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SOME VEGETATION TYPES OF TROPICAL AUSTRALIA IN RELATION TO THOSE OF AFRICA AND AMERICA

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INTRODUCTION

The vegetation of tropical Australia is a subject about which relatively little has been written, and we have accordingly little information on which to base comparisons with other continents. In tropical Africa much work has been done and much published, culminating in recent years with an attempt at a unified terminology and a simple broad classification of plant formations (Scientific Council for Africa South of the Sahara 1956), followed by the publication of the A.E.T.F.A.T. vegetation map (Keay 1959). Some years before, the present writer had attempted a synthesis of the vegetation types of tropical America in a similar manner (Beard 1944, 1955). The material with which to compare tropical Australia thus exists, and the present paper will set out to describe the principal plant formations of a portion of the Australian tropical zone, namely that part lying within the State of Western Australia, which have been observed during 1964 and 1965 in the course of fieldwork.

GENERAL DESCRIPTION OF NORTH-WESTERN AUSTRALIA

About a quarter of Western Australia lies north of the Tropic of Capricorn, stretching as far as 13° N. Geologically this region can be said to consist of two continental blocks, the Kimberley block in the north and the Pilbara block in the south-west, with a relatively low-lying sedimentary basin, the Canning Basin, between them, and another, the Carnarvon Basin, west of the Pilbara Block. Both blocks consist of granites with substantial areas of Proterozoic sediments and basalts often more or less horizontally stratified. The Kimberley block consists of a central core, the Hann Plateau, formed of horizontally bedded quartzites, shales and basalts, and attaining 750 m above sea level. Around the southern and eastern margins of the plateau, the rocks are folded and form steep rocky quartzite ranges with a maximum elevation of 960 m at Mount Ord. This system of ranges bears a variety of names in different localities, the King Leopold Range and the Durack Range being the most significant parts. The Pilbara block consists of granite plains in the north and west, rising gently inland to a capping of basalt in the Chichester Range and beyond and above this to the dolomite and jaspilite of the Hamersley Range with a maximum elevation at Mount Bruce of 1216 m, the highest point in Western Australia. The Hamersley Range is fronted by a great north-facing escarpment 400 km long, but is rather a plateau than a mountain range. Upon it important deposits of iron ore are now being exploited.

The Canning Basin is, for the most part, low lying with elevations of only 100–200 m, and consists of sediments from palaeozoic to tertiary of which the outcrop is mainly sandstone. Under conditions of arid erosion this has broken down into loose sand which has commonly been piled into dunes, creating the popular conception of a sandy

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desert. In point of fact the Pilbara block is little less arid than the Canning Basin but as the rocks do not weather to produce much sand, so that there are no dunes, and the plant cover permits of pastoral use, it is not popularly regarded as desert, or even semi-desert. The so-called 'Great Sandy Desert' which occupies the Canning Basin is without water supplies and has a vegetation largely unpalatable to stock, but is well vegetated and is not desert in terms of plant cover.

Between the Kimberley block and the desert is a belt of transitional country of sediments and alluvia containing in the east and centre the basins of three great rivers, the Fitzroy and Ord which reach the sea, and the Sturt Creek which flows into the desert. These rivers carry violent flash floods in the rainy season, and cease to flow altogether in the dry. To the west of these, forming a seaward margin to the Canning Basin and running up into the Dampier peninsula, there is a belt of low-lying horizontal sandy sediments which, as will be seen, forms a unit ecological region.

The Pilbara block is drained by a number of similar intermittent rivers of which the de Grey–Oakover system and the Fortescue are the most important. The Ashburton River which rises farther south and flows north-westward, marks the western boundary of the Pilbara block. Between its lower course and the west coast of the continent lies the low-lying country of the Carnarvon Basin, formed of Tertiary and Quarternary sediments, an expanse of sandhills, claypans and marshes with some low, limestone ranges striking north and south. The sandhill country in this area resembles and carries a very similar flora to the Great Sandy Desert.

CLIMATE

A rainfall map appears as Fig. 1 and meteorological data for three coastal and two inland stations (a fourth coastal station—Kunmunya—for rainfall only) are given in Table 1. The inland stations, Hall's Creek and Marble Bar, are at altitudes of 180 m and 367 m respectively. The climate in general is both hot and arid. In a small section of the north-west Kimberley coast the rainfall reaches an average of over 1200 mm per annum, but this declines rapidly to the south and east. Most of the Kimberley block receives over 700 mm but the rest of the area is arid to desertic; the total rainfall decreases steadily in a southward direction with only a small local rise attracted by the Pilbara highlands. Rain is received almost entirely from summer thunderstorms and cyclonic disturbances. There is a short rainy season of 4 months from December to March when precipitation is quite heavy and humidity high at coastal stations. The rest of the year is virtually rainless except in the Pilbara where a faint influence of the winter rains of the south may be felt until June.

Evaporation varies from 2000 mm annually on the north-west coast to over 2500 mm in the interior. Daily maximum temperatures are everywhere high, and are at their highest just before the onset of the rainy season. Marble Bar has particularly high figures and boasts of being the hottest place in Australia although Wyndham has the highest annual mean temperature (29·2° C). The daily maximum has been known to exceed 100° F (38° C) for 156 consecutive days at Marble Bar. Daily minima descend to a reasonably cool level from May to September, especially in the interior and it is evident from the 'lowest ever' reading of −1° C at Hall's Creek that light frost may very occasionally be experienced in the interior at higher elevations. All considered, the climate is a severe one, and may be compared with that of the Sudan region which crosses Africa south of the Sahara. Cyclones are a regular annual feature during the

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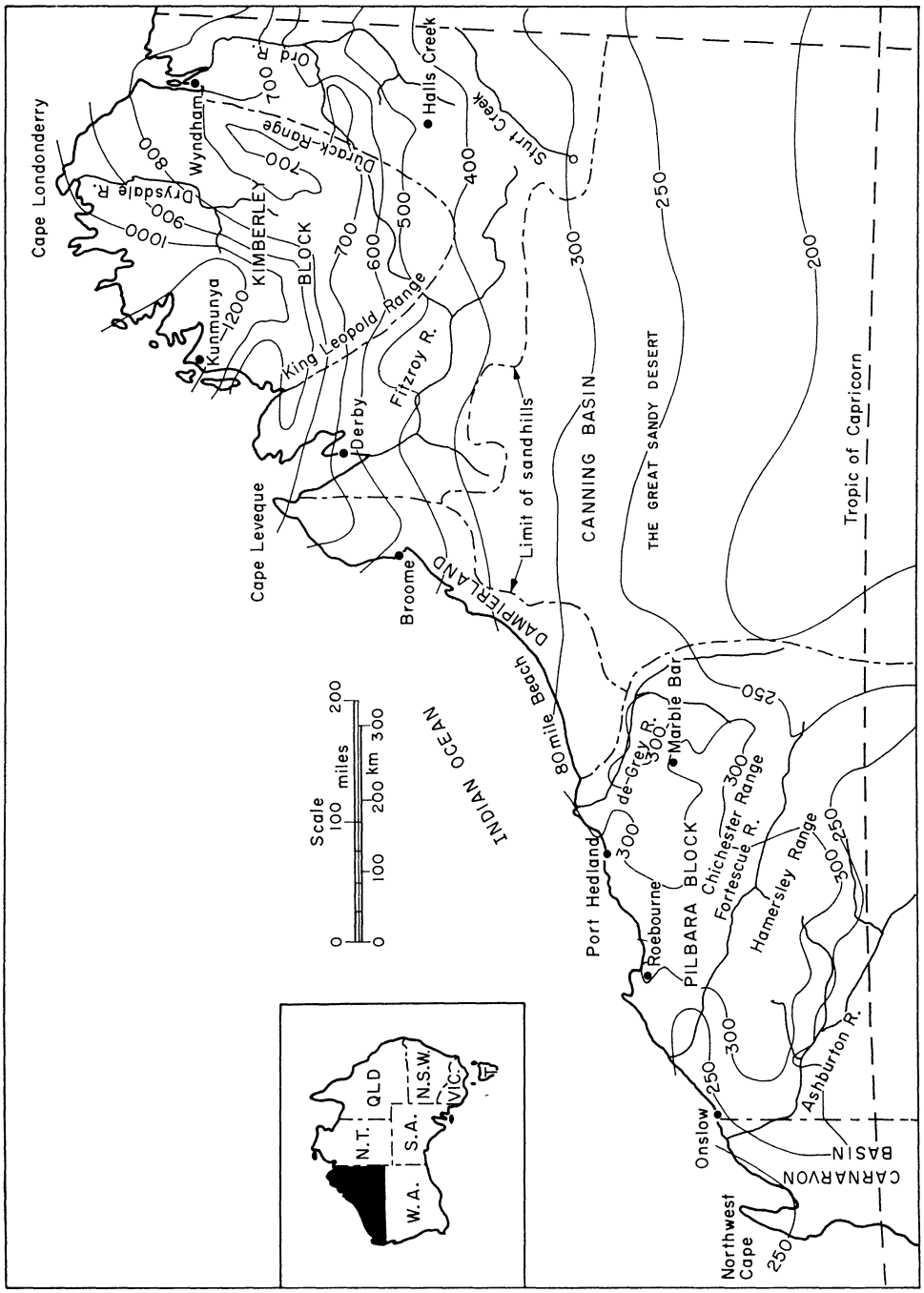

FIG. 1. Map of north-western Australia showing principal physiographic divisions and rainfall. Isohyets in millimetres.

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Table 1. *Meteorological data (from* Climatic Averages, Australia, *Commonwealth Bureau of Meteorology* 1956)

Station	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Average daily maximum temperature (°C)													
Broome	33·0	33·4	34·1	34·2	31·2	28·2	27·8	29·6	31·7	32·3	34·0	34·1	32·0
Derby	34·5	35·0	35·1	35·0	32·1	29·6	29·2	31·2	33·8	35·3	36·0	36·0	33·6
Halls Creek	36·5	36·1	35·3	33·6	30·0	27·1	26·9	30·1	33·8	37·0	38·2	37·6	33·6
Marble Bar	41·4	41·0	39·5	36·1	31·2	27·2	27·1	30·0	34·4	37·9	41·2	42·0	35·8
Wyndham	35·8	35·2	35·2	35·0	32·3	30·0	29·6	31·5	34·3	36·0	37·1	36·5	34·0
Average daily minimum temperature (°C)													
Broome	26·3	26·3	25·6	22·1	18·2	15·2	13·9	15·5	18·4	22·4	25·0	26·4	21·3
Derby	26·3	26·2	26·9	22·6	19·2	16·0	14·7	16·2	19·3	23·2	26·0	26·8	21·9
Halls Creek	24·2	17·9	21·9	17·1	13·2	10·3	8·7	11·2	15·0	20·8	23·5	24·2	17·8
Marble Bar	26·1	26·0	25·0	20·8	16·2	12·6	11·3	13·0	16·4	20·4	24·1	25·8	19·7
Wyndham	27·0	26·8	26·5	25·1	22·4	20·0	19·0	20·8	23·9	26·8	27·5	27·3	24·4
Average index of mean relative humidity (%)													
Broome	75	76	73	56	54	53	52	54	56	64	66	70	63
Derby	71	71	68	56	49	50	49	51	52	54	60	65	59
Halls Creek	54	54	50	40	41	44	42	39	35	38	38	46	45
Marble Bar	42	44	35	38	44	48	42	38	34	31	31	36	39
Wyndham	66	67	63	46	41	40	38	40	44	52	55	60	51
Average rainfall (mm)													
Broome	176	129	99	22	15	16	4	4	0·5	0·5	6	75	547
Derby	183	118	114	27	12	8	6	1	–	–	12	89	570
Halls Creek	129	99	66	13	6	4	6	2	4	12	32	75	448
Marble Bar	75	58	43	21	16	22	5	4	1	7	7	37	296
Wyndham	162	151	125	12	3	5	2	0·5	1	8	37	94	600
Kunmunya	357	272	250	48	21	16	6	1	2	7	44	182	1206

Extreme temperatures (°C)

Station	Max.	Min.
Broome	44·2	4·6
Derby	49·0	5·5
Halls Creek	44·5	−1·0
Marble Bar	53·7	1·2
Wyndham	45·4	8·9

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rainy season. They form over the sea and generally follow a south-westerly course keeping just off the coast, but may eventually swing inland. Apart from wind damage these cyclones bring heavy falls of rain mainly on and near the coast which may amount to half the average annual rainfall in one event.

