General Report on Lands of the West Kimberley Area, W.A.

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PART I. INTRODUCTION AND SUMMARY DESCRIPTION OF THE WEST KIMBERLEY AREA

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I. Introduction

The area surveyed covers approximately 47,000 sq miles and includes the following four-mile sheets: Pender, Yampi, Broome, Derby, Lennard River, Lansdowne, Mt. Anderson, Noonkanbah, and Mt. Ramsay. It includes the country between lat. 17°S. and 19°S. and long. 122°E. and 127°E., with an extension to the north of one degree between 122°E. and 124°30′E. (Fig. 1).

Although the need for investigating the alluvial country of the main river systems of the area prompted the survey, the surrounding country was included. The area is bounded on the west by the sea, to the north by the country of the North Kimberley survey, and to the east by the Ord–Victoria area. It has been designated the "West Kimberley area" but its boundaries do not correspond to either the topographical or political divisions of that name.

(*a*) *Origin of Survey*

In 1951 the Director of Agriculture for Western Australia requested the C.S.I.R.O. Division of Land Research and Regional Survey to conduct a survey of the Fitzroy River area and a small party made a brief investigation of several small areas at that time. The request for a survey was renewed in 1958 because of development in the Kimberley region and the desirability of investigating the potential for land settlement of the Fitzroy basin.

(*b*) *Survey Procedure*

The general procedure was similar to that of previous surveys carried out by the Division of Land Research and Regional Survey (Christian and Stewart 1953; Christian *et al.* 1953; Christian *et al.* 1954; Speck *et al.* 1960; Perry *et al.* 1962). In these surveys scientists representing several disciplines (including geomorphology, pedology, and ecology) work in close collaboration.

The method of survey is based on the assumption that each type of country is represented on aerial photographs by a distinctive pattern (Plate 1, Fig. 2) and thus a complete cover of aerial photographs is necessary. In this area the scale of photography was 1 : 50,000.

The team traversed about 3000 miles (Fig. 1) and made more detailed observations at about 300 sites previously selected on the air photos. The field period was from July 12 to October 20, 1959.

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The area was mapped into 50 land systems (Plate 1, Fig. 1). A land system has been defined (Christian and Stewart 1953) as an "area or group of areas throughout which a recurring pattern of topography, soils, and vegetation can be recognized". The factual land system descriptions provide a basis for assessing potential.

II. History of the Area

As a fully documented record of the history and development of the Kimberley area has been prepared by Bolton (1953), only a brief outline is given here.

The first contacts with the Kimberley coast by Europeans were made by various Dutch navigators, including Abel Tasman, who touched along the coast without landing. The first to land was William Dampier, who came ashore at Roebuck Bay in 1688 and 1699. His impression of the country and the inhabitants was not very favourable.

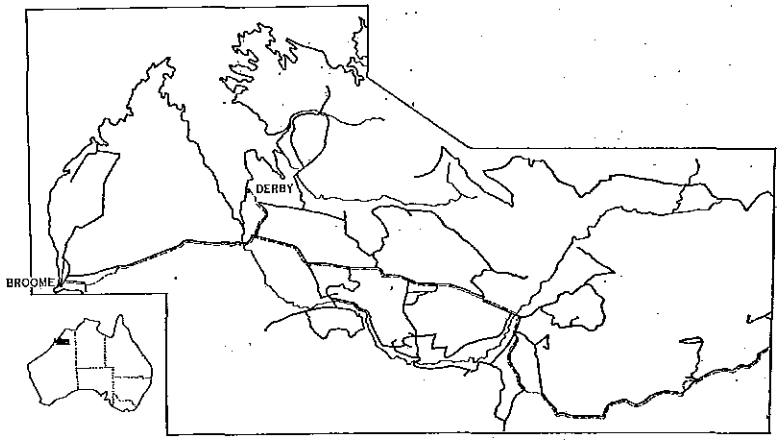

Fig. 1.—Traverse map.

The first attempts at settlement (1863–65), by Victorians, with sheep, at Camden Harbour and on the Denison Plains, were repelled by difficult country, inadequate preparations for the wet season, total loss of sheep, and dissension among the settlers. Similarly a Western Australian attempt at Roebuck Bay ended with a brush with the natives and loss of life on both sides, but in their retreat to Nicol Bay they reported "3,000,000 acres of perennial grasses".

Although the area was left untouched during the 'sixties and 'seventies, gradually the outposts of settlement were approaching from two directions. Financial pressures and a growing consumer population were causing cattlemen from Queensland and New South Wales to overland into the adjacent Northern Territory. Western Australia was not subject to these pressures but by 1875 successful settlement with sheep had been made as far north as Nicol Bay.

Forrest's report in 1879 that the Fitzroy valley was capable of depasturing a million sheep provoked new enthusiasm. (It occurred to few that the area was far from established markets, roads, and stock routes and was entirely without regular transport facilities. Those who finally succeeded were either veteran pastoralists with resources behind them or companies combining the resources of several "small" squatters.) Because of this enthusiasm severe stocking laws were passed that required that blocks with watercourse frontage must be planned to have a depth three times that of the frontage and that 20 sheep or two large stock had to be carried for every 1000 acres. Despite this, 51,000,000 acres were held by lease by 1883. Much of this was speculation and by 1887 the acreage had stabilized to 16,000,000 acres.

The first settlers from the east and west had little in common. West Kimberley was occupied by men who came by sea from established settlements further down the coast, found a suitable landing point, and from there moved inland along the river valleys. This form of pioneering had been adopted along the Fortescue, the Gascoyne, and the Murchison. The East Kimberley was colonized by overlanders at the frontier of continuous spread of settlement moving across the Northern Territory and having its origins in the eastern States. The West Kimberley pastoralists were in the main from the south-west of Western Australia. In a country with a small consumer population, they were woolgrowers and practised paddocking. The East Kimberley cattlemen held to the open-range tradition of grazing, and even the terms used in mustering stock were different. The two settlements did not immediately merge. The district was known as "the Kimberleys" — indicative of the dualism, the double origin that characterized its development. Eventually, the open-range methods proved, on the whole, more easily adaptable to conditions in the district, but the process of adaptation did not entirely eliminate the Western Australian sheep-grazing tradition.

The town sites (ports) of Broome and Derby were declared by John Forrest in 1883. By 1885 three major groups had completed the trek across the north and 10,000 cattle had been introduced to the East Kimberleys with Fossil Downs the western outpost. Meanwhile the sheep-men had pushed up the Fitzroy and occupied Upper Liveringa, Noonkanbah, and beyond. This distribution is still reflected in these industries to the present time.

Discovery of gold in the vicinity of Halls Creek in 1884–85 produced a gold rush which resulted in a temporary market for the growing cattle industry, the opening of a port at Wyndham, and well-defined tracks between the gold-fields settlements and the ports of Derby and Wyndham.

By 1887 Broome had become the centre of the pearling industry and five new cattle stations opened in that area.

Stock numbers increased until in 1890 there were 100,000 sheep and 18,000 cattle in the Kimberleys.

In a region so remote, marketing became a great problem. Several unsuccessful attempts were made to establish overseas markets for beef. Alexander Forrest pioneered cattle movement to Perth and southern markets.

In spite of distant markets, inadequate shipping facilities, trouble with the natives, and low prices, stock numbers had risen by 1905 to 380,000 cattle and 283,000 sheep and marketing and shipping facilities were taxed to the utmost. Although in 1906 the Canning Stock Route was opened, the length of the stages and hostility of desert natives made it impracticable as a major outlet.

A second result of the increase of stock numbers was not so quickly discerned. Except for a brief period immediately after rains the stock were concentrated along the fertile river frontages throughout the year. The degrading effect on the pastures of the continuous heavy grazing and trampling of thousands of beasts was masked by the recuperative power of the country until a run of seasons below the average revealed what had been happening. Bolton quotes, "Hardly a beast could be seen about the frontage, which was bare and almost nothing but a lot of scalded ground. The effect was so disastrous that all the pastures on the river frontages had completely disappeared for the time being". The denudation of the frontages was furthered by wallabies which had increased greatly following settlement. Better seasons and subartesian boring brought some relief but to the Royal Commission on the Meat Industry in Western Australia in 1928, the Kimberleys presented a highly discouraging picture. Marginal country was being abandoned and attempts to expand marketing outlets had been abortive. As a result of the Royal Commission lease tenure was extended and exemption from taxation was granted but a number of other recommendations were not implemented.

Since then the introduction of regular air transport, the Flying Doctor Service, Air Beef centres, and better internal communications have improved conditions but great distances, unfavourable seasons, deteriorating pastures, and inadequate markets remain the problems.

III. Summary Description

(a) *Population and Communications*

The area has two ports, Broome on Roebuck Bay and Derby on King Sound. Neither of these is a deep-water port and because of the very high tides (in excess of 30 ft) the ports are served by special flat-bottomed ships which actually sit on the mud during low tide. A third port, Wyndham, which is outside the area, serves the most eastern parts as an alternative outlet. Derby and Broome are also the main towns of the area, both having, exclusive of pure-blood aborigines, just under 1000 inhabitants. Fitzroy Crossing, consisting of little more than a hotel, police station, and hospital is the only other town in the area. Halls Creek is just beyond the eastern boundary. The Great Northern Highway traverses the area from east to west but apart from this roads are few and much of the country is difficult of access. Most stations have an air strip and are served at least bi-weekly by planes with mails and supplies. The Flying Doctor Service radio network supplies medical service and school of the air, and brings the most isolated stations into daily contact with the outside world.

The total population* of the area is approximately 3500 whites and mixed races with about 2700 full-blood aborigines. The latter are mostly connected with a mission or employed in the pastoral industry and live on the stations.

(b) *Climate*

The area has an arid to semi-arid monsoonal climate. Almost all the rainfall occurs between November and April. During the rest of the year falls are light and

* Personal communication from Commonwealth Bureau of Census and Statistics.

sporadic, and several consecutive rainless months are common. Mean annual rainfall varies from 40 in. in the extreme north-west of the area to about 16 in. in the south-east. Rainfall is less reliable than in most parts of northern Australia with similar mean rainfall. Variability ranges in the order of 30–40% and is greater in the lower-rainfall parts.

Mean temperatures are high throughout the year. They are lowest in July and highest just prior to the wet season. Mild frosts may occur in inland areas from June to August. From August to the end of the dry season daily maxima of over 100°F are common, with the temperatures increasing inland. A decline of mean maximum temperature of 2° as a result of increased cloudiness with the onset of the wet season is followed in March by a slight rise before the decline to winter levels.

The onset of the wet season is preceded by an increase in absolute humidity. This normally commences in September and October, two of the driest months of the year. However, highest absolute humidities are not generally observed until January and February. Absolute humidities are higher at the coast than inland. Relative humidity follows a similar course except that there is a secondary peak in the cooler months which does not denote an increase in water vapour content but is a reflection of the lower saturation vapour pressures at the lower temperatures of those months.

The amount of sunshine from April to November is high, with a gradual build-up of cloud from September reaching a peak of cloudiness in January and February.

Throughout the area, tank evaporation ranges from approximately 80 to 100 in. per year. The highest evaporation rates occur during the latter part of the dry season, being then 8–10 in. per month at coastal locations and about 12 in. per month in the interior. Evaporation rates over the whole area during the cool months are about 6 in. per month. During the wet season, evaporation rates are from 2 to 3 in. higher per month for inland areas than they are for the coast.

A study of the estimated agricultural growing period for the area indicates that, with the exception of the climatically more favoured north-western parts, the area is unsuitable for dry-land agriculture.

The estimated mean total duration of useful pasture growth within the area ranges from approximately 19 wk in the north-western peninsular areas to 10 wk at Halls Creek. It is also significant that for the area as a whole somewhat more than half of the total duration of useful pasture growth consists of weeks during which some degree of water stress is imposed. Conditions for pasture growth are distinctly inferior to those at Katherine.

(c) *Physiography and Geology*

The area takes in Fitzroyland and the southern part of the North Kimberley Division (Jutson 1934). In Part IV these two continental divisions have been further subdivided into five provinces and a number of regions. A small area of a third division defined by Jutson occurs in the south-western corner.

(i) *The North Kimberley Division.*—This consists of relatively stable plateaux dissected only to early maturity and comprises Upper Proterozoic quartzite, sandstone, and shale with intrusive rocks of Upper Proterozoic or Lower Cambrian age. Only the southern part of the division falls within the survey area but as defined in Part IV it also includes Yampi peninsula. It consists of two provinces.

(1) Kimberley plateau province constitutes the core of the North Kimberley division and consists mainly of high, rugged, quartzite plateaux up to about 2500 ft above sea-level.

(2) Kimberley foreland province forms the western and southern margin of the Kimberley plateau province and comprises high, rocky, quartzite and sandstone strike ridges and narrow, hilly basalt and dolerite vales. Summits are commonly above 2000 ft.

(ii) *Fitzroyland Division*.—This comprises the Fitzroy basin and contrasts with the North Kimberley division by being maturely dissected. It is characterized by a great thickness of Palaeozoic sediments overlying a Pre-Cambrian basement of crystalline rock. The basement crops out along the north-eastern and eastern margins where it includes metamorphic rocks. Three provinces were recognized.

(1) Fitzroyland uplands province includes the highest and most dissected parts of Fitzroyland and is underlain mainly by the crystalline basement and consists of plateaux, mountain and hill ranges, and valley plains. Relief is mainly between 800 and 1500 ft above sea-level.

(2) Fitzroy plains province constitutes the greater part of the structural unit of the Fitzroy basin and is underlain by gently folded sedimentary rocks mainly of Permian age. Altitudes range from 100 ft to 800 ft with restricted plateaux to 1000 ft above sea-level. The province includes the extensive Fitzroy–Lennard flood-plains and north and south Fitzroy plains.

(3) Sand plain province comprises the extensive western areas of sand plain and dune field. They are mainly underlain by a Jurassic–Cretaceous sequence of conglomerate, sandstone, and siltstone and by Permian and Triassic sandstone and siltstone. Relief is mainly below 400 ft above sea-level.

(*d*) *Geomorphic History*

The oldest landscape element, the Kimberley surface, has two parts. The High Kimberley surface (Plate 2, Fig. 1), which remains mainly as quartzite plateaux in the North Kimberley division, is regarded as part of a Jurassic land surface; the Low Kimberley surface (Plate 2, Fig. 2) typically consists of partially dissected plains in Fitzroyland division and was cut below the higher Kimberley surface and across the emerged Cretaceous sea floor following uplift. Both Kimberley surfaces have been lateritized.

Further uplift of the area ensued, probably in the Upper Miocene, and apparently consisted of tilting hinging on the coastline and on an axis parallel with the Fitzroy River. This initiated an erosion cycle forming the relatively unweathered plains of the Fitzroy surface in Fitzroyland division.

Late Tertiary uplift caused shallow dissection of the Fitzroy plains. This was followed by the growth of extensive alluvial plains in a period of increasing aridity which culminated in the formation of sand plains on relicts of the Kimberley surface and of sand dunes on the Fitzroy surface. Subsequent climatic amelioration is indicated by the stabilization of sand surfaces and by reactivation of drainage. This has been accompanied by eustatic recovery of sea-level forming the indented coastline and causing littoral aggradation in embayments.

(*e*) *Soils*

The most extensive soils are skeletal and shallow and show minimal profile development. There are also extensive areas of strongly weathered and leached soils which are formed on deeply weathered or redistributed products of earlier weathering and in part on sedimentary rocks containing only minor amounts of weatherable minerals. They include red earths, yellow earths, and brown soils of light texture. Limited discontinuous areas of fine- and medium-textured alluvial soils are associated with the major stream lines. The remaining four soil groups are soils that are typical of arid and semi-arid zones. Calcareous earths are associated with limestone and very calcareous sedimentary rocks. They are generally brownish and silty. The texture-contrast soils are solonetzic soils and red-brown earths which are characteristic of arid and semi-arid areas in central and southern Australia. The solonetzic soils have loose sandy or loamy surface horizons over hard alkaline reddish and brownish loam and clay subsoils whilst the red-brown earths have reddish loamy neutral topsoils over hard alkaline reddish finer-textured and well-structured subsoils.

There are considerable areas of moderately structured, self-mulching, cracking clay soils which are generally black or brownish and may contain lime.

In general the soils are of low fertility as they are derived from strongly weathered materials or from sedimentary rocks that have passed through one or more weathering cycles. The most fertile soils are the darker-coloured self-mulching cracking clays and the alluvial soils. Although mainly skeletal the soils formed on basic igneous rocks produce pastures which are favourably regarded.

(*f*) *Vegetation*

Although the area falls within the Northern Province (Gardner 1942), it occupies only the southern part of it and lacks most of the higher-rainfall elements. Monsoon forests occur only along the main stream lines. Monsoon woodlands, characterized by deciduous elements, are more widespread but are also restricted to special habitats. Various *Eucalyptus* species characterize most communities but such species as *Adansonia gregorii* (baobab) and species of *Cochlospermum*, *Bauhinia*, and *Terminalia* give a distinctive appearance to many communities.

The decrease of rainfall from 40 in. in the north-west to 16 in. in the south-east is associated with changes in vegetation and floristics. Sclerophyll forests occur only on the deep sands in the higher-rainfall parts. These forests grade into woodlands with a ground storey of *Plectrachne pungens* and annual sorghum and characterize the country to the north of the King Leopold Ranges. To the south of these the tree layer is more open and the grass layer better developed. Further south the tree layer is still more open and stunted until on the borders of the Eremean Province the vegetation is characterized by spinifex with sparse stunted trees and shrubs. Grasslands occur on the cracking clay plains associated with the main stream lines and limestone areas.

(g) *Pastures*

The native pastures of the West Kimberley area have developed under an average rainfall of from 16 to 40 in. and in many respects have affinities with those of both arid and higher-rainfall parts of northern Australia. On the one hand the grassy ground storeys resemble those of higher-rainfall, tropical Australia, while on the other, like pastures of an arid environment, many of the trees and shrubs are grazed by stock. Unlike country further south there is little or no winter rainfall or the subsequent growth of useful forbs.

The pasture types can be grouped according to their method of surviving the unfavourable period.

(i) *Pastures Characterized by Perennial Drought-evading Species.*—The predominant plants in this group comprise species of *Astrebla, Chrysopogon, Dichanthium, Sorghum, Sehima,* and other medium-height to tall perennial grasses. These plants grow rapidly during the short favourable wet season, and at this time are generally palatable and nutritious. During the long dry season the fodder consists of dry, mature pasturage of low nutritive value. These pastures carry most of the stock in the area.

(ii) *Pastures Characterized by Drought-resistant Sclerophyllous Grasses.*—This group comprises species in which the vegetative parts remain alive and green through the dry periods. During this period growth is suspended but is resumed under favourable conditions. The main representatives are spinifexes (*Triodia* and *Plectrachne* spp.) which have tough lignified leaves and are common in arid Australia. In general they produce low-quality fodder, which although of low nutritive quality may be superior to "better" pasture species during long dry periods, and are considered as drought reserves. Normally not highly palatable to stock, they are eaten when plants are very young or when there is little else to eat. Pastoralists recognize hard and soft types mainly on the basis of palatability.

(iii) *Pastures Characterized by Short Grasses and Succulents.*—This group consists of upland and coastal types.

(1) Upland, short-grass pasture types comprise mainly short-lived low grasses. They are either ephemeral drought-evading plants or are short-lived perennials that, in this climate, behave as ephemerals. After rain these plants grow quickly and are the first to be grazed and heavy concentration of stock on the new growth is characteristic of their utilization. They lack the bulk to maintain stock over long periods and are susceptible to overgrazing.

(2) Coastal pastures comprise rather diverse pasture types. The most important are the *Sporobolus virginicus* pastures, which are highly regarded for stock-fattening but are limited to coastal areas near Broome. A less important pasture is characterized by samphire, a succulent, drought-resisting undershrub.

(h) *Land Systems and Pasture Lands*

The land system descriptions (Part II) provide a basic inventory of the natural features of the area. To provide a simpler basis for considering land use and potential they have been grouped into 14 pasture lands (Part VII) arranged in 7 types of country. Their distribution is shown on the pasture lands map.

(i) *Mitchell Grass Country.*—Mitchell grass characterizes three pasture lands.

(1) Mitchell grass pasture land (2000 sq miles) comprises dark cracking clay plains associated with stable flood-plains and limestone or shale country (Plate 3, Fig. 1). Although the area is characterized by Mitchell grasses, many other grasses occur. The wealth of perennial and annual grasses and scattered top feed provides some of the most valuable grazing in the area. This land has a high carrying capacity, is favourably regarded by pastoralists, and shows comparatively little evidence of degradation. Five land systems, all characterized by Mitchell grasses and dark cracking clay soils, comprise this land. They are differentiated on parent material, soil, and vegetation pattern, and proportion of the constituent units.

Fossil land system comprises extensive plains associated with limestone country.

Alexander land system comprises stable, older flood-plains.

Leopold land system resembles the above but also has marginal outcrop plains and entrenched valleys with spinifex.

Duffer land system comprises plains over shales. It is restricted to one area slightly west of centre.

Gladstone land system also occurs on shales and is distinguished by broad, low rises with yellow loamy soils and grassy woodlands.

(2) Mitchell grass–ribbon grass pasture land (2200 sq miles) comprises the active flood-plains of the main rivers of the area and is referred to locally as frontage or flood-plain country. The soils consist of a pattern of brownish, juvenile, cracking clays and levee soils. It is potentially one of the best lands, and on many stations provides the most valuable grazing. However, it has suffered the most damage from partial degradation to complete denudation.

The two land systems grouped in this pasture land are both characterized by Mitchell grass, ribbon grass–blue grass, and frontage pastures; they are distinguished by different proportions of these pastures and their associated soils.

Djada land system has only minor areas of levee soils and frontage pastures.

Gogo land system has much greater areas of levee soils and frontage pastures.

(3) Mitchell grass–spinifex pasture land (1100 sq miles) is limestone country comprising cracking clay plains with Mitchell grass pastures and a number of other elements including outcrop plains, undulating country, and scattered low hills with shallow calcareous soils and limestone outcrop characterized by spinifex and grassy woodlands.

This land is valued as a pasture because of the Mitchell grass and associated perennial grasses but the spinifex is not grazed. The two land systems in this land are both characterized by a complex of Mitchell grass and spinifex pastures but in different proportions.

Oscar land system contains a large proportion of cracking clay soils with Mitchell grass pastures.

Neillabublica land system contains a much smaller proportion of the above soils and pastures.

(ii) *Ribbon Grass Country.*—Ribbon grass (*Chrysopogon* spp.) is the most common and widespread of the grasses. It commonly forms pastures in combination with other species. One pasture land only is characterized by it (Plate 3, Fig. 2).

(1) Ribbon grass pasture land (1100 sq miles) is characterized by low beefwood grassy woodlands with ribbon grass ground storey and extensive yellowish clayey to loamy soils. Grazing pressure on this land has been heavy and degradation severe. Two land systems are included.

Calwynyardah land system comprises loamy alluvial plains downslope from lateritic remnants.

Egan land system consists of outcrop plains with low lateritic rises, restricted sand plain islands, and small cracking clay plains.

(iii) *Volcanic Country.*—This type of country is restricted to north of the King Leopold Ranges and to the Yampi peninsula. It is characterized by hilly and gently undulating country with broad cracking clay plains formed over basalt and dolerite. One pasture land is included (Plate 4, Fig. 1).

(1) White grass–annual sorghum pasture land (3200 sq miles) is, with the exception of the cracking clay plains, characterized by the unpalatable white grass (*Sehima nervosum*) but with a wealth of other species which enables it to be rated moderate pasture land. Three land systems, characterized by volcanic country and white grass pastures but differing in topography and in proportion of the various elements, are included.

Cowendyne land system is characterized by gently undulating basalt country but has extensive cracking clay plains with ribbon grass–blue grass pastures.

Looingnin land system consists of basalt mountains and hills and minor cracking clay plains.

Forrest land system is mountainous country consisting of quartzite ridges and hilly basalt vales.

(iv) *Coastal Country.*—Two pasture lands occur in this environment.

(1) Salt-water couch pasture land (200 sq miles) comprises broad depositional saline plains above the high-tide level and is characterized by salt-water couch (*Sporobolus virginicus*) pastures. These are eaten by stock at all stages and are suitable for stock-fattening.

Roebuck land system is the only one included. It is restricted to the Broome area.

(2) Littoral pasture land (1200 sq miles) comprises the saline flats, sand dunes, and shallow tidal flats occurring along the coastline, and is best developed in the estuarine environments. It is characterized by yellowish sandy soils, greyish calcareous saline loams, and extensive bare saline muds. The complex of ribbon grass, rice grass, samphire, and littoral pastures contains many palatable elements but its linear distribution limits its usefulness.

The Carpentaria land system is the only one included in this land.

(v) *Pindan Country.*—Pindan is the local name given to low scrubby woodlands with a prominent tall shrub layer, mainly of *Acacia* spp., occurring on extensive areas of sand plain and dune field in the south and west. Two pasture lands are included, differentiated on drainage and pastures (Plate 4, Fig. 2).

(1) Pindan pasture land (12,200 sq miles) comprises extensive sand plains with fixed dunes, swales, pans, and depressions and lacks organized drainage. It is characterized by curly spinifex–ribbon grass pastures. This land has a moderate grazing potential during the wet season where it is adjacent to other pasture lands. Large areas have not been grazed to any extent because of lack of established waters. The three land systems have similar pastures but are distinguished by different topography and slight differences in soil characteristics.

Yeeda land system consists of sand plain with deep red and yellow sands and extends into the higher-rainfall parts.

Camelgooda land system consists of extensive dune fields with deep reddish sands. It is widespread in the south-eastern lower-rainfall parts.

Luluigui land system consists of sand plain, dune field, and stony scalded plains with deep red sands, red and yellow loams, and skeletal soils. It occurs in the centre and south of the area.

(2) Pindan–ribbon grass pasture land (3300 sq miles) comprises extensive sand plain and dune field with pindan vegetation, but has some through drainage and lower valley floors characterized by yellow clayey soils with ribbon grass pastures. Grazing potential is similar to pindan pasture land but slightly higher because of the more extensive ribbon grass pastures and more numerous waters. The six land systems differ in topography but are characterized by curly spinifex–ribbon grass and ribbon grass pastures in varying proportions.

Wanganut land system is characterized by extensive low-lying sand plain with dunes.

Sisters land system comprises low sandy plateaux and lower sand plain.

Lowangan land system comprises broad sandy interfluves and lower sand plain.

Fraser land system consists of sand plain with irregular dunes with drainage and local stony surfaces.

Reeves land system consists of sand plain with drainage, scattered sandstone hills, and minor plateaux.

Mandeville land system comprises quartzite ridges and broad sandy lowlands.

(vi) *Spinifex Country*.—This country consists of four pasture lands characterized by different spinifex pastures and accessible to stock. It occupies almost one-quarter of the area.

(1) Spinifex–short grass pasture land (4700 sq miles) includes a wide topographic range from broad alluvial plains to hilly country with massive granite domes. The six land systems are characterized by a complex of spinifex and short grass pastures (Plate 5, Fig. 1). These are useful but have low carrying capacity. The short-lived grasses, that are so important in this land, provide fodder during the short growing season but stock must depend on spinifex for most of the year.

