lenses occur within both units, and in one section there is a thick band of gravel separating the two units. There are also sections along the stream where the reddish sandy soil rests directly on the pebble bed above the bedrock. Thus the two units are not co-extensive and so are not components of a single soil profile.

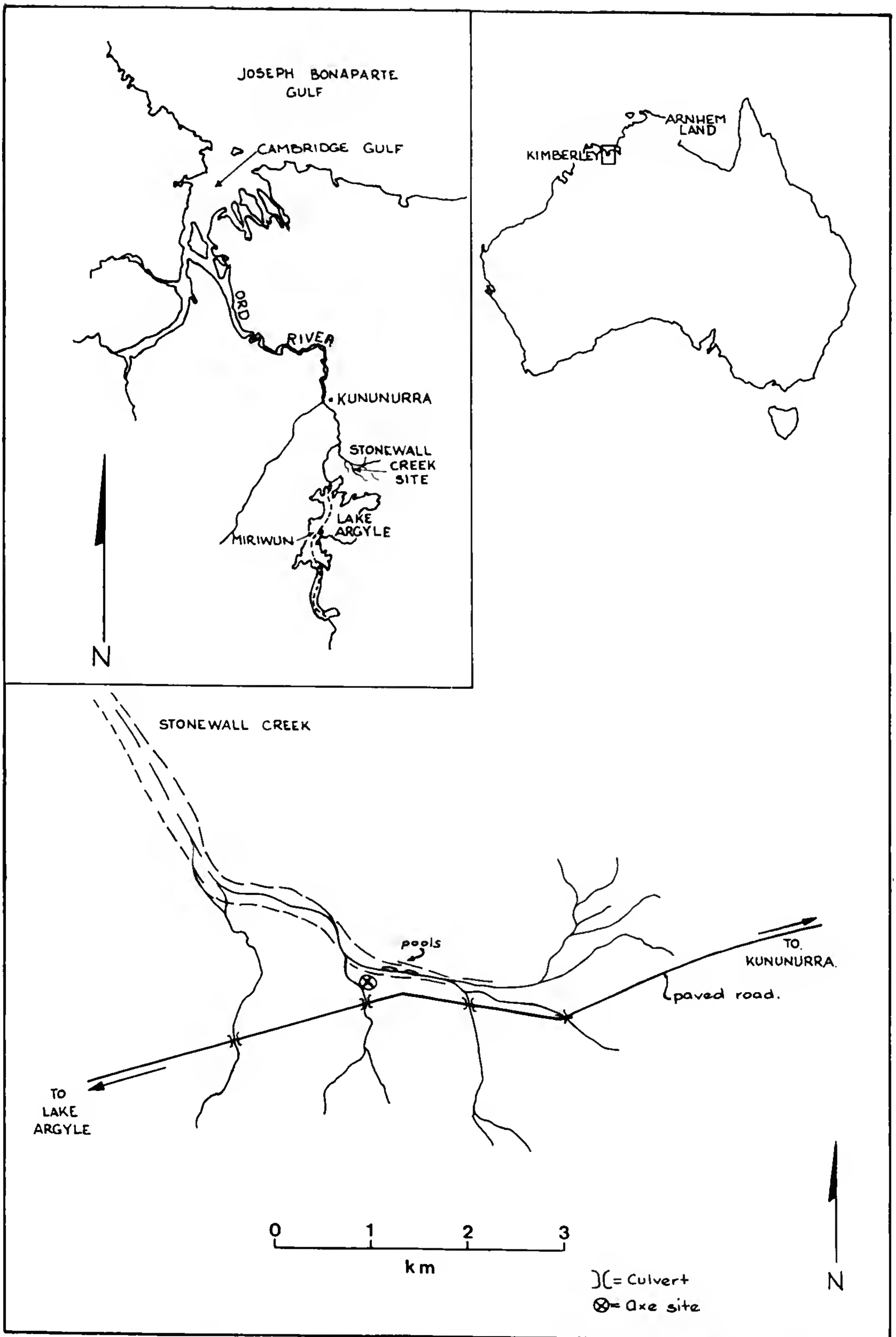

Figure 1.—The Stonewall Creek terrace site and the lower Ord valley, showing sites and localities mentioned in the text.

In all sections or horizontal exposures the light-coloured deposit has the appearance of a truncated soil. Using Stewart's classification of soils in the Ord-Victoria basin (Stewart 1970) the unit was tentatively identified as the subsoil of a lateritic podzol. Dr. G. A. Stewart, Land Resources Management, C.S.I.R.O., Canberra, has in part confirmed this identification, and suggests that it is the subsoil of a lateritic podzol of the Florina type or a meadow podzolic soil of the Marrakai type (G. A. Stewart, personal communication, 1973: Stewart 1970, p. 98). Both types of soils are poorly drained, decalcified, with ferruginous concretions or orange mottling throughout their profiles.