HUMAN INFLUENCES

Part of the coast of north-western Australia was explored from the sea for the first time by William Dampier in 1699 who reported adversely on its barren and waterless nature. As a result no further interest was taken by the civilized world for many years. Following visits by French parties early in the nineteenth century the coast was finally charted for the British Admiralty by Lieutenant King in 1818–22.

The first land expeditions were mounted by the brothers Augustus and Frank Gregory in 1856 and 1861, using horses. Colonel P. E. Warburton using camels crossed from Alice Springs to the Oakover River in 1873 across the heart of the Great Sandy Desert. Gold was discovered at Hall's Creek in 1885, the first gold strike in Western Australia, and attracted a mining population. Pastoralists began to ship sheep up from the south to the Pilbara in 1863 and to establish 'sheep stations'. In the Kimberley, where tall grass predominates, cattle were brought in, mostly by droving from Queensland beginning in 1880. Outside the desert, most of the country has gradually been taken up in pastoral properties which are held on leasehold from the Crown. They are very large, the average size in Western Australia being 375 000 ac (150 000 ha), the stocking rate is low and the management primitive. Up to now, pastoral use has not significantly modified the general nature of the plant cover in tropical Western Australia. There is no agriculture except in the Ord River irrigation scheme undergoing development and the Camballin rice project on the Fitzroy. The population at the 1961 census was approximately 9000, an average density of one person/28 square miles (70 km^2). This figure does not include aboriginals, of whom at least 5000 are thought to be living in tropical Western Australia.

Before the arrival of Europeans, the country had been occupied by small nomadic groups of aborigines for a long period, probably at least 10 000 years. During this period fires were regularly set, burning off the long-grass country probably every winter, and the 'spinifex' (see p. 283) country sporadically. Of course, grasses must have adapted themselves to the climate and soil of this region millions of years previously, and as electric storms are frequent in summer it is to be supposed that lightning had set fire to grass from time immemorial. To what extent aborigines intensified the fire pattern is unknown. Early explorers all graphically described the practice of desert aborigines of setting fire to spinifex while hunting. At all events, the vegetation of the north-west has clearly been much modified by fire, mainly as regards the woody species occurring in the grasslands.

PLANT GEOGRAPHY

It is thought that the flora of the north-west comprises about 1600 species of flowering plants, and it has long been recognized that it represents a mingling of two distinct elements, an Indo-Malaysian element whose affinities lie to the north in south-east Asia and an Australian element. Species belonging to the former are mainly of local occurrence, congregating on stream banks and on drainage lines, so that it is the Australian element which gives the predominant and distinctive physiognomy to the vegetation.

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PLANT FORMATIONS

A vegetation map has been prepared and is presented as Fig. 2. This is of necessity of very small scale but has been reduced in part from the 1 : 1 000 000 map of the north Kimberley published by Speck *et al.* (1960) and for the remainder from mapping by the present writer on a scale of 1 : 250 000, some of it in detail and some of it of a reconnaissance nature only. Terminology is as far as possible based on and correlated with the standard generalized African types of the Scientific Council for Africa South of the Sahara (1956) and Keay (1959). For climatic reasons forests of any kind are absent, and for topographic reasons there is no montane vegetation. Swamp and riparian formations are of minor importance and will be neglected in the present paper. To give a general picture, woodland may be recognizable as a formation in the highest rainfall belt of the north-west Kimberley. Gallery woodlands occur along all major rivers. These are the tallest and most luxuriant types to be found in north-western Australia. Most of the Kimberley block is covered with savanna woodland which opens up to the southward first as tree savanna, then as tree and shrub steppe. Thicket, known locally as 'pindan', occurs on sandy soil, principally in Dampierland.

Along the southern border of the Pilbara block *Acacia* scrubs are found, scrub being defined as an open shrubland whereas thicket is a closed one. The *Acacia* scrub of which the principal type is dominated by *A. aneura* and known as 'mulga', belongs properly to the arid sector of the winter rainfall area of the south and is not, properly speaking, a type of tropical vegetation. Certain *Melaleuca* scrub is found in the desert.

A full list of the vegetation units mapped is as follows:

TREE FORMATIONS
1. Woodland

SHRUBLAND FORMATIONS
2. Thicket
3. Scrub

BUNCH-GRASS FORMATIONS
4. Savanna woodland
5. Tree savanna
6. Grass-savanna

HUMMOCK-GRASS FORMATIONS
7. Steppe woodland
8. Tree steppe
9. Shrub steppe
10. Grass steppe

MISCELLANEOUS
11 Succulent stenne

Having regard to the low rainfall of north-western Australia it is obvious that comparisons will lie with the drier and more xeromorphic types of African vegetation. Within this range, comparisons are interestingly close, with differences due to the occurrence of plant forms peculiar to Australia. Comparisons with tropical America

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(1) Woodland.

(2) Thicket (Pindan): a, b, c, d—local variations.

(3) Scrub: a, Mulga (*Acacia aneura*); b, mixed *Acacia*; c, *Melaleuca* spp.

(4) Savanna woodland: a, *Eucalyptus tetradonta* type, on quartzite; b, *Eucalyptus tectifica* type, on basalt.

(5) Tree savanna: a, on black and grey soils; b, on yellow alluvium; c, on granite hills; d, on quartzite ridges.

(6) Grass savanna.

(7) Steppe woodland.

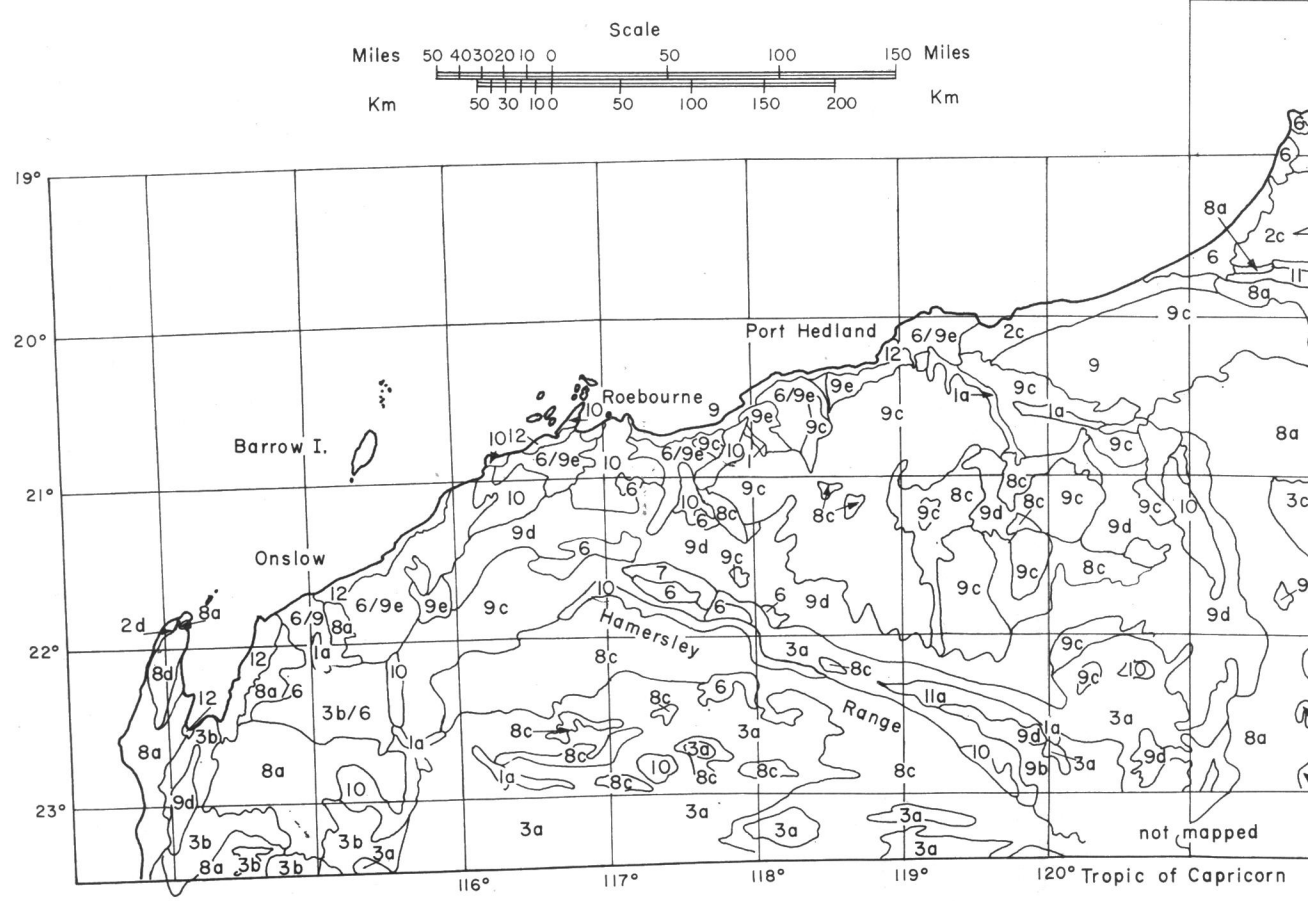
(8) Tree steppe: a, on desert sandhills; b, on desert flats; c, Hamersley Range; d, Cape Range; e, Oscar Range, etc.

(9) Shrub steppe: a, desert, *Acacia pachycarpa*; b, desert, *Hakea lorea*; c, granite, *Acacia pyrifolia*; d, basalt, *Acacia pyrifolia* sparse; e, coastal, *Acacia translucens*; f, Limestone, *Ficus*.

(10) Grass steppe.

(11) Succulent steppe: a, samphire; b, saltbush.

(12) Littoral complex (mangrove, tidal marsh and dunes).