O'Donnell land system consists of gently undulating country with scattered hills formed on granite, gneiss, and metamorphic rocks with loamy skeletal soils.

Coonangoody land system consists of sandy, tributary alluvial plains with through-going drainage floors and variable soils.

Koongie land system is characterized by low lateritic plateaux and scattered hills on crystalline rocks, with restricted cracking clay plains and reddish sandy to loamy gravelly soils.

Amy land system consists of massive granite domes, colluvial lower slopes, and alluvial drainage floors.

Pigeon land system consists of stony plains and undulating country with scattered low rocky hills underlain by granite, gneiss, and metamorphic rocks with sandy skeletal soils.

Tarraji land system consists of gently undulating country with scattered rocky granite domes, and sandy and loamy soils.

(2) Soft spinifex pasture land (200 sq miles) comprises stable alluvial plains adjacent to and mainly above the active flood-plains. The soils are characteristically deep reddish sands and loams carrying soft spinifex (*Plectrachne pungens* and *Triodia pungens*). The soft spinifex is highly regarded by pastoralists as drought reserve fodder. This land has, in most cases, suffered severe degradation under grazing pressure and excessive trampling.

Chestnut land system is the only one in this land and is limited to small areas near the Fitzroy River and Christmas Creek.

(3) Curly spinifex pasture land (2200 sq miles) comprises plains, sand plains, broad stripped surfaces, and upland plains and undulating country characterized mainly by curly spinifex, which in the absence of better grasses is eaten by stock. This land (Plate 5, Fig. 2) provides a subsistence diet and drought reserve and has a low carrying capacity. Its value is increased when it is utilized in association with better country. The five land systems included are all characterized by curly spinifex pastures and differ mainly in topography.

Gidgia land system consists of plains on lateritized granitic rocks and red loamy soils.

Fork land system consists of upland plains and rocky undulating country and yellowish sandy and gravelly soils.

Mamilu land system consists of plains of lateritized sedimentary rocks with red and yellow loamy soils.

Tableland land system is characterized by undulating shale–sandstone country with lateritic surfaces and yellowish gravelly skeletal soils.

Glenroy land system consists of stony undulating shale country with broad alluvial drainage floors, with yellowish fine-textured skeletal soils.

(4) Hard spinifex country (4000 sq miles) comprises extensive plains with ferruginized outcrop and undulating to hilly country with mainly shallow, skeletal, reddish sandy or loamy soils (Plate 6, Fig. 1). Pastoral value is low, and at best is a subsistence fodder. The five land systems are characterized by winged spinifex (*Triodia intermedia*) pastures and differ mainly in topography and underlying rocks.

Burramundi land system consists of rounded conglomeratic hills and undulating terrain.

Bohemia land system consists of lateritic plateaux and hilly sandstone country.

Margaret land system includes extensive shaly lower slopes with upstanding, rocky quartzite plateaux and ridges.

Ruby land system consists of undulating terrain comprising extensive lateritic remnants, stony lower slopes, and sand plain islands.

Myroodah land system consists of outcrop plains with extensive scalded surfaces.

(vii) *Inaccessible Country*.—Steep stony country, mostly inaccessible to stock and occupying about one-quarter of the area, has been placed in one pasture land.

(1) Inaccessible pasture land (10,700 sq miles) includes rugged mountain ranges, elevated plateaux, and steep rocky hills with a complex geological pattern of quartzite, sandstone, schist, basalt, dolerite, and limestone (Plate 6, Fig. 2).

Utilization is possible only where this land is adjacent to better lands and even here it is more likely to have a nuisance value as a hideout for scrub bulls. The eight land systems are characterized by various spinifex pastures and differ mainly in topography and geology.

Precipice land system comprises rocky quartzite plateaux with narrow, hilly basalt valleys.

Clifton land system consists of closely dissected sandstone plateaux.

Richenda land system consists of mountainous country on granite–gneiss complexes, schists, and other metamorphic rocks.

Lubbock land system comprises rocky sandstone cuestas, ridges, and plateaux.

Rose land system comprises hilly terrain characterized by granite domes and some lateritic summit remnants.

Dockrell land system comprises closely-spaced rocky mountain ridges on metamorphic rocks.

St. George land system consists of rocky sandstone hill lands.

Windjana land system comprises rocky limestone hill ranges.

(*i*) *The Pastoral Industry*

Sheep are grazed over about 6000 sq miles near the centre of the area. The eight properties carry 1·2% of the Western Australian sheep population and range in size from about 80,000 to 1,000,000 ac. Their boundaries are fenced and most are subdivided internally by fences on a 4-mile grid. The average stocking rate is 1 sheep to 25 ac. The best properties have a lamb marking rate of about 60% and a wool clip per head of 8 to 8·5 lb, but the averages for all properties are only 26% and 7·3 lb respectively.

The remainder of the area (34,000 sq miles), except where shortage of water or inaccessibility prevents expansion of live-stock enterprises, is occupied by cattle holdings (Plate 7, Fig. 1). Although nominally occupied, substantial areas (10,700 sq miles) are rugged and the effective productive cattle area is about 23,300 sq miles. The 40 leases are held in 18 ownership groups ranging in size from less than 1000 to about 6000 sq miles and carry about 280,000 head or 27% of the cattle population of Western Australia (Plate 7, Fig. 2). Cattle are run on an extensive system with few fences and widely-spaced waters, low investment per unit area, low operating costs per beast, and a small labour force per beast or unit area. On the average breeders comprise about 45% of the herd, branding percentage is about 49%, and turn-off is less than 10%.

Continuous heavy stocking has caused degeneration, and in some places denudation, of large areas of frontage country. This has been accentuated by wallabies, which have increased to plague proportions since the advent of settlement (Plate 8, Fig. 1).

(j) *Agricultural Potential*

Environmental limitations and remoteness impose severe restrictions on the agricultural potential of the area. The development of rain-grown crop production is unlikely because of unreliable rainfall and a short agricultural growing season (Plate 8, Fig. 2). On Yampi peninsula, where rainfall is more favourable, rugged terrain and inaccessibility present major obstacles.

There are no known underground water resources suitable for irrigation. The Fitzroy, Margaret, and Lennard Rivers provide the only possibilities for irrigation development on an appreciable scale but assessment of their potential is limited by lack of knowledge of their hydrologic characteristics and basin topography. Even in their lower reaches, the flow of these rivers is restricted to the wet season and varies greatly both within and between seasons. Thus, without storage, the rivers are an unreliable source of water and constitute a flood hazard on most of the potentially irrigable area. The existence of apparently excellent dam sites offers possibilities for water storage and for at least some flood control. The potential regulated flow available for irrigation in the three major rivers is in excess of 1 million ac ft. Potential crops include cotton, oil seeds, and rice.

Improved utilization of the naturally flooded riverine pastures with only minimum investment in engineering works merits future attention.

The cracking clay plains on the Margaret River are the most promising irrigable area because of their partial freedom from flooding but they may not be commandable from the proposed reservoir at Dimond Gorge.

Experience acquired at the Kimberley Research Station will be useful in the West Kimberley area but will require confirmation by local experiment.

IV. Acknowledgments

The cooperation of many individuals and organizations is acknowledged.

The Western Australian Department of Agriculture made available K. Fitzgerald for the major part of the survey. The Bureau of Agricultural Economics seconded F. Thomas for the survey period. The Bureau of Mineral Resources made available maps and current geological information. The Division of National Mapping, Department of National Development, compiled the base map. Meteorological information was supplied by the Commonwealth Bureau of Meteorology. Commonwealth Bureau of Census and Statistics supplied population figures.

The preparation of all maps, diagrams, illustrations, and the manuscript was done by the staff of the Division. The guidance and criticism of G. A. Stewart, Chief of the Division, and R. A. Perry are gratefully acknowledged.

The members of the survey team are indebted to various station owners and managers for assistance and hospitality during the field season.

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PART II. LAND SYSTEMS OF THE WEST KIMBERLEY AREA

By N. H. Speck,* R. L. Wright,* and G. K. Rutherford†

I. General

The lands of the West Kimberley area have been mapped and described in 50 land systems. Land systems are composite mapping units (Plate 1, Fig. 1) developed and defined by Christian and Stewart (1953) as "an area or group of areas throughout which there is a recurring pattern of topography, soils, and vegetation". Subsequently the land system concept has been used on all surveys conducted by the Division of Land Research and Regional Survey, C.S.I.R.O.

The land systems, arranged in geomorphological groups, are described in tabular form and illustrated with block diagrams. Solid geology is very generalized where shown on the block diagrams, and is not shown where extensively concealed by superficial deposits. Alluvial fills are not represented because, in most cases, it is not possible to do so at the scale of the diagrams.

The areas of the land systems were determined with a dot grid (25 dots per sq in.) on semi-controlled mosaics at a scale of 4 in. to 1 mile, and where these were not available, on topographic maps at the same scale. These figures were then rounded to the nearest 100 in large land systems and to the nearest 50 in the small ones.

The proportions occupied by the various units (shown as percentages) were estimated on a method of random sampling on air photos and are intended merely as guides. The main characteristics of the soil groups are given, but a simple numbering system supplies a reference to more detail in the soils chapter. Similarly the numbers in the vegetation column refer to community descriptions in the vegetation chapter. For conciseness in the descriptions *Eucalyptus* has been abbreviated to *E.*

In Part IV and on the land system map, the land systems are arranged in geomorphological groups. The land systems are also delineated on the pasture lands map where they are grouped according to their major pastoral characteristics into 14 pasture lands described in Part VII.

The land systems of the northern part of the West Kimberley area are comparable with the land systems, groups of land systems, or parts of land systems of the adjoining North Kimberley area (Speck 1960). These comparisons are shown at the bottom of the appropriate land system descriptions and in the legend to the land system map.

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The relationship in reverse order is as follows: The Buldiva land system has been divided into the Precipice, Clifton, Lubbock, and parts of the Forrest land systems. The Pago land system is comparable to Glenroy and Fork land systems. The Isdell, Barton, and Kennedy, because of very limited occurrence, have been grouped to form the Cowendyne land system. The Karunjie land system is comparable to the Tableland land system. The Napier land system is comparable to the Looingnin and parts of the Forrest land systems.

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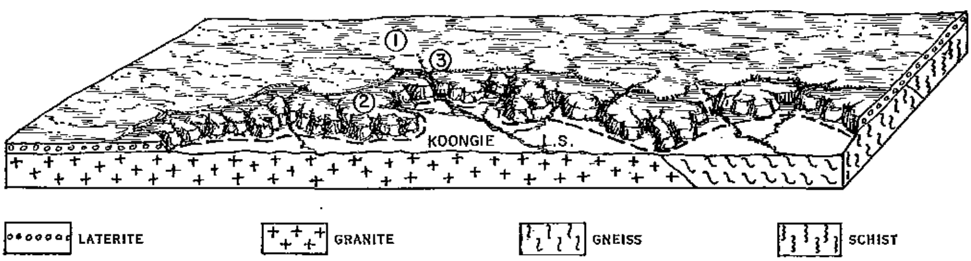
Gidgia Land System (100 sq miles)

Plains on deeply weathered granitic rocks, red sandy to loamy soils, woodlands with shrubs and spinifex.

Geology.—Lateritized granite, gneiss, and schist of Lower Proterozoic and (?)Archaeozoic age.

Geomorphology.—Part of the Kimberley surface: gently sloping lateritized plains forming divides up to 12 miles in extent; surface drainage absent except for moderately dense branching pattern of incised channels on marginal stripped surfaces.



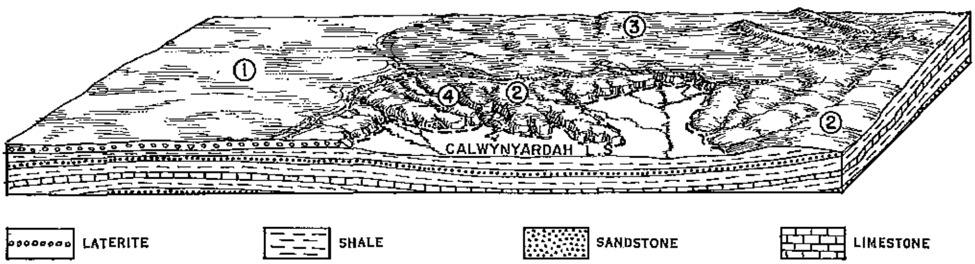
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	85	Stable plains: slopes less than 1%; sandy surfaces sparsely strewn with ironstone gravel	Reddish, sandy to loamy soils, with variable amounts of lateritic gravels: Tippera family (2)	Woodlands with dense patches of *Acacia* shrubs and *Plectrachne pungens*. *E. brevifolia* alliance (1*d*); lowest-rainfall areas 1*a*
2	14	Stripped margins: up to ½ mile wide with slopes up to 5% and marginal breakaways up to 40 ft high; cobble-strewn rocky surfaces with exposures of laterite and weathered rock	Mainly exposed laterite with minor pockets of reddish sandy soils: Yabbagoddy family (1)	Very open woodland with scattered shrubs and *Triodia intermedia* and *T. inutilis*. *E. brevifolia* alliance (1*a*, 1*b*); also 57
3	1	Channels: up to 15 ft wide and 6 ft deep; gradients above 1 in 200	Channels, bed-loads of sand and cobbles on bed-rock. Banks, brownish sandy and loamy alluvial soils: Fitzroy family (21)	Open woodlands with frontage grasses. *E. brevifolia* community (1*g*)

MAMILU LAND SYSTEM (200 SQ MILES)

Plains and sand plains, deep red sands and yellowish loamy soils, pindan and grassy woodlands.

Geology.—Lateritized gently folded sandstone, shale, and sandy limestone of Permian age; Quaternary aeolian sands.

Geomorphology.—Part of the Kimberley surface: gently sloping lateritized plains, up to 14 miles in extent; with sand plain tracts; surface drainage absent except for moderately dense branching pattern of incised channels on marginal stripped surfaces.



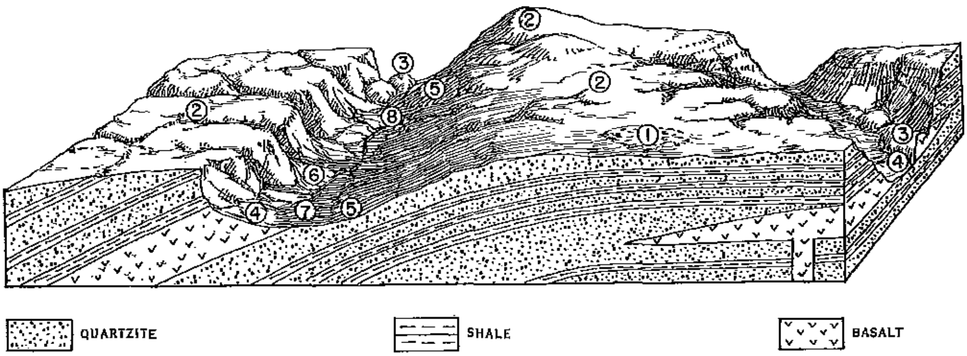
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	43	**Stable plains:** slopes less than 1%; sandy surfaces sparsely strewn with ironstone gravel	Yellowish sandy and loamy soils with laterite gravels: Elliott family (6)	Low woodlands with *Chrysopogon* spp. *Grevillea striata* and *Bauhinia cunninghamii* alliances (34*a*, 37*b*)
2	12	**Stripped margins:** up to 3 miles wide with slopes less than 1%; delimited by breakaways up to 30 ft high or marginally dissected up to 30 ft into gently rounded spurs with slopes up to 5%; cobble-strewn rocky surfaces with exposures of laterite and weathered rock	Laterite exposure, with some reddish loamy skeletal soils (24). Some reddish loamy soils: Tippera family (2)	Low shrubby woodlands. Communities 8*b*, 16, 31, 34*b*, 57
3	44	**Sand plain:** up to 2 miles wide, slopes less than 1%, locally with linear dunes up to 30 ft high and 1 mile long, flanks slope up to 15%	Deep red sands: Cockatoo family (7)	Low shrubby woodland (pindan) with prominent *Acacia* shrub layer with *Plectrachne pungens–Chrysopogon* spp. ground storeys. *E. dichromophloia–E. zygophylla–Acacia* spp. community (10)
4	1	**Channels:** up to 15 ft wide and 6 ft deep; gradients 1 in 200 to 1 in 300	Bed-loads of sand and cobbles on outcrop	Fringing woodland. *E. camaldulensis–Terminalia platyphylla* fringing communities (40, 41)

Precipice Land System (3200 sq miles)

Rocky, mountainous sandstone country with narrow or restricted basalt valleys, low open woodlands with curly spinifex.

Geology.—Upper Proterozoic, gently dipping and folded quartzite, sandstone, and shale, with basalt and dolerite flows and intrusions of Upper Proterozoic or Lower Cambrian age.

Geomorphology.—Formed by dissection of the Kimberley surface—plateaux and mountain ranges: extensive, high plateaux, cuestas, and upstanding mountain summits in strike belts up to 25 miles wide, with steep escarpments and upper slopes and restricted lower slopes; basalt and dolerite hills in valley floors; moderately dense, rectangular pattern of narrow, incised valleys; relief up to 1750 ft.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	2	**Summit remnants:** up to 2 miles in extent; pebble-strewn slopes mainly less than 1%	Yellowish sandy soils high in laterite gravels: Tableland family (5)	Low open woodland with scattered shrubs and *Plectrachne pungens*. *E. brevifolia–E. collina* and *E. collina–E. dichromophloia* communities (4, 6)
2	74	**Quartzite plateaux and mountain summits:** plateaux and dip slopes typically less than 5%, with indented escarpments up to 1000 ft high comprising vertical upper walls and benched steep slopes; mountain slopes up to 50%; basal screes and boulder fans sloping up to 35%	Mainly outcrop with some sandy skeletal soil (24)	Low, very open woodland, scattered or patchy shrubs and *Plectrachne pungens*. *E. brevifolia* community (1*d*)
3	5	**Basalt and dolerite hills:** up to 250 ft high; rounded crests up to 100 yd wide and benched slopes up to 60%, with boulder mantles	Outcrop with red basaltic soil: Walsh family (4)	Very open, grassy woodland, with scattered shrubs and ground storeys of combinations of *Sehima nervosum*, *Sorghum* spp., *Dichanthium fecundum*, and *Plectrachne pungens*. *E. tectifica* alliance (14*a*, 14*c*, 15)
4	4	**Lower slopes on basalt and dolerite:** concave, up to 5%, and up to ½ mile long, colluvial mantles and local outcrop	Moderate to deep, reddish sandy to loamy basaltic soils: Frayne family (3)	Similar to unit 2
5	4	**Lower slopes on quartzite:** concave, up to 10%, and up to ½ mile long; colluvial mantles and local outcrop	Some outcrop with yellowish sandy soils of variable depth: Tableland family (5)	Open woodland with moderately dense shrub layer and *Plectrachne pungens*. *E. brevifolia* community (1*d*); locally 28
6	2	**Colluvial aprons and fans:** up to 500 yd long with gradients 1 in 20 to 1 in 60 and gullied up to 10 ft	Mainly yellowish sandy soils: Tableland family (5)	Spinifex with scattered trees and shrubs and patches of open woodland. *Plectrachne pungens* grassland (54) and *E. collina–E. dichromophloia* community (6)
7	4	**Drainage floors:** up to ⅛ mile wide, gradients 1 in 200 to 1 in 500; marginal slopes up to 1%	Variable soils but mainly greyish sands over tough loamy subsoils: Tarraji family (18), commonly mottled	Grassy woodland, sparse to moderate shrubs and *Aristida hygrometrica*. *E. papuana* community (22*b*); also 25
8	5	**Channels:** up to 300 ft wide and 30 ft deep	Channels, bed-loads range from sand to boulders. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing woodlands. *E. camaldulensis–Terminalia platyphylla* community (42)

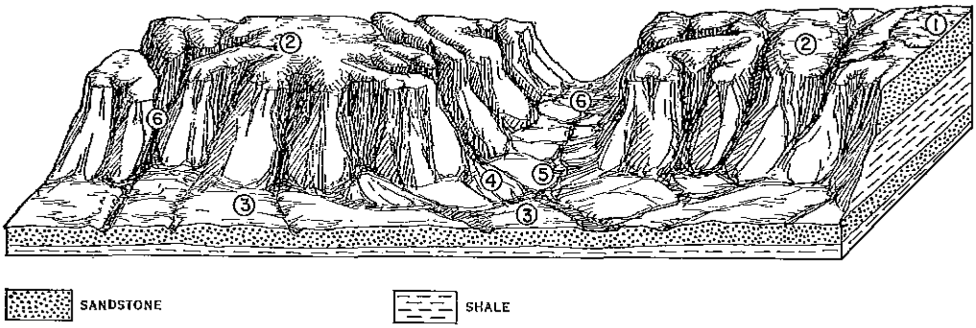
Comparable with the rocky quartzite plateaux and mountain ranges of Buldiva land system, North Kimberley area.

CLIFTON LAND SYSTEM (200 SQ MILES)

Sandstone plateaux with deep valleys, low open woodlands with curly spinifex.

Geology.—Subhorizontal sandstone and shale of Upper Proterozoic age.

Geomorphology.—Formed by dissection of the Kimberley surface—plateaux and mountain ranges: rocky plateaux up to 14 miles in extent, with high escarpments and restricted lower slopes; moderately dense, branching pattern of narrow, incised valleys; relief up to 1000 ft.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	7	**Summit remnants:** up to 3 miles in extent; sandy slopes less than 1% with laterite exposures locally	Mainly deep red sands: Cockatoo family (7). Some deep brown sands: Kalyeeda family (9); and minor laterite	Open woodland with scattered shrubs and *Plectrachne pungens* (4, 6). Locally 3 and 28
2	70	**Rocky plateaux:** gently sloping or undulating, with relief up to 50 ft and slopes up to 5%; indented escarpments up to 1000 ft high with vertical upper walls and steep slopes and with basal scree slopes up to 45%	Mainly outcrop with some reddish loamy skeletal soil (24)	
3	9	**Lower slopes:** concave, up to 5%, and up to 1 mile long; dissected up to 30 ft into spurs with flat or gently sloping crests up to 200 yd wide and marginal slopes up to 60%; mantled with colluvium	Reddish, loamy and clayey lithic soils: Yabbagoddy (1, 23) and Tippera (2,23) families	Open woodland with scattered shrubs and *Plectrachne pungens. E. brevifolia–E. perfoliata* community (3)
4	2	**Boulder fans:** up to 300 yd long, slopes up to 30%	Bouldery, medium-textured skeletal soils (24)	Soft spinifex grassland with scattered trees and shrubs. *Plectrachne pungens* community (54)
5	4	**Alluvial drainage floors:** up to 600 yd wide, gradients 1 in 200 to 1 in 300; marginal slopes up to 2%	Gravels, with locally developed greyish sands over tough loamy subsoils: Tarraji family (18)	Open woodland with *Plectrachne pungens–Chrysopogon* spp. ground storeys. *Adansonia gregorii* alliance (31)
6	8	**Channels:** up to 100 ft wide and 15 ft deep	Bed-loads range from sand to boulders	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing community (42)

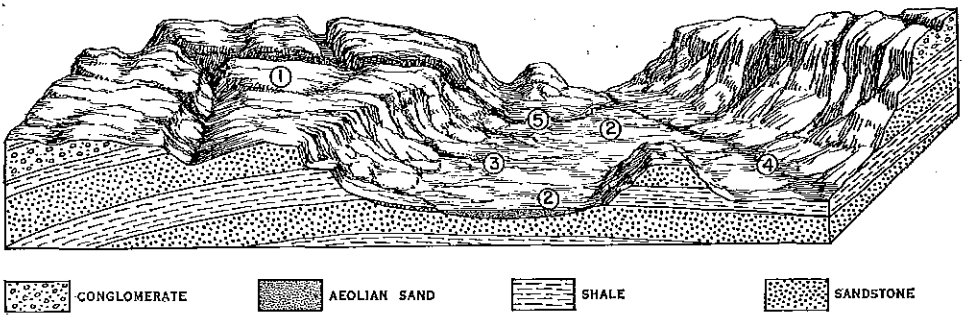
Comparable with closely dissected plateaux of Buldiva land system, North Kimberley area.

St. George Land System (600 sq miles)

Sandstone plateau and hill lands with open spinifex and stunted trees, and pindan on the intervening sand plain.

Geology.—Gently dipping sandstone, conglomerate, and shale of Permian and Jurassic age; Quaternary aeolian sands.

Geomorphology.—Formed by dissection of the Kimberley surface—plateaux and mountain ranges: bevelled plateaux and narrow elongated hills with extensive lower slopes; sand plain occurs in the lowest parts; dense rectangular pattern of incised valleys with narrow alluvial drainage floors; relief up to 500 ft.



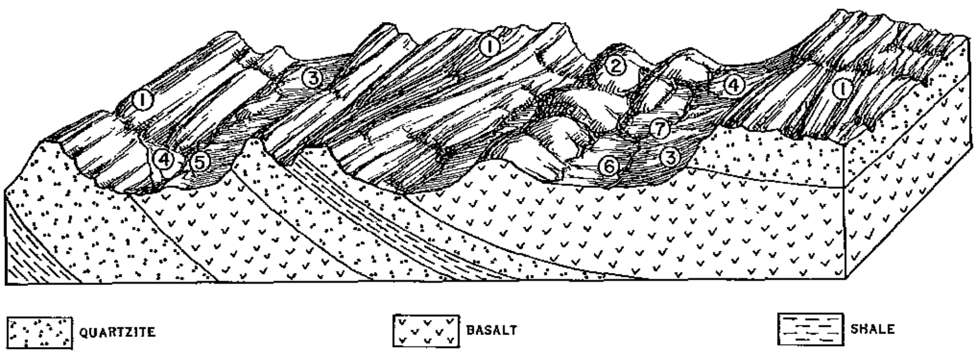
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	58	Rocky plateaux and hill slopes: boulder-strewn plateau surfaces with benched escarpments and hill slopes up to 80%, and with basal scree slopes up to 45%, lower hill slopes up to 10% and 1 mile long, dissected up to 30 ft, with laterite exposures locally	Mainly rock outcrop with some laterite	Open spinifex with scattered stunted trees grading into open woodlands. *Triodia intermedia* and *T. pungens* communities (55, 57) and *E. dichromophloia* and *Adansonia gregorii* alliances (11, 31); also 17
2	19	Sand plain: up to 1 mile in extent, slopes less than 1%, attaining 2% locally	Probably red sands of variable depth: Cockatoo family (7)	Woodlands (pindan) with prominent *Acacia* tall shrub layer and *Plectrachne pungens–Chrysopogon* spp. *E. dichromophloia–Adansonia gregorii* alliances (10, 31)
3	14	Sand plain with run-on: up to 1 mile wide and extending downslope for up to 2 miles; slopes less than 0·5%	Mainly mottled yellowish sandy soils: Tableland family (5)	Ribbon grass grassland with scattered trees and shrubs. *Chrysopogon* spp. community (49)
4	5	Drainage floors: up to ½ mile wide, gradients 1 in 100 to 1 in 500; marginal slopes up to 2%; scalded, hummocky surfaces	Mainly greyish to brownish sands and loams over tough clays: Hooper family (20). Commonly scalded and degraded	Mixed woodlands with *Plectrachne pungens–Chrysopogon* spp. and *Triodia pungens* ground storeys. *Adansonia gregorii* and *Bauhinia cunninghamii* alliances (31, 38*b*)
5	4	Channels: up to 250 ft wide and 15 ft deep	Channels, bed-loads range from sand to boulders. Banks, brownish stony alluvial soils: Robinson family (21)	Fringing woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (40, 42)

FORREST LAND SYSTEM (800 SQ MILES)

Mountainous country with quartzite ridges and hilly basalt vales, sandy soils and red earths, low open woodlands with spinifex and grassy woodlands.