Preliminary first-hand examination of the light-coloured deposit shows that it is a pallid (yellowish-grey), cemented gritty clay with orange mottling; it is decalcified, weathered, and has a blocky columnar structure with cracks extending downward 30-70 cm (Fig. 2). Exposed horizontal surfaces contain numerous small ferruginous concretions, some clearly weathering out of the deposit. At one horizontal exposure, referred to below as the axe site, a small part of the surface, a few centimetres higher than the rest, has on it a 3 mm thick carbonate encrustation which is regarded as a remnant of a band of secondary carbonate derived from the weathering of the formerly overlying reddish sandy unit.

Stone artifact assemblages

The reddish sandy unit extends over most of the terrace within the fork of the two channels; it is completely removed in places leaving the surface of the underlying light-coloured deposit exposed over areas 50 to 1 000 m². The surface of the upper unit contains several hundred stone artifacts including numerous pointed blades of the leilira category, various kinds of invasively flaked points, some large (non-microlithic) backed points, some adze flakes and small flake-scrapers, a few flakes probably struck from discoidal or Levallois cores, a bifacially flaked edge-ground axe, denticulated and notched flakes, blades and bladelets, a number of core and pebble tools, and several grindstones or anvils, all of which typify the Ord valley late stone industrial phase (Dortch 1972; 1977).

This assemblage is concentrated on the northern and eastern parts of the terrace surface, where the reddish unit is largely uneroded, and on an adjacent, 600 m² deeply eroded exposure of the light-coloured deposit. A 30 cm² test pit dug into a partly eroded area of the reddish unit yielded two flakes about 10 cm below the surface and 20 cm above the lower unit.

None of the artifacts from the terrace shows signs of rolling or battering, and it is assumed that most if not all result from occupation of the terrace itself. Until now only one stone artifact has been collected from the stream bed