(*Facing p.* 276)

FIG. 2. Map of tropical north

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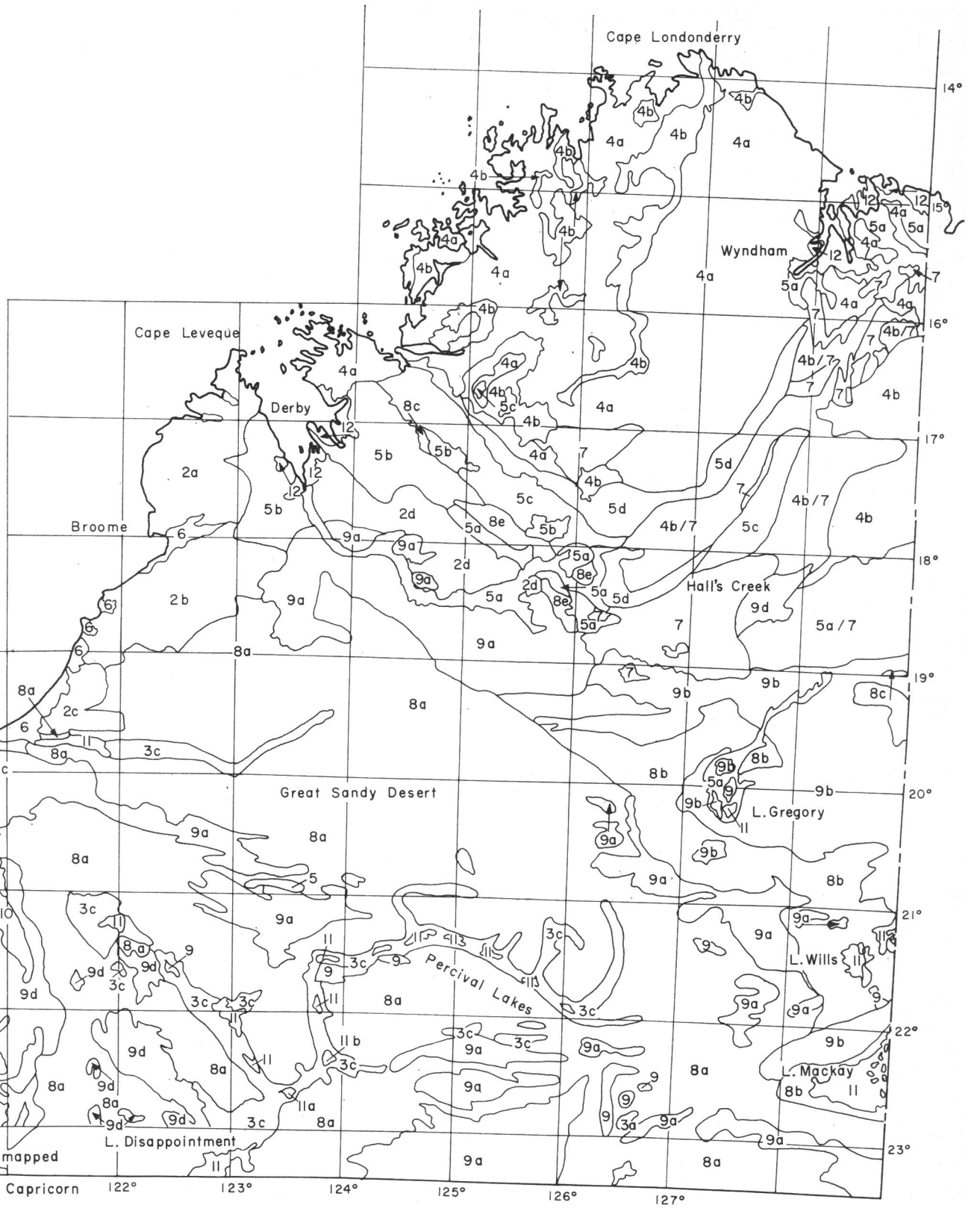

opical north-western Australia showing vegetation.

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are rather more difficult and remote, owing partly to the relatively minor extent of arid vegetation in that area and partly to the evolution of quite different plant forms to constitute it. For this reason the correlations with tropical America will be separately discussed following the general descriptions.

Data on vegetation given below are from the present writer's original observations except where acknowledged to Burbidge (1944, 1945), Gardner (1923, 1942) and Speck (1960, 1963). The quoted definitions of vegetation units are from the Scientific Council for Africa South of the Sahara (1956). Plant names cited follow Beard (1965).

1. *Woodland*

'Open forest; tree stratum deciduous of small or medium-sized trees with the crowns more or less touching, the canopy remaining light; grass stratum sometimes sparse, or mixed with other herbaceous and suffrutescent vegetation.'

For Australian conditions the words 'evergreen or partly' need to be inserted before 'deciduous' owing to the prevalence of the genus *Eucalyptus* which has only one deciduous member, *E. brachyandra.*

On climatic grounds one would certainly expect the presence of woodland in the local high-rainfall area of the north-west Kimberley, where in fact Gardner (1923) reported 'Northern sclerophyllous woodlands' ('Monsoon woodlands' in his 1942 paper) distinguished from the more widespread savanna woodland by a denser stand of more slender trees, the prevalence of xeromorphic shrubs in the understorey and the comparative scarcity of grass. The commonest trees were said to be *E. tetrodonta* and *E. terminalis* with patches of *Callitris intratropica* (*C. columellaris*), associated with the palm *Livistona eastonii* and species of *Acacia, Jacksonia* and *Grevillea.*

In the more detailed account by Speck (1960) it becomes clear that Gardner's sclerophyllous woodlands merge into and form part of a much larger assemblage, the *Eucalyptus tetrodonta–E. miniata* alliance, which is characterized by Speck as 'open forests', e.g. 'open forests of the sandstone areas with good development of shrubby undergrowth and ground storeys of soft spinifex (*Plectrachne pungens*) and annual *Sorghum* spp.'. Within the same floristic alliance there is a variation in structure from savanna woodland to true woodland, but on the whole it seems preferable to regard the whole alliance as savanna woodland (which the greater part of it is). To distinguish the two types in mapping would be most difficult. The only community cited by Speck which would be indubitably woodland in the African sense, apart from some minor riparian communities, is his *Brachychiton* spp.–*Terminalia* spp.–*Eucalyptus confertiflora* community of the sandstone scarps and gorges of the north Kimberley. 'This community is very variable, but typically consists of two or more tree layers. . . . The foliage is mostly of the broad-leaved kind and even the eucalypts are much more leafy than is typical. . . . The main species of the tree layer are *Brachychiton* sp. nov., *B. paradoxum, Terminalia canescens, Eucalyptus confertiflora, Vitex glabata, Planchonella* sp. and *Ficus orbicularis.* The lower layers include *Gardenia megasperma, Strychnos lucida, Ehretia saligna, Ixora* sp., *Atalaya variifolia, Gardenia pyriformis* and *Buchanania obovata.* The ground storeys were very poorly developed except for sparse annual *Sorghum*' (Speck 1960).

Other woodlands are the gallery woodlands which line the major rivers in the Pilbara. In the Kimberley the floodplains of the Fitzroy and Ord Rivers and their tributaries carry a more open formation which may properly be regarded as tree savanna, but in

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the Pilbara and farther south into the Ashburton and Gascoyne basins the braided beds of the streams and their floodplains, often to a considerable width, habitually carry a grassy woodland, evergreen and of limited composition. There are two principal communities. In stream beds and on banks, growing on unconsolidated detritus, *Eucalyptus camaldulensis* is dominant. Sometimes over 20 m tall, it has smooth white bark with a greenish tinge. Smaller trees are *Sesbania grandiflora* and *Melaleucal eucadendron*. Both of these may in favourable situations grow very tall and as dense as a forest but are more commonly stunted and damaged by floodwaters. In the ground layer the introduced grass *Cenchrus ciliaris* is tending to oust native grasses and annuals. The shrub *Aerua tomentosa* is often common. On floodplains away from the river bank, on a matured red loam soil with calcium carbonate concretions, the dominant species changes to *Eucalyptus microtheca*, also a smooth, white-barked tree but commonly smaller than *E. camaldulensis*. Associates may include *Atalaya hemiglauca* and *Bauhinia cunninghamii*. The ground layer is open, comprising short grass and forbs, of which a comprehensive list was given by Burbidge (1945).

2. *Thicket*

'Shrubby vegetation, evergreen or deciduous, usually more or less impenetrable, often in clumps, with grass stratum absent or discontinuous.'

A very interesting and remarkable type of vegetation known locally as 'pindan' is physiognomically referable to thicket, though it is doubtful if it has much in common with African thickets. Pindan is the vegetation of deep red sands with moderate to good rainfall, say exceeding 350 mm per annum, and on such soil it replaces savanna and savanna woodland. Pindan is typically the vegetation of Dampierland, along the Eighty-Mile Beach as a narrow coastal fringe to the desert and broadening northward with increasing rainfall to occupy, north of Broome, the whole Dampier peninsula. It occurs also on broad sandy plains east of Derby, and on minor patches elsewhere in the Kimberley. Below about 350 mm annual rainfall the pindan opens out into tree and shrub steppe, which thus replaces it in arid areas. The word pindan appears to be of aboriginal origin.

No physiognomic description of the pindan seems to have been made, nor has anyone remarked its unique features. Gardner (1923) gave a general account of it and later (1942) referred to it briefly in his general account of the vegetation of Western Australia, and Burbidge (1944) gave a detailed account of its floristic composition at the southern limit of its range. Essentially the pindan is a grassland wooded by a sparse upper layer of trees, and a dense, thicket-forming, middle layer of unarmed, phyllodal *Acacia*. It has, however, many aspects, being subject to fire which destroys the ground layer and the middle *Acacia* layer, leaving the trees intact. The grasses regenerate from seed or rhizomes, the *Acacia* from seed. The grasses are quickly re-established and for the first season or two after fire the pindan has the aspect, according to local rainfall, of a tree steppe, tree savanna or savanna woodland. Gradually the *Acacia* shrubs regenerate, grow taller and become dominant, suppressing the grasses, forbs and small woody plants. After a certain number of years the aspect is three-layered, with scattered trees, a shrub thicket and a sparse ground layer. Later still the *Acacia* individuals reach the height of the trees, which disappear from view, giving the aspect of a tall thicket or low forest of Acacia. At minimal rainfall the pindan merges into tree/shrub steppe by attenuation of the *Acacia* layer.

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The floristic composition of the pindan varies according to rainfall. In the eighty-mile Beach area with a 300–350 mm rainfall, the tree species are low (4–5 m) and include *Owenia reticulata*, *Dolichandrone heterophylla*, *Bauhinia cunninghamii*, *Gardenia keartlandii*, *Eucalyptus dichromophloia* and *E. setosa*. In the *Acacia* layer *A. pachycarpa* is dominant together with *A. impressa*, *A. tumida* and *Grevillea pyramidalis*, while the grass layer is a mixture of the hummock-grasses *Triodia pungens* and *Plectrachne schinzii* with a few bunch-grasses, mainly *Eragrostis eriopoda*. In a northerly direction changes occur so that on reaching the 500 mm rainfall line in the vicinity of Broome the trees, which have risen to 9 m in height, number *Eucalyptus dichromophloia* and *E. setosa* (the eucalypts now more abundant than the non-eucalypts), *Bauhinia cumninghanii*, *Erythrophloeum chlorostachys* and *Gyrocarpus americanus*. In the 6 m high middle layer *Acacia eriopoda* is dominant, associated with *A. tumida*, *A. holosericea*, *Hakea macrocarpa*, *Grevillea pyramidalis* and *G. wickhamii*. The grass layer is predominantly of *Plectrachne pungens* and *Sorghum* sp.

Above roughly the 600 mm rainfall line in the Dampier peninsula tree height increases to 12–15 m and *Eucalyptus tectifica* becomes the principal species with *E. dichromophloia* and locally *E. jensenii*. *Acacia tumida* replaces *A. eriopoda* as dominant in the shrub layer but all species listed above are still present. Grasses tend to disappear.