Geology.—Folded Upper Proterozoic quartzite, sandstone, and shale, with basalt and dolerite flows of Upper Proterozoic or Lower Cambrian age.

Geomorphology.—Formed by dissection of the Kimberley surface—plateaux and mountain ranges: extensive quartzite ridges, rounded basalt hills, and narrow basalt floors, in strike belts up to 6 miles wide and 50 miles long; moderately dense, rectangular pattern of incised valleys, comprising strike-controlled trunk drainage and short, steep tributaries.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	50	**Quartzite ridges:** up to 500 ft high and 20 miles long; narrow, rocky crests and benched slopes exceeding 100%; locally with boulder fans up to 300 yd long, slopes up to 20%	Mainly outcrop with areas of shallow, sandy skeletal soil (24). With bouldery yellowish sandy soils on aprons: Tableland family (5)	Open woodland, with scattered shrubs and *Plectrachne pungens*. *E. brevifolia* and *E. dichromophloia* alliances (1*d*, 3, 6, 8*c*)
2	18	**Basalt hills and ridges:** 20–200 ft high, locally up to 3 miles long; benched rocky slopes up to 60%, with basal scree slopes up to 20%	Mainly outcrop with shallow red basaltic soil: Walsh family (4)	Open box woodland, scattered shrubs and *Sehima nervosum–Sorghum* spp. ground storey. *E. tectifica* alliance (14*a*)
3	14	**Lower slopes:** concave, up to 5%, and up to ½ mile long; extensively masked with colluvium	Deep red basaltic soil: Frayne family (3)	Grassy woodland with scattered shrubs and *Sehima nervosum–Dichanthium fecundum* ground storey. *E. tectifica* alliance (15)
4	5	**Alluvial fans:** up to 600 yd long, gradients between 1 in 20 and 1 in 60; gullies eroded to 10 ft	Yellowish sandy soils high in quartz fragments: Tableland family (5)	Grassy woodlands with scattered shrubs and *Plectrachne pungens*. *E. brevifolia* and *E. tectifica* alliances (1*d*, 14*c*)
5	3	**Stony rises:** up to 30 ft high, gently rounded crests up to 200 yd wide, marginal slopes less than 5%	Dark, weakly self-mulching heavy clays: Cununurra family (12), with fine strew cover	Very open, low woodlands with *Chrysopogon* spp.–*Dichanthium fecundum* and *Aristida browniana* ground storeys. *Bauhinia cunninghamii* alliance (37*a*, 38*c*)
6	2	**Drainage floors:** up to 300 yd wide, gradients 1 in 200 to 1 in 500	Locally developed reddish and brownish, stony, clayey alluvial soils: Fitzroy family (22)	Grassy woodlands with scattered shrubs, frontage grasses, and *Aristida hygrometrica*. *E. papuana* alliance (22*a*, 22*b*)
7	8	**Channels:** up to 100 ft wide and 10 ft deep, ranging from hill-slope channels, gradients up to 1 in 6, to main channels with gradients as low as 1 in 500	Channels, bed-loads range from sand to boulders. Banks, brownish loamy alluvial soil: Robinson family (21)	Fringing woodland. *E. camaldulensis–Terminalia platyphylla* fringing communities (41, 42)

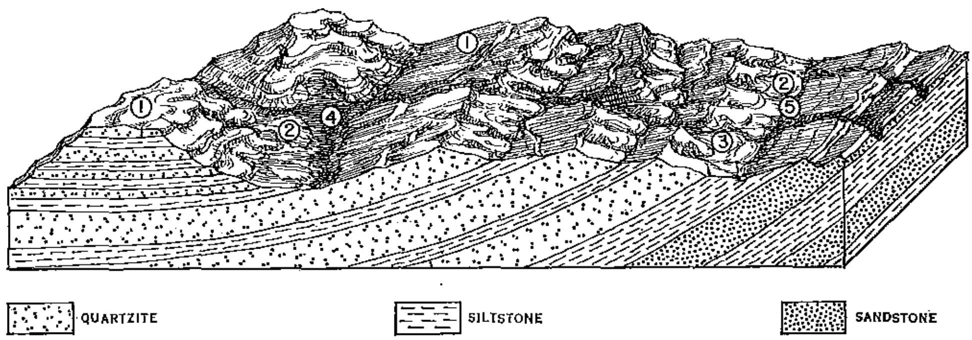
A complex of the basalt vales of Napier land system and the quartzite ridges of Buldiva land system, North Kimberley area.

LUBBOCK LAND SYSTEM (1900 SQ MILES)

Rugged sandstone cuestas, ridges, and plateaux; low open woodlands and curly spinifex.

Geology.—Gently dipping or folded quartzite, sandstone, and shales of Upper Proterozoic age.

Geomorphology.—Formed by dissection of the Kimberley surface—plateaux and mountain ranges: strike belts up to 16 miles wide with extensive rocky surfaces comprising dissected cuestas, steep-sided ridges, and plateaux; short lower slopes with fans and aprons locally; dense rectangular or branching pattern of incised valleys with strike-controlled trunk drainage; relief up to 500 ft.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	72	**Rocky surfaces:** dip slopes up to 10% and 3 miles long, plateau surfaces less than 2% and up to 2 miles wide; benched hill slopes up to 70%, locally vertical, and mantled with boulders	Outcrop with variable, gravelly, sandy skeletal soils (24)	Open woodland, patchy shrub layer, and *Plectrachne pungens*. *E. brevifolia* community (1*d*). Lowest-rainfall parts 1*a*
2	16	**Lower slopes:** concave, up to 5%, and up to ½ mile long; dissected up to 30 ft into narrow spurs with benched marginal slopes; cobble mantles and outcrop in upper parts, masked with colluvium in lower sectors	Bouldery, coarse-textured skeletal soils (24) with some outcrop	
3	2	**Fans and aprons:** up to ¼ mile long with gradients 1 in 20 to 1 in 60 and gullied up to 10 ft	Mainly yellowish sandy soils: Tableland family (5)	Woodlands with moderately dense shrub layer and *Plectrachne pungens*. *E. collina–E. dichromophloia* community (6). Lower-rainfall parts 1*a*
4	2	**Drainage floors:** up to ¼ mile wide, gradients 1 in 100 to 1 in 800; marginal slopes up to 1%	Mainly reddish sandy soils: Yabbagoddy family (1). Minor occurrences of brownish sands over red clay: Moonah family (17)	Woodlands with *Plectrachne pungens*. *E. brevifolia* community (1*d*). Lowest-rainfall parts 1*a*
5	8	**Channels:** up to 100 ft wide and 15 ft deep; ranging from hill-slope channels with gradients up to 1 in 6, to main channels with gradients as low as 1 in 800	Channels, bed-loads range from sand to boulders. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (42, 43)

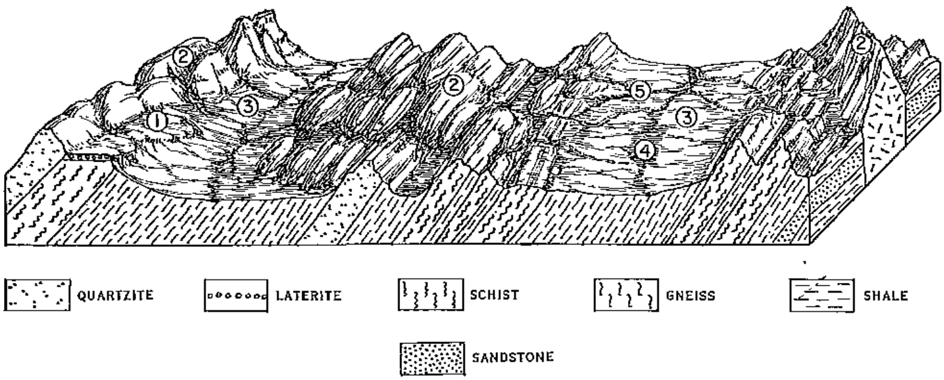
Comparable with the rocky cuestas of Buldiva land system, North Kimberley area.

Dockrell Land System (600 sq miles)

Rocky, mountain ridges on metamorphic rocks, skeletal soils, open stunted woodlands with spinifex.

Geology.—Strongly metamorphosed quartzite, schist, sandstone, slate, and shale, with quartz veins and dolerite intrusions.

Geomorphology.—Formed by dissection of the Kimberley surface—plateaux and mountain ranges: mountain ranges in strike belts up to 14 miles wide, with closely-spaced strike ridges above the level of, or produced by dissection of, restricted lateritized remnants, and with strike-aligned valley plains; dense rectangular pattern of incised drainage with strike-controlled trunk drainage; relief up to 500 ft.



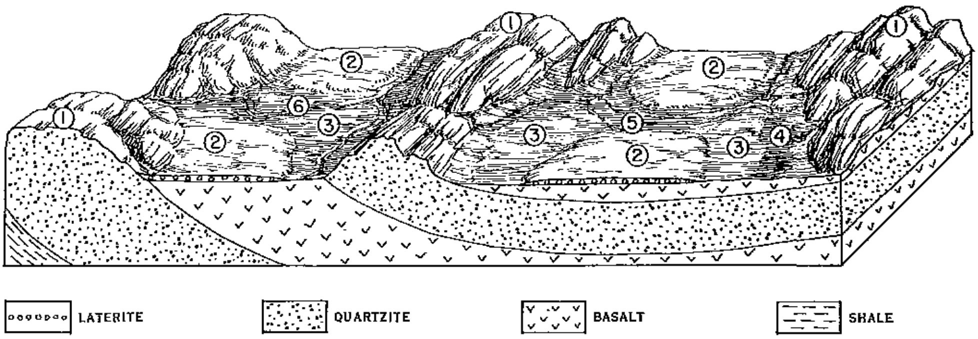
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	2	**Stable remnants:** up to 2 miles in extent; sandy slopes mainly less than 1% but with marginal slopes up to 5%; laterite exposures locally	Reddish sandy soils with laterite horizon: Yabbagoddy family (1)	Woodland with patches of dense *Acacia* shrubs and *Plectrachne pungens*. *E. brevifolia* community (1*d*)
2	47	**Ridges:** up to 500 ft high and 3 miles long; narrow, rocky crests and benched slopes up to 70%, locally vertical with basal scree slopes up to 35%; concave lower slopes up to 10% and ½ mile long, colluvial mantles and local outcrop	Much outcrop with shallow, micaceous sandy skeletal soils (24)	Open woodland of small, stunted trees, moderately dense to sparse shrub layer and *Triodia intermedia* and *T. inutilis*. *E. brevifolia* alliance (1*a*, 1*b*)
3	33	**Valley plains:** up to 3 miles wide and 10 miles long, cobble-strewn slopes mainly less than 0·5%; dissected up to 30 ft with local slopes up to 10%	Shallow brownish sands and loams over red clay commonly high in rock fragments: Moonah family (17)	
4	8	**Alluvial drainage floors:** up to ¼ mile wide, gradients 1 in 100 to 1 in 500	Locally developed, commonly scalded areas of greyish to brownish sands and loams over tough clays: Hooper family (20)	Open spinifex grassland with scattered low trees and shrubs. *Triodia intermedia* community (57)
5	10	**Channels:** up to 100 ft wide and 15 ft deep, ranging from hill-slope channels, gradients up to 1 in 30, to main channels with gradients as low as 1 in 500	Channels, bed-loads range from sand to boulders. Banks, probably brownish sandy and loamy alluvial soils: Robinson family (21)	Small streams fringed by low trees and spinifex of adjacent community. *E. brevifolia* community (1*a*). Larger streams with fringing woodlands. *E. camaldulensis–Terminalia platyphylla* fringing community (40)

Mandeville Land System (100 sq miles)

Broad rocky ridges with low open woodlands and curly spinifex, and sandy lowlands with tall woodlands.

Geology.—Dipping quartzite and sandstone of Upper Proterozoic age, and lateritized basaltic rocks of Upper Proterozoic or Lower Cambrian age; Quaternary aeolian sands.

Geomorphology.—Land systems formed by dissection of the Kimberley surface—plateaux and mountain ranges: broad, rocky ridges up to 1 mile wide and extending along the strike for up to 6 miles; lower, gently sloping sandy interfluves, and valley floors with restricted ill-drained depressions; moderately dense rectangular pattern of strike-controlled drainage; relief up to 500 ft.



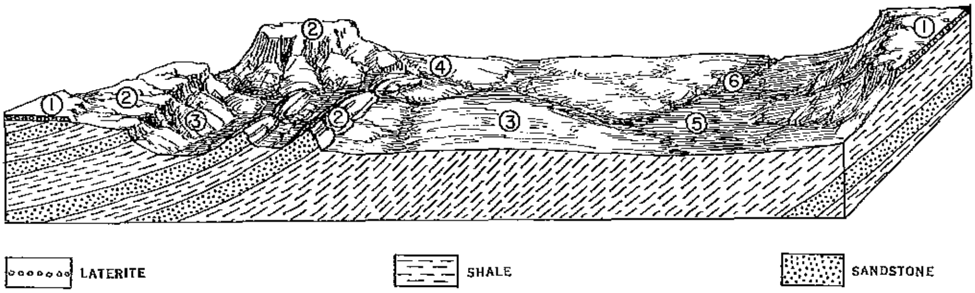
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	24	**Ridges:** up to 500 ft high; rounded, rocky crests and boulder-strewn slopes up to 50%	Mainly outcrop	Low depauperate woodland with moderately dense shrubs and *Plectrachne bynoei*. *E. perfoliata–Adansonia gregorii –E. dichromophloia* community (32)
2	40	**Interfluves:** up to 40 ft high and 2 miles wide, extending along the strike for up to 5 miles; sandy crest slopes less than 1%, and marginal slopes up to 25%, with low, discontinuous, laterite breakaways	Deep yellow sands on laterite: Pago family (8)	Tall grassy woodland with smaller tree layer, abundant shrubs and *Plectrachne pungens–Chrysopogon* spp., and *Chrysopogon* spp. ground storey. *E. miniata* alliance (28, 29)
3	20	**Valley floors:** up to 1 mile wide; sandy slopes mainly less than 0·2%, locally up to 1%, strewn with pisoliths	Mainly mottled yellowish loamy soils: Elliott family (6). Greyish to brownish sands and loams over tough clays: Hooper family (20)	Open grassy woodland of coolibah trees with *Chrysopogon* spp. *E. microtheca* alliance (20*a*)
4	7	**Ill-drained depressions:** linear, up to ½ mile wide and 2 miles long; flat, hummocky floors and short marginal slopes up to 1%	Mottled yellowish sandy soils: Tableland family (5). With brownish, mottled powdery sandy soils over tough mottled loamy subsoils: Tarraji family (18)	Fringing woodlands and paperbark thickets. Communities 26, 36
5	2	**Alluvial drainage floors:** up to ¼ mile wide, gradients 1 in 200 to 1 in 500	Clayey alluvial soils: Fitzroy family (22)	Open grassy woodland with frontage grass. *E. papuana* community (22*a*)
6	7	**Channels:** up to 200 ft wide and 15 ft deep	Channels, bed-loads of deep sand. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing community (42)

MARGARET LAND SYSTEM (500 SQ MILES)

Rocky plateaux and ridges and lower slopes, spinifex and stunted open woodlands.

Geology.—Lateritized or relatively unweathered subhorizontal or gently dipping quartzite, sandstone, and shale of Upper Proterozoic age.

Geomorphology.—Formed by dissection of the Kimberley surface—plateaux and mountain ranges: rocky plateaux and ridges with lateritized summit remnants forming narrow drainage divides, and extensive lower slopes and interfluves on sandstone or shale; dense branching or rectangular pattern of incised tributary drainage with through-going trunk drainage flanked by narrow alluvial plains in lower parts; relief up to 350 ft.



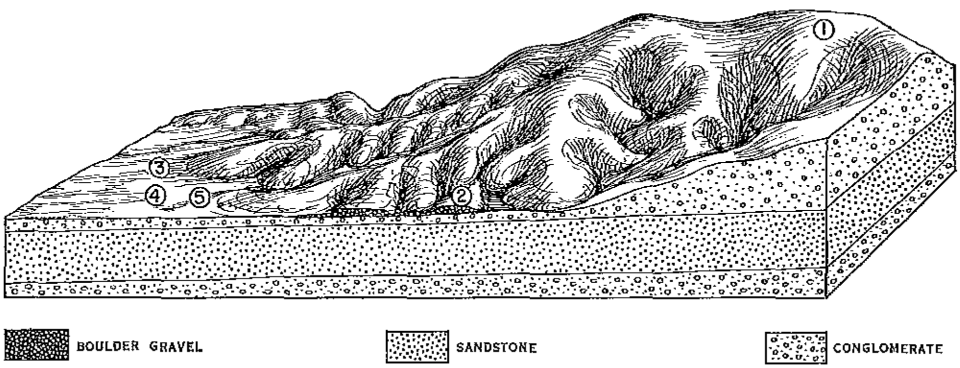
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	11	**Lateritic summits:** remnant cappings up to 3 miles in extent, slopes mainly less than 3%; marginal breakaways up to 40 ft high; boulder- or cobble-strewn surfaces with exposures of laterite and weathered rock	Rock outcrop, laterite exposure, and reddish sandy skeletal soils (24)	Depauperate snappy gum woodland with scattered shrubs and *Triodia intermedia*, grading into spinifex grassland. *E. brevifolia* community (1*a*); also 57
2	16	**Stripped plateaux and ridges:** up to 350 ft high; gently sloping plateaux up to 2 miles in extent, and dissected ridges up to 6 miles long, with dip slopes up to 20% and benched scarps up to 70%; rocky, boulder-strewn surfaces	Mainly outcrop with some reddish loamy to clayey skeletal soils (24)	
3	36	**Lower slopes and interfluves on shale:** concave lower slopes, up to 10% and 3 miles long, dissected up to 40 ft into spurs with flat or gently sloping crests up to 800 yd wide and marginal slopes up to 40%; interfluves up to 25 ft high and 2 miles wide, slopes less than 2%; patchy cobble-strewn surfaces with local outcrop	Shallow reddish loamy soils: Tippera family (2). With shallow brownish loams over red clay: Moonah family (17). Both soils high in shale fragments	Depauperate woodland with scattered shrubs and *Triodia intermedia*, grading into spinifex grassland. *E. brevifolia* alliance (1*a*, 2); also 57
4	20	**Lower slopes on sandstone:** concave, up to 10%, and up to 2 miles long, dissected up to 30 ft into spurs less than ¼ mile wide with marginal slopes up to 60%; mantled with colluvium	Probably deep yellow sands: Pago family (8). Locally stony	Similar to units 1 and 2
5	9	**Alluvial plains:** up to 1 mile wide and traversed by drainage floors up to ¼ mile wide; sealed, scalded surfaces with pebble patches; gradients 1 in 100 to 1 in 500	Reddish clayey alluvial soils: Fitzroy family (22). Some scalded brownish sands over red clays: Moonah family (17)	Much bare ground. Patches of short annual grasses (61). Patches of very open woodlands. *Grevillea striata* and *Bauhinia cunninghamii* alliances (34*a*, 38*b*)
6	8	**Channels:** up to 300 ft wide and 20 ft deep, ranging from hill-slope channels, gradients 1 in 20, to main channels with gradients as low as 1 in 500	Channels, bed-loads range from sand to boulders. Banks, brownish alluvial soils: Robinson family (21)	Fringing woodlands. *E. camaldulensis*–*Terminalia platyphylla* fringing community (42); also 39

Burramundi Land System (400 sq miles)

Rocky rounded hills and undulating terrain, skeletal soils, spinifex and scattered low trees.

Geology.—Flat-bedded or gently dipping Devonian conglomerate and sandstone, or Upper Proterozoic tillite.

Geomorphology.—Formed by dissection of the Kimberley surface—hill lands: secondary divides up to 12 miles wide, consisting of hills with gently rounded or bevelled crests up to ½ mile wide, and marginal alluvial aprons; moderately dense, radial pattern of incised drainage with restricted alluvial drainage floors in the lowest sectors; relief up to 500 ft.



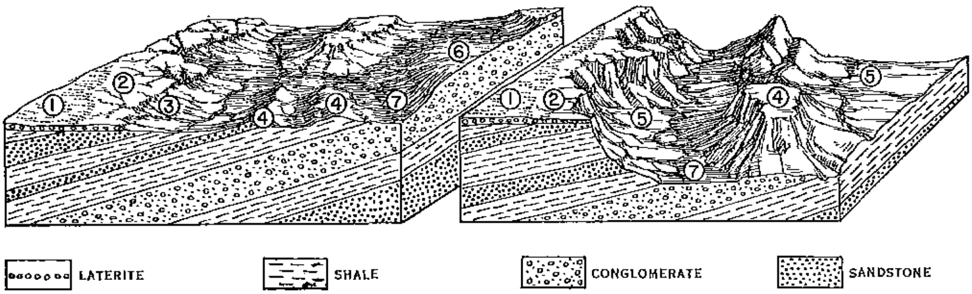
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	68	Hill slopes: boulder- and cobble-strewn slopes up to 40%, with lower slopes dissected up to 50 ft into rounded spurs, up to ¼ mile wide, with marginal slopes up to 25%	Outcrop and reddish bouldery coarse-textured skeletal soils (24)	Open spinifex with scattered small trees and low open woodlands with *Triodia intermedia*. *E. brevifolia* alliance (1*a*) and 57. Communities 1*d* and 54 in higher-rainfall parts
2	2	Boulder fans and aprons: up to ¾ mile long, slopes less than 10%, with upper talus fans up to 25%; dissected up to 30 ft at head and 5 ft distally	Bouldery, coarse-textured skeletal soils (24)	Very open woodlands with *Plectrachne pungens*. *E. brevifolia* alliance (1*d*)
3	20	Alluvial aprons: up to 1½ miles long, gradients 1 in 80 to 1 in 200; sealed surfaces with pebble patches	Shallow, reddish and yellowish sandy soils: Yabbagoddy (1) and Tableland (5) families	Open woodland with *Chrysopogon* spp. and scattered short annual grasses. *E. dichromophloia* alliance (9*b*)
4	5	Alluvial drainage floors: up to 300 yd wide, gradients 1 in 100 to 1 in 300	Brownish loamy alluvial soils: Robinson family (21)	Very open woodland with clumps of *Plectrachne pungens*. *E. dichromophloia* alliance (8*c*)
5	5	Channels: up to 100 ft wide and 6 ft deep	Bed-loads range from sand to boulders	Open fringing woodland with mixed tall frontage grasses. *Bauhinia cunninghamii* and *Adansonia gregorii* alliances (39, 33)

BOHEMIA LAND SYSTEM (800 SQ MILES)

Lateritic plateaux and hilly sandstone country with sandy and gravelly soils, spinifex with scattered trees and shrubs.

Geology.—Lateritized or relatively unweathered subhorizontal or gently dipping sandstone, conglomerate, tillite, and shale of Permian and Jurassic age.

Geomorphology.—Formed by dissection of the Kimberley surface—hill lands: strike tracts up to 12 miles wide, with intact and stripped summit remnants, rocky plateaux and hill slopes, dissected hill-foot slopes, and restricted valley floors; dense branching pattern of incised valleys with strike-controlled, through-going trunk drainage; relief up to 500 ft.



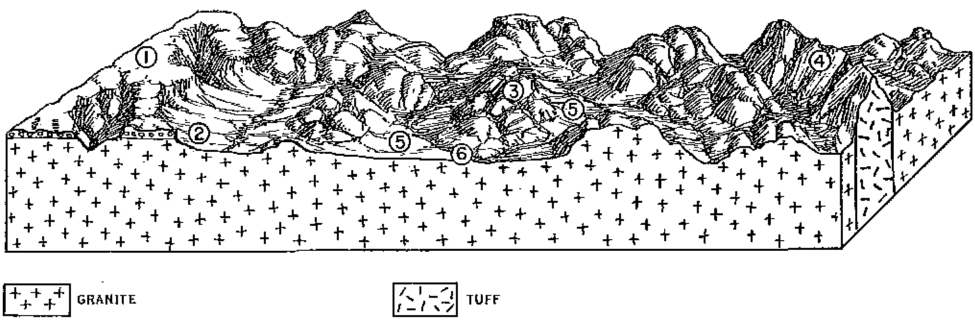
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	9	**Summit remnants:** up to ½ mile wide; pebble-strewn sandy slopes, less than 1%	Red sands of variable depth on laterite: Cockatoo family (7)	Spinifex grassland and very open woodland. *Triodia intermedia* community (57) and *E. brevifolia* alliance (1*a*, 2)
2	17	**Stripped surfaces and marginal breakaways:** up to 1 mile wide; stony slopes up to 5%, with frequent laterite exposures and with marginal breakaways up to 20 ft high	Laterite and pallid-zone remnants, some outcrops of bedrock and some deep red sands: Cockatoo family (7)	
3	7	**Slopes below breakaways:** concave, up to 5%, and up to ½ mile long; dissected up to 20 ft into narrow rounded spurs with marginal slopes attaining 10%; colluvial mantles	Much outcrop with some shallow reddish sands high in laterite fragments: Yabbagoddy family (1)	Much bare ground. Low open woodland with *Triodia intermedia*. *E. brevifolia* alliance (1*a*, 2); locally 1*c*
4	28	**Rocky plateaux and hills:** flat or gently sloping plateaux up to 500 ft high, with steep escarpments; hills up to 300 ft high with slopes up to 70%, and basal scree slopes up to 45%	Much sandstone outcrop with some reddish gravelly skeletal soils (24)	Open spinifex with scattered stunted trees, much bare rock. *Triodia intermedia* community (57)
5	17	**Hill-foot slopes:** concave, up to 10% and up to 1 mile long; dissected up to 30 ft into narrow spurs with marginal slopes up to 60%; colluvial mantles	Much outcrop with some yellowish stony skeletal soils (24)	
6	8	**Valley floor slopes:** mainly less than 2% and up to 1 mile long; dissected up to 10 ft with local slopes up to 10%; scaled, scalded surfaces	Probably brownish stony sands and loams over red clay: Moonah family (17)	Mixed open grassy woodland communities (1*f*, 38*c*, locally 15)
7	3	**Drainage floors:** up to ¼ mile wide, gradients 1 in 100 to 1 in 500	Brownish loamy alluvial soil: Robinson family (21)	Low woodland with *Plectrachne pungens*. *Bauhinia cunninghamii* alliance (38*a*)
8	11	**Channels:** up to 100 ft wide and 15 ft deep, gradients ranging from 1 in 30 in hill-slope channels to 1 in 500 in main channels	Bed-loads mainly sand and pebbles	Fringing communities (40, 41)

Rose Land System (200 sq miles)

Granite domes with lateritic summit remnants, shallow soils and outcrop, spinifex and low open woodlands.