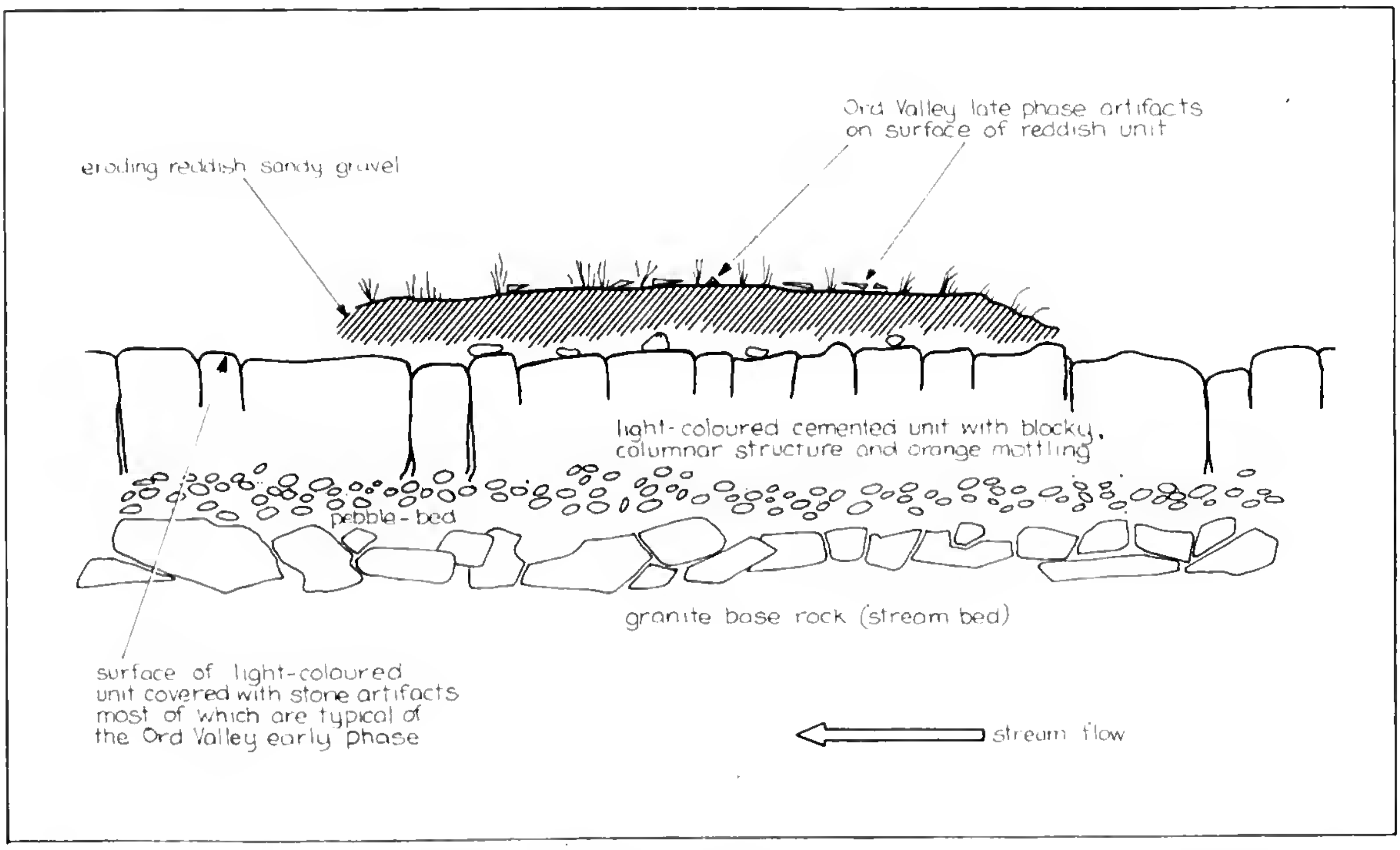

Figure 2.—Schematized view of the western edge of the axe site at the Stonewall Creek terrace site, Kimberley, Western Australia. The face of the reddish sandy unit is 50 m east of the lower unit's face.

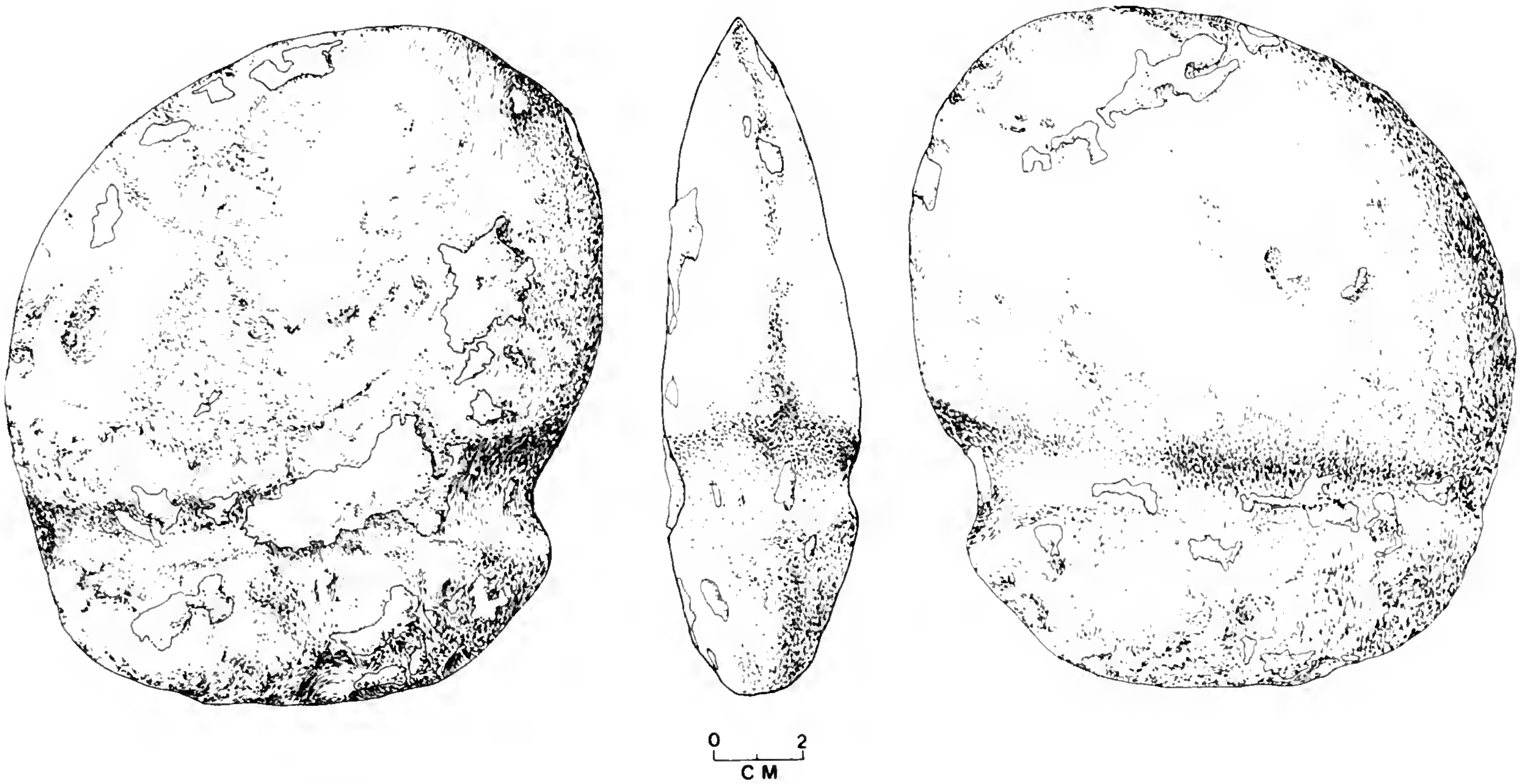

Figure 3.—Axe B2212 from the Stonewall Creek terrace site.

immediately downstream from the terrace and none from the two channels forming the fork. However there are numbers of rolled artifacts in the stream bed a few kilometres downstream as well as in other stream channels in the Ord valley.