In the Fitzroy Basin east of Derby, the pindan contains the eucalypts *Eucalyptus dichromophloia*, *E. polycarpa*, *E. setosa* and *E. perfoliata*, with a rather occasional *Adansonia*, also *Gyrocarpus*, *Bauhinia*, *Hakea* and *Grevillea*. The shrub layer is dominated by *Acacia tumida* together with *A. eriopoda* and *A. impressa*. The grass layer is sparse. In this area the pindan occurs on deep red sand and grades into tree savanna where the sand shallows.

Elsewhere in the Kimberley patches of deep sand occur locally, derived from quartzite, but this is bleached sand differing from the red sands described above and the thicket vegetation found on it differs from the true pindan. There is no longer the distinct stratification and the dominance of *Acacia* is lost in a mixed assemblage containing *Grevillea*, *Hakea*, *Jacksonia* and other species.

3. *Scrub*

It is implicit in the name and definition of thicket that it is a closed community and no provision is made in the African classification for any open shrubland. Possibly the latter would be regarded, having a grassy ground layer, as shrub savanna or shrub steppe. In Australia, however, the recognition of open shrubland as 'scrub' (usually without a grass layer) is obligatory though for the most part it occurs outside the tropics. *Acacia* scrubs are found along the south-western border of tropical north-western Australia, but they are essentially interlopers from the south. *Acacia* scrub is the typical vegetation of the arid sector of the southern, winter-rainfall region of the State, wherever the rainfall is less than 250 mm annually and has a predominantly winter seasonality. On the west coast the Tropic of Capricorn roughly marks the transition between the summer and winter rainfall zones. On moving from south to north it is found that hummock grass first appears on sandy soils, with *Acacia* persisting on clays. Eventually the *Acacia* drops out even on soils most favourable to it.

The most widespread *Acacia* scrub community in Australia is one dominated by *A. aneura*, known as 'mulga.'

A. aneura grows to some 6 m in height and is generally the only arborescent species

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in the community, though it has many ecotypes. It is erect, with a rounded crown, and is not flat-topped like the typical African thorny *Acacia*. *A. aneura* is unarmed and has linear, glaucous phyllodes disposed pointing upwards at the sky. The bark is thin, smooth and not fire-resistant. A sparse shrub layer occurs in which species of *Eremophila* are predominant and there is an open ground layer with short grasses (both annual and perennial species of *Danthonia*, *Eragrostis*, *Aristida*, *Eriachne*, etc.) and also forbs. In the southern mulga the latter are mainly Compositae but in the north they are mainly Amarantaceae—*Ptilotus* and *Gomphrena*. *Ptilotus exaltatus* is the most characteristic species.

There is a detailed account of mulga associations farther south by Speck (1963).

On the Tertiary sediments of the Carnarvon basin *Acacia aneura* is no longer dominant and is replaced by a variety of other species, some forming mixed and some forming single-dominant communities. These may be referred to for our purposes as Mixed *Acacia* scrubs and being largely extra-tropical are of no great immediate concern. Height is usually much less than in the mulga, 2–3 m being normal. *A. xiphophylla* tends to form pure stands on low-lying clay flats or patches of country receiving run-on. The ground layer consists of annuals. *A. coriacea* and *A. sclerosperma* form communities on low limestone hills and ridges in the Exmouth Gulf area.

The only genuine tropical scrub community is one formed by *Melaleuca lasiandra* and *M. glomerata* in the Great Sandy Desert, occurring in depressions where there appears to be some accumulation of ground water. Concretionary calcium carbonate is usually found in the sand in such areas, indicating the ground-water factor. The shrubs grow up to 2 m in height, dense and spreading, and almost touching one another. There is a ground layer of hummock grass, but the density of the shrub layer is such as to indicate a classification as scrub rather than shrub steppe.

4. *Savanna Woodland*

Savanna is characterized as 'Formations of grasses at least 80 cm high, forming a continuous layer dominating a lower stratum. Usually burnt annually. Leaves of grasses flat, basal and cauline. Woody plants usually present'.

Savanna woodland is distinguished by 'Trees and shrubs forming a canopy which is generally light'.

The greater part of the Kimberley block is covered with savanna woodland in the above African sense. Rainfall is from 600 to 1000 mm annually. Outside the Kimberley block savanna woodland occurs to the east in the Ord River Basin, fairly generally in the northern part but otherwise only on the basaltic soils. Two major types of savanna woodland can be recognized, as both Gardner (1923, 1942) and Speck (1960) have agreed, distinguished floristically and to some degree also in physiognomy, and associated with differing soil and soil material. The one, the *Eucalyptus tectifica–E. grandifolia* alliance of Speck occurs on heavy soil derived from basalt and shale, while the other, the *E. tetrodonta–E. miniata* alliance occurs on sandy soil derived from quartzite and sandstone. Both types were shown by Speck to be widespread also in the Northern Territory and Queensland.

In the *E. tectifica–E. grandifolia* alliance the upper tree layer is open, the trees usually one to several crown-widths apart, and from 7·5 to 10 m tall. Characteristic trees in the Kimberley block are *E. tectifica*, *E. grandifolia*, *E. jensenii* and *E. foelscheana*. Tree crowns are rounded and carried high above the ground, owing no doubt to the effect

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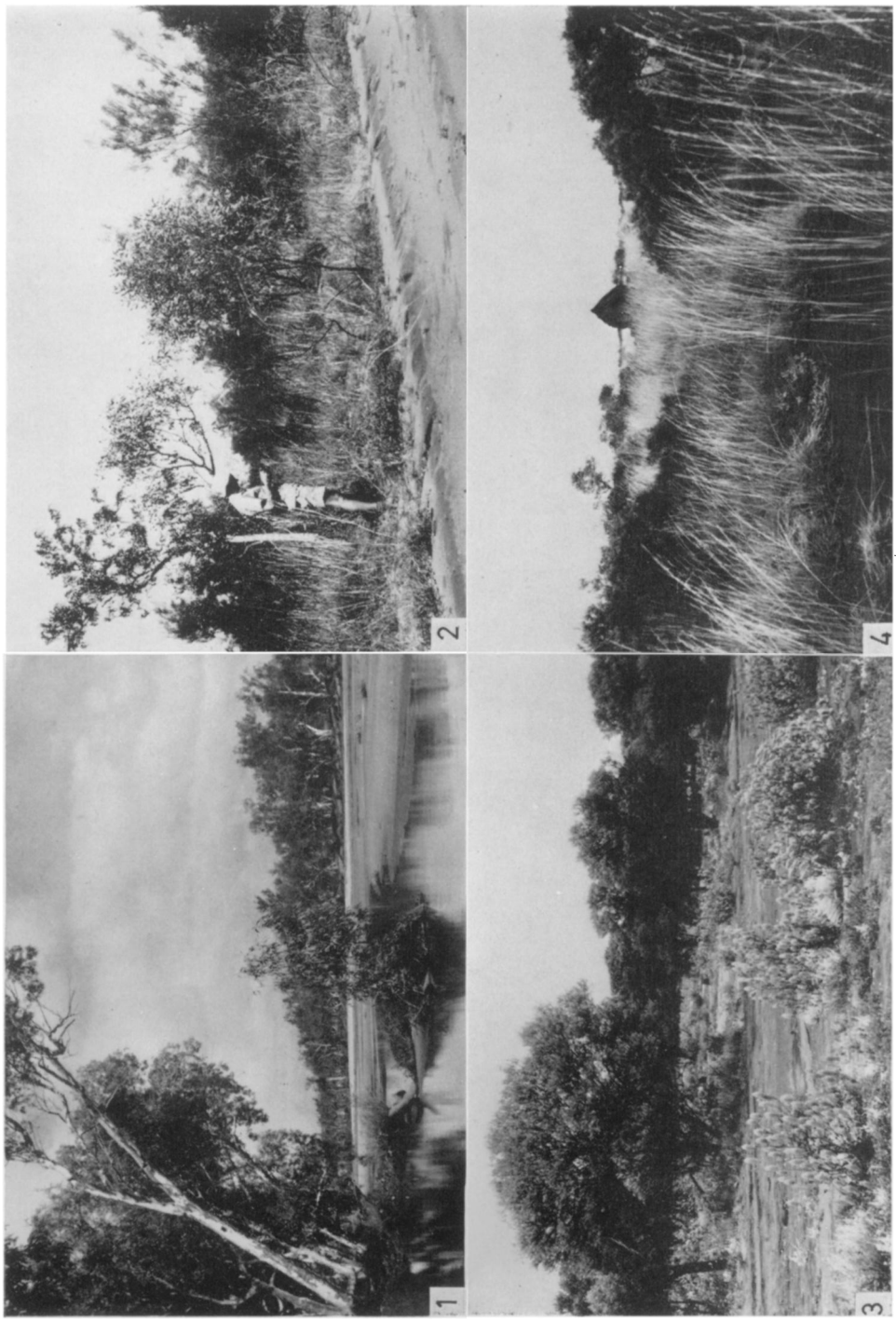

PHOT. 1. Riverain woodland of *Eucalyptus camaldulensis* along a typical river-bed in the north-west. Lyons River.
PHOT. 2. Pindan at its southern extent, a scrubby example. *Dolichandrone heterophylla* at left with a small eucalypt, otherwise *Acacia* spp. Dry season aspect of grass layer.
PHOT. 3. Mulga scrub (*Acacia aneura*) in the Fortescue valley. Ground layer of forbs, mostly *Ptilotus exaltatus*.
PHOT. 4. *Melaleuca* scrub in the Great Sandy Desert with clumps of *Triodia*. Large termitarium centre.

(*Facing p.* 280)