Geology.—Lateritized or relatively unweathered granite of Lower Proterozoic or Archaeozoic age; minor quartz reefs.

Geomorphology.—Formed by dissection of the Kimberley surface—hill lands: closely-spaced granite domes, short lower slopes, restricted lateritized summit remnants, and minor quartz reef ridges; dense to moderately dense rectangular pattern of incised valleys with subparallel, through-going trunk drainage; relief mainly less than 300 ft, but attaining 600 ft locally.



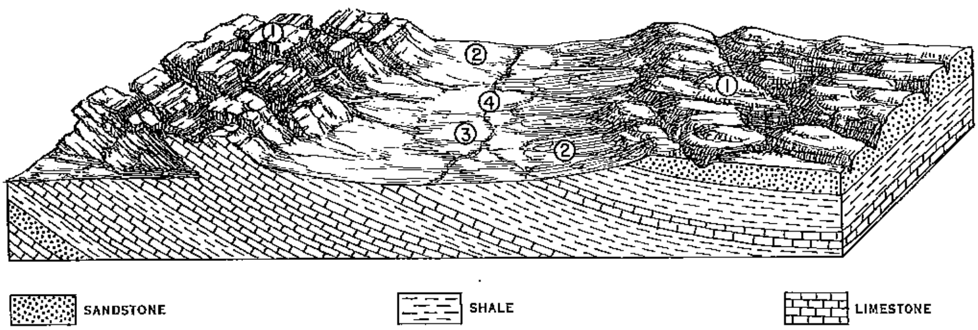
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	12	Summit remnants: less than 1 mile in extent; sandy slopes less than 1%, and marginal rocky slopes up to 5%; delimiting laterite breakaways up to 40 ft high	Reddish sandy to loamy soils commonly high in lateritic gravels: Tippera family (2), with laterite outcrop near breakaways	Open woodland with *Plectrachne pungens*. *E. brevifolia* community (1*d*); locally 1*a*
2	7	Slopes below breakaways: concave, up to 5% and less than ¼ mile long; colluvial mantles with local outcrop	Reddish loamy and clayey lithic soils: Yabbagoddy family (1, 23); commonly high in lateritic gravels	Much bare ground. Very open, low woodland with *Enneapogon* spp. and other short grasses. *E. brevifolia* community (1*f*)
3	42	Domes: up to 500 ft high; rounded crests, locally with joint-block cappings, and convex, rocky slopes up to 80%	Outcrop with very limited pockets of sandy skeletal soils (24)	Much bare rock, vegetated only in cracks, crevices, and pockets of soil. Scattered trees and shrubs and tussocks of *Plectrachne bynoëi* and other grasses. *Adansonia gregorii* alliance (32)
4	2	Ridges: up to 200 ft high and 1¼ miles long; narrow rocky crests and benched slopes up to 70%, with basal scree slopes up to 35%	Rock outcrop	Open depauperate woodland with scattered *Plectrachne pungens*. *E. brevifolia* and *E. tectifica* alliances (1*d*, 14*c*)
5	29	Lower slopes: concave, up to 10% and ¼ mile long; cobble mantles and local outcrop	Mainly brownish sands and loams over tough loamy subsoils: Tarraji family (18). Minor deep brown sands: Kalyeeda family (9)	Grassy woodland with *Enneapogon* spp., *Plectrachne pungens*, and *Aristida hygrometrica* ground storeys. *E. brevifolia* and *E. tectifica* alliances (1*f*, 14*c*, 14*d*)
6	8	Channels: up to 300 ft wide and 15 ft deep, locally flanked by alluvial floors up to 300 yd wide with marginal slopes up to 1%; gradients 1 in 100 to 1 in 400	Channels, bed-loads range from deep sand to cobbles. Banks, areas of loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis*–*Terminalia platyphylla* fringing communities (41, 42) and 33

WINDJANA LAND SYSTEM (1900 SQ MILES)

Rocky limestone hill ranges, outcrop and shallow calcareous earths, spinifex and scattered trees. Locally grasslands on cracking clay soils.

Geology.—Dipping or gently folded limestone, calcareous sandstone, and shale of Devonian age.

Geomorphology.—Formed by dissection of the Kimberley surface—hill lands: strike belts up to 4 miles wide and 50 miles long, comprising hill ranges, plateaux, and cuestas, with narrow bevelled crests and with short lower slopes; restricted cracking clay plains in the lowest parts; sparse to moderately dense rectangular or branching pattern of incised valleys with strike-directed trunk drainage; relief up to 250 ft.



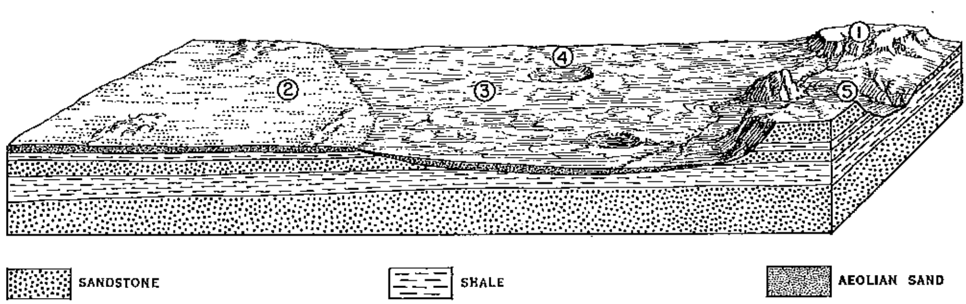
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	68	**Rocky hills, plateaux, and cuestas:** bevelled hill and plateau crests up to ½ mile wide with slopes less than 2%; cuestas up to 1 mile wide with dip slopes up to 5%; boulder-covered hill and scarp slopes up to 50% with vertical upper walls; pitted, fluted outcrop surfaces	Mainly limestone outcrop with limited areas of shallow dark grey, loamy to clayey, calcareous soils: Oscar family (11)	Very open woodlands, scattered shrubs and *Triodia wiseana*. *E. dichromophloia* and *Adansonia gregorii* alliances (8*a*, 30)
2	23	**Lower slopes:** concave, up to 5%, and less than ½ mile long; locally with alluvial fans, gradients 1 in 20 to 1 in 30; pebble-strewn surfaces with local outcrop	Limestone outcrop with shallow dark brown to dark grey, loamy to clayey calcareous soils: Oscar family (11)	Open woodlands, very scattered shrubs and ground storey of *Triodia wiseana*. *E. dichromophloia* alliance (8*a*, 9*a*)
3	5	**Cracking clay plains:** up to ½ mile wide, with slopes less than 0·5%; hummocky surfaces	Dark, strongly self-mulching heavy clays: Cununurra family (12), with minor gilgai formation	Mitchell grass and ribbon grass–blue grass grasslands with scattered trees and shrubs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48); also 37*a*
4	4	**Channels:** up to 100 ft wide and 10 ft deep, gradients 1 in 100 to 1 in 500	Channels, bed-loads range from sand to boulders on bed-rock. Banks, outcrop with local areas of shallow brownish loamy alluvial soils: Robinson family (21)	Fringing woodland. *E. camaldulensis*–*Terminalia platyphylla* fringing communities (42, 43); smaller streams 38*b*

Reeves Land System (150 sq miles)

Sand plain with scattered hills and minor plateaux, reddish sandy soils, pindan.

Geology.—Subhorizontal or gently dipping sandstone, sandy siltstone, and silicified quartz sandstone of Cretaceous age; Quaternary aeolian sand.

Geomorphology.—Formed by dissection of the Kimberley surface—hill lands: strike belts up to 3 miles wide, with scattered hills, dip slopes with thin sand cover and local outcrop, and sand plain; sparse, branching drainage pattern; relief up to 200 ft.



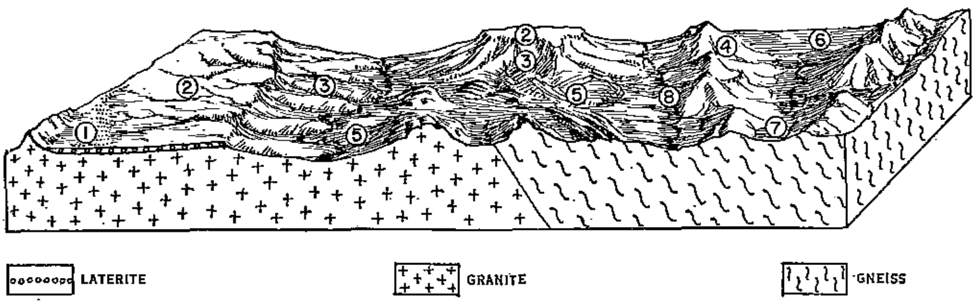
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	11	Hills: up to 200 ft high; flat or gently sloping rocky crests up to ½ mile wide, with marginal escarpments up to 70%, locally vertical, and basal scree slopes up to 45%	Mainly outcrop with scree slopes	Depauperate woodland and spinifex grassland with scattered trees and shrubs. *E. confertiflora* community (13)
2	29	Sandy surfaces with local outcrop: up to 1 mile in extent; sandy slopes up to 1% with frequent outcrop	Outcrop with reddish sandy soils of variable depth: Yabbagoddy family (1)	Low woodland (pindan) with prominent *Acacia* tall shrub layer and *Plectrachne pungens–Chrysopogon* spp. ground storey. *E. dichromophloia–E. zygophylla–Acacia* spp. community (10)
3	52	Sand plain: up to 1½ miles wide with slopes up to 2%	Reddish sandy soils: Yabbagoddy family (1)	Low woodland (pindan type) with *Plectrachne pungens–Chrysopogon* spp. ground storey. *Adansonia gregorii* and *E. dichromophloia* alliances (31, 10)
4	7	Pans and depressions: up to ½ mile wide; shallow depressions with firmed sandy surfaces, and pans up to 5 ft deep with bare cracking surfaces and with short marginal slopes up to 1%	Mottled yellowish sandy soils: Tableland family (5) on slopes. Greyish, massive, intractable, silty to heavy clays (30) in pans	Mostly bare, with paperbark fringing communities. *Melaleuca* spp. community (36)
5	1	Channels: up to 30 ft wide and 5 ft deep; gradients 1 in 100 to 1 in 500	Channels, bed-loads range from deep sand to cobbles. Banks, limited narrow areas of brownish loamy alluvial soils (21)	Fringing woodlands. *E. camaldulensis* and *E. camaldulensis–Melaleuca* spp. communities (40, 41)

Koongie Land System (1200 sq miles)

Low laterite plateaux and scattered hills, reddish loamy gravelly soils, low open woodlands and spinifex.

Geology.—Lateritized or relatively unweathered granite and schist–gneiss complexes of Lower Proterozoic and (?) Archaeozoic age.

Geomorphology.—Formed by dissection of the Kimberley surface—hill lands: strike belts up to 25 miles wide, with low lateritic plateaux, scattered gneiss hills, narrow schist ridges, and granite domes; restricted cracking clay plains; dense to moderately dense branching pattern of incised valleys with through-going trunk drainage; relief up to 100 ft.



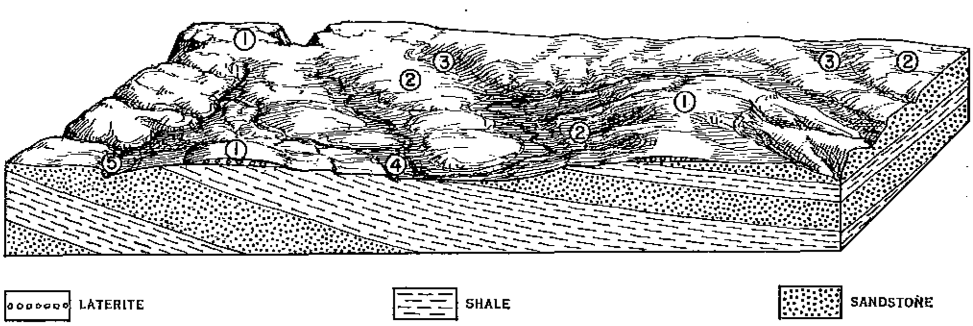
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	3	**Summit remnants:** sandy slopes less than 1% and up to 2 miles in extent; minor upstanding rocky ridges up to 50 ft high with slopes up to 50%	Reddish, sandy to loamy soils: Tippera family (2) with minor outcrop	Woodlands with patches of dense *Acacia* shrubs and *Plectrachne pungens*. *E. brevifolia* community (1*d*); also 17, and locally 1*a*
2	25	**Stripped surfaces:** up to 3 miles in extent; rocky slopes up to 5%, with laterite exposures and with marginal breakaways up to 40 ft high	Mainly exposed laterite surface with pockets of reddish sandy soils: Yabbagoddy family (1)	Very open woodland of small trees and *Triodia intermedia*. *E. brevifolia* community (1*a*); also 57
3	14	**Slopes below breakaways:** concave, up to 5%, dissected up to 20 ft into rounded spurs up to ¼ mile wide, with marginal slopes up to 10%; laterite scree and outcrops of weathered rock in upper parts, colluvial mantles in lower sectors	Shallow reddish, loamy and sandy soils commonly high in laterite gravel: Yabbagoddy family (1, 23). Local, minor areas of brownish sands over red clay: Moonah family (17)	Much bare ground or with sparse cover of annual grasses; local patches of *Triodia intermedia* and low open woodland. *E. brevifolia* alliance (1*a*); also 8*d*, 12, 57
4	25	**Rocky hill slopes:** benched slopes on gneiss and schist, up to 70%, with basal scree slopes up to 35%; smooth convex slopes on granite, up to 80%, locally with joint-block cappings	Mainly outcrop with some areas of reddish, sandy skeletal soil (24)	Much bare rock. Pockets of *Triodia intermedia*, *T. inutilis*, and *Enneapogon* spp. and low open woodlands. *E. brevifolia* alliance (1*a*, 1*b*, 1*f*)
5	16	**Hill-foot slopes:** concave, up to 5%, and up to 2 miles long; colluvial mantles with pebble patches and local outcrop	Shallow reddish sandy and loamy soils: Tippera family (2, 23). Some reddish sands and loams over red clay: Moonah family (17)	Spinifex grasslands and very open woodlands with *Triodia intermedia* and *Chrysopogon* spp. *E. brevifolia* alliance (1*a*, 1*e*); also 57
6	6	**Cracking clay plains:** hummocky slopes less than 0·5% and less than 2 miles in extent	Dark brown self-mulching clays: Wonardo family (14)	Mitchell grass and ribbon grass–blue grass grasslands with scattered trees and shrubs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48)
7	5	**Alluvial drainage floors:** up to ½ mile wide, gradients 1 in 80 to 1 in 500; marginal slopes up to 0·5%	Brownish sands and loams over red clay: Moonah family (17)	Open woodlands with *Chrysopogon* spp., locally short annual grasses. *E. brevifolia* community (1*e*)
8	6	**Channels:** up to 300 ft wide and 30 ft deep	Channels, bed-loads mainly deep sands with pebble gravels. Banks, brownish loamy alluvial soils: Robinson family (21)	Small streams with open fringing communities (1*a*, 1*g*). Large streams, fringing forests and woodlands. *E. camaldulensis*–*Terminalia platyphylla* fringing communities (41, 42, 43)

Fork Land System (500 sq miles)

Upland plains and rocky undulating country, sandy and skeletal soils, low open woodlands with shrubs and curly spinifex.

Geology.—Lateritized or relatively unweathered, gently dipping sandstone and shale of Upper Proterozoic age.

Geomorphology.—Formed by dissection of the Kimberley surface—undulating terrain: rocky surfaces, comprising rounded hills less than 100 ft high, and cuestas up to 50 ft high, with upland plains and gently rounded interfluve crests; moderately dense branching pattern of incised valleys with shallow unchannelled floors in upper parts; relief less than 100 ft, but marginal escarpments up to 300 ft high.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	13	**Plains and interfluve crests:** plains up to 2 miles wide and interfluve crests up to 1 mile wide; sandy slopes less than 1% with pebble patches	Mainly yellowish sandy soils high in laterite gravels: Tableland family (5). Some yellowish loamy soils, high in laterite gravels and slate fragments: Elliott family (6)	Low woodland with moderately dense to dense shrub layers and *Plectrachne pungens*. *E. brevifolia* and *E. phoenicea* alliances (5, 7). Locally, *Melaleuca* thickets (36)
2	65	**Rocky surfaces:** up to 3 miles in extent; benched hill slopes up to 70% and cuesta dip slopes up to 5%; boulder mantles and laterite exposures locally	Much rock outcrop with yellowish and reddish gravelly skeletal soils and some laterite remnants (24)	Low woodlands with moderately dense shrub layer and *Plectrachne pungens*. *E. phoenicea–E. ferruginea* alliance (7); locally 1*a* and 36
3	11	**Headwater valley floors:** up to ½ mile wide; sandy slopes up to 2%; with lightly sealed surfaces and pebble patches	Yellowish loamy soils, commonly with moderate amounts of rock fragments: Elliott family (6)	Grassy woodlands characterized by *Aristida hygrometrica*. *E. polycarpa* community (25); locally 36
4	4	**Drainage floors:** up to ¼ mile wide, gradients 1 in 100 to 1 in 300	Limited areas of clayey alluvial soils: Fitzroy family (22)	
5	7	**Channels:** up to 100 ft wide and 6 ft deep, incised in bed-rock	Channels, bed-loads range from sand to boulders. Banks, brownish stony alluvial soils: Robinson family (21)	Fringing woodlands. *E. camaldulensis–Melaleuca* spp. fringing community (41)

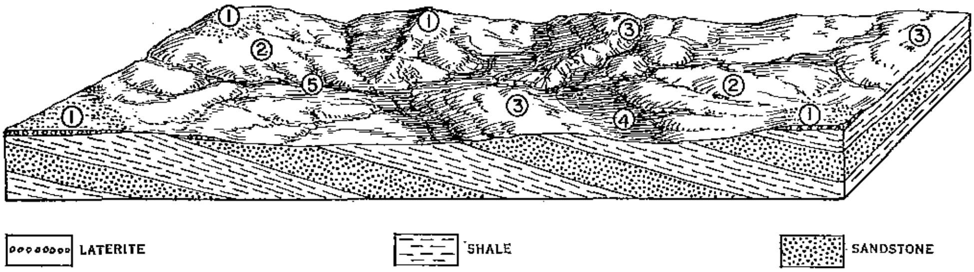
Comparable with high undulating country (unit 2) of Pago land system, North Kimberley area.

Tableland Land System (700 sq miles)

Undulating shale country with yellowish gravelly soils, open woodlands with curly spinifex.

Geology.—Lateritized or relatively unweathered, gently dipping Upper Proterozoic shale and sandstone.

Geomorphology.—Formed by dissection of the Kimberley surface—undulating terrain: strike tracts up to 20 miles wide, with rocky surfaces comprising interfluves up to 30 ft high and rounded hills and cuestas up to 50 ft high; stripped gently sloping lateritized surfaces with intact remnants forming upland plains or gently rounded interfluve crests; moderately dense rectangular pattern of incised drainage, with unchannelled tributary valley floors.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	5	**Plains and interfluve crests**: up to 2 miles in extent; sandy slopes less than 1%; with pebble patches	Mainly yellowish sandy to loamy soils, high in laterite gravels and shale fragments: Elliott (6) and Tableland (5) families	Open woodland with moderately dense shrub layer and *Plectrachne pungens*. *E. brevifolia* alliance (1*d*, 5)
2	30	**Stripped surfaces**: up to 2 miles in extent; pebble-strewn slopes up to 5%, with frequent laterite exposures	Shallow, red sands high in lateritic gravels on laterite: Cockatoo family (7, 23); some laterite outcrop	Open woodland with moderately dense shrub layer and *Plectrachne pungens*. *E. phoenicea–E. ferruginea* community (7)
3	48	**Rocky surfaces**: interfluve crests up to 1% and 1 mile wide with marginal slopes up to 10%; hill and scarp slopes up to 35%; cobble-strewn surfaces with much outcrop	Much outcrop with shallow, yellowish gravelly soils: Tableland family (5, 23)	Open woodland with moderately dense shrub layer and *Plectrachne pungens* and *Aristida hygrometrica*. *E. brevifolia* and *E. tectifica* alliances (1*d*, 14*d*); also 36
4	9	**Unchannelled valley floors**: up to ¼ mile wide, gradients 1 in 80 to 1 in 200; sealed surfaces with sand and pebble patches	Mainly yellowish sandy to loamy soils: Elliott family (6). With dark brown self-mulching heavy clays: Wonardo family (14) on black soil plain element	Grassy woodland with patches of paperbarks, with *Chrysopogon* spp., *Aristida hygrometrica*, and frontage grasses. *E. brevifolia* and *E. polycarpa* alliances (1*e*, 25, 27)
5	8	**Channels**: up to 100 ft wide and 6 ft deep, and locally flanked by alluvial floors up to ½ mile wide; gradients 1 in 100 to 1 in 500	Probably brownish loamy alluvial soils: Robinson family (21)	Open woodland fringing community with frontage grasses and *Aristida hygrometrica*. *Adansonia gregorii* and *E. polycarpa* alliances (25, 33)

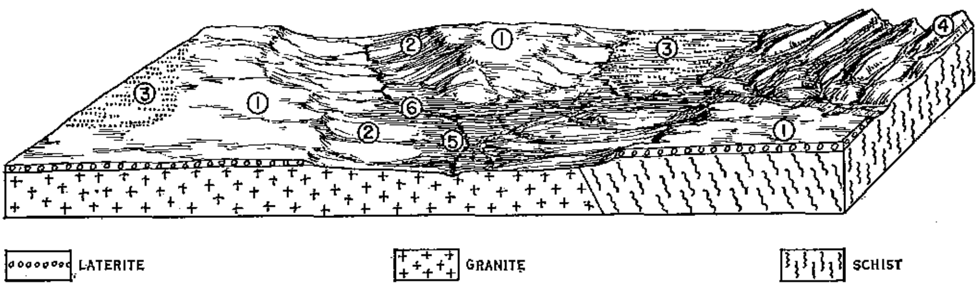
Comparable with Karunjie land system and with some places in Pago land system, North Kimberley area.

Ruby Land System (200 sq miles)

Undulating country with extensive lateritic remnants and sand plain, low woodlands with spinifex.

Geology.—Lateritized granitic and metamorphic rocks of Lower Proterozoic and (?)Archaeozoic age; Quaternary aeolian sands.

Geomorphology.—Formed by dissection of the Kimberley surface—undulating terrain: summit remnants forming low divides, stony lower slopes, sand plain islands, and scattered ridges; moderately dense branching pattern of incised headwater drainage, and sparse pattern of trunk drainage; relief mainly less than 30 ft.



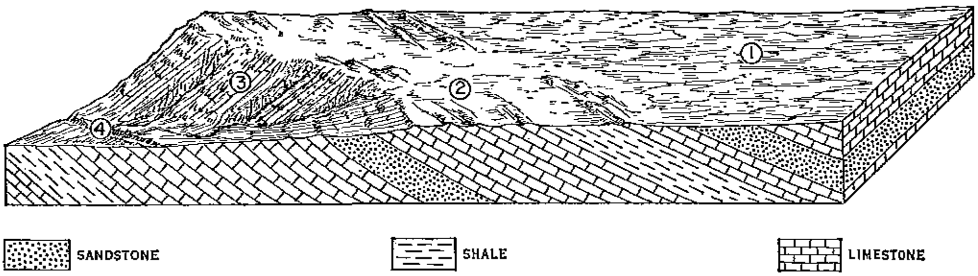
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	52	**Summit remnants**: up to 4 miles wide, with slopes mainly less than 1% but attaining 5% locally, and with marginal breakaways up to 30 ft high; sandy surfaces with pebble patches and laterite exposures locally	Reddish sandy to loamy soils of variable depth, commonly high in laterite gravels: Tippera family (2)	Probably woodland with patches of dense *Acacia* shrubs and *Triodia intermedia* and *Plectrachne pungens*. *E. brevifolia* alliance (1*a* or 1*d*)
2	19	**Lower slopes**: concave, up to 5%, and up to 1 mile long; locally dissected up to 20 ft into rounded spurs up to 300 yd wide, with marginal slopes up to 10%; colluvial mantles and local outcrop	Reddish, loamy and clayey skeletal soils with laterite gravels and some outcrop (24). Local minor occurrences of brownish sands and loams over red clay: Moonah family (17)	Much bare ground, sparse cover of short annual grasses with patches of *Chrysopogon* spp. and *Triodia intermedia*. Probably *E. brevifolia* and *E. dichromophloia* alliances (1*a*, 2, 8*d*, 12) and 57
3	16	**Sand plain**: slopes less than 1% and up to 1½ miles in extent	Deep red sands: Cockatoo family (7)	Probably woodland (pindan) with prominent *Acacia* shrub layer and *Plectrachne pungens–Chrysopogon* spp., *Triodia pungens*. *E. dichromophloia* alliance (10, 8*b*)
4	4	**Ridges**: up to 200 ft high and ½ mile long; narrow, rocky crests and benched slopes up to 70%, with basal scree slopes up to 35%	Mainly outcrop	Probably open woodland with *Triodia intermedia* and patches of short annual grasses. Much bare ground. *E. brevifolia* community (1*a*); also 57
5	5	**Drainage floors**: up to ½ mile wide, gradients 1 in 100 to 1 in 500; sealed, scalded surfaces with sand hummocks	Probably greyish sands over tough loamy subsoils: Tarraji family (18). Some loamy alluvial soils: Robinson family (21)	Probably very open woodland with *Triodia intermedia*, other tall to medium-height grasses, patches of short annual grasses, and much bare ground. *E. brevifolia* alliance (1*a*, 1*e*, 1*f*); also 61
6	4	**Channels**: up to 40 ft wide and 5 ft deep	Channels, bed-loads range from deep sand to cobbles. Banks, brownish loamy alluvial soils: Robinson family (21)	Open fringing woodland. *E. camaldulensis* fringing community (40); smaller streams 1*a*

LEOPOLD LAND SYSTEM (150 SQ MILES)

Cracking clay plains and marginal outcrop plains, grasslands and very open grassy woodlands.

Geology.—Gently dipping limestone, calcareous sandstone, and shale of Devonian age.

Geomorphology.—Formed by dissection of the Kimberley surface—plains: strike belts up to 6 miles wide and 25 miles long, comprising cracking clay plains with marginal outcrop plains, and lower outcrop plains occurring in entrenched valleys; sparse, strike-controlled pattern of incised drainage; relief less than 100 ft.