The main exposure of the underlying light-coloured deposit is at the terrace's western edge (Fig. 2). This is one of the most extensively eroded parts of the terrace, possibly because a large culvert a few metres upstream (Fig. 1) has the effect of confining and so increasing the velocity and scouring capacity of flood waters in the smaller channel. On the surface of this 1 000 m^2 exposure there are numerous weathered stone artifacts most of which are considered to be representative of the early Ord valley stone industrial phase (Dortch 1972; 1977; see discussion), a few points and blades typical of the later phase, and several tool forms common to both phases. Included are three pecked, ground and grooved axes, horsehoof cores and pebble tools, a number of thick flake-scrapers and notched flakes, and several grindstones and anvils. This assemblage is interpreted as a mixture of tools of different ages, though most of them, including the three axes, probably result from early-phase occupation at the site.

The three grooved axes were found within 60 m of one another on this exposure (i.e. the axe site, Figs. 1, 2). One of them (B2212; Fig. 3) was partly buried in what seemed to be superficially re-worked surface sediments from the light-coloured deposit. Another (B2213; Fig. 4) lay in a shallow gully cutting through the light-coloured deposit. Carbonate and iron encrustations on both faces of these two axes show that they have been buried within or beneath a weathering deposit. The third grooved axe (B2226; Fig. 5), an extremely weathered specimen, was found on a gravel bed exposed in a heavily eroded part of the light-coloured deposit. A photograph of this axe *in situ* is seen in Mulvaney (1975, pl. 63).

Each of these axes has been partly shaped by pecking or hammer dressing though specimen B2212 seems to have been invasively flaked on one face (Fig. 3, left) before being pecked and ground. Bifacial grinding on specimens B2212 and B2226 (Fig. 5) extends from cutting edge to groove, whereas on specimen B2213 (Fig. 4) this is restricted to the cutting edge. The groove encircling each specimen has presumably been produced by pecking, or by a combination of pecking and abrasion. The very weathered condition of these axes prevents positive surface identification of the rock of which they are made. Mr. J. Clarke, Conservation Department, Western Australian Museum, has tentatively identified the stone of each specimen as gabbro or dolerite (J. Clarke, personal communication, 1976).

Since the light-coloured deposit is decalcified, the source of the carbonate encrustations on axes B2212 and B2213 is the younger unit, the reddish sandy soil. These two axes were either exposed on the truncated surface of the light-coloured deposit, prior to its burial by the reddish soil, or they were buried within this younger unit. The first alternative is more likely, since, as noted above, the surface on which they lay itself retains fragmentary remains of a secondary carbonate crust. No other artifacts from the terrace site are encrusted, and the only other encrusted artifacts presently known from the area are several weathered flakes, a pebble chopper and a possible upper grindstone from an exposure of a truncated soil several hundred metres downstream which is similar to the light-coloured deposit at the axe site.