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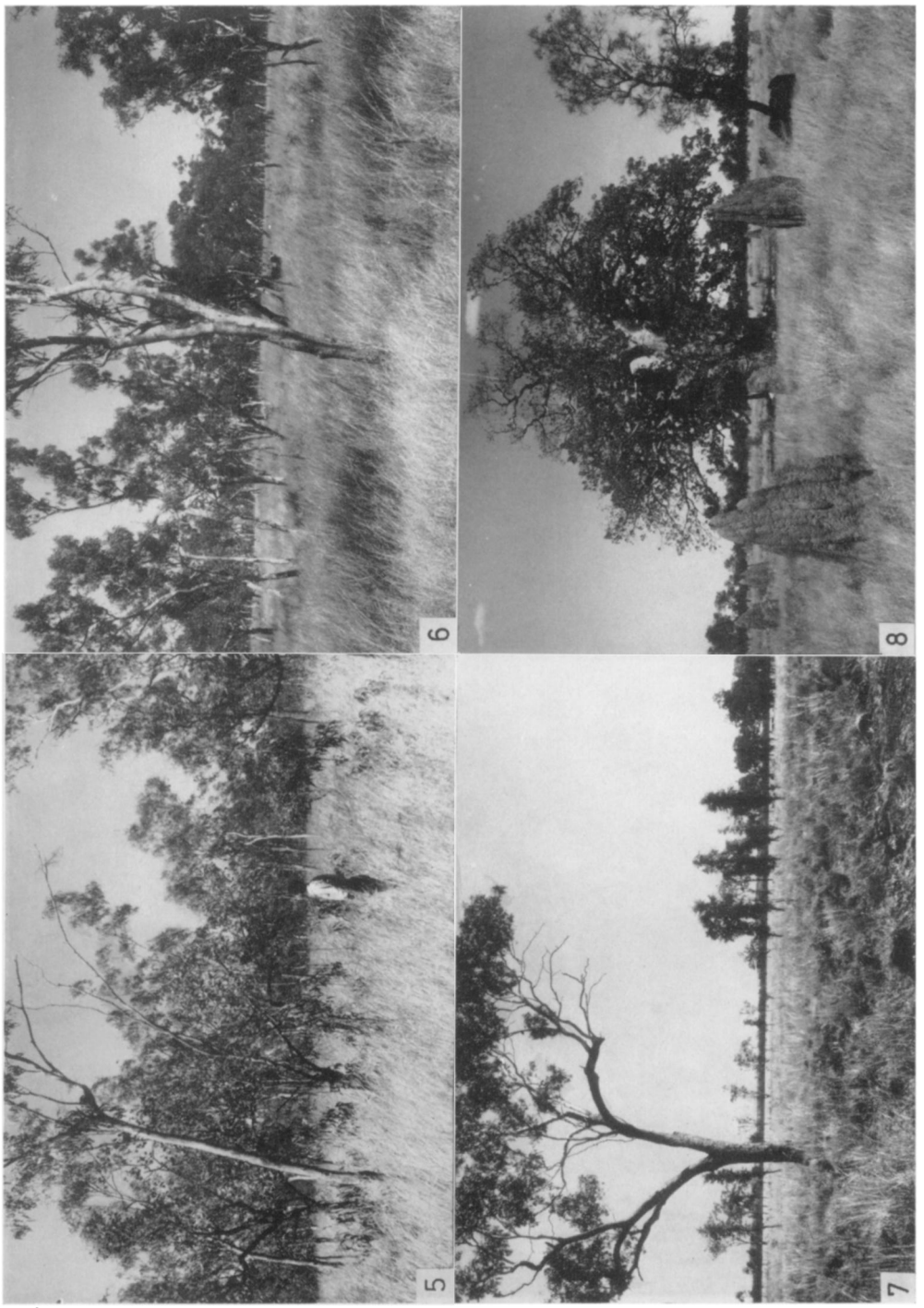

PHOT. 5. Savanna woodland on quartzite with *Eucalyptus tetrodonta* dominant. Beverley Springs Station.
PHOT. 6. Savanna woodland on basalt with *Eucalyptus tectifica* dominant. Mount House Station.
PHOT. 7. Tree savanna opening to grass savanna on a black soil plain. Mount House Station. In foreground and rear, *Eucalyptus intertexta*: in middleground *Acacia suberosa*.
PHOT. 8. Tree savanna with the Australian baobab, *Adansonia gregorii*. *Grevillea* at right. Large termitaria typical of this assemblage.

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of fire. The trees are evergreen, their leaves simple, mesophyll, falcate and pendent. The bark type conforms to no consistent pattern: *E. tectifica* is a 'Box' (rough, persistent but only lightly fissured bark), *E. grandifolia* and *E. foelscheana* are 'Bloodwoods' (rough and scaly persistent bark) and *E. jensenii* is an 'Ironbark' (very thick, deeply fissured).

With *Eucalyptus* constituting the tree layer in this savanna woodland, there are considerable differences of detail from African examples, but the general appearance is actually much the same. A few smaller trees may at times occur with the eucalypts and include *Cochlospermum gregorii*, *Terminalia circumalata*, *Erythrophloeum chlorostachys* and *Atalaya hemiglauca*. Shrubs are virtually absent. Grasses form a dense ground layer 1–1·5 m tall. The dominant species are *Dichanthium* spp., *Botriochloa* spp., *Sehima nervosum*, *Chrysopogon fallax*, *Sorghum plumosum*, *Heteropogon contortus* and *Themeda australis*, and there are many species of forbs. The grasses would be classed as tall bunch-grasses in the sense of Bews (1929).

In the Ord River Basin there is a large extent of savanna woodland on basalt which has not been well studied. It is believed that *Eucalyptus tectifica* continues to be the principal species.

In the *E. tetrodonta–E. miniata* alliance, trees on the whole tend to be taller (up to 15 m) and straighter and more closely spaced. There are at least a dozen upper tree storey dominants in the alliance as recognized by Speck, not all simultaneously present. *E. tetrodonta* (a 'stringybark') is the most common and characteristic species associated with *E. miniata*, a 'woollybutt' (rough black and scaly persistent bark on the lower trunk). Other dominants of more local occurrence are *E. phoenicea* (another woollybutt), *E. polycarpa* and *E. ferruginea* (roughbarked bloodwoods), *E. dichromophloia* (a bloodwood with more or less smooth bark), *Callitris columellaris* and several other eucalypts of minor importance. Smaller sub-canopy trees are often common in this alliance and are an interesting mixture of Indo-Malayan and Australian genera, viz. *Petalostigma quadriloculare*, *Gardenia pyriformis*, *Grevillea pteridifolia*, *G. cunninghamii*, *G. heliosperma*, *Persoonia falcata*, *Buchanania obovata*, *Ventilago viminalis*, *Planchonia careya*, *Eugenia suborbicularis*, *Brachychiton diversifolium*. Shrubs also are not uncommon locally and include *Petalostigma quadriloculare*, *Acacia* spp., *Grevillea agrifolia*, *Livistona loriphylla*, *Bossiaea phylloclada*, *Verticordia cunninghamii*, *Calythrix brachyphylla*, *Jacksonia argentea* and *J. thesioides* (details from Speck). The grass layer is formed largely of *Plectrachne pungens* together with annual *Sorghum*.

5. *Tree and Shrub Savanna*

Savanna, as defined, with 'Trees and shrubs scattered'.

Between about 500–600 mm annual rainfall the vegetation tends to regress to tree and shrub savanna. These are therefore seen along the southern boundary of the Kimberley block, on the King Leopold and Durack Ranges, on the belt of granite country to the south of the King Leopold Range, and on the alluvia in the Fitzroy Basin (except where these are sandy, when the vegetation is thicket instead).

On the quartzite ranges the plant cover is predominantly *Plectrachne pungens* with scattered small trees including *Eucalyptus dichromophloia*, *Callitris columellaris*, *Eucalyptus perfoliata* and *Brachychiton viscidulum*, and shrubs of *Gardenia*, *Grevillea* and *Acacia*.

The granite country is very bouldery, but mixed grasses similar to those of the basalt plains occur in pockets of soil. Tree and shrub growth is low (3–6 m) and scattered,

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much of it deciduous, e.g. *Cochlospermum heteroneurum*, *Brachychiton viscidulum*, *Adansonia gregorii* and *Gyrocarpus americanus*. Evergreen trees include *Eucalyptus tectifica*, *Albizzia* sp., *Terminalia circumalata*, *Eucalyptus perfoliata* and *Bauhinia cunninghamii*.

It is therefore on the heavy soils of the Fitzroy Basin that the tree savanna is most fully developed, and features the Australian baobab, *Adansonia gregorii*. These grow rather widely spaced in a dense grassland on yellow soil with termitaria, a scrubby growth of small trees filling in between them, typically *Grevillea striata*, *Bauhinia cunninghamii* and *Terminalia circumalata* with local patches of *Eucalyptus tectifica–E. dichromophloia* savanna or of open grass-savanna. The baobabs reach heights of 10–15 m and diameter of 6 m, and it is one's general impression that they do not, in general, reach such large sizes as their African counterparts. The baobab does not flourish in sand and is thus more or less absent from the sandy inclusions in this country. It is for this reason absent, naturally, from Dampierland farther to the west, although planted specimens in the town of Broome have been entirely successful. To the south and east it peters out with declining rainfall, and in the mountainous Kimberley block becomes confined to alluvia on drainage lines and drops out at about the 700 mm rainfall line. In the north and east Kimberley, however, it reappears as a component of savanna woodland with *E. grandifolia* on steep shale scarps, apparently a radical change of habitat. The botanical identity of these two ecotypes should be investigated. The *Adansonia gregorii* is believed to be confined to Western Australia and neighbouring parts of the Northern Territory.

Tree savanna of *Terminalia* sp. and *Dichanthium foecundum* was reported by Speck to occur on patches of ill-drained grey soil in the north Kimberley. This is seen also in the Ord River Basin. The irrigation area of the lower Ord was covered before being put to agricultural use with tree savanna of spindly *Bauhinia cunninghamii*, 3–4·5 m tall, with some *Atalaya hemiglauca* in tall grass. This is black soil. The floodplains along the Fitzroy River and some of its tributaries carry a tree savanna, patchy but usually rather open, in which the principal trees are *Eucalyptus intertexta* and *E. papuana*, with *Bauhinia*, *Atalaya* and *Terminalia*.

6. *Grass-Savanna*

Savanna with 'Trees and shrubs generally absent'.

According to the thinking of most Australian ecologists, 'grass-savanna' would be a contradiction in terms, for they define savanna as a wooded grassland, to be classified separately from 'grassland' as such. This is recommended practice, for example, in Beadle & Costin (1952). In this, however, they are mistaken. As Beard has shown (1953) savanna historically means a grassland in tropical America with or without trees. The African workers have followed the correct practice in classifying all tropical closed grassland communities as savanna irrespective of their tree components.

As elsewhere in high-rainfall areas, grass-savanna in the better-watered parts of Australia is an expression of ill-drained soils, typically occupying relatively small areas of black soil which are waterlogged in the rainy season, dry and deeply cracked in the dry season. These occur on basalt plains in the Kimberley block and on alluvium along the Meda and Fitzroy Rivers and their tributaries. *Eucalyptus intertexta* and/or *Bauhinia cunninghamii* tend to occur around the edges of the open areas, which are commonly treeless but may occasionally carry a few strange spindly *Acacia suberosa*, a thorny and

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bipinnate not phyllodal species. The thick growth of grass and forbs appears to be similar to the ground layer of the *Eucalyptus tectifica–E. grandifolia* alliance. The ground surface is unevenly pitted. This is called gilgai in Australia, and resembles the 'hogwallow' structure of the Americas. In central Africa also the treeless, grassy 'dambos' are an expression of defective drainage and seasonally waterlogged soils.

In the more arid parts of tropical Australia, in Dampierland and in the Pilbara, there are local areas of grass savanna with short grass, corresponding to the short bunch-grass savanna of Bews (1929). These occur on clay plains of grey soil where there is no run-off, and often run-on is received from surrounding slopes or from rivers. Owing to this factor and the moisture retentivity of the soil, the bunch-grass habit is preserved. These grass plains are entirely devoid of trees or shrubs, from which it is suspected that an adverse drainage factor is still present. The grasses are perennial, but strongly seasonal in growth, sprouting, growing to a height of 30–45 cm and flowering during the rainy season but becoming dry during the dry season. When in full growth a continuous cover of the ground is effected, though the grasses are actually growing in scattered clumps. Forbs of a similar height may be sparingly present. Small prostrate succulent plants occur in some areas. Species composition has been studied by Burbidge (1944, 1945). It is very heterogenous but species of *Eragrostis* appear to be the most common elements, with *Xerochloa*, *Enneapogon*, *Sporobolus*, *Triraphis*, *Dichanthium*, *Chloris* and *Panicum*. The introduced species *Cenchrus ciliaris* is gradually spreading.