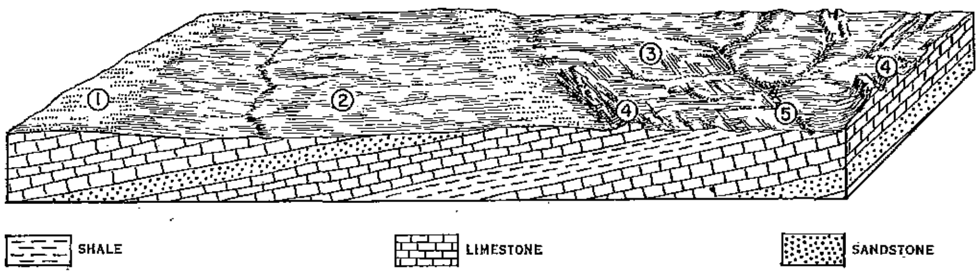
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	49	**Cracking clay plains:** up to 1 mile wide; hummocky slopes less than 0·5%, with local outcrop	Dark grey self-mulching cracking clay with structure-controlled linear gilgai: Cununurra family (12)	Mitchell grass and ribbon grass–blue grass grasslands and open woodlands with *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* ground storeys. Communities 47, 48, 37*a*
2	36	**Outcrop plains:** up to 2 miles wide; boulder-strewn slopes up to 1% with much outcrop	Dark grey strongly self-mulching heavy clay with some outcrop and commonly flat limestone "floaters": Cununurra family (12)	Grasslands and very open woodlands with *Chrysopogon* spp.–*Dichanthium fecundum* ground storey. *Bauhinia cunninghamii* community (37*a*) and 48
3	9	**Valley sides:** concave, up to 10%; benches up to 10 ft high with outcrop and boulder strew	Complex of a limestone outcrop and shallow dark brown to dark grey, loamy to clayey calcareous soils: Oscar family (11). With dark grey self-mulching heavy clays: Cununurra family (12), showing structure-controlled gilgais	Complex of grasslands and open woodlands as in unit 2, also *Triodia wiseana* with scattered trees on rock outcrops. *E. dichromophloia* alliance (8*a*) and 48
4	6	**Channels:** up to 200 ft wide and 6 ft deep, gradients 1 in 100 to 1 in 500; incised in bed-rock	Channels, bed-loads range from cobbles to boulders. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (42, 43)

OSCAR LAND SYSTEM (100 SQ MILES)

Cracking clay plains and limestone outcrop plains, grasslands, spinifex, and open woodlands.

Geology.—Dipping or gently folded limestone, calcareous sandstone, and siltstone of Devonian age.

Geomorphology.—Formed by dissection of the Kimberley surface—plains: upland plains up to 4 miles wide with low rises, slightly lower cracking clay plains, and outcrop plains with scattered low hills; sparse rectangular drainage pattern; relief less than 40 ft.



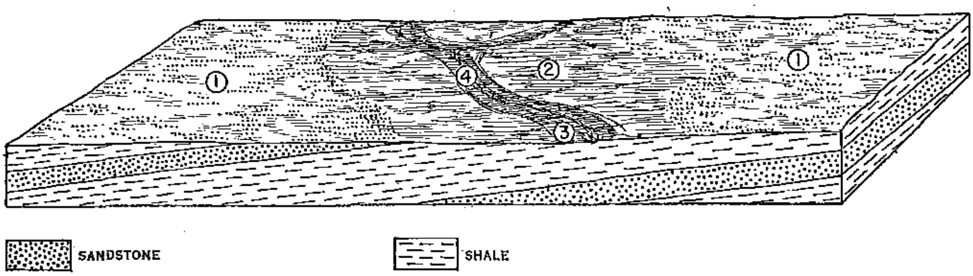
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	11	Low rises: up to 2 miles wide; sandy slopes less than 0·5%; with pebble patches	Limestone outcrop with shallow dark brown and reddish brown to dark grey, loamy to clayey calcareous soils: Oscar family (11). Local minor patches of dark, self-mulching heavy clays: Cununurra family (12) in depressions	Grasslands and open woodlands. *Chrysopogon* spp.–*Dichanthium fecundum*. *Chrysopogon* spp. communities (48, 49); *E. dichromophloia* community (8*a*)
2	42	Cracking clay plains: up to 2 miles in extent; hummocky slopes less than 1%	Dark self-mulching strongly cracking heavy clays: Cununurra family (12) commonly shallow with structure-controlled gilgais. Minor amounts of shallow, dark brown clayey calcareous soils: Oscar family (11) on crests	Mitchell grass and ribbon grass–blue grass grasslands with scattered trees and shrubs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48); locally 37*a*, 37*b*
3	35	Outcrop plains: up to 3 miles wide; cobble-strewn slopes up to 5%, and frequent outcrop	Limestone outcrop with shallow dark brown to dark grey, loamy to clayey, calcareous soils: Oscar family (11). Minor local patches of dark grey self-mulching heavy clays: Cununurra family (12)	Spinifex grassland and very open woodland with *Triodia wiseana*. *E. dichromophloia* community (8*a*) and 58
4	7	Hills: up to 30 ft high; narrow, rocky crests and boulder-strewn slopes up to 50%, locally vertical	Mainly limestone outcrop with minor areas of shallow, dark brown to dark grey, loamy, calcareous soils: Oscar family (11)	Very open woodlands with scattered *Triodia wiseana*. Much bare rock. *E. dichromophloia* and *Adansonia gregorii* alliances (8*a*, 30)
5	5	Channels: up to 50 ft wide and 6 ft deep; incised in bed-rock	Channels, bed-loads range from sand to cobbles. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis*–*Terminalia platyphylla* community (42); small streams 39

Gladstone Land System (50 sq miles)

Cracking clay plains and broad loamy rises, grasslands and grassy woodlands.

Geology.—Subhorizontal or gently dipping sandstone and shale of Upper Proterozoic age.

Geomorphology.—Formed by dissection of the Kimberley surface—plains: broad, gently sloping interfluves and lower plains; sparse branching pattern of ill-defined drainage floors; relief less than 10 ft.



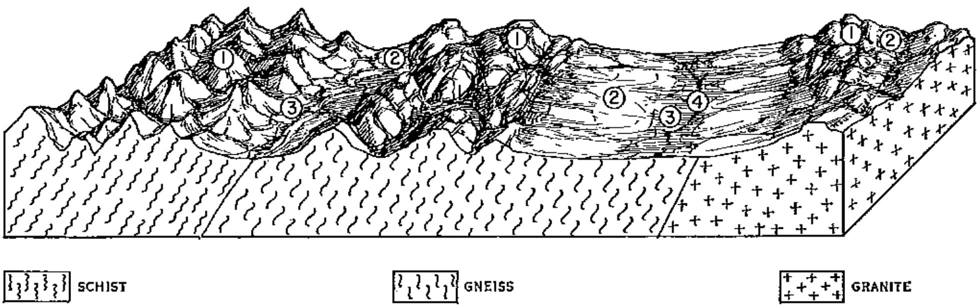
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	55	**Interfluves:** up to 3 miles wide with slopes up to 1%; sealed surfaces with pebble patches and local outcrop	Yellowish loamy soils: Elliott family (6), commonly high in shale fragments with depth	Open, grassy, snappy gum woodland with *Chrysopogon* spp. *E. brevifolia* community (1*e*)
2	39	**Plains:** hummocky surfaces up to 3 miles across with slopes less than 0·5%	Dark self-mulching heavy clays with linear gilgai: Wonardo family (14), minor Cununurra family (12)	Mitchell grass, ribbon grass–blue grass grassland, and very open woodlands. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48); also *Bauhinia cunninghamii* community (37*a*)
3	3	**Drainage floors:** mainly up to 200 yd wide but attaining 400 yd in lowest sectors; gradients 1 in 200 to 1 in 500	Only very local soil development	Open grassy woodland. *Adansonia gregorii* and *Bauhinia cunninghamii* alliances (33, 39)
4	3	**Channels:** up to 40 ft wide and 5 ft deep	Bed-loads of sand and pebbles	

RICHENDA LAND SYSTEM (2100 SQ MILES)

Inaccessible mountainous country, open stunted woodlands with curly spinifex, and grassy woodlands.

Geology.—Granite, gneiss, and schist of Lower Proterozoic or Archaeozoic age.

Geomorphology.—Mountain and hill ranges eroded below the Kimberley surface: mountain ranges in strike belts up to 16 miles wide; with elongated gneiss hills, narrow schist ridges, and granite domes; dense rectangular pattern of incised tributary drainage and through-going strike-aligned alluvial floors; relief up to 500 ft.



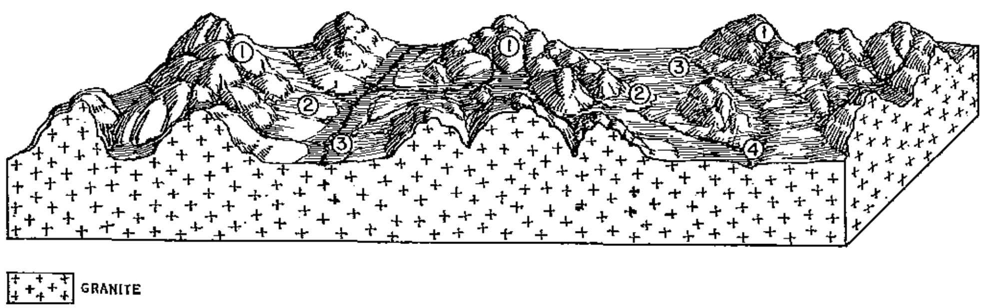
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	66	Rocky hill slopes: benched slopes on gneiss and schist, up to 70%, locally vertical, with basal scree slopes up to 35%; convex rocky slopes on granite, up to 80%, locally with joint-block cappings	Mainly outcrop with limited areas of shallow, reddish, sandy skeletal soils (24)	Low open woodland. Communities 3, 8*a*, 14*a*, 16, 32
2	24	Lower slopes: concave, up to 10%, mainly less than ¼ mile long but up to 1 mile long; outcrop and cobble mantles in upper parts, colluvial mantles in lower sectors	Mainly outcrop with shallow, sandy skeletal soils (24). Minor occurrences of greyish to brownish sands and loams over tough clays: Jurgurra family (19)	Open grassy woodlands with *Plectrachne pungens*, *Chrysopogon* spp., and *Sehima nervosum–Sorghum* spp. ground storeys. *E. tectifica* alliance (14*a*, 14*b*, 14*c*)
3	3	Drainage floors: up to 400 yd wide, gradients 1 in 100 to 1 in 400 with transverse slopes up to 1%; locally with central unchannelled drainage zones up to 100 yd wide and 6 in. deep; sandy surfaces with pebble patches	Loamy alluvial soils: Robinson family (21)	Very open grassy woodland with sparse shrubs, and *Sehima nervosum–Sorghum* spp., *Sehima nervosum–Dichanthium fecundum*, and *Chrysopogon* spp. ground storeys. *E. tectifica* alliance (14*a*, 15); also 48, 36
4	7	Channels: up to 300 ft wide and 15 ft deep, ranging from hill-slope channels, gradients up to 1 in 10, to main channels with gradients as low as 1 in 400	Channels, bed-loads range from deep sand to cobbles on bedrock. Banks, brownish stony alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (40, 41, 42); small streams 33

AMY LAND SYSTEM (700 SQ MILES)

Granite domes with scattered spinifex and low trees, and intervening alluvial flats with open grassy woodlands.

Geology.—Lower Proterozoic or Archaeozoic granite.

Geomorphology.—Mountain and hill ranges eroded below the Kimberley surface: strike belts up to 12 miles wide, with granite domes and broad, alluvial drainage floors; moderately dense rectangular pattern of strike-controlled drainage; relief up to 500 ft.



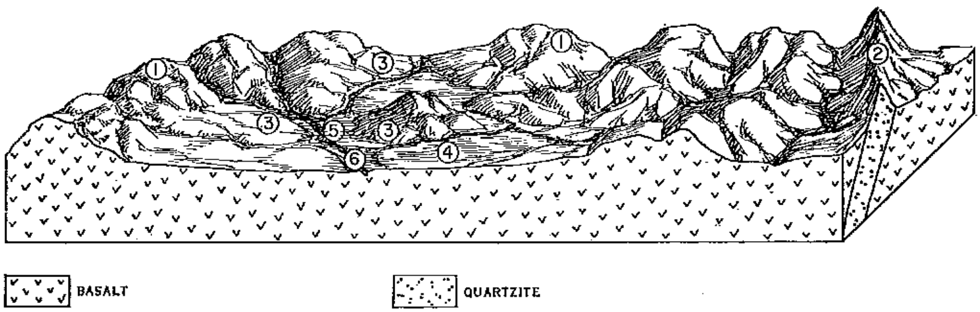
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	41	**Domes:** up to 500 ft high; rounded crests, commonly with joint block cappings, and convex slopes up to 80%	Rock outcrop with very limited pockets of sandy skeletal soils (24)	Much bare rock, vegetated only in cracks, crevices, and pockets of soil. Scattered trees and shrubs with tussocks of *Plectrachne bynoei* and other grasses. *Adansonia gregorii* alliance (32)
2	16	**Lower slopes:** typically less than 2% and ¼ mile long; colluvial mantles and local outcrop	Deep brown sands: Kalyeeda family (9)	Very open woodland with scattered tussocks of *Chrysopogon* spp. and *Plectrachne pungens*. *E. tectifica* and *E. argillacea* alliances (14*b*, 14*c*, 18); also 9*b*
3	37	**Alluvial drainage floors:** up to 1 mile wide, gradients 1 in 100 to 1 in 500; scalded, sandy surfaces	Mainly greyish to brownish sands and loams over tough domed clays: Jurgurra family (19). Some deep brown sands: Kalyeeda family (9)	Very open grassy woodland with *Sehima nervosum–Sorghum* spp. and *Enneapogon* spp. ground storeys. *E. brevifolia* and *E. tectifica* alliances (1*f*, 14*a*); also 36 and 49
4	6	**Channels:** up to 100 ft wide and 15 ft deep	Bed-load deep coarse sand and gravel	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (41, 42); and 33 on smaller channels

Looingnin Land System (1600 sq miles)

Basalt mountains and hills, shallow stony red earths, and grassy grey box woodlands.

Geology.—Basalt and dolerite of Upper Proterozoic or Lower Cambrian age; minor Upper Proterozoic quartzite and sandstone.

Geomorphology.—Mountain and hill ranges eroded below the Kimberley surface: basalt hills and ridges, restricted lower slopes, and minor quartzite ridges, in strike belts up to 80 miles long and 16 miles wide; moderately dense rectangular pattern of incised valleys; relief up to 300 ft.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	58	Basalt hills and ridges: up to 200 ft high and 3 miles long; benched slopes up to 60% with basal scree slopes up to 20%	Mainly outcrop with locally developed shallow red basaltic soil: Walsh family (4)	Low, very open grassy woodland with scattered shrubs and *Sehima nervosum–Sorghum* spp. ground storey. *E. tectifica* alliance (14*a*); locally 14*b* and 1*e*
2	5	Quartzite ridges: up to 300 ft high and 4 miles long; narrow, rocky crests and steep benched slopes with boulder mantles	Mainly outcrop with very limited soil development	Low open woodland with *Plectrachne pungens*. *E. brevifolia* community (1*d*)
3	26	Lower slopes: concave up to 7%, and up to ½ mile long; dissected into interfluves up to 15 ft high and ¼ mile wide; patchy cobble mantles	Mainly shallow red basaltic soil: Walsh family (4). Locally developed dark self-mulching heavy clays: Cununurra family (12)	Open grassy woodland with *Sehima nervosum–Dichanthium fecundum* ground storey. *E. tectifica* alliance (15); also 14*a* and 1*e*
4	2	Plains: hummocky surfaces up to 1 mile wide with slopes less than 1%; patchy cobble mantles and local outcrop	Dark, self-mulching heavy clays: Cununurra family (12)	Ribbon grass–blue grass grassland with scattered trees. *Chrysopogon* spp.–*Dichanthium fecundum* community (48); also 49
5	2	Drainage floors: up to ¼ mile with channelled tracts up to 100 yd wide; gradients 1 in 200 to 1 in 500	Predominantly reddish sandy to loamy soils:.Tippera family (2). Minor yellowish loamy soils: Elliott family (6). Minor greyish, mottled, loamy soils over tough mottled clayey subsoils: Hooper family (20)	Open grassy woodland with frontage grasses and *Sehima nervosum–Dichanthium fecundum* ground storeys. *E. tectifica* and *E. papuana* alliances (15, 22*a*)
6	7	Channels: up to 50 ft wide and 15 ft deep, incised in bed-rock; ranging from hill-slope channels, gradients up to 1 in 10, to main channels with gradients as low as 1 in 500	Channels, bed-loads range from sand to boulders. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing woodland. *E. camaldulensis–Terminalia platyphylla* fringing communities (41, 43)

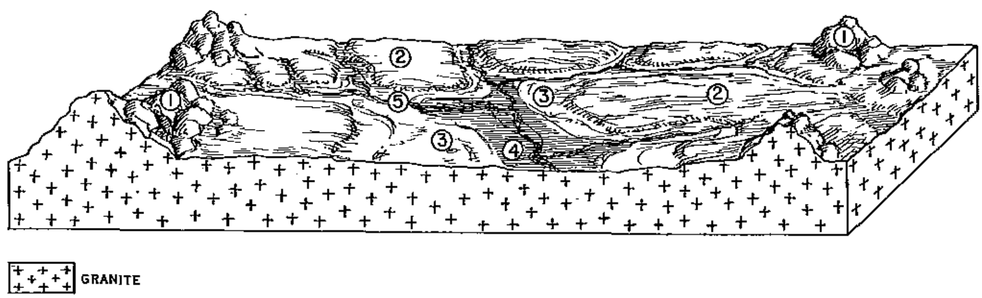
Comparable with Napier land system, North Kimberley area.

TARRAJI LAND SYSTEM (200 SQ MILES)

Gently undulating country with grassy woodlands, scattered granite domes with sparse spinifex and low trees and shrubs.

Geology.—Lower Proterozoic or Archaeozoic granite.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—undulating terrain: gently sloping interfluves, and restricted valley plains, with scattered granite domes up to 400 ft high; dense to moderately dense rectangular pattern of incised drainage; relief mainly less than 30 ft.



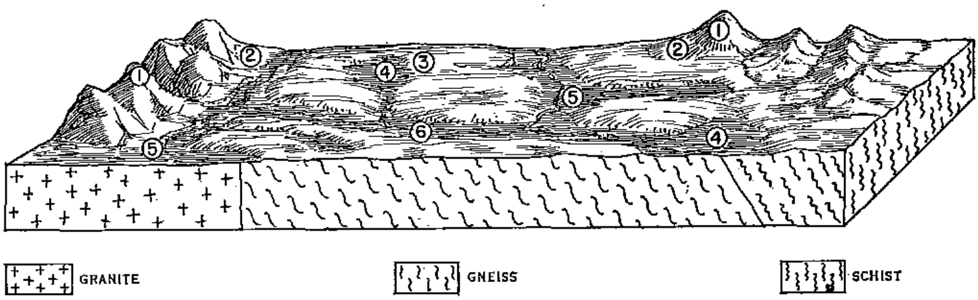
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	18	**Domes**: smooth, convex, outcrop slopes, up to 80%, with joint-block cappings	Predominantly outcrop	Much bare rock. Vegetated only in cracks, crevices, and pockets of soil. Very open woodlands with sparse ground storey of tussocks of *Plectrachne bynoei* and other grasses. *E. perfoliata–Adansonia gregorii–E. dichromophloia* community (32)
2	58	**Interfluves**: up to 1 mile wide with slopes less than 0·5%, attaining 3% adjacent to domes; marginally dissected up to 30 ft with slopes up to 20% and local outcrop; sandy, pebble-strewn surfaces	Greyish sands over tough loamy subsoils: Tarraji family (18). With deep brown sands: Kalyeeda family (9)	Open woodlands with patches of paper-bark trees, scattered shrubs with *Plectrachne pungens*, short grasses, and *Chrysopogon* spp. *E. brevifolia*, *E. dichromophloia*, and *E. tectifica* alliances (1*d*, 1*f*, 8*d*, 14*b*)
3	8	**Valley plains**: up to 3 miles in extent with slopes less than 0·2%; lightly firmed, locally scalded surfaces with grit patches	Weakly mottled yellowish loamy soils: Elliott family (6)	Grassy woodland with *Chrysopogon* spp. *E. tectifica* community (14*b*)
4	8	**Drainage floors**: up to 1 mile wide, gradients 1 in 100 to 1 in 500	Clayey alluvial soils with loose subsoils: Fitzroy family (22)	Grassy woodland with frontage grasses. *E. papuana–E. alba* community (23)
5	8	**Channels**: up to 200 ft wide and 20 ft deep	Channels, bed-loads of deep sand and pebble. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing community (42)

O'Donnell Land System (500 sq miles)

Stony undulating country with scattered hills, loamy skeletal soils, open woodlands with short grasses and restricted cracking clay plains.

Geology.—Gneiss, granite, and schist of Lower Proterozoic or Archaeozoic age.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—undulating terrain: gently sloping low interfluves, scattered, rocky hills and ridges with restricted hill-foot slopes, and local cracking clay plains; moderately dense rectangular pattern of incised drainage; relief mainly less than 30 ft.



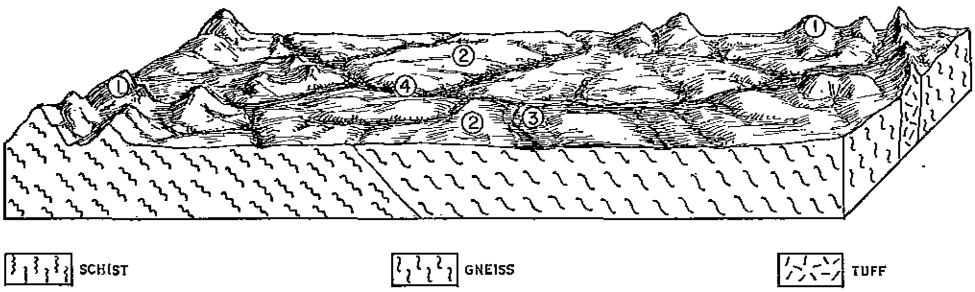
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	12	**Hills and ridges:** less than 200 ft high; benched slopes up to 70%, locally vertical, and basal scree slopes up to 35%	Outcrop with limited areas of reddish, shallow, gravelly skeletal soil (24)	Open snappy gum woodland with *Plectrachne pungens. E. brevifolia* community (1*d*)
2	12	**Hill-foot slopes:** concave, up to 10%, and less than ¼ mile long; outcrop and cobble debris in upper parts, colluvial mantles in lower parts	Outcrop, with reddish skeletal soil (24). Some shallow red sands: Cockatoo family (7)	Mixed grasslands with scattered trees and shrubs. Local bare patches. *Chrysopogon* spp.–*Dichanthium fecundum* and *Enneapogon* spp. communities (48, 61)
3	51	**Interfluves:** flat or gently sloping crests up to 1% and 1 mile wide, with marginal slopes up to 2%; cobble mantles and local outcrop	Outcrop, with reddish sandy and loamy skeletal soils (24). With shallow brownish sands and loams over red clay: Moonah family (17)	Very open grassy woodland with *Enneapogon* spp. and other short grasses. *E. brevifolia* community (1*f*)
4	6	**Cracking clay plains:** less than 1% and 2 miles wide; hummocky surfaces	Dark brown self-mulching clays: Wonardo family (14)	Mitchell grass and ribbon grass–blue grass grasslands with sparse trees and shrubs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* and *Chrysopogon* spp. communities (47, 48, 49)
5	10	**Alluvial drainage floors:** up to ¼ mile wide with gradients 1 in 100 to 1 in 400; sandy surfaces with pebble patches	Complex of greyish to brownish sands and loams over tough domed clays: Jurgurra family (19). Mottled yellowish sandy to loamy soils: Elliott family (6). Clayey alluvial soils: Fitzroy family (22)	Mixed grasslands as in unit 2
6	9	**Channels:** up to 300 ft wide and 15 ft deep	Channels, bed-loads range from deep sand to cobbles. Banks, brownish loamy alluvial soils: Robinson family (21)	Open woodland fringing community with patches of frontage grasses. *E. camaldulensis* community (40)

Pigeon Land System (1300 sq miles)

Stony undulating country with scattered rocky hills, sandy shallow soils, grassy woodlands and curly spinifex.

Geology.—Gneiss, schist, minor granite, and minor quartz reefs of Lower Proterozoic or Archaeozoic age.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—undulating terrain: strike belts up to 10 miles wide and 30 miles long, comprising broad interfluves and hill-foot slopes with relief up to 30 ft, scattered gneiss hills, schist ridges, and minor quartz reef ridges, mainly less than 100 ft high but locally attaining 300 ft; dense rectangular or branching pattern of incised tributary drainage, with through-going alluvial trunk floors.



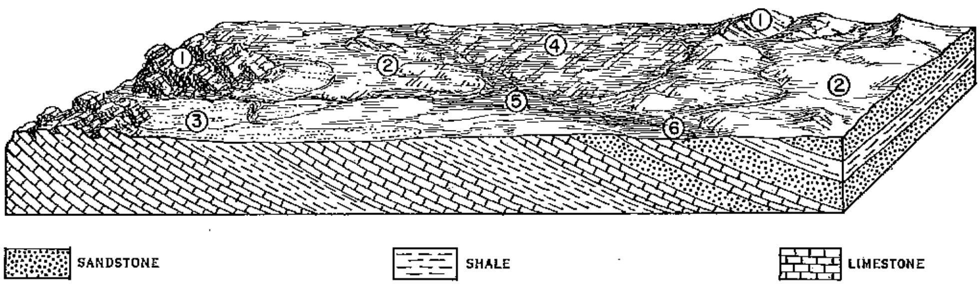
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	24	**Rocky hill slopes:** benched, up to 70%, locally vertical, with basal scree slopes up to 35%	Predominantly outcrop	Very open woodlands with *Plectrachne pungens*. *E. brevifolia* community (3); also 16, 54
2	55	**Lower slopes and interfluves:** concave lower slopes, up to 10% and less than 1 mile long; interfluves up to 3 miles in extent, and 10 ft high, with slopes less than 5%; locally dissected up to 30 ft into spurs with gently sloping crests and marginal slopes up to 25%; colluvial mantles with cobble patches and local outcrop	Sandy and loamy, gravelly skeletal soils (24) with some outcrop	Very open grassy woodland with *Plectrachne pungens* and *Enneapogon* spp. *E. brevifolia* and *E. dichromophloia* alliances (1*f*, 3, 8*c*, 11); locally 8*a*
3	11	**Drainage floors:** up to 1 mile with marginal slopes up to 2% and gradients 1 in 200 to 1 in 800; pebble-strewn scalded surfaces	Brownish sands and loams over red clay: Moonah family (17), lithic in nature on marginal slopes	Grassy woodland with *Chrysopogon* spp. and frontage grasses. *E. dichromophloia* and *E. papuana* alliances (8*d*, 22*a*)
4	10	**Channels:** up to 200 ft wide and 10 ft deep, incised in bed-rock; ranging from head-water channels, gradients up to 1 in 30, to main channels with gradients as low as 1 in 800	Channels, bed-loads range from sand to cobbles. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (42, 43); smaller streams 33

Neillabublica Land System (1000 sq miles)

Undulating limestone country with scattered low hills and cracking clay plains. Open grassy woodlands, grasslands, and spinifex.