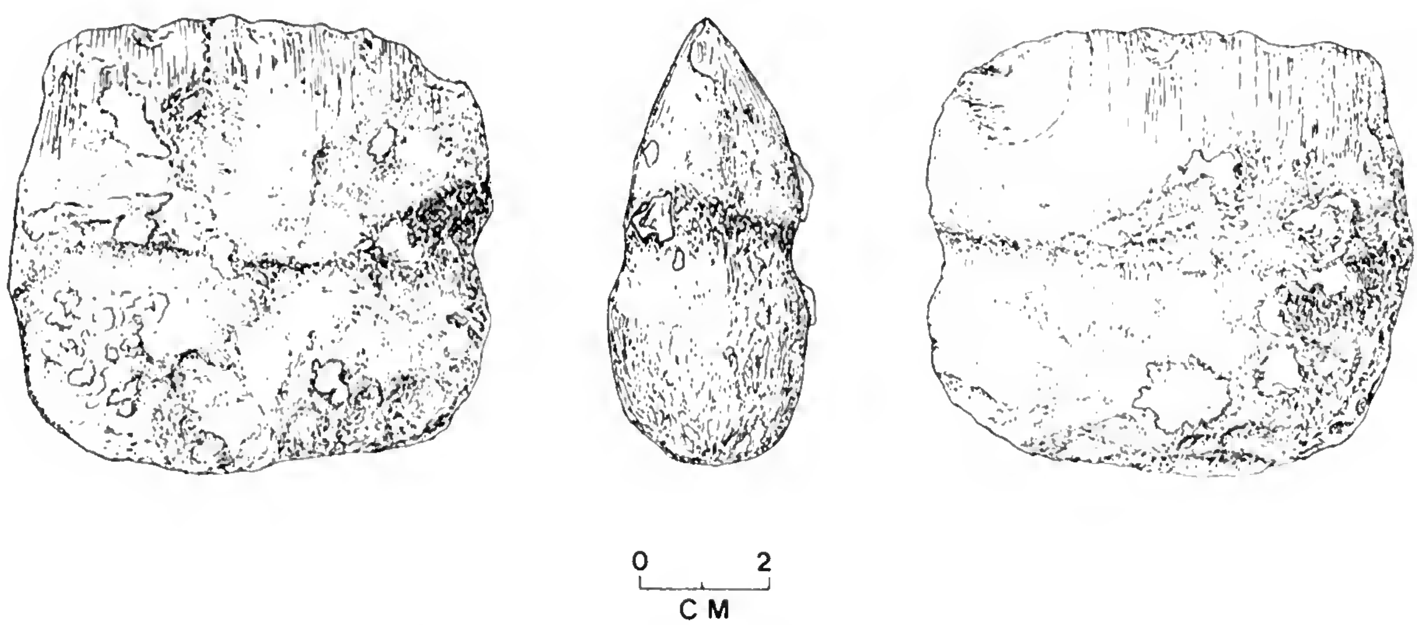

Figure 4.—Axe B2213 from the Stonewall Creek terrace site.

It is clear that the two carbonate and iron encrusted axes are older than the stone artifacts from the surface of the reddish sandy soil, though they are not necessarily older than the soil itself. The two flakes excavated from within the reddish deposit could be younger than or much the same age as the two axes. None of the other artifacts from the various exposures of the light-coloured deposit at this terrace, including axe B2226 and other likely or probable early-phase artifacts from the axe site, can be unequivocally related to the artifact groups whose relative positions in the stratigraphical sequence is shown here.

The foregoing description of the stratigraphy of the terrace and its occupational sequence is firmly supported by this concise statement compiled by Dr. G. A. Stewart (personal communication, 1973).

"From its thickness, colour and texture the lower light coloured sandy clay with orange mottles appears to be a truncated profile of either Florina (lateritic podzolic) or Marrakai (meadow podzolic) soil. It would have been formed under prolonged water-logging, but with enough through drainage that all soluble materials such as calcium carbonate would have been leached from the profile. The calcium carbonate crusting on tools on the surface of the light coloured material must have been leached from younger overlying sediments from which the reddish sandy soil was formed."

Discussion

In the above, the grooved axes from the older unit, and the point and blade assemblages from both units of the Stonewall Creek terrace site are regarded as representing, respectively, the earlier and later Ord valley stone industrial phases. The interpretation of the Ord valley stone industrial sequence as having early and