7. *Steppe Woodland*

In the 1965 paper of the Scientific Council for Africa South of the Sahara, open herbaceous vegetation is separated from savanna under the title of steppe, with this definition:

'*Steppe:* Open herbaceous vegetation, sometimes also with woody plants. Usually not burnt. Perennial grasses usually less than 80 cm high, widely spaced. Leaves of grasses narrow, rolled or folded, mainly basal. Annual plants very often abundant between the perennials.'

The implication is that steppe is a reflection of drier conditions than savanna. Like savanna, steppe may be wooded to various degrees, creating classes of steppe woodland, tree steppe, shrub, steppe, etc.

One cannot help feeling a certain reservation about this usage, in that the word steppe is proper to the grasslands of southern Russia, in a temperate region. Warming (1909) classed all the world's temperate grasslands as grass-steppe, including the prairies of North America and the pampas of Argentina. If, of course, there is no essential physiognomic difference between the Russian steppe vegetation and the dry grasslands of tropical Africa, we have no real basis for any distinction between tropical and temperate. Possibly the African workers felt this to be the case. In Australia, however, we do have a very real physiognomic difference, since the transition from closed to open grassland is accompanied by a change in the life form of the grasses from bunch-grass to hummock-grass. This 'hummock grassland' (the term is due to Beadle & Costin in 1952) seems to be peculiar to Australia, representing the evolution of a unique plant form adapted to arid conditions. An analogous evolution has taken place in the Cactaceae in the Americas and in the Aizoaceae and Liliaceae in southern Africa. The hummock-grasses are popularly known as spinifex, an apt expressive term, but one apt to cause confusion scientifically as they do not belong to the genus *Spinifex* but to *Triodia* and *Plectrachne*. Two

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species of *Spinifex*, properly speaking, do occur in Western Australia, but are confined to recent coastal dunes and are absent from the interior.

In the hummock-grass form, each plant branches repeatedly into a great number of culms which intertwine to form the hummock and bear rigid, terete, pungent leaves presenting a serried phalanx to the exterior. When flowering takes place in the second half of the summer, given adequate rains, upright, rigid inflorescences are produced over the crown of the hummock, rising from 50 to 100 cm above it (Phot. 10). The flowers quickly set seed, which is shed within 2 months, although this is then the beginning of the dry season. The size of the hummock varies considerably according to the site, from about 30 cm in height and diameter on the poorest, stoniest sites up to about 100 cm in height and 2 m in diameter on some deep sands. One forms a visual impression that in the former case there are more clumps per unit area than in the latter, but no numerical surveys have been made. Old hummocks, if unburnt, tend to die out in the centre or on one side, leading to ring or crescentic growth. At this stage the original root has died and the outer culms have rooted themselves adventitiously in the soil. Individual hummocks do not touch, and there is much bare ground between, surfaced with a desert pavement in stony areas. Measurements to give the proportion of cover in spinifex vegetation would be interesting and should be undertaken. A very few perennial forbs, principally *Ptilotus*, occur between the hummocks.

Not all species of *Triodia* and *Plectrachne* are hummock-grasses. Of the three dozen known species of *Triodia*, one (*T. cunninghamii*) is a soft bunch-grass, while in *Plectrachne* only *P. schinzii* is properly a 'spinifex', many if not all of the others being harsh and prickly but not hummock formers.

Hummock-grass steppe is the characteristic vegetation of the more arid parts of tropical Australia where the rainfall is less than 300 mm on the coast or 500 mm in the interior. It is possible to recognize steppe woodland, tree steppe, shrub steppe, grass steppe and succulent steppe.

Steppe woodland

This type is not included in the African classification but is required here. It is similar to savanna woodland, being well wooded with an open stand of small trees, but differs in that these are shorter (6 m) and the ground layer is open and composed of hummock-grasses. *Eucalyptus brevifolia* is the characteristic tree, generally pure, sometimes with *E. dichromophloia* or others, while the typical hummock-grasses are *Triodia wiseana*, and *T. intermedia*.

There appears to be a correlation with fine-grained Proterozoic rocks in a rainfall belt of 350–500 mm. These conditions are mainly satisfied in the east Kimberley from a point about 130 km west of Hall's Creek ranging across to the State boundary and north almost to the Cambridge Gulf, where *Eucalyptus brevifolia* is characteristic of the hilly ground, alternating with a savanna woodland on alluvial flats in which *E. tectifica* is the principal species. In the Pilbara, owing to the lower rainfall, while *E. brevifolia* is still characteristic of Proterozoic rocks, it tends to occur mainly as the more open tree steppe. Patches of steppe woodland are confined to favourable low-lying sites, e.g. in the Fortescue valley between Millstream and Mount Florence Stations. A second important area of steppe woodland is found within the Kimberley block on shale plains on Mount House and Glenroy Stations. The shale does not weather readily and there is little soil, depressing the vegetation to a more depauperate type than the rainfall would

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indicate. The trees concerned are *E. brevifolia* and *E. argillacea* with *Melaleuca minutifolia*, 3–5 m in height, with shrubs of *Acacia pyrifolia*, *A. translucens* and *Grevillea pyramidalis*. The ground layer consists of *Triodia pungens* and *Plectrachne pungens* with occasional patches of savanna grasses.

8. *Tree steppe*

'Steppe with Trees (mostly small) present'.

In tree steppe, scattered trees up to 10 m in height with spreading rounded crowns occur in hummock grassland very erratically and often without any apparent logical pattern. Distribution varies from less than one tree per mile to groves forming local patches almost as dense as woodland. Shrubs are always present, rather more commonly than trees, but are equally irregular. No doubt fire has much to do with the situation, coupled with difficulties of regeneration in an unreliable rainfall. Trees concerned are mainly but not invariably eucalypts and are of varied forms. Some eucalypts are 'ghost gums' with smooth white bark (*Eucalyptus brevifolia*, *E. aspera*), some are bloodwoods with rough persistent bark of a pinkish tinge (*E. dichromophloia*). They are all evergreen, having mesophyll leaves falcate and pendent or opposite, cordate and erectly disposed. The non-eucalypts *Owenia reticulata* (desert walnut), *Erythrophloeum chlorostachys* (ironwood) and *Casuarina decaisneana* (desert oak) have dark, very thick, deeply fissured bark. The first two have large smooth-surfaced pinnate leaves. The *Casuarina* bears green branchlets with leaves reduced to scales. All trees are resistant to fire once established.

Tree and shrub steppe occur on most soils below the 400 mm rainfall line and are thus characteristic of the whole of the southern part of tropical Western Australia from the western coastal plain through the Pilbara block and the Great Sandy Desert. This is a big area and there is thus much variation in detail. At the North-West Cape the Cape Range consists of limestone hills up to 300 m high, very rocky with little soil. The vegetation is a stunted tree steppe (4–5 m trees), mainly *Eucalyptus dichromophloia* with some *E. microtheca*, *Brachychiton australe* and *Ficus platypoda*. Shrubs include *Acacia bivenosa*, *A. xylocarpa*, *A. gregorii*, *Cassia* spp., *Eremophila* spp., *Grevillea* spp. and *Melaleuca cardiophylla*. Hummock-grasses are *Triodia pungens* and *Triodia* sp.

Apart from the Range, the country west of the Ashburton River is low lying with extensive areas of sandhills. Floristic composition varies greatly, but trees include *Owenia reticulata*, *Eucalyptus dichromophloia*, *E. aspera* and *Acacia pyrifolia*, shrubs *Grevillea stenobotrya*, *G. eriostachya*, *Hakea lorea*, *Acacia coriacea*, *A. bivenosa* and *A. translucens*.

The hummock-grasses are typically *Triodia pungens* and *Plectrachne schinzii* on sand, *Triodia lanigera* on heavier soil. In addition to the above which constitute a typical steppe flora there are indications of a maquis flora with relationships in the temperate south-west. Its members, species of *Banksia*, *Calythrix*, *Verticordia*, *Pileanthus*, *Hibbertia* and *Thryptomene* are scattered and irregular in distribution and seem to suggest a state of recession in favour of the steppe flora, perhaps due to fire. They are confined to the western coastal plain where some appreciable winter rainfall is experienced.

East of the Ashburton is the highland area of the Pilbara block formed largely of Proterozoic basalts and jaspilites. In the Hamersley Range and Plateau, on jaspilite, *Eucalyptus brevifolia*, *E. gamophylla* and *E. setosa* form tree steppe with *Triodia wiseana*. On rocky ranges along the Oakover River a sparse form of this community is repeated.

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Further to the east lies the vast extent of the so-called Great Sandy Desert, whose flora and vegetation were quite unknown until recently. A collection of botanical specimens was made by a geologist, J. N. Casey, during a reconnaissance in 1954 but it is thought that no botanist had entered the area prior to April 1964 when the present writer was accorded facilities by the West Australian Petroleum Company Ltd for a visit to an exploration camp in the heart of the desert. Over 1600 km of ground traversing was done by Landrover, observations made from the air at a low level, and a collection of botanical specimens secured. As a result it is now possible to say that in terms of vegetation this is no desert. It is sandhill country and difficult to traverse, there is no drinkable surface water and the herbage is mostly unpalatable to stock, being predominantly of the inedible *Plectrachne schinzii*, but the plant cover is of the same general type as the Pilbara and is no more sparse, open or depauperate. The total flora is much poorer in species but this is probably due to the low-lying sandy country, rather than to rainfall, the rich gully and creekbed habitats of the mountainous Pilbara being absent.

The physiography of the desert country consists basically of a gently undulating plain rising almost imperceptibly from the coast to an altitude of about 300 m. This plain possessed at one time a well-developed dendritic drainage system which must have led by some major rivers to the sea. The surface rocks on which the plain is developed are all more or less horizontally bedded sandstones and conglomerates of Permian to Cretaceous age. During the Tertiary these were uplifted and subjected to weathering and erosion, with development of the drainage system. Subsequently, it is supposed in the Quaternary, an immense system of parallel seif dunes tending for the most part west-north-west was superimposed on the older topography. These dunes are up to 35 m in height, averaging about 12 m and mostly braided, with several crests. Their spacing is very variable, mostly 0·5–1 per km, sometimes up to 4 per km. The dunes march relentlessly in immensely long lines up and down hill across the older topography, blocking drainage lines and often engulfing small mesas. They are only interrupted by salt lakes, of which a number occur disposed in long chains presumably indicating ancient river valleys. High ground tends to be somewhat free of dunes, probably owing to migration of the surface sand to lower country, and there are a number of low plateaux of lateritic gravel, carrying shrub steppe as described later.

Lower-lying sandy ground has a more luxuriant vegetation of tree steppe with *Eucalyptus aspera*, *E. setosa*, *E. tessellaris* or rarely *Erythrophoeum chlorostachys* in a general cover of the feathertop spinifex, *Plectrachne schinzii*. There is a richer shrub flora than on the plateaux, including the same species but with notable additions such as *Grevillea eriostachya* and *Codonocarpus cotinifolius*.

The actual sand ridges have an entirely distinct flora of their own, a limited one to some extent different from that of the intervening sandy country. The vegetation would still be considered tree steppe but the only tree species is one close to *Eucalyptus cliftoniana* which occurs sparingly along either side of the dune crests, the summit itself being normally bare sand and unvegetated. Where the trees occur fairly thickly they can be distinguished in aerial photographs forming a double row along the dunes. Flanks of dunes are well vegetated with *Plectrachne schinzii*. Shrubs feature *Grevillea stenobotrya*, *G. eriostachya* and some *Acacia* spp.