Geology.—Dipping or gently folded limestone, calcareous sandstone, and shale of Devonian age.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—undulating terrain: undulating plains in strike belts up to 4 miles wide and 50 miles long, with low interfluves and rocky surfaces, comprising plateaux, rounded hills, and cuestas, up to 100 ft high; sandy or calcareous alluvial plains in the lowest parts; moderately dense rectangular pattern of strike-controlled drainage; relief mainly less than 30 ft.



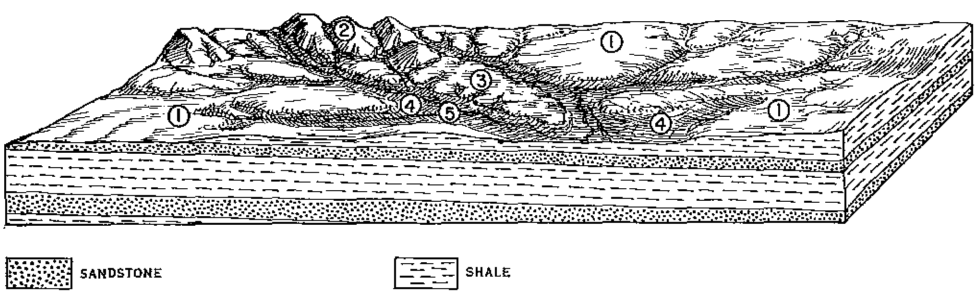
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	13	**Rocky surfaces:** up to 1 mile in extent; plateaux and hill crests sloping less than 2%, dip slopes up to 5%; scarp and hill slopes comprise vertical upper walls rising above boulder-strewn slopes up to 50%	Mainly outcrop with very limited shallow soil formation	Very open baobab and bloodwood woodlands with *Triodia wiseana*. *E. dichromophloia* and *Adansonia gregorii* alliances (8*a*, 30)
2	51	**Interfluves:** up to 3 miles wide; pebble-strewn slopes typically less than 2%, with local outcrop; marginally dissected up to 20 ft	Shallow dark brown and reddish brown to dark grey, loamy to clayey, calcareous soils: Oscar family (11)	Spinifex steppe and open woodlands with *Triodia wiseana* and *Chrysopogon* spp. *E. dichromophloia* alliance (8*a*, 8*d*); locally 1*c*, 9*a*, 9*b*, 58
3	10	**Sandy alluvial aprons and plains:** aprons up to ½ mile long, gradients 1 in 20 to 1 in 60, and plains up to 5 miles wide with gradients less than 1 in 200; traversed by shallow flood channels	Dark brown to dark grey loamy to clayey calcareous soils: Neillabublica family (10). Minor areas of reddish sandy soils: Yabbagoddy family (1)	Grassy bloodwood and box woodlands with *Chrysopogon* spp. *E. dichromophloia–E. argillacea* community (9*b*)
4	20	**Cracking clay plains:** up to 1 mile in extent with slopes less than 0·5%; hummocky surfaces	Dark strongly self-mulching heavy clays: Cununurra family (12)	Mitchell grass and ribbon grass–blue grass grasslands with scattered trees and shrubs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48); locally 37*a*
5	2	**Drainage floors:** up to 300 yd wide, gradients 1 in 100 to 1 in 500	Clayey alluvial soils: Fitzroy family (22)	Grassy woodlands with frontage grasses. *E. papuana* community (22*a*)
6	4	**Channels:** up to 150 ft wide and 10 ft deep	Bed-loads range from sand to boulders on bed-rock	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* community (42); small streams 39

Glenroy Land System (600 sq miles)

Stony undulating shale country with broad alluvial drainage floors, yellowish fine-textured skeletal soils, open woodlands with curly spinifex and grassy woodlands.

Geology.—Subhorizontal and gently dipping sandstone and shale of Upper Proterozoic age.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—undulating terrain: broad, gently rounded interfluves with scattered low hills and minor cracking clay plains; dense branching pattern of tributary drainage in upper parts and through-going alluvial trunk drainage; relief typically less than 30 ft with infrequent hills up to 100 ft.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	50	**Interfluves**: up to 2 miles wide and less than 30 ft high with slopes up to 2%; locally with "stepped" slopes comprising steeper facets, up to 1·5%, separating gently sloping facets, less than 0·5%; locally dissected up to 20 ft into spurs with flat or gently sloping crests up to ½ mile wide and marginal slopes up to 25%; cobble mantles and local outcrop	Yellowish, fine-textured skeletal soils (24)	Open woodlands with moderately dense shrub layers and *Plectrachne pungens* and *Chrysopogon* spp. *E. brevifolia* alliance (*1d*, *1e*); also 54
2	7	**Hills**: up to 100 ft high; bevelled rocky crests up to ½ mile wide and hill slopes up to 60%	Outcrop and yellowish skeletal soils high in rock fragments (24)	Open woodlands with moderately dense shrub layers and *Plectrachne pungens*. *E. brevifolia* community (*1d*)
3	3	**Cracking clay plains**: up to 2¼ miles in extent with slopes less than 0·5%; marginally dissected up to 10 ft with slopes up to 5%; hummocky surfaces	Olive brown moderately mulching weakly cracking heavy clays: Wonardo family (14)	Ribbon grass–blue grass grasslands with scattered trees and shrubs. *Chrysopogon* spp.–*Dichanthium fecundum* community (48)
4	25	**Alluvial drainage floors**: sealed surfaces up to ¾ mile wide with levees up to 3 ft high and 300 yd wide; gradients 1 in 200 to 1 in 500	Mainly yellowish sandy to loamy soils of variable depth: Elliott family (6). Some local areas of clayey alluvial soils: Fitzroy family (22)	Grassy woodland with frontage grasses. *E. papuana* community (*22a*); also 19, 27
5	15	**Channels**: up to 100 ft wide and 20 ft deep, locally incised in bed-rock	Channels, bed-loads range from sands to cobbles. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis*–*Terminalia platyphylla* fringing communities (40, 42, 43)

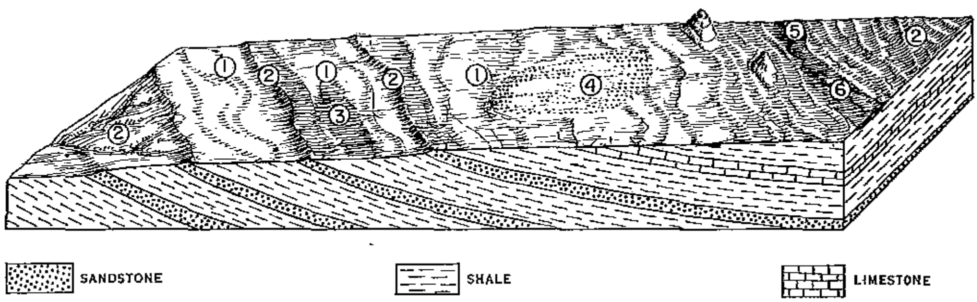
Comparable with the low undulating country (units 1, 4) of Pago land system, North Kimberley area.

MYROODAH LAND SYSTEM (2000 SQ MILES)

Outcrop plain, with extensive scalded surfaces, spinifex and low very open woodlands.

Geology.—Gently folded Permian sandstone, shale, and sandy limestone; Jurassic lamproite; Quaternary aeolian sands.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—plains: up to 70 miles in extent; soil-covered areas, consisting of strike-aligned flats with degraded soils and low rises with relatively stable soil surfaces; stony surfaces comprising outcrop plains and low cuestas; ill-drained linear depressions and sand plain islands; sparse, through-going, channelled drainage floors with strike-aligned, generally unchannelled, tributary floors; relief mainly less than 30 ft.



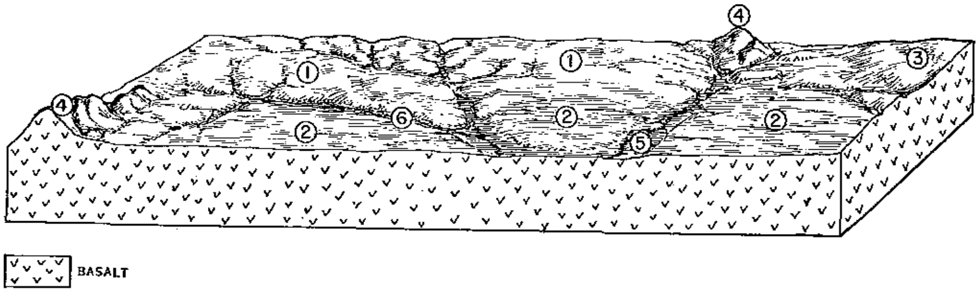
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	66	**Soil-covered plains**: regional slopes generally less than 0·3%; pebble-strewn flats with sealed, scalded soil surfaces; strike rises up to 1 ft high and 400 yd wide on steeper slope facets up to 1%, with loose sandy surfaces	Mainly brownish sands and loams over red clay: Moonah family (17). Some reddish loamy soils with variable strew cover: Tippera family (2)	Much bare ground. Extensive *Triodia intermedia* grasslands (57). Groves of low depauperate woodlands: *Grevillea striata* and *Bauhinia cunninghamii* alliances (34*a*, 34*b*, 34*c*, 37*b*) and 8*b*
2	18	**Stony surfaces**: plains sloping less than 0·5%, in strike belts up to 2 miles wide and up to 10 miles long; cuestas with scarp slopes up to 10% and 30 ft high; concave slopes up to 2% and up to 1 mile long, marginal to main rivers outside land system	Ferruginized outcrop and strew with reddish loamy skeletal soils (24)	Spinifex grassland with very scattered low trees and shrubs and local groves of depauperate woodland. *Triodia intermedia* grassland (57) and *Adansonia gregorii* woodland (31)
3	5	**Ill-drained strike depressions**: up to 1 mile wide and 2 miles long, slopes less than 0·3%; alternate scalded flats and sandy steeper facets, up to 1% and 100 yd wide	Probably reddish brown crusty heavy clays: Cherrabun family (15)	Fringing woodlands of coolibah and *Triodia pungens*. *E. microtheca* community (20*c*)
4	4	**Sand plain islands**: up to 3 miles in extent, slopes less than 1%	Deep red sands, commonly with some lateritic gravels: Cockatoo family (7)	Pindan and depauperate beefwood woodlands. *E. dichromophloia* and *Grevillea striata* alliances (10, 34*b*); also 54
5	6	**Drainage floors**: up to ½ mile wide and 1 ft deep; gradients 1 in 200 to 1 in 600, sealed surfaces with sand hummocks	Complex of brownish sands and loams over red clays: Moonah family (17). With reddish sandy and loamy soils: Tippera family (2). Both commonly scalded and sealed	Low beefwood woodland with *Chrysopogon* spp. *Grevillea striata* alliance (33); locally 34*a*, 48
6	1	**Channels**: up to 100 ft wide and 10 ft deep	Channels, bed-loads of deep sand. Banks, brownish loamy alluvial soil: Robinson family (21)	Fringing woodland. *E. camaldulensis*–*Melaleuca* spp. community (41)

Cowendyne Land System (700 sq miles)

Stony, undulating basalt country with red earths and grassy woodlands, also extensive cracking clay plains with grasslands.

Geology.—Basalt and dolerite of Upper Proterozoic or Lower Cambrian age.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—plains: stony interfluves and cracking clay plains, with low rises in headwater areas and scattered hills; moderately dense branching drainage pattern in upper parts with sparse pattern of trunk drainage in lower parts; relief mainly less than 20 ft.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	36	Stony interfluves: flat or gently rounded crests up to 1 mile wide, with marginal slopes less than 5% but attaining 7% locally; colluvial mantles with local outcrop	Deep red basaltic soil: Frayne family (3)	Open grassy woodland. On hills and rocky slopes: *E. tectifica* with *Sehima nervosum–Sorghum* spp. (14*a*). On lower slopes: *E. tectifica–E. dichromophloia* with *Sehima nervosum–Dichanthium fecundum* ground storey (15)
2	46	Cracking clay plains: up to 4 miles wide with slopes less than 1%; marginally dissected up to 10 ft into rounded spurs up to ¼ mile wide with slopes up to 3%; hummocky surfaces	Dark self-mulching clays: Cununurra family (12)	Grassland of *Chrysopogon* spp.–*Dichanthium fecundum* (48); with scattered trees and shrubs
3	7	Low rises: up to 3 miles wide; pebble-strewn slopes less than 1%	Deep red basaltic soils: Frayne family (3)	Open grassy woodland as in unit 1
4	2	Hills: mainly less than 100 ft high, but up to 200 ft; rounded, rocky crests and benched slopes up to 60%, with boulder mantles	Mainly outcrop with shallow red basaltic soils: Walsh family (4)	Low open grassy woodland, scattered shrubs with *Sehima nervosum–Sorghum* spp. ground storey. *E. tectifica* alliance (14*a*)
5	3	Drainage floors: up to ½ mile wide, gradients 1 in 200 to 1 in 500; central channelled tracts up to 100 yd wide	Limited areas of soils. Reddish clayey alluvial soils: Fitzroy family (22)	Low, open grassy woodland with scattered shrubs and *Sehima nervosum–Sorghum* spp. ground storey. Community 14*a*
6	6	Channels: up to 100 ft wide and 10 ft deep	Bed-loads range from fine sand to cobbles	Fringing forest or woodland. *E. camaldulensis–Terminalia platyphylla* fringing communities (41, 42); and 33 on smaller channels

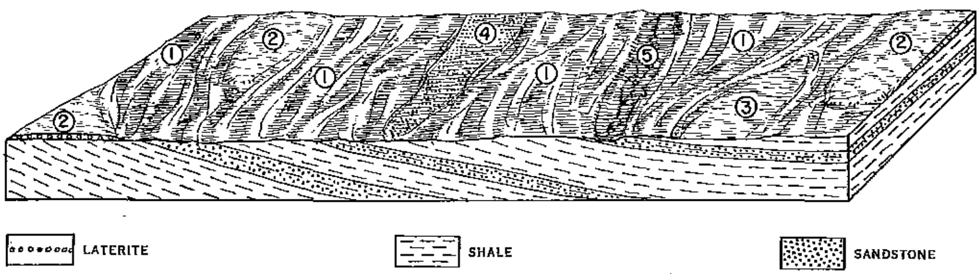
Comparable to a combination of Isdell, Barton, and Kennedy land systems, North Kimberley area.

EGAN LAND SYSTEM (600 SQ MILES)

Outcrop plains with low lateritic rises, grassy woodlands and spinifex. Restricted cracking clay plains.

Geology.—Weathered gently folded silty sandstone and shale of Permian and Triassic age; Quaternary aeolian sands.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—plains: plains up to 8 miles wide, extending along the strike up to 24 miles, with low, lightly stripped lateritic rises, restricted black earth plains, and minor sand plain tracts; sparse, ill-defined drainage pattern locally with alluvial floors; relief less than 10 ft.



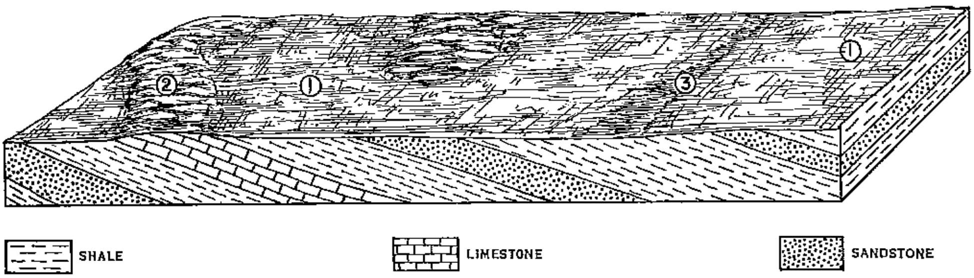
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	70	**Plains:** slopes mainly less than 0·5%, but attaining 1% locally; bevelled outcrop evident in linear rises less than 1 ft high and up to 200 yd wide; extensively scalded sandy surfaces with pisolith detritus	Yellowish loamy soils, commonly with lateritic gravels: Elliott family (6)	Low grassy woodland with variable shrub layers and ground storeys. *E. dichromophloia*, *Grevillea striata*, and *Bauhinia cunninghamii* alliances (11, 34*a*, 37*a*, 38*c*); also locally 8*d*, 10, 49, 55
2	15	**Lightly stripped rises:** less than 10 ft high and up to 1 mile wide; sandy surfaces with lateritic detritus	Reddish sandy and loamy soils, commonly with rock fragments and/or lateritic gravels: Yabbagoddy (1) and Tippera (2) families	Open spinifex. *Triodia intermedia* community (57); with patches of 10 and 16
3	8	**Cracking clay plains:** up to 1 mile wide and extending along the strike for up to 3 miles; gilgais and scalds locally, with cobble patches	Light olive brown self-mulching clays: Wonardo family (14)	Mitchell grass and ribbon grass–blue grass grasslands. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48)
4	5	**Sand plain:** up to ½ mile wide, with slopes less than 1%	Deep red sands: Cockatoo family (7)	Low woodland (pindan) with prominent *Acacia* shrub layer and *Plectrachne pungens*–*Chrysopogon* spp. ground storey. *E. dichromophloia*–*E. zygophylla*–*Acacia* spp. community (10)
5	2	**Drainage floors:** up to ¼ mile wide, gradients 1 in 200 to 1 in 500; sealed, scalded surfaces with numerous runnels and locally with channels up to 30 ft wide and 4 ft deep; bed-loads of deep sand	Probably brownish sand and loams over red clay: Moonah family (17). Minor reddish loamy soils: Tippera family (2)	Grassy woodland with *Chrysopogon* spp. and frontage grasses. *E. dichromophloia* and *Adansonia gregorii* alliances (12, 33)

Duffer Land System (200 sq miles)

Cracking clay plains with grasslands and scattered trees and shrubs.

Geology.—Gently folded Permian shale, siltstone, limestone, and sandstone; Triassic shale.

Geomorphology.—Formed by partial dissection of the Fitzroy surface—plains: strike tracts up to 20 miles long and 10 miles wide, comprising almost flat cracking clay plains and restricted outcrop plains; sparse ill-defined pattern of strike-controlled drainage; relief less than 10 ft.



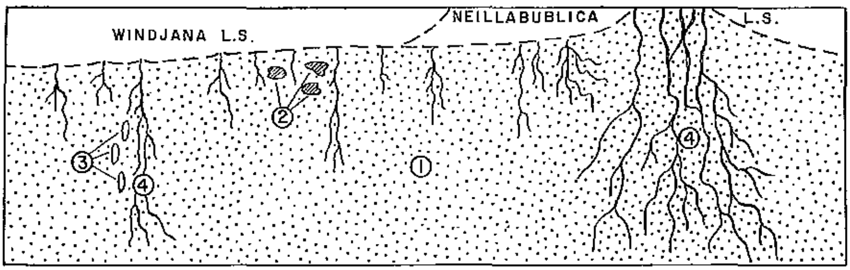
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	86	**Cracking clay plains:** up to 10 miles wide with slopes less than 0·2%; sealed, cracking surfaces with gilgais locally	Dark grey and brown self-mulching heavy clays: Cununurra (12) and Wonardo (14) families	Grasslands with scattered trees and shrubs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48); locally 37*a*
2	10	**Outcrop plains:** up to 1 mile wide; cobble-strewn slopes up to 2% with local outcrop	Yellowish sandy soils of variable depth: Tableland family (5). Some outcrop	Open grassy woodland with *Chrysopogon* spp. *E. dichromophloia*–*E. grandifolia* community (12)
3	4	**Drainage floors:** up to 300 yd wide with numerous shallow channels; gradients 1 in 300 to 1 in 500	Clayey alluvial soils: Fitzroy family (22) and juvenile cracking clays (16)	Open coolibah and *Bauhinia* fringing communities. *E. microtheca* and *Bauhinia cunninghamii* alliances (20*a*, 20*c*, 39)

Fossil Land System (1200 sq miles)

Extensive dark cracking clay plains formed on limestone deposits with grasslands.

Geology.—Quaternary calcareous alluvium; outcrops of Devonian limestone locally.

Geomorphology.—Alluvial plains—tributary alluvial plains: strike belts up to 30 miles long and 10 miles wide at the foot of limestone ranges, comprising cracking clay plains with minor outcrop rises up to 20 ft high and restricted, low, linear sandy rises; sparse subparallel pattern of short drainage zones at upper margin, and moderately dense pattern of subparallel anastomosing distributary drainage in belts up to 6 miles wide in lowest sectors.



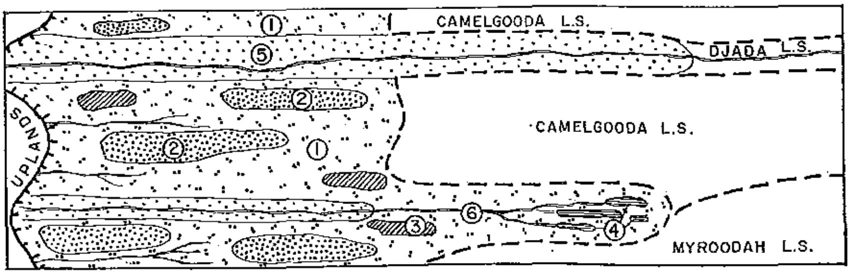
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	83	**Cracking clay plains**: gradients mainly less than 1 in 500 but up to 1 in 100; locally with marginal dissection up to 20 ft; hummocky surfaces with gilgais	Dark grey and brown, strongly self-mulching heavy clay: Cununurra (12), Wonardo (14) families. Commonly with gilgais	Mitchell grass, ribbon grass–blue grass, and ribbon grass grasslands and very open grassy woodlands. *Astrebla* spp., *Chrysopogon* spp.–*Dichanthium fecundum*, and *Chrysopogon* spp. communities (47, 48, 49) and *Bauhinia cunninghamii* alliance (37*a*, 38*c*); locally 20*b*
2	4	**Outcrop slopes**: less than ¼ mile in extent; cobble-strewn slopes up to 10%	Outcrop with shallow, dark brown and grey, loamy to clayey calcareous soils: Oscar family (11)	Spinifex with scattered trees and shrubs, and open woodlands. *Triodia wiseana* community (58) and *E. dichromophloia* alliance (8*a*, 8*b*)
3	1	**Sandy rises**: up to 2 ft high and less than 100 yd long, flanked by narrow linear depressions up to 1 ft deep	Yellowish sandy soils: Tableland family (5)	Open grassy woodland with *Chrysopogon* spp. *E. dichromophloia*–*E. argillacea* community (9*b*)
4	12	**Drainage zone**: up to ½ mile wide, with numerous channels up to 60 ft wide and 15 ft deep; gradients 1 in 200 to 1 in 2000	Dark grey and brown, strongly self-mulching heavy cracking clay: Cununurra (12) and Wonardo (14) families	Open grassy woodland with *Chrysopogon* spp.–*Dichanthium fecundum*, frontage grasses, and *Chrysopogon* spp. ground storeys. *Bauhinia cunninghamii* alliance (37*a*, 37*b*, 39); locally 43

COONANGOODY LAND SYSTEM (800 SQ MILES)

Sandy alluvial plains with broad through-going drainage floors, low grassy woodlands.

Geology.—Quaternary alluvium derived mainly from sandstone and shale; aeolian sands.

Geomorphology.—Alluvial plains—tributary alluvial plains: sandy plains extending up to 3 miles downslope, with low interfluves formed by sand plain and minor outcrop plains; trunk drainage floors with anastomosing channels and broad linear drainage depressions in the lowest parts, elsewhere broad tracts receiving diffuse run-on from adjacent uplands; gradients mainly between 1 in 500 and 1 in 100.



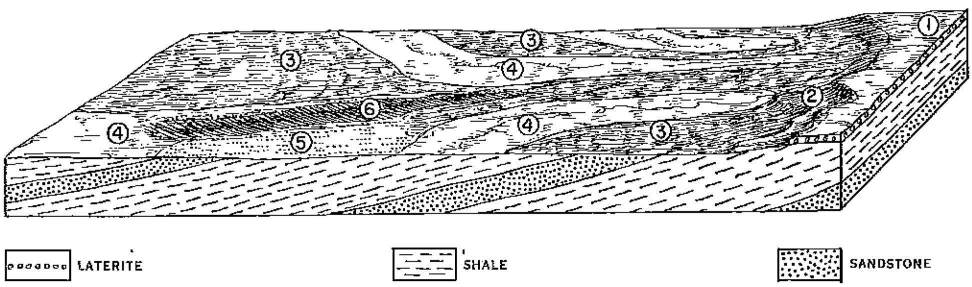
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	52	**Alluvial plains**: gradients mainly less than 1 in 500 but attaining 1 in 150 at upper margins; degraded soil surfaces	Yellowish sandy soils with local alluvial or solonetzic tendencies: Tableland family (5)	Very open, low grassy woodland with short grasses and patches of *Chrysopogon* spp. *Bauhinia cunninghamii–Ventilago viminalis* community (38*c*); also 1*f*
2	23	**Sand plain islands**: up to 2 miles across; uniformly sloping or gently undulating, with relief up to 6 ft and slopes up to 3%	Mainly deep red sands: Cockatoo family (7). With deep yellow sands: Pago family (8) in shallow depressions	Open stunted woodland with patchy shrub layer and *Triodia pungens*, *Chrysopogon* spp., and *Aristida browniana*. *Grevillea striata* and *Bauhinia cunninghamii* alliances (34*b*, 37*b*, 38*c*)
3	8	**Outcrop plains**: stony surfaces up to 2 miles across, slopes less than 1%, marginally dissected up to 30 ft; thin patchy cover of sand and grit and much outcrop	Variable soil cover depending on lithology. Mainly reddish skeletal soil (24), high in rock fragments with 90% strew cover. Minor amounts of shallow, dark brown and reddish brown, loamy to clayey, calcareous soils: Oscar family (11)	Much bare ground; patches of grasslands. Communities 57, 55, 54; and 58 on calcareous soils
4	3	**Linear drainage depressions**: up to ½ mile wide and 3 miles long; firmed surfaces locally with pans up to ¼ mile across	Yellowish sandy soils commonly with lateritic gravels and hard subsoils: Tableland family (5). Brownish, massive, intractable, silty to heavy clay in pans (30)	Low beefwood woodland with *Chrysopogon* spp. *Grevillea striata* community (34*a*)
5	11	**Drainage floors**: up to 2 miles wide, gradients mainly between 1 in 200 and 1 in 500; lightly firmed hummocky surfaces with scalds up to ½ mile across; levees up to ½ mile wide; loose sand rises up to 6 ft high at outer margins	Grey to brownish sands and loams over tough loamy subsoils or tough, domed clays: Tarraji (18) and Jurgurra (19) families	Low beefwood woodland with *Triodia pungens*. *Grevillea striata* community (34*b*)
6	3	**Channels**: up to 500 ft wide and 20 ft deep	Bed-loads of deep sand	Fringing woodland with *Chrysopogon* spp. Community 20*a*

Calwynyardah Land System (500 sq miles)

Alluvial plains downslope from lateritic remnants, yellowish loamy soils, beefwood grassy woodlands.