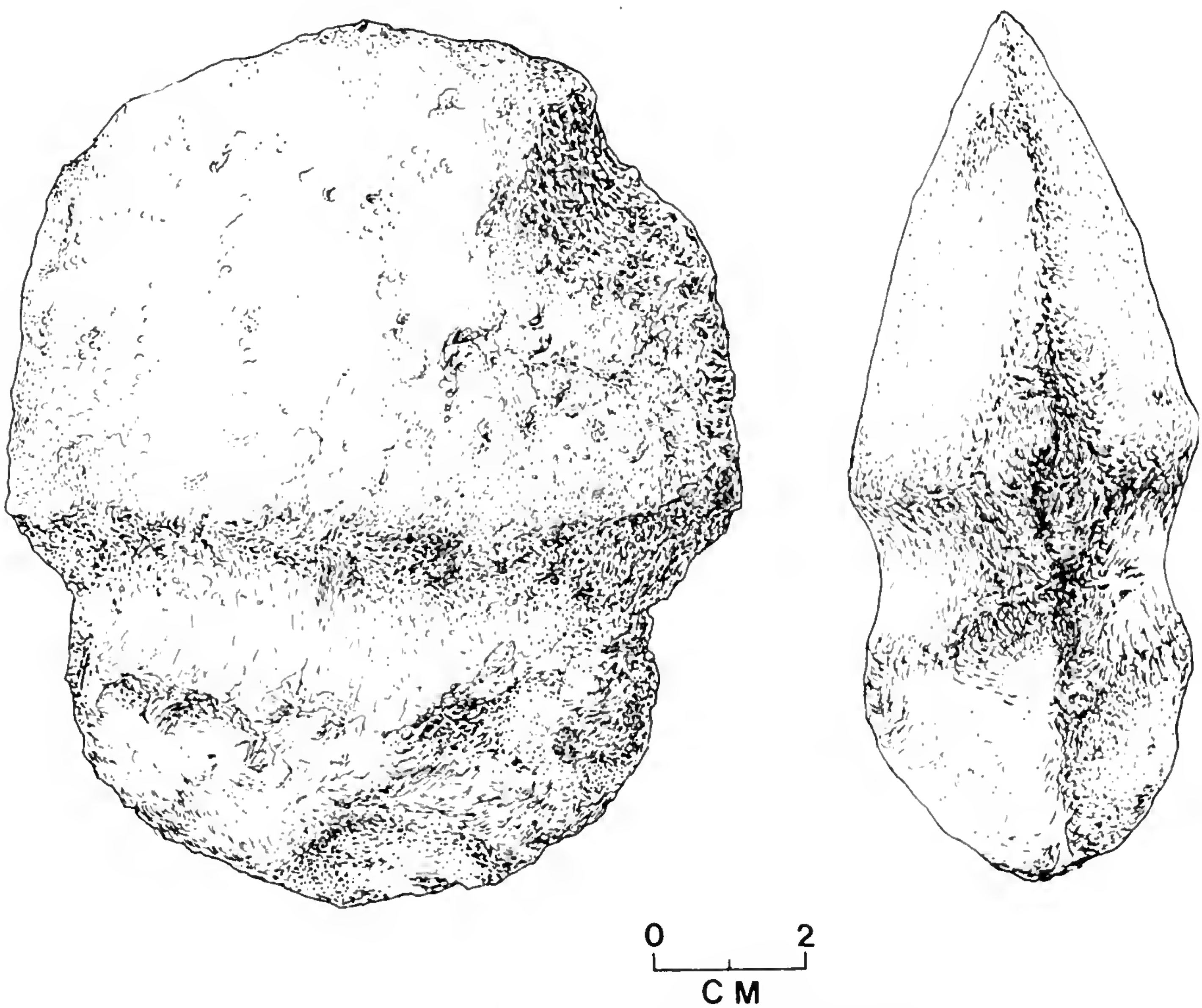

Figure 5.—Axe B2226 from the Stonewall Creek terrace site.

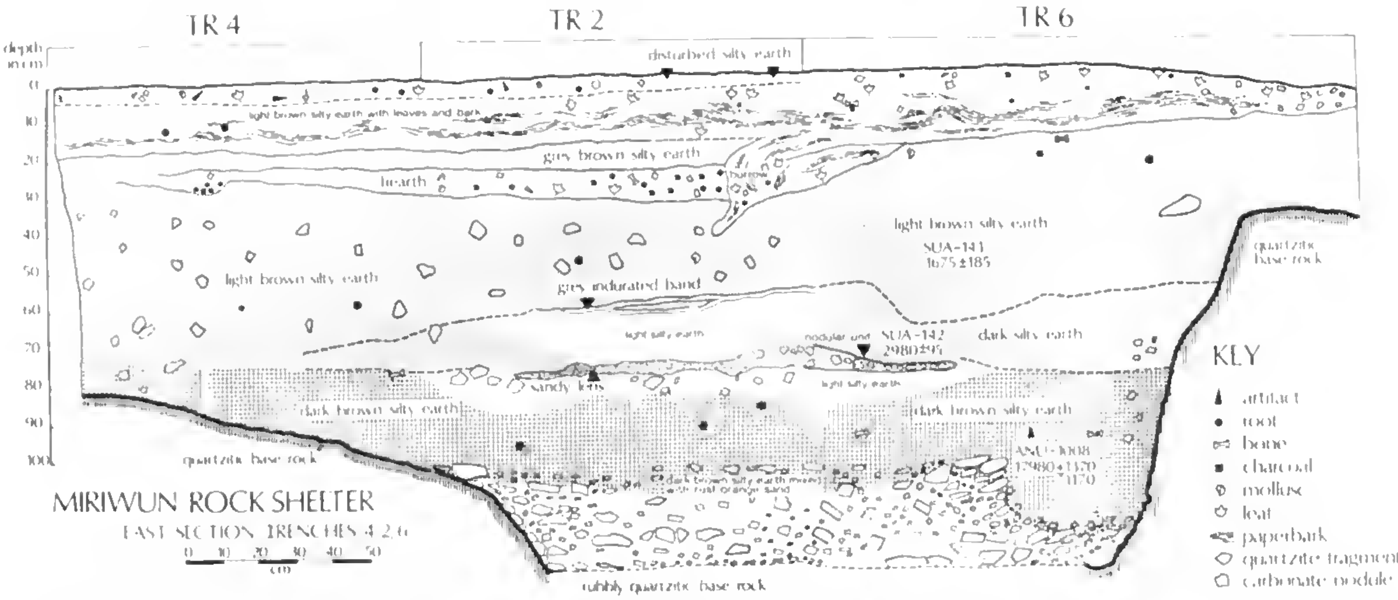

Figure 6.—East section of trenches 4, 2 and 6, Miriwun rock shelter, Lake Argyle, Kimberley, Western Australia. Approximate positions of radiocarbon dates mentioned in the text are shown.

late phases is very largely based on the succession of assemblages found in the stratified deposit at Miriwun rock shelter, a site 35 km SSW of Stonewall Creek which is now permanently inundated in Lake Argyle (Fig. 1; Dortch 1972; 1977).