On the coastal fringe of the desert there is tree steppe with *Owenia reticulata*, a tree known as desert walnut, in a ground layer of both *Triodia pungens* and *Plectrachne schinzii*. Groves of the desert oak, *Casuarina decaisneana*, in *Triodia pungens*, occur on the lower Sturt Creek, 250 km south of the settlement of Hall's Creek. This is flat sandy

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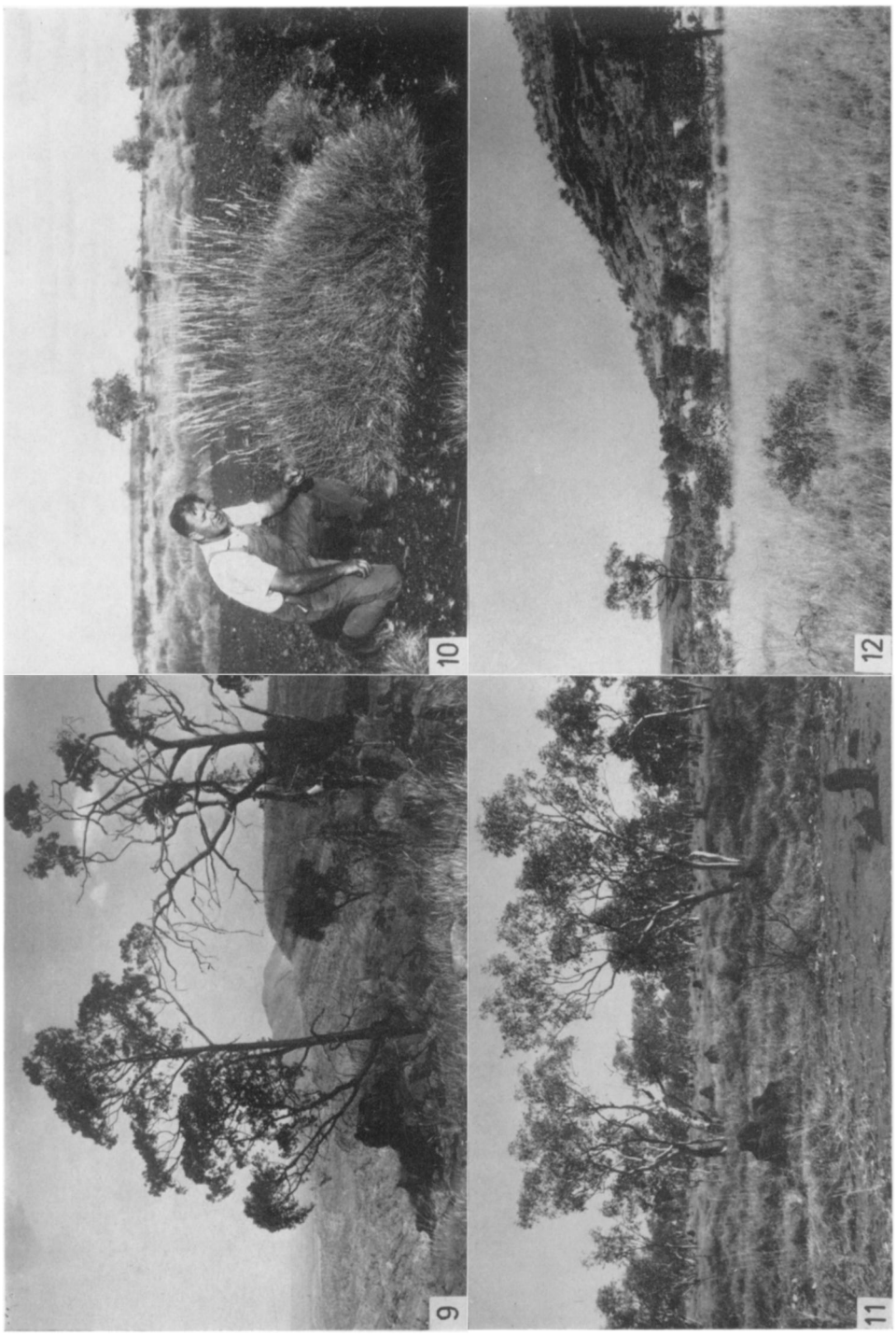

PHOT. 9. Tree savanna on the Durack Range with *Callitris columellaris* and *Plectrachne pungens*.
PHOT. 10. The hummock-grass form. A large clump of *Triodia pungens* in flower. Note hamada surface between clumps.
PHOT. 11. Steppe woodland near Hall's Creek. *Eucalyptus brevifolia*, *Triodia wiseana* and *T. intermedia*, small termitaria.
PHOT. 12. Tree steppe in the Hamersley Range. *Eucalyptus brevifolia* and other species with *Triodia wiseana*.

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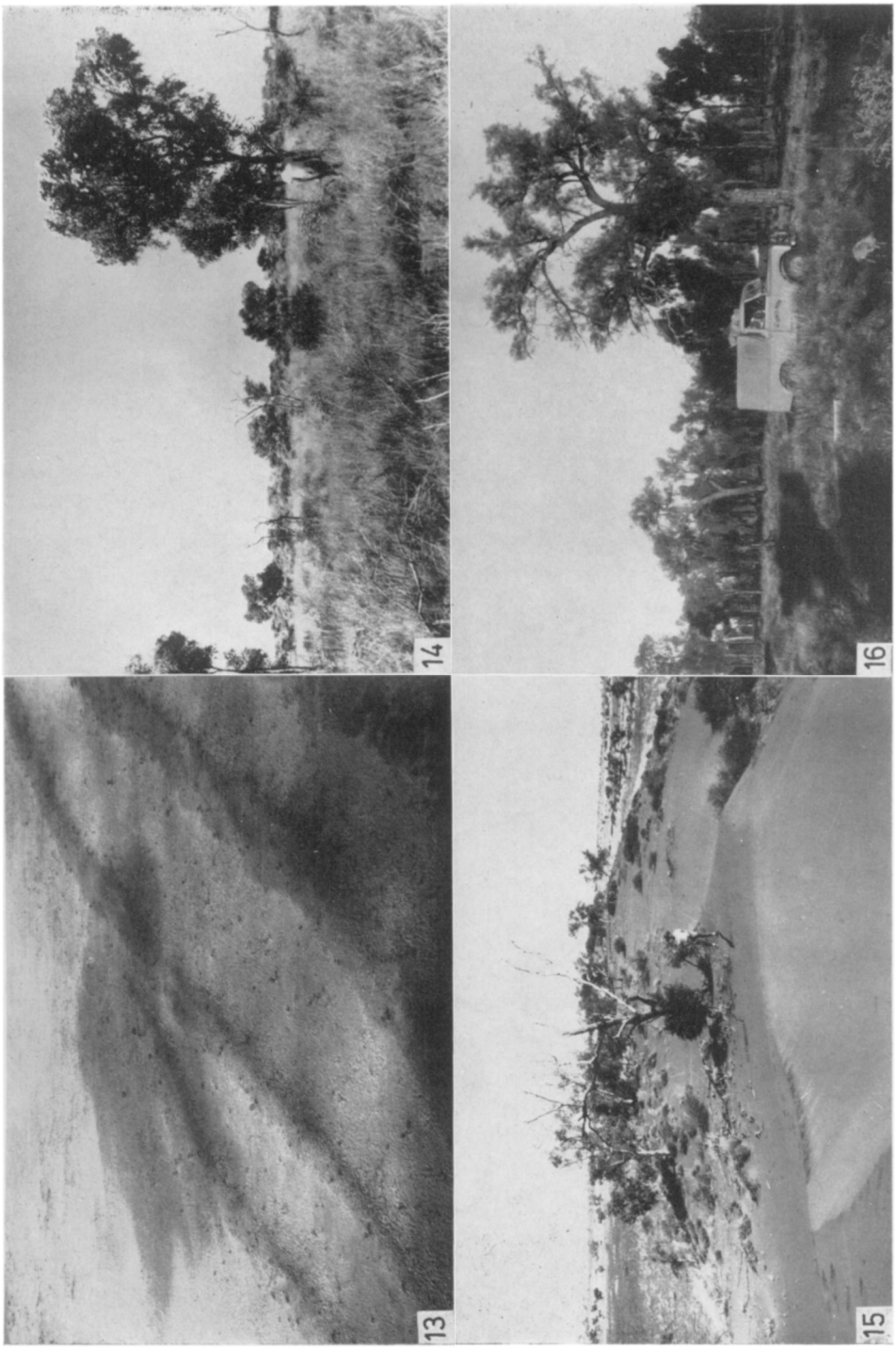

PHOT. 13. Low-level aerial photograph in the Great Sandy Desert, showing braided seifdunes and scattered trees in hummock grassland.
PHOT. 14. Tree steppe in the Great Sandy Desert. Sandy valley with feather-top spinifex (*Plectrachne schinzii*). Trees are *Eucalyptus tessellaris*, many of them dead.
PHOT. 15. Summit of a dune in the Great Sandy Desert with its typically bare crest. The trees on the dune are *Eucalyptus* sp. (? *E. cliftoniana*).
PHOT. 16. Tree steppe of the 'desert oak', *Casuarina decaisneana*, and ground cover of *Triodia pungens* on low-lying sandy country of the lower Sturt Creek. Billiluna Station.

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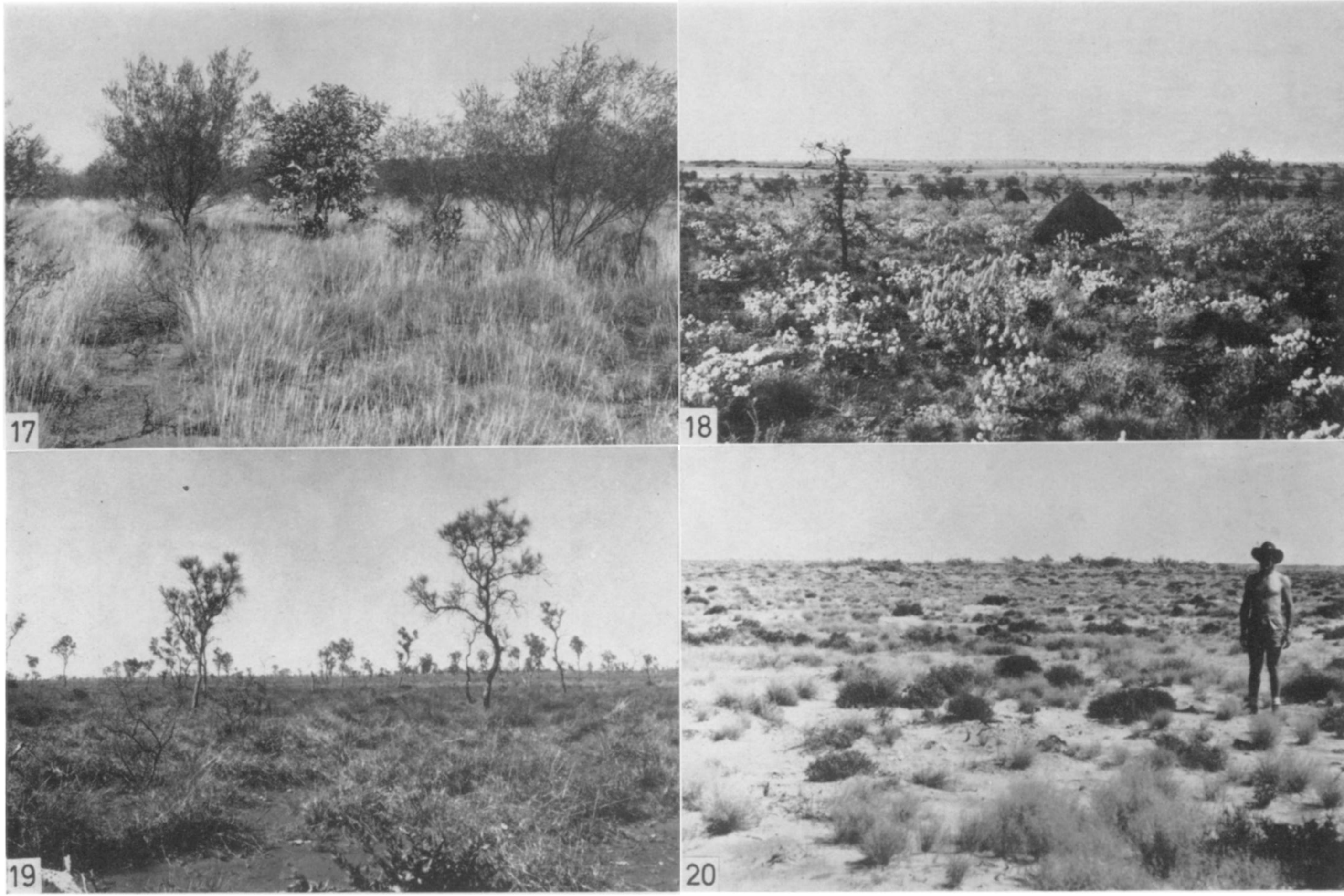