Geology.—Quaternary alluvium; weathered gently folded sandstone and shale of Permian and Triassic age.

Geomorphology.—Alluvial plains—tributary alluvial plains: up to 12 miles in extent, comprising loamy alluvial plains with extensive scalded areas and minor sand plain islands, occurring downslope from restricted lateritized summit remnants; sparse pattern of subparallel alluvial drainage floors.



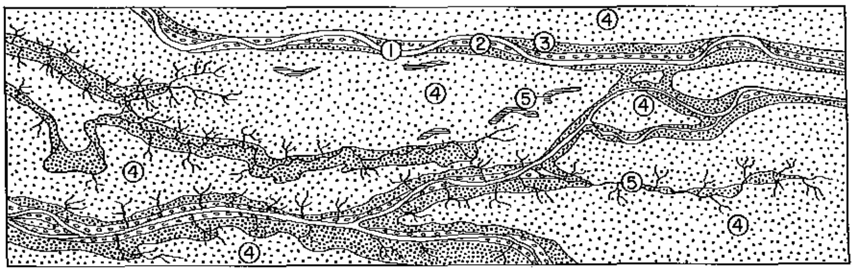
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	8	Summit remnants: up to 50 ft high; sandy slopes less than 0·3%, but up to 7% adjacent to breakaways, with local exposures of laterite and weathered rock; delimited by breakaways up to 40 ft high or by stony slopes up to 2%	Reddish loamy soils: Tippera family (2). Laterite exposure in and marginal to breakaways	Mainly spinifex grassland with scattered trees and shrubs. *Triodia intermedia* community (57); locally 54 and 16
2	4	Lower slopes: concave, up to 3%, and less than 1 mile long, forming gently rounded spurs up to 5 ft high and ¼ mile wide with marginal slopes less than 1%; colluvial mantles and local outcrop	Complex association of reddish sandy and loamy soils: Tippera family (2); and brownish loams over red clay: Moonah family (17)	Spinifex grassland and low beefwood woodland. *Triodia intermedia* community (57) and *Grevillea striata* alliance (34*b* and 34*c*)
3	44	Alluvial plains: up to 2 miles in extent with gradients 1 in 200 to 1 in 500; lightly sealed sandy surfaces with pebble patches	Yellowish sandy soils with laterite gravel horizon: Tableland family (5)	Low beefwood woodland with *Plectrachne pungens*, *Chrysopogon* spp., and *Triodia pungens*. *Grevillea striata* alliance (34*a*, 34*b*, 34*c*)
4	36	Scalded tracts: extending up to 4 miles downslope, gradients 1 in 150 to 1 in 600; sealed, pebble-strewn surfaces traversed by shallow runnels	Association of greyish to brownish sands and loams over tough domed clays: Jurgurra family (19). With yellowish sandy to loamy soils: Elliott family (6)	Much bare ground; patches of beefwood and *Bauhinia* woodlands with *Plectrachne pungens* and *Chrysopogon* spp. *Bauhinia cunninghamii* and *Grevillea striata* alliances (34*a*, 34*c*, 38*a*); also locally grasslands (49, 54)
5	4	Sand plain islands: up to 1 mile wide with slopes up to 2%	Deep red sands: Cockatoo family (7)	Woodland with prominent *Acacia* tall shrub layer and *Plectrachne pungens*–*Chrysopogon* spp. ground storey. *E. dichromophloia* alliance (10, 11) and 56
6	4	Drainage floors: up to ¼ mile wide, gradients 1 in 100 to 1 in 500; locally with channels up to 20 ft wide and 4 ft deep	Brownish sands and loams over red clay: Moonah family (17). Minor occurrence of reddish sandy soils: Yabbagoddy family (1)	Fringing communities (20*c*, 33)

ALEXANDER LAND SYSTEM (500 SQ MILES)

Stable, old flood-plains, dark cracking clays, Mitchell grass grasslands and open grassy woodlands.

Geology.—Quaternary alluvium.

Geomorphology.—Alluvial plains—stable flood-plains: extensive plains of dark cracking clays with shallow marginal dissection adjacent to restricted active levee zones; meandering, anastomosing channels; gradients 1 in 2000 to 1 in 4000.



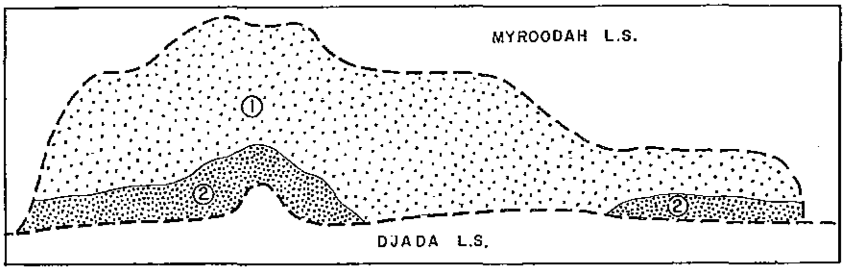
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	2	**Main channels**: up to 500 yd wide and 60 ft deep, distributaries up to 100 yd wide and 20 ft deep; locally incised in bed-rock	Channels, no soil. Banks, brownish loamy alluvial soil: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing community (42)
2	5	**Levee crests**: up to 4 ft high and less than ¼ mile wide; river banks dissected up to 20 ft	Clayey, micaceous, alluvial soils: Fitzroy family (22)	Open grassy woodland with scattered or patchy shrubs, moderately dense, tall to medium-height grass layer and patches of short annual grasses. Forbs seasonal. *E. papuana* alliance (22*a*, 22*b*)
3	16	**Levee back slopes**: up to 1% and ½ mile long; hummocky, scalded surfaces	Brownish juvenile cracking clays (16)	Similar to unit 2 but more open, grasses sparser, scalding common. Communities 22*a*, 22*b*; locally 20*a*
4	73	**Plains**: almost flat plains up to 15 miles in extent with marginal slopes about 0·2%; sealed, hummocky surfaces, and gilgais up to 3 ft deep locally	Dark self-mulching heavy clays: Cununurra family (12)	Grassland communities with scattered trees and shrubs. *Astrebla* spp. (47), *Chrysopogon* spp.–*Dichanthium fecundum* (48) and locally 20*b*
5	4	**Minor channels and billabongs**: channels up to 200 yd wide and 15 ft deep, billabongs typically about 100 yd wide and less than ½ mile long	Brownish, silty to heavy clays: billabong floor soils (30)	Open coolibah woodland fringing communities. *E. microtheca* alliance (20*a*, 20*c*)

Chestnut Land System (150 sq miles)

Restricted stable flood-plains above the level of the active flood-plains, sandy to loamy reddish soils with soft spinifex grasslands with scattered trees.

Geology.—Quaternary alluvium.

Geomorphology.—Alluvial plains—stable flood-plains: plains up to 30 ft above active flood-plains; with marginal, stony erosional slopes; surface drainage absent except for minor ill-defined floors with shallow channels.



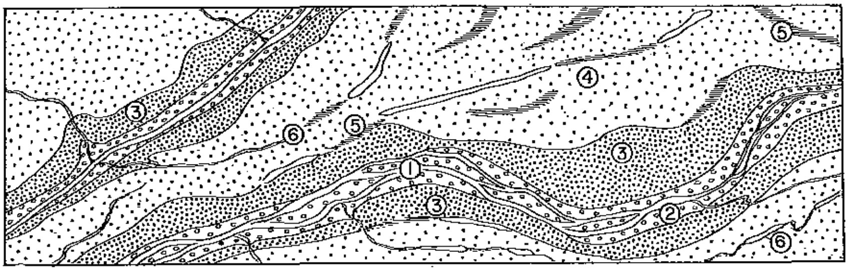
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	88	Plains: up to 10 miles in extent, locally with drainage floors up to 100 yd wide; lightly firmed sandy surfaces with pebble patches; gradients less than 1 in 200	Mainly reddish loamy soils: Tippera family (2). Some reddish sandy soils: Yabbagoddy family (1)	Soft spinifex grassland and very open woodlands with *Triodia pungens* and *Plectrachne pungens*. Communities 55, 8*b*, 8*c*, and locally 34*b*, 20*c*
2	12	Erosional slopes: pebble-strewn concave slopes, up to 2%; minor structural benches	Mainly reddish sandy soils: Yabbagoddy family (1). Some reddish skeletal soil and outcrop (24)	Spinifex grassland with very scattered, stunted trees and shrubs. *Triodia intermedia* community (57)

DJADA LAND SYSTEM (1600 SQ MILES)

Active flood-plains with extensive back plains of cracking clays, grasslands and grassy woodlands.

Geology.—Quaternary alluvium.

Geomorphology.—Alluvial plains—active flood-plains: extensive back plains of dark cracking clays with shallow linear depressions and deeper billabongs, traversed by minor channels; scalded, levee zones flanking meandering and anastomosing channels; main gradients between 1 in 2000 and 1 in 4000 but up to 1 in 400 on tributary flood-plains.



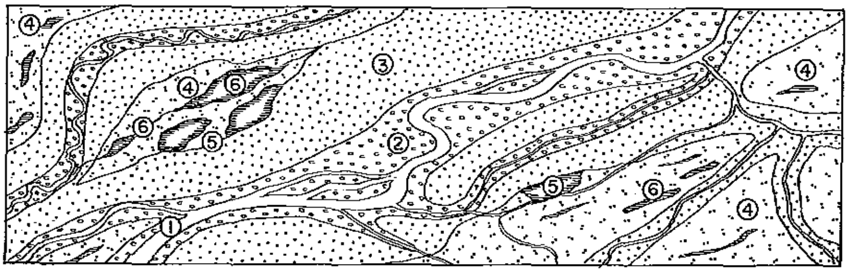
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	5	**Main channels**: up to ½ mile wide and 40 ft deep	Channels no soil. Banks brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (42, 43)
2	8	**Levee crests**: mainly up to 5 ft high and ¼ mile wide, but attaining ½ mile inside meanders; bank slopes up to 1%	Mainly clayey alluvial soils: Fitzroy family (22)	Open grassy woodland with scattered or patchy shrubs moderately dense, tall to medium-height grass layer, and patches of short annual grasses. *E. papuana* alliance (22*a*); locally 22*b*. Forbs seasonal
3	24	**Levee back slopes**: up to 0·5% and ½ mile long, locally up to 2 miles long; broadly undulating with low rises up to 2000 ft across and local slopes up to 1%; hummocky, scalded surfaces	Brownish juvenile cracking clays (16)	Very open grassy woodland or grassland. Subject to degradation and scalding. Patchy, tall to medium-height grasses, short annual grasses, and forbs in season. *E. papuana*, *E. microtheca*, and *Bauhinia cunninghamii* alliances (20*a*, 20*b*, 21, 22*a*, 37*a*, 38*c*); and locally 48. Highest-rainfall parts also include 23, 24
4	46	**Back plains**: almost flat plains up to 5 miles wide with marginal slopes up to 0·2%, including rises up to 3 ft high and 1 mile across with slopes up to 0·4%; sealed, hummocky surfaces with microrelief, and gilgais up to 3 ft deep locally	Mainly dark self-mulching clays with some dark brown self-mulching clays: Cununurra (12) and Wonardo (14) families	Grasslands with scattered trees and shrubs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48); locally 20*b*, 37*b*, 55. Also areas of annual grasses and forbs
5	7	**Depressions**: up to ½ mile wide and 3 ft deep; hummocky, sealed surfaces	Grey crusty heavy clays: Myroodah family (13)	Variable, but commonly tall to medium-height perennial grasses. *Chrysopogon* spp.–*Dichanthium fecundum* and *Chrysopogon* spp. communities (48, 49). Locally annual grasses or forbs
6	10	**Minor channels and billabongs**: channels up to 200 ft wide and 15 ft deep, occurring singly or in zones up to 1½ miles wide; billabongs up to ¼ mile wide and 2 miles long, often linked in series	Mainly brownish, massive, intractable silty to heavy clay (30)	Fringing woodlands (20*a*, 20*c*, 21)

Gogo Land System (600 sq miles)

Active flood-plains with broad levee zones and moderately extensive back plains of cracking clays with grasslands and grassy woodlands.

Geology.—Quaternary alluvium.

Geomorphology.—Alluvial plains—active flood-plains: extensive levee zones, locally flanked by broad flat-bottomed depressions; restricted back plains with billabongs, traversed by minor channels; meandering anastomosing channels; gradients 1 in 2000 to 1 in 4000.



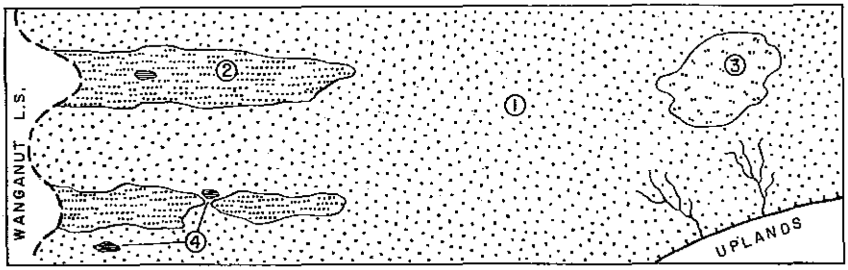
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	6	Main channels: up to ½ mile wide and 40 ft deep	Channels, no soil. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests of several layers. *E. camaldulensis–Terminalia platyphylla* fringing community (42)
2	20	Levee crests: up to 8 ft high and ½ mile wide; bank slopes up to 1%	Mainly clayey, micaceous alluvial soils: Fitzroy family (22). Some loamy alluvial soils: Robinson family (21)	Open grassy woodland with scattered or patchy shrubs, moderately dense tall to medium-height frontage grasses, patches of short natnual grasses. Forbs seasonal. *E. papuana* alliance (22*a*, 22*b*); also 8*d*
3	47	Levee back slopes: up to 0·5%, but attaining 1% locally, and up to 1 mile long; hummocky, scalded surfaces	Brownish juvenile cracking clays (16)	Grassy woodlands more open than in unit 2, with bare scalded areas. *E. papuana* and *E. microtheca* alliances (20*a*, 21, 22*a*, 22*b*); also locally 48. Highest-rainfall parts also 24
4	11	Back plains: up to 1 mile wide, with slopes less than 0·1% but attaining 0·5% at margins; with linear depressions up to ¼ mile wide and 3 ft deep; hummocky, sealed surfaces with gilgais locally	Mainly dark self-mulching heavy clays: Cununurra family (12). With dark brown self-mulching clays: Wonardo family (14). Gilgais common	Mitchell grass and ribbon grass–blue grass grassland with scattered trees and shrubs; also large areas of annual grasses and forbs. *Astrebla* spp. and *Chrysopogon* spp.–*Dichanthium fecundum* communities (47, 48); locally 37*b*
5	6	Depressions: up to ⅝ mile wide and 3 ft deep; short marginal slopes up to 1%	Dark grey crusty heavy clay: Myroodah family (13), commonly showing recent alluvial influence	Tall to medium-height perennial grassland, or annual grasses and forbs, varying according to conditions of flooding. *Chrysopogon* spp.–*Dichanthium fecundum* and *Chrysopogon* spp. (48, 49)
6	10	Minor channels and billabongs: channels up to 10 ft deep and 300 yd wide; billabongs up to 2 miles long, often in linked series	Brownish, massive, intractable, silty to heavy clays (30)	Grassy woodland fringing communities, varying according to conditions of flooding. *E. microtheca* alliance (20*a*, 20*c*, 21)

YEEDA LAND SYSTEM (6100 SQ MILES)

Sand plain, deep red and yellow sands, pindan and tall woodlands.

Geology.—Quaternary aeolian sands.

Geomorphology.—Sand plain and dune fields with little organized drainage; sand plain up to 10 miles in extent, with shallow valleys, plains with thin sand cover, and scattered pans; with limited surface drainage in zones of sheet-flow up to 2 miles wide and extending up to 5 miles downslope from adjacent uplands.



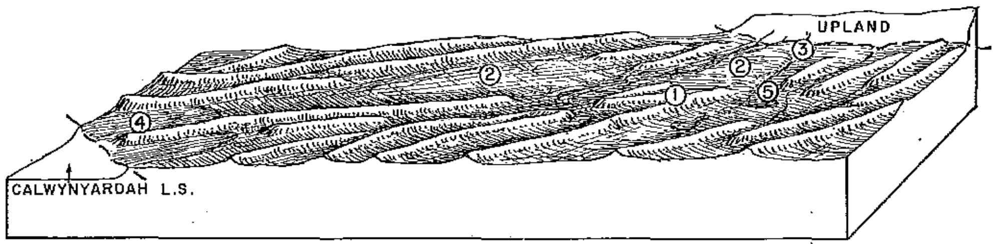
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	82	**Sand plain**: up to 10 miles in extent; slopes mainly less than 1% but up to 2% locally; infrequent rocky hills less than 100 ft high with boulder-strewn slopes up to 60%	Deep red sands: Cockatoo family (7)	Woodland (pindan) with prominent *Acacia* shrub layer and *Plectrachne pungens–Chrysopogon* spp. ground storey. *E. dichromophloia* alliance (10, 11). Higher-rainfall parts: *E. miniata* alliance (28, 29); also 14*c*
2	14	**Shallow valleys**: up to 3 miles wide; gently undulating floors, with slopes up to 3%	Reddish sandy soils: Yabbagoddy family (1). With deep yellow sands: Pago family (8) in higher-rainfall areas	Grassy woodlands with patchy *Acacia* shrub layer and *Chrysopogon* spp. *E. tectifica* and *E. argillacea* alliances (14*b*, 18); also 31. Higher-rainfall parts: *E. miniata* alliance (28, 29)
3	3	**Plains with thin sand cover**: up to 2 miles wide, with slopes less than 0·5%; strike-aligned, scalded flats with intervening rises up to 250 yd wide and 1 ft high; discontinuous sand mantles with pebble patches and outcrop locally	Probably yellowish sandy soils: Tableland family (5). Scalded areas of greyish sands over tough loamy subsoils: Tarraji family (18)	Open patchy woodland with *Chrysopogon* spp. and *Plectrachne pungens*, patches of paperbark trees. *Grevillea striata*, *Bauhinia cunninghamii*, and *Melaleuca* spp. alliances (34*a*, 34*c*, 37*b*, 36)
4	1	**Pans**: less than ½ mile wide and 5 ft deep, with short marginal slopes up to 1%; sealed, cracking surfaces	Brownish, massive, intractable, silty to heavy clays (30)	Various tall grasses (48), with fringes of bloodwood and paperbark woodlands. *E. polycarpa* and *Melaleuca* spp. alliances (26, 36)

Camelgooda Land System (5400 sq miles)

Extensive dune fields, pindan and other low woodlands.

Geology.—Quaternary aeolian sands.

Geomorphology.—Sand plains and dune fields, with little organized drainage: stable dune fields with swales opening locally into sand plain; restricted marginal plains with thin sand cover occur adjacent to dissected tracts and there are minor, isolated hills up to 200 ft high; limited surface drainage mainly as sheet-flow in tracts downslope from uplands and extending for short distances into dune fields; relief up to 40 ft.



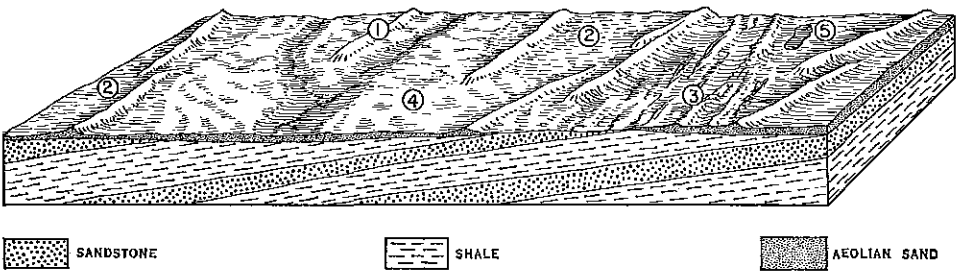
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	26	Dunes: linear, up to 40 ft high and 20 miles long, with narrow uneven crests; flanks slope 3–15% on north side and up to 20% on south	Deep red sands: Cockatoo family (7)	Low woodland of bloodwood and/or *Bauhinia* with prominent tall shrub layer characterized by *Acacia* spp. and *Plectrachne pungens*, *Triodia pungens*, and *Plectrachne pungens–Chrysopogon* spp. ground storeys. *E. dichromophloia* and *Bauhinia cunninghamii* alliances (10, 38*a*, 38*b*); crests 38*c*, locally 55
2	66	Swales and sand plain: swales up to 1 mile wide with flat floors and concave marginal slopes up to 2%; locally opening into sand plain up to 2 miles in extent	Reddish sandy soils: Yabbagoddy family (1)	Low scrubby woodland with prominent tall shrub layer and *Plectrachne pungens–Chrysopogon* spp., *Plectrachne pungens*, and *Chrysopogon* spp. ground storeys. *E. dichromophloia* and *Grevillea striata* alliances (10, 8c, 12, 34*a*); locally 34*b*, 37*b*, 57
3	3	Tracts receiving run-on: up to 1 mile wide and extending downslope for up to 3 miles; slopes less than 0·5%	Mottled yellowish sandy soils: Tableland family (5)	Similar to unit 2 but with patches of paperbark trees (36)
4	2	Plains with thin sand cover: up to 1 mile wide; lightly firmed slopes up to 5% with linear scalds and local outcrop	Mainly reddish sandy soils: Yabbagoddy family (1), with some laterite and rock outcrop	Complex of spinifex grasslands with scattered trees and low open woodlands, *Plectrachne pungens* and *Triodia pungens* communities (54, 55); *Bauhinia cunninghamii* alliance (38*a*, 38*b*)
5	3	Pans and depressions: up to 2 miles wide; depressions very shallow with firmed sandy surfaces; pans up to 6 ft deep, with heavily cracking surfaces and marginal slopes up to 1%	Depressions mainly greyish, mottled, sandy to loamy soils over tough, mottled, clayey subsoils: Hooper family (20). Pans brownish, massive, intractable silty to heavy clays: Billabong floor soils (30)	Commonly *Chrysopogon* spp. grassland (49). Fringes of *Melaleuca* spp. (36) and 21

LULUIGUI LAND SYSTEM (700 SQ MILES)

Sand plain and dune fields with stony surfaces and scalded plains, spinifex and low open grassy woodlands.

Geology.—Quaternary aeolian sands; gently folded Permian sandstone, shale, minor sandy limestone.

Geomorphology.—Sand plain and dune fields with little organized drainage: stable dune fields with pans and shallow drainage depressions, with limited surface drainage mainly as sheet-flow; soil-covered plains traversed by channelled drainage floors; minor stony outcrop plains; relief mainly less than 30 ft but locally attaining 70 ft.



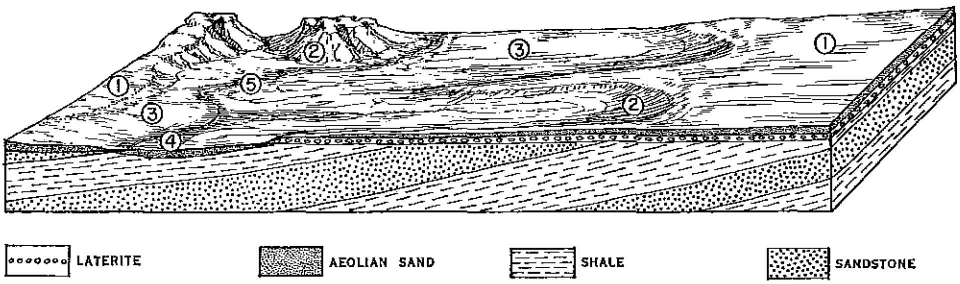
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	16	**Dunes:** linear, up to 30 ft high and 7 miles long with uneven crests; flanks slope up to 15% on north side and up to 20% on south	Deep red sands: Cockatoo family (7)	Low open woodlands (pindan), sparse to moderately dense *Acacia* spp. shrub layer with *Plectrachne pungens–Chrysopogon* spp., *Triodia pungens*, and *Aristida browniana* ground storeys. *E. dichromophloia*, *Grevillea striata*, and *Bauhinia cunninghamii* alliances (10, 34*b*, 38*c*); locally 55
2	40	**Swales and sand plain:** swales up to 1 mile wide with flat floors and marginal slopes less than 2%; opening into sand plain up to 5 miles in extent, with slopes less than 1%	Reddish sandy soils: Yabbagoddy family (1)	Low open woodland (pindan), with prominent *Acacia* spp. shrub and small tree layers and *Plectrachne pungens–Chrysopogon* spp., *P. pungens*, and *Triodia pungens*. *E. dichromophloia*, *Grevillea striata*, and *Bauhinia cunninghamii* alliances (10, 12, 34*a*, 34*b*, 37*b*)
3	14	**Stony outcrop plains:** strike belts, up to 1 mile wide and up to 5 miles long; with slopes generally less than 0·5%; localized escarpments up to 70 ft high with slopes up to 60%	Ferruginized outcrop and strew with loamy and clayey skeletal soils (24)	Spinifex grassland and open baobab woodlands with *Plectrachne pungens–Chrysopogon* spp. ground storey. *Triodia intermedia* community (57) and *Adansonia gregorii–E. perfoliata* community (31)
4	25	**Soil-covered plains:** strike belts up to 3 miles wide and 8 miles long extending in tongues up to ½ mile wide between dunes; traversed by drainage floors up to ½ mile wide, gradients between 1 in 200 and 1 in 600, with channels up to 100 ft wide and 6 ft deep; extensively scalded soil surfaces	Mainly brownish sands and loams over red clay: Moonah family (17). Some reddish loamy soils with variable strew cover: Tippera family (2)	Much bare ground with patches of low, open beefwood or bloodwood woodland with *Chrysopogon* spp. or *Triodia pungens*. *Grevillea striata* and *E. dichromophloia* alliances (34*a*, 34*b*, 8*b*)
5	5	**Pans and drainage depressions:** up to 2 miles wide; depressions less than 1 ft deep with firmed sandy surfaces, pans up to 5 ft deep with bare, cracking surfaces	Yellowish sandy and loamy soils with tough subsoil: Elliott family (6)	Fringing woodlands of coolibah with *Triodia pungens*. *E. microtheca* alliance (20*c*)

SISTERS LAND SYSTEM (1200 SQ MILES)

Low sandy plateaux and sand plain with through-going drainage, deep red sands and yellow loamy soils, pindan and tall woodlands.

Geology.—Quaternary aeolian sand on weathered, gently folded, or subhorizontal Permian, Triassic, and Jurassic sandstone and shale.

Geomorphology.—Sand plain and dune fields with through-going drainage: sand plain crest surface, with laterite exposures and rocky marginal slopes, restricted lower slopes, and extensive sandy valley plains; moderately dense to sparse branching drainage pattern; relief mainly up to 40 ft, locally attaining 200 ft.