The two lowermost layers (dark silty earth and dark brown silty earth) of the Miriwun deposit (Fig. 6) contain the definitive artifact assemblages of the Ord valley early stone industrial phase. These layers are overlain by several layers containing point, blade and flake tool assemblages typical of the Ord valley late phase, an industry identified at numerous open sites and rock shelters in the region. The later phase at Miriwun and other sites persisted until the modern era, and is part of the late-phase industrial complex which extends over the whole of Kimberley and western Arnhem Land (Dortch 1977). (For discussion of the distribution of stone points, adze flakes and other small flaked tools pertaining to this complex see Mulvaney 1975, p. 210-237.)

The upper of the two Miriwun early-phase layers (dark silty earth) is radiocarbon dated at 2 980 ± 95 BP (SUA 142). This date is unexpectedly young and needs confirmation by others relating to terminal early-phase assemblages in this region. A charcoal sample from the lower layer at Miriwun containing an early-phase assemblage (dark brown silty earth) was radiocarbon dated at $17\,980 \begin{smallmatrix} +1370 \\ -1170 \end{smallmatrix}$ BP (ANU 1008). Thus early-phase occupation at the Miriwun site extended over a very long period, perhaps as much as 16 000 radiocarbon years.

It is significant to note that, aside from the Stonewall Creek specimens, the only other pecked, ground and grooved axe known from the Ord valley comes from the upper part of dark silty earth at Miriwun (Fig. 6), and so is dated less than 3 000 BP (SUA 142). Also, from the lower part of the dark brown silty earth at Miriwun, dating to the late Pleistocene, there is a single flake with smoothing and striations on its dorsal face which has probably been struck from the face of a partly ground axe (Dortch 1977).

Stone axes are common features in Ord valley and other Kimberley late-phase assemblages. These axes are typically invasively flaked on both faces and only partly ground, and grooving is absent (cf. McCarthy 1967, fig. 30:11). Axes of this kind were being made by Ord valley Aborigines until a few decades ago, and older men of the Miriwung tribe, whose rightful lands extend over the area under discussion (cf. Tindale 1974, maps), are perfectly familiar with their technique of manufacture. I have shown the Stonewall Creek and Miriwun grooved axes to several Miriwung men, and they suggested that these are an earlier type.

The Ord valley grooved axes are typologically similar to the grooved axes associated with early-phase assemblages in Arnhem Land which are dated between about 6 500 and 25 000 BP (White 1967, 1971). It is probable that axes of this kind are also one of the characteristic components of the Ord valley early-phase stone industry, considering the provenances of the Stonewall Creek and Miriwun grooved axes, and the complete absence of such specimens in numerous Ord valley late-phase assemblages. The single flake with striated and smoothed surfaces from the dark brown silty earth at Miriwun also suggests that ground axes in the Ord valley date back to the late Pleistocene. However, tentative evidence for a grooved axe in a late-phase context in eastern Kimberley is provided by Tindale who found a site on Moolabulla Station 250 km south of Lake Argyle where ". . . a Pirrian camping ground [presumably a point or late-phase assemblage] had in it a grooved pebble axe, while the overlying layer, representing the present time, had edge-ground axes . . ." (Tindale 1974, p. 85). The only other published report of Kimberley grooved axes seems to be in McCarthy (1967, p. 48).

The radiocarbon-dated faunal and stone industrial sequences at Miriwun show that early-phase economy there, dating back as far as the late Pleistocene, was similar to that recorded in this site's late-phase layers, the uppermost of which belong to the modern era (Dortch 1972, 1977). All these layers (Dortch 1977, fig. 4, tables 2, 3) contain the same range of animal foods, and the stone artifact assemblages in both phases include most of the same basic kinds of scraping, cutting, adzing, chopping and pounding tools. Several unequivocal grindstones are present in the late-phase assemblages, and a few probable fragments of lower grindstones and one definite upper grindstone occur in the early-phase assemblages. In short the most striking difference between the two phases is a very diverse and easily recognised range of small flaked tools (pointed blades, bifacе and unifacе points, burins, etc.) present in the late-phase assemblages and absent in the early phase.