PHOT. 17. Shrub steppe with *Acacia pachycarpa* and *Triodia pungens*. Nerrima station, northern fringe of the Great Sandy Desert.
PHOT. 18. Shrub steppe with *Acacia pyrifolia* on basalt in the Chichester Range. Seasonal aspect with forbs in flower, *Ptilotus* and *Gomphrena*.
PHOT. 19. Shrub steppe with *Hakea lorea* and *Triodia pungens* on sandy plain. Billiluna Station.
PHOT. 20. Succulent steppe. Mixed samphires and subshrubs in the bed of Lake Auld, Great Sandy Desert.

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country with a high water table. North of the desert there is a disjunct occurrence of Tree Steppe on a narrow rocky ridge of Devonian limestone which runs for hundreds of miles across the country south of and parallel to the King Leopold Range. This is an extraordinary feature, representing an ancient barrier reef formed offshore to the Kimberley block. The ridge runs entirely through tree-savanna country but there is so little soil on the limestone that it is sparsely covered with hummock-grass (*Triodia wiseana*) and scattered trees and shrubs which include notably *Adansonia gregorii*, *Ficus* spp., *Brachychiton viscidulum*, *Terminalia circumalata*, *Grevillea pyramidalis*, *Bauhinia cunninghamii* and *Cochlospermum heteroneurum*. The trees are those of the tree savanna but the grass is that of steppe.

9. *Shrub steppe*

In shrub steppe, trees are more or less absent and grass hummocks tend to be smaller. In the Great Sandy Desert the shrubs mostly occur in groups in the form of 'bush islands' or in gullies. The shrub steppe is found on shallower, stonier soil than tree steppe. The life-forms of the shrubs concerned are diverse. In general they are sclerophyllous and from 1·2 to 2·5 m in height, the majority being phyllodal *Acacia* spp., but the type of phyllode (or leaf in other genera) varies greatly between species. It is linear and vernicose in *Acacia pachycarpa*, broad and glaucous in *A. holosericea* and *Grevillea wickhamii*, small but flat in *Acacia impressa*, minute and terete in *A. lycopodifolia*, massive and terete in *Hakea lorea*. All are evergreen and leaf size is for the most part mesophyll or microphyll. Disposition of the leaves is also very varied. *H. lorea* has thick corky bark and resists fire, but other species, including all the *Acacia* spp., have thin smooth bark and are killed by fire, regenerating from seed.

Describing the occurrences of shrub steppe from west to east as was done for the tree steppe, there is first an interesting example on Barrow Island, off the coast above Onslow. The island consists of a low dome of Tertiary limestone, with very little soil, vegetated with *Triodia wiseana* and clumps of shrubby *Ficus platypoda*. A few sparse small shrubs of other species occur.

On the mainland, there are widespread granite plains in the Pilbara on which there is a very typical and well-developed shrub steppe of *Triodia pungens* with scattered *Acacia pyrifolia*, *Grevillea pyramidalis* and *Hakea lorea*, the shrubs often well grown and 3–5 m tall. Scattered eucalypts occur along drainage lines. Within 30 km of the coast the tall shrubs are replaced by dwarf shrubs of *Acacia translucens*, still with *Triodia pungens*. Towards the interior on hills and plateaux, as has been seen, the vegetation is tree steppe with *Eucalyptus brevifolia* and *Triodia wiseana* on Proterozoic sediments and metamorphics. However, on basalt and granite it is instead a very poor and sparse shrub steppe of *T. pungens* and other *Triodia* species with stunted shrubs of *Acacia pyrifolia*, *Cassia*, *Grevillea*, *Hakea* and others, as well as very occasional and stunted trees of *Eucalyptus brevifolia*.

In the desert country there are two types of shrub steppe, the one occupying gravelly rises where it appears that the sand has been stripped off by wind action, and the second occurring on sandy flats round the fringes of the desert where there are no dunes. In the former case there is a general cover of *Triodia pungens* or *T. basedowii* (the distribution is probably controlled by the underlying rock), with shrubs, mainly in clumps and gullies, of *Acacia pachycarpa*, *A. impressa*, *A. holosericea*, *Grevillea wickhamii* and *Hakea lorea*. *Grevillea refracta* is a feature of gullies near the coast and *Eucalyptus setosa* (in a shrub

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form) inland. There appear to be no ephemerals, but a small number of subshrubs occur, notably *Ptilotus calostachyus* and *P. asterolasius.*

The sandy plains type occurs over wide areas on the lower Sturt Creek. The hummock grass is *Triodia pungens* and not *Plectrachne schinzii*, as is found in sandhill country. *Hakea lorea*, up to 3 m tall, is characteristic and often the sole shrub species present. Associates may include *Grevillea pyramidalis* and *G. wickhamii*, *Acacia pachycarpa* and *A. impressa*, *Hakea macrocarpa*, *Dolichandrone heterophylla* and *Cassia* spp. with *Melaleuca crosslandii* and eucalypts in depressions. Dense patches of this community resemble in structure and composition the southern pindan of Dampierland.

10. *Grass steppe*

Pure hummock-grass steppe without trees or shrubs is seldom encountered and is confined to local patches of rocky and stony ground. A few larger occurrences have been mapped.

11. *Succulent steppe*

In Australia the only conspicuous development of the succulent life form producing plants which impress a dominant physiognomy on vegetation is in the family Chenopodiaceae and is characteristic of saline soil. Arid vegetation is otherwise woody and grassy, and there are no succulents other than some small members of the Aizoaceae and Portulacaceae. The Chenopodiaceae take two forms: *saltbushes*, which are dwarf shrubs, with leaves generally semi-succulent and silver-tomentose (generally *Atriplex*, *Bassia*, *Kochia*, etc.) and *samphires* which are stem-succulent, small, sprawling woody plants (*Arthrocnemum*).

Samphires are a feature of the beds of salt lakes, which occur throughout the desert country, while the saltbushes tend to form peripheral communities round the lake margin.

12. *Littoral complex*

In small-scale mapping the coastal communities of dunes and marshes have been included together under the title of Littoral Complex. The principal communities are these:

(a) Grass steppe of recently fixed drift sand, dominated by *Spinifex longifolius.*

(b) Sparse shrub steppe of stabilized dunes, covered by *Triodia pungens* with some shrubs of *Acacia bivenosa*, *A. translucens* and others.

(c) Mangrove in tidal inlets and marshes. This is shrubby in the arid areas, comprising *Avicennia marina* and *Rhizophora mucronata.* Around the Kimberley coast under higher rainfall, stature increases to as much as 15 m and species composition is much richer, with the addition of *Bruguiera conjugata*, *Ceriops lagal*, *Sonneratia caeseolaris*, *Aegiceras corniculatum* and *Lumnitzera racemosa.*

(d) Other tidal marshes, which are often extensive, for the most part consist of bare expanses of mud. At times colonies of samphire (*Arthrocnemum* spp.) may exist.

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COMPARISONS WITH TROPICAL AMERICA

The vegetation of tropical north-western Australia has been described in terms of African formations which correspond with more or less closeness to the Australian. Comparison with the American tropics is more difficult for two reasons, the relative scarcity of aridity in the American Tropics and the difference in the evolution of plant forms adapted to aridity. In tropical America areas receiving less than 100 mm of precipitation a year are the exception, but in tropical Africa and Australia they are the rule. In Africa and Australia grasses have become widely adapted to the prevailing dry habitats, so that savanna and steppe types are predominant. In tropical America, however, this seems not to have occurred and there has instead been an evolution of succulent life forms, principally in the Cactaceae and Bromeliaceae. The present writer's classification of the vegetation types of tropical America (Beard 1955) includes savanna in a special sense, but not steppe. The vegetation of low-rainfall areas is characterized as 'Deciduous Seasonal Forest', 'Thorn Woodland' and 'Cactus Scrub'. The first of these may be equated with the dry deciduous forest of the African workers, with the exception that there is no grassy floor in the Americas, but under more arid conditions than this the entire African range of grassy woodlands, savannas and steppes is lacking. Owing probably to the relatively small extent of dry vegetation in tropical America the whole series is telescoped but even allowing for this there is a fundamental difference: in tropical America climatically controlled vegetation of low rainfall areas is never grass-dominated. Grasses are not a conspicuous element in any of the formations cited above, deciduous seasonal forest, thorn woodland or cactus scrub. In thorn woodland, flat-topped, spiny leguminous trees are dominant and there is a marked resemblance in the tree layer to African types of tree and shrub steppe. In the ground layer, however, succulents replace the grasses of Africa, typically colonies of terrestrial Bromeliads. Similarly cactus scrub is essentially a succulent community with grasses, if present at all, playing a minor role.

It will no doubt be objected that there are very considerable areas of grasslands in tropical America, and indeed the very word savanna is of Amerindian origin. This is true but the important point is that these are edaphically and not climatically controlled (Beard 1953) and occur in areas of moderate to high rainfall (1000–3000 mm). There does not appear to be any climatically controlled grassland in the American tropics. In Africa and Australia there are also, in some cases, edaphically controlled grasslands which have been cited in this paper, on flat lands seasonally waterlogged. The major part of the grasslands of these continents, however, shows no sign of being edaphically controlled. The role of fire is debatable and outside the scope of this paper. Discussion of it being reserved, we may say that in the arid and semi-arid areas of tropical Africa and Australia we have a grassland climate.

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SUMMARY

A brief general description is given of the physiography and climate of tropical north-western Australia, followed by data on the plant formations of which twelve are

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recognized. Comparisons are drawn throughout with plant formations of tropical Africa and there is an endeavour to equate with the standardized types of the Scientific Council for Africa South of the Sahara (1956) and to adapt their terminology. Comparisons with tropical America are discussed in conclusion.

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