As noted elsewhere (Dortch 1977), Miriwun and the Stonewall Creek site can with some validity be interpreted as wet and dry season camps respectively. Hundreds of eggshell fragments of a summer-breeding water fowl, the pied goose (*Anseranas semipalmata*), throughout the Miriwun deposit show that the shelter was typically occupied during the summer wet season, though dry season occupation there cannot be discounted. Stonewall Creek, however, would often have been an uncomfortable or even unsafe campsite during the wet season, at least during past times when the stream regime was similar to that prevailing now. At present the stream system is notorious for sudden and violent flooding, and even after floods have subsided the terrace is sufficiently waterlogged and muddy to make camping unpleasant. On the other hand, during much of the dry season the site is attractive because of its very reliable pools; these can not only contain water through most of the dry months (June to November), but also during the early part of the season provide surprisingly large amounts of fish. Admittedly the evidence supporting season of occupation at these two sites is in need of further development and testing. Nevertheless these data show that in this part of the Ord valley occupation and subsistence patterns are likely to have been stable for a long time, and that the marked change in the stone industrial succession which took place here a few thousand years ago is not necessarily indicative of significant shifts in land use or economy.

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Obituary

Desmond Andrew Herbert 1898-1976

It is with sadness that we record the death, at Brisbane on 8 September 1976, of Desmond Andrew Herbert, Emeritus Professor of Botany in the University of Queensland. Professor Herbert had a special interest for us in Western Australia as his first appointment after graduating B.Sc. at Melbourne University was to the position of Economic Botanist and Plant Pathologist to the State. After taking up his duties here early in 1918, in due course he became a foundation member of the Royal Society of Western Australia and served on some of its committees. He appreciated the importance of communicating to the State the results of his scientific researches, and he did this largely through the medium of the Journal of the Royal Society of Western Australia.

In retrospect it seems almost incredible the amount of botanical work Herbert published in the relatively short period that he was Economic Botanist here. Despite his comparative youth (I believe he was not yet 20 when he was appointed) his work has the stamp of scientific maturity, and his paper dealing with the structure and parasitism of the Christmas Tree (*Nuytsia floribunda*), read to the Society in April 1919, is a classic. His interest in the problem was aroused when, in his capacity as Plant Pathologist, he investigated the matter of a field of carrots in Como which were starting to die off when only half grown. He found white collar-like structures strangling the carrot roots and traced the connections of these back to a clump of *Nuytsia* trees 40 m away. He then began a careful study of the Christmas Tree and demonstrated that it could parasitise the roots of many other plants. His work ended, once and for all, the long-standing botanical controversy as to whether *Nuytsia* was or was not parasitic, and vindicated the theoretical views of Harvey. His anatomical studies of the plant also led to an understanding of its curious growth habit. His work on the parasitism of the Sandalwood (carried out jointly with C. A. Gardner, whose interest in botany he had aroused and fostered) followed. Believing that it was essential to have a continuing record of new plants discovered and described, Herbert next inaugurated a series of papers called "Contributions to the Flora of W.A." and up to the end of 1921 four papers had been published. However, these three exciting discovery years were all that Herbert was to spend in Western Australia as he accepted an invitation to the Chair of Botany in Manila.

It has been pointed out elsewhere (Presidential Address, 1971) that the measure of the potential importance for Western Australia of botanists like Herbert, had they stayed longer, is indicated by the quality of their later work. It may be appropriate, therefore, to briefly outline Des Herbert's contribution to botany in Queensland, where he joined the University in 1924 and became the foundation Professor of Botany in 1948. His interests now lay more in ecology and plant geography, and in 1935 he devoted his presidential address to the Royal Society of Queensland to an account of the relationships of the Queensland flora. In the same year his presidential address to Section M of ANZAAS dealt with the question of the climatic sifting of Australian vegetation. Being again President of Section M in 1960 (a rare honour) he reported on the tropical and sub-tropical rain forests of Australia. Despite the demands of teaching and administration (he was twice dean of the faculty of science in the University and for many years the local secretary for ANZAAS in Brisbane), Professor Herbert published over 40 significant scientific papers and also wrote the highly successful horticultural work entitled "Gardening in warm climates".

It was through ANZAAS that I first met Des Herbert in Perth in 1947 not long after I had arrived here myself. I found him to be a stimulating personality, and he had an extraordinarily good knowledge of the vegetation of Western Australia although he had been out of the State for many years. I saw him frequently after that at various meetings and profited much from discussions with him.

Professor Herbert retired in 1965 and in 1966 he was awarded the C.M.G. for his services to botany. It can truly be said that the foundations for these services were laid during his time in Western Australia and were, in part, expressed through the medium of our Journal. His continuing interest in the scientific work going on in this State is reflected in the fact that over the years he retained his membership of the Society. In 1964 Council honoured him by electing him to Honorary Membership.

B.J.G.

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Contents

	Page
Regeneration after fire in King's Park, Perth, Western Australia. By A. M. Baird	1
Ancient grooved stone axes from an alluvial terrace on Stonewall Creek, Kimberley, Western Australia. By C. E. Dortch	23
Obituary. Desmond Andrew Herbert	31

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