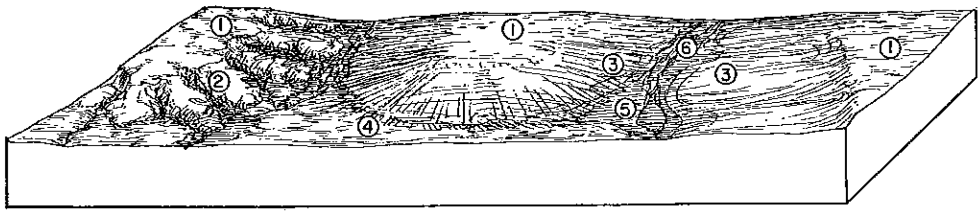
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	49	Crest surface: up to 5 miles in extent, with slopes less than 0·5%, attaining 1% marginally; delimited by sandy slopes up to 5% and 40 ft high, or by slopes up to 25% and 30 ft high, with low discontinuous breakaways and outcrops of laterite and weathered rock; stripped rocky surfaces up to 2 miles in extent behind breakaways, or forming outlying plateaux up to 200 ft high with benched escarpments up to 80% and with basal scree slopes up to 35%	Deep red sands, high in lateritic gravels on laterite, on crest surfaces, Cockatoo family (7); with mainly laterite and minor occurrences of reddish sandy soils, Yabbagoddy family (1) on breakaways	High-rainfall: tall woodland with smaller tree layer, abundant tall shrubs, and *Plectrachne pungens–Chrysopogon* spp. ground storey. *E. miniata* alliance (28); also 26 and 29. Lower-rainfall: open woodland, patches of dense *Acacia* shrubs with *Plectrachne pungens–Chrysopogon* spp. ground storey. *E. dichromophloia* alliance (10, 11) and 17
2	13	Lower slopes: up to 5% and 1½ miles long, traversed by shallow runnels; colluvial mantles	Much outcrop. Some deep red sands with lateritic gravels: Cockatoo family (7)	High-rainfall: similar to unit 1. Lower-rainfall: open woodland with patchy shrub thickets and *Plectrachne pungens–Chrysopogon* spp. and *Plectrachne pungens* ground storeys. *Adansonia gregorii* and *E. brevifolia* alliances (31, 3)
3	32	Valley plains: up to 5 miles wide; grit- and pisolith-strewn slopes mainly less than 0·2% but locally attaining 1%; linear scalds up to 6 in. deep, 200 yd wide, and 1 mile long locally	Mainly yellowish sandy to loamy soils: Elliott family (6). Areas of scalded greyish to brownish sands and loams over tough clays: Hooper family (20)	High-rainfall: grassy woodland with *Chrysopogon* spp. ground storey. *E. microtheca* community (20*a*); also 14*b*. Lower-rainfall: low beefwood woodland with *Chrysopogon* spp. and *Plectrachne pungens*. *Grevillea striata* and *Adansonia gregorii* alliances (34*a*, 34*c*) and 14*b*, 37*b*
4	2	Drainage floors: up to ½ mile wide, gradients 1 in 200 to 1 in 500, with marginal slopes up to 0·5%; hummocky, scalded surfaces	Mainly yellowish sandy soils, with greyish sands over tough loamy subsoils — usually stripped: Tableland (5) and Tarraji (18) families	Grassy woodland with frontage grasses and *Aristida hygrometrica*. *E. papuana* alliance (22*a*, 22*b*, 23, 24)
5	4	Channels: up to 200 ft wide and 15 ft deep	Channels, bed-loads of deep sand. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing forests and woodland. *E. camaldulensis–Terminalia platyphylla* fringing community (42)

Lowangan Land System (50 sq miles)

Sandy interfluves and lower sand plain, grassy woodlands and pindan.

Geology.—Quaternary aeolian sand; weathered rock and silicified nodular limestone of Jurassic age.

Geomorphology.—Sand plain and dune fields with through-going drainage: gently sloping sandy interfluve crests with dissected lower slopes; lower sand plain and restricted alluvial plains; moderately dense drainage pattern of branching tributaries and through-going alluvial floors; relief less than 50 ft.



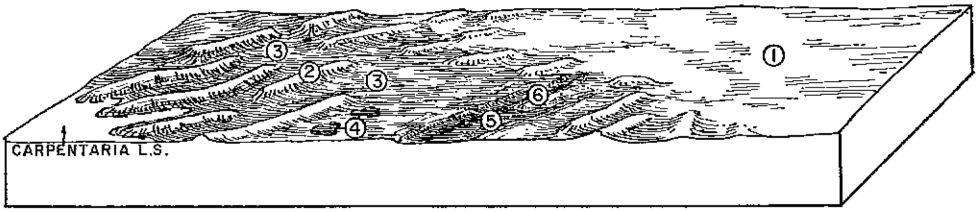
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	21	**Interfluve crests:** up to 1 mile in extent, sandy slopes mainly less than 0·5%, up to 1% locally; delimited by sandy slopes up to 5% and by outcrop slopes up to 25%	Probably mainly outcrop with minor areas of reddish skeletal soil (24)	Probably low open beefwood woodland with *Chrysopogon* spp. Locally dense *Acacia* thickets on laterite exposures. *Grevillea striata* community (34*a*); also 17
2	15	**Lower slopes:** concave up to 5% and 1 mile long; shallowly dissected into spurs less than 300 yd wide; colluvial mantles	Reddish sandy soils of variable depth: Yabbagoddy family (1)	Open spinifex grassland with scattered shrubs. *Triodia intermedia* community (57)
3	33	**Sand plain:** up to 1 mile in extent, slopes less than 1% but attaining 2% locally	Mainly deep sandy soils: Cockatoo family (7)	Low open woodland (pindan) with prominent *Acacia* shrub layer and *Plectrachne pungens–Chrysopogon* spp. and *Plectrachne pungens* ground storey. Locally *Acacia*-dominated thickets. *E. dichromophloia* and *E. tectifica* alliances (10, 16); higher-rainfall parts 28
4	11	**Alluvial plains:** up to 2 miles wide, gradients below 1 in 200; scalded surfaces locally	Probably yellowish, loamy soils: Elliott family (6)	Probably low beefwood woodland with *Chrysopogon* spp. *Grevillea striata* community (34*a*)
5	13	**Drainage floors:** up to ¼ mile wide with extensive scalded tracts; gradients 1 in 100 to 1 in 500	Complex of yellowish sandy soils: Tableland family (5). With scalded tracts of greyish to brownish sands and loams over tough domed clays: Jurgurra family (19)	Probably low open beefwood woodland with *Chrysopogon* spp. *Grevillea striata* community (34*a*)
6	7	**Channels:** up to 200 ft wide and 15 ft deep	Channels, bed-loads of deep sand. Banks, brownish loamy alluvial soil: Robinson family (21)	Fringing woodlands. *E. camaldulensis–Terminalia platyphylla* fringing communities (40, 41); also 39

Wanganut Land System (1500 sq miles)

Low-lying sand plain and dune fields with through-going drainage, pindan.

Geology.—Quaternary aeolian sands.

Geomorphology.—Sand plain and dune fields with through-going drainage: sand plain, mainly in the upper parts, with stable dune fields, low-lying sand plain, and scattered pans and depressions; sparse to moderately dense branching drainage pattern; relief up to 30 ft.



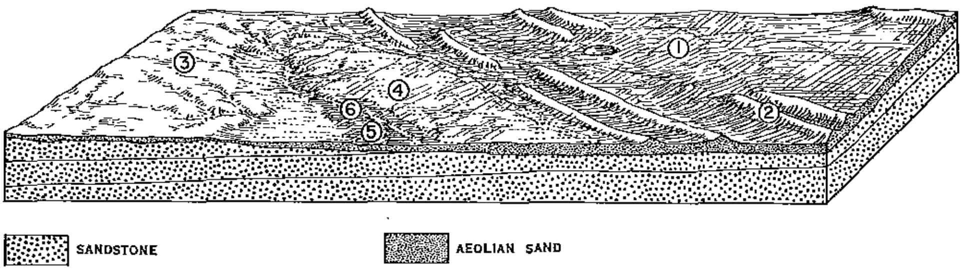
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	37	**Sand plain:** up to 3 miles in extent; broadly undulating, with relief up to 4 ft and slopes up to 2%, or gently sloping, less than 1%	Deep red sands: Cockatoo family (7)	Woodlands (pindan) with prominent *Acacia* shrub layer and *Plectrachne pungens–Chrysopogon* spp. *E. dichromophloia* alliance (10). High-rainfall parts: *E. miniata* alliance (28, 29); also 14*c*
2	11	**Linear dunes:** up to 30 ft high and 12 miles long, with flank slopes up to 15%	Mainly deep red sands: Cockatoo family (7). Pindan dunes with reddish sandy soils: Yabbagoddy family (1) common	Low woodland (pindan) with patches of dense *Acacia* shrubs and *Plectrachne pungens–Chrysopogon* spp. and *Aristida* spp. ground storeys. *E. dichromophloia* and *Bauhinia cunninghamii* alliances (10, 38*c*). High-rainfall parts: *E. miniata* community (28)
3	43	**Dune swales and low-lying sand plain:** swales up to 1 mile wide with concave marginal slopes up to 5%, rapidly decreasing to less than 1%; low-lying sand plain up to 10 miles in extent with slopes less than 0·3%, attaining 1% locally	Mainly yellowish sandy soils: Tableland family (5). Minor amounts of reddish sandy soils: Yabbagoddy family (1)	Grassy woodlands with patchy *Acacia* shrub layer, *Plectrachne pungens* and *Plectrachne pungens–Chrysopogon* spp. ground storeys. *E. dichromophloia*, *E. tectifica*, and *E. microtheca* alliances (10, 14*c*, 21)
4	5	**Pans and depressions:** linear, up to ½ mile wide and 3 miles long, commonly in linked series; depressions shallow with lightly firmed sandy surfaces, and pans up to 5 ft deep with heavily cracking surfaces and microrelief; short marginal slopes up to 1%	Yellowish, strongly mottled loamy soils: Elliott family (6) on depressions. Brownish, massive, intractable heavy clays (30) in pans	Ribbon grass grasslands with patches of *Plectrachne pungens* and fringing paperbark and bloodwood woodlands. *E. polycarpa*, *E. microtheca*, and *Melaleuca* spp. alliances (26, 21, 36)
5	2	**Drainage floors:** mainly less than ½ mile wide but up to 1 mile locally, with marginal slopes about 0·5%; hummocky, extensively scalded surfaces	Complex of yellowish sandy soils: Tableland family (5); and scalded greyish and brownish sands and loams over tough clays: Hooper family (20)	Complex of ribbon grass and paperbark trees. *Melaleuca* spp. community (36) and *Chrysopogon* spp. community (49)
6	2	**Channels:** up to 100 ft wide and 15 ft deep	Channels, bed-loads of deep sand. Banks, brownish sandy and loamy alluvial soils: Robinson family (21)	Fringing forests and woodlands. *E. camaldulensis–Terminalia platyphylla* fringing community (42)

FRASER LAND SYSTEM (300 SQ MILES)

Sand plain with irregular dunes and local stony surfaces, pindan and low grassy woodlands.

Geology.—Quaternary aeolian sand; minor outcrops of gently dipping Cretaceous sandstone.

Geomorphology.—Sand plain and dune fields with through-going drainage: sand plain with irregular linear dunes, plains with thin sand cover and local outcrop, and low-lying sand plain flanking drainage floors; sparse through-going trunk drainage with branching, locally incised tributaries; relief less than 30 ft.



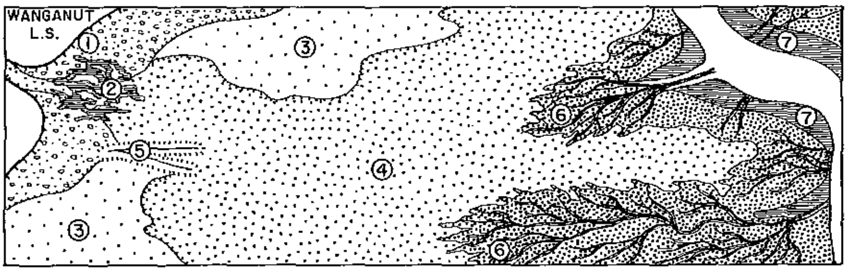
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	36	**Sand plain:** up to 3 miles in extent with slopes less than 1%; pans up to ¾ mile wide and 5 ft deep locally, with bare cracking floors	Reddish sandy soils: Yabbagoddy family (1). With brownish massive heavy clays in pans (30)	Low woodland (pindan) with prominent *Acacia* shrub layer and *Plectrachne pungens–Chrysopogon* spp. ground storey. *E. dichromophloia–E. zygophylla–Acacia* spp. community (10)
2	13	**Sand dunes:** up to 4 miles long and 30 ft high; flanks slope up to 15%	Deep red sands: Cockatoo family (7)	Variable. Woodlands as in unit 1. Also more open woodlands with *Triodia pungens* and *Aristida browniana*. *Bauhinia cunninghamii* alliance (38*b*, 38*c*)
3	16	**Sand plain with outcrop:** up to 2 miles in extent with slopes less than 0·5%, marginally dissected up to 30 ft into narrow spurs with slopes up to 5%, discontinuous sand mantles and local outcrop	Shallow, gravelly, reddish skeletal soil (24). Some reddish sandy soils: Yabbagoddy family (1). Some outcrop	Open woodlands and patches of pindan with *Plectrachne pungens–Chrysopogon* spp. ground storey. *Adansonia gregorii* and *E. dichromophloia* alliances (31, 10); locally 57 and 54
4	27	**Low-lying sand plain:** up to 1 mile wide; slopes less than 0·3% but attaining 1% locally	Yellowish, mottled, sandy soils: Tableland family (5)	Complex of grassy woodlands and pindan vegetation with *Chrysopogon* spp.–*Plectrachne* spp., *Chrysopogon* spp., and *Plectrachne pungens*. *Bauhinia cunninghamii* and *E. dichromophloia* alliances (10, 12, 37*b*, 38*a*); locally 34*a* and 38*c*
5	4	**Drainage floors:** up to 300 yd wide, gradients 1 in 200 to 1 in 500; sealed, scalded surfaces with sand hummocks	Probably yellowish, mottled loamy soils: Elliott family (6)	Low grassy woodland with *Chrysopogon* spp. *Grevillea striata* and *Bauhinia cunninghamii* alliances (34*a*, 37*b*)
6	4	**Channels:** up to 100 ft wide and 10 ft deep	Channels, bed-loads of deep sand. Banks, brownish loamy alluvial soils: Robinson family (21)	Fringing woodlands and forests. *E. camaldulensis–Terminalia platyphylla* fringing communities (41, 42, 43); also 39

Carpentaria Land System (1200 sq miles)

Coastal country, bare mud flats and saline soils with halophytic vegetation.

Geology.—Quaternary estuarine and littoral calcareous mud and silty sand; aeolian sand.

Geomorphology.—Saline coastal flats: saline estuarine and littoral flats with extensive bare mud surfaces and slightly higher samphire flats; mangrove fringes occur along the seaward margin, and short sandy slopes, with outlying low sandy rises, occur at the landward margin; minor fixed dunes; dense, intricately branching pattern of shallow tidal inlets; slopes mainly less than 0·3%.



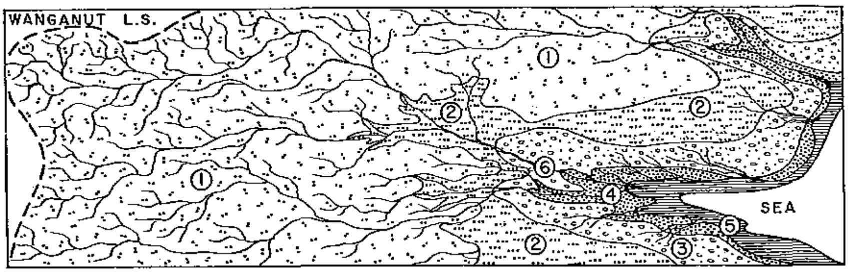
Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	8	Inner slope: concave, up to 1% and 250 yd long; lightly firmed sandy surfaces	Yellowish sandy soils, commonly mottled and showing saline influence: Tableland family (5)	Thickets of *Melaleuca* spp. with variable ground storeys. *Melaleuca acacioides* alliance (35*a*, 35*b*)
2	2	Drainage mouths: up to 2 miles wide, traversed by numerous runnels and channels 3–150 ft wide and up to 3 ft deep; vegetated sandy rises up to 2 ft high with intervening bare sealed surfaces	Variable soil complex mainly yellowish, sandy soils: Tableland family (5); and loamy alluvial soils: Robinson family (21). Both exhibiting local saline influence	
3	19	Samphire flats: up to 3 miles in extent, with slopes less than 0·3%; margins up to 9 in. above mud flats	Brownish and greyish, calcareous, saline loams (26)	Halophytic shrubland. Samphire community (66)
4	40	Mud flats: up to 4 miles wide with slopes less than 0·3%; sealed, cracking surfaces with microrelief	Dark saline muds (28)	Bare mud
5	2	Dunes: linear, up to 2 miles long and 20 ft high, with narrow, irregular crests; flanks slope up to 5%	Sandy commonly calcareous beach dunes (29)	*Spinifex longifolius* and other perennial tussock grasses and forbs with an open shrub layer (*Acacia* spp.) and scattered trees. Beach-dune community (66)
6	18	Slopes at lower margin of mud flats: up to 0·3% and ¼ mile long	Dark saline muds (28)	Low open mangrove community (46)
7	11	Outer flats: up to 2 miles in extent; in shallow water or exposed at low tide		Dense mangrove communities. Medium-height (6–10 ft) mangrove community (45) occupies the inner part of this zone and a taller community 10–25 ft high (44) occupies the outer or seawards margin

ROEBUCK LAND SYSTEM (150 SQ MILES)

Saline coastal flats with broad plains of salt-water couch grasslands, samphire, and bare mud flats.

Geology.—Quaternary estuarine and littoral calcareous mud and silty sand.

Geomorphology.—Saline coastal flats: estuarine and littoral flats comprising grassy plains above high tides, traversed by a close network of channels, and bare tidal mud flats; intervening samphire flats; mangrove fringe along the seaward margins; dense, intricately branching pattern of shallow tidal inlets in lower sectors.



Unit	Approx. Area (%)	Land Forms	Soils	Vegetation
1	56	**Plains:** up to 16 miles in extent; sandy, shell-strewn slopes, less than 0·1% but attaining 0·5% at lower margin and 1% at landward margin	Salt flat soils (25)	Salt-water couch grassland, locally degraded. *Sporobolus virginicus* community (64)
2	13	**Samphire flats:** up to 2 miles in extent with slopes less than 0·3%; margins up to 9 in. above mud flats	Brownish and greyish, calcareous, saline loams and clays (26, 27)	Halophytic shrubland. Samphire community (66)
3	5	**Mud flats:** up to 1 mile wide with slopes less than 0·3%; sealed, cracking surfaces with microrelief	Dark saline muds (28)	Mostly bare mud
4	4	**Slopes at lower margins of mud flats:** up to 0·3% and 300 yd long		Low mangrove community (46)
5	4	**Outer flats:** up to ¼ mile wide; in shallow water or exposed at low tide		Medium-height and tall mangrove communities (44, 45)
6	18	**Channels:** up to 300 ft wide and 3 ft deep, bed-loads of deep sand	Mainly salt flat soils (25)	Grasslands. *Sporobolus virginicus* community (64)

PART III. CLIMATE OF THE WEST KIMBERLEY AREA

By E. A. FITZPATRICK* and JENNIFER M. ARNOLD†

I. INTRODUCTION

(a) *Principal Climatic Features*

The area lies within a region which, according to the Köppen (1931), Thornthwaite (1931), and Meigs (1953) classifications, may be described as having semi-arid and arid monsoonal climates. Almost all of the rainfall occurs between November and April. During the remainder of the year falls are light and sporadic, and several consecutive rainless months at this time are not uncommon. Temperatures during the day are high throughout the year, but particularly so during the months just prior to the wet season, when maxima over 100 °F are frequent. Temperatures at night are also normally high throughout the year, but at inland locations frosts do sometimes occur during the coolest months of the dry season. Marked seasonal contrasts in humidity, cloud, and radiation are also characteristic.

(b) *Meteorological Conditions*

The following summary of meteorological conditions controlling the climate of the area is based upon a statement provided by the Commonwealth Bureau of Meteorology.

Two major weather types can be recognized, each characterizing one of the major seasons; these are separated by short transitional periods.

Between May and October an anticyclonic belt over the southern half of Western Australia and extending over the whole of the State is normal and prevailing winds over the Kimberleys are easterly with little cloud. On occasion, however, as a large southern depression moves eastward off the south coast, a low-pressure trough extends to the Kimberleys. Winds back to north-west in advance of the trough, change from west to south-west behind it, and then return rapidly to the normal state.

Towards the end of the dry season a low-pressure system develops over the Kimberleys and extends southward, while a ridge of high pressure extends from the semi-permanent anticyclone in the Indian Ocean parallel with the north-west coast. Under these conditions surface winds are westerly in the coastal districts and easterly in the eastern parts of the area. As the low-pressure system extends in inland areas during November this situation occurs more frequently. Westerly winds bring increased humidity, and scattered thunderstorms develop as the wet season approaches. These westerlies are not permanent, being displaced from time to time by easterlies as anticyclones over the southern divisions intensify and extend northward.

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During the wet season, a low-pressure area is generally situated over northern Australia and a trough extends from the Northern Territory towards the Onslow–Carnarvon area. The prevailing winds are westerlies in the coastal regions, but further inland they are more variable, and at Halls Creek the frequencies of easterlies and westerlies are about equal. Compared with the preceding four months, there is a marked increase in humidity, cloud cover, and rainfall. Much of the rain comes from thunderstorms, but the most widespread heavy falls occur as the result of cyclonic disturbances.

Cyclones frequently originate in the Timor Sea, but occasionally come from the Arafura Sea or even further eastward. Early signs of cyclone development are low barometric pressure, increasing cloud and rain, and strengthening easterly winds. Cyclones of this type generally bring extremely heavy rains and very strong winds. As the cyclonic centres move inland or pass southward, wind speed abates, but heavy rain may continue for several days. Such disturbances are likely throughout the wet season but are distinctly most frequent in January. Only rarely do they occur before December or after April.

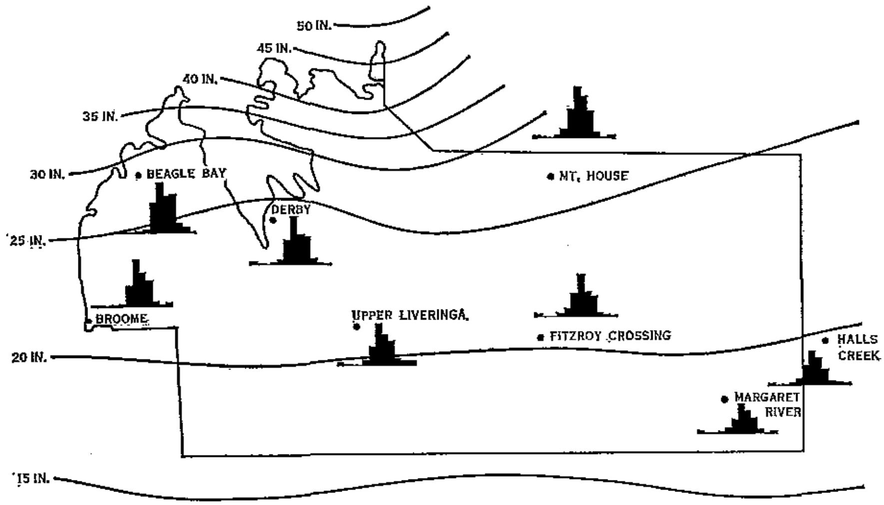

Fig. 2.—Isohyets and histograms of annual rainfall distribution (July to June) at recording stations.

Towards the end of March and in April, the northward return of the anticyclones is accompanied by a retreat of the trough over the Kimberleys to the north, at times beyond the coast. Under these conditions the northern part of the Kimberleys is often influenced by westerly winds while easterlies prevail in the southern districts. The extent of the retreat of the trough largely governs the characteristics of April weather and the subsequent onset of the dry season.

II. General Climatic Characteristics

(a) Rainfall

Mean annual rainfall ranges from more than 40 in. in the extreme north-west of the area to about 16 in. in the south-east. As shown in Figure 2, the annual iso-

TABLE 1

MEAN RAINFALL AND MEAN RAINFALL PER RAIN DAY (IN.) AT EIGHT STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Oct.-Mar.	Apr.-Sept.	Year
							Beagle Bay								
Mean rainfall	7·88	5·89	5·91	1·66	1·01	0·47	0·35	0·06	0·04	0·09	0·50	4·70	24·97	3·59	28·56
Mean rainfall per wet day	0·66	0·65	0·59	0·55	1·07	0·47	0·35	—	—	0·09	0·25	0·67			
							Broome								
Mean rainfall	7·35	5·38	4·12	0·93	0·65	0·70	0·15	0·15	0·03	0·02	0·27	3·12	20·26	2·61	22·87
Mean rainfall per wet day	0·73	0·67	0·59	0·46	0·32	0·70	0·15	—	—	—	0·27	0·52			
							Derby								
Mean rainfall	7·65	4·91	4·76	1·16	0·50	0·34	0·26	0·06	0·01	0·10	0·51	3·70	21·63	2·33	23·96
Mean rainfall per wet day	0·64	0·55	0·53	0·58	0·50	0·34	0·26	—	—	—	0·25	0·46			
							Upper Liveringa								
Mean rainfall	6·55	4·80	3·94	0·87	0·38	0·29	0·27	0·09	0·02	0·14	1·02	3·12	19·57	1·92	21·49
Mean rainfall per wet day	0·65	0·69	0·56	0·56	0·38	0·29	0·27	—	—	0·14	0·51	0·44			

	Mt. House (1924–57)														
Mean rainfall	8·00	6·46	4·10	1·07	0·45	0·45	0·27	0·12	0·07	0·39	1·31	4·22	24·48	2·43	26·91
Mean rainfall per wet day	0·67	0·65	0·51	0·53	0·45	0·45	0·27	—	—	0·39	0·32	0·47			
	Fitzroy Crossing														
Mean rainfall	6·56	3·98	3·46	0·54	0·29	0·18	0·31	0·07	0·04	0·24	1·15	3·63	19·02	1·43	20·45
Mean rainfall per wet day	0·50	0·40	0·43	0·27	0·29	0·18	0·13	—	—	0·12	0·29	0·36			
	Margaret River (1914–36, 1938–44, 1947–48)														
Mean rainfall	4·94	3·65	2·65	0·73	0·27	0·45	0·33	0·14	0·03	0·25	0·88	2·48	14·85	1·95	16·80
Mean rainfall per wet day	0·67	0·65	0·51	0·53	0·45	0·45	0·27	—	—	0·39	0·32	0·47			
	Halls Creek														
Mean rainfall	5·37	4·16	2·77	0·54	0·24	0·18	0·24	0·07	0·15	0·49	1·36	3·15	17·30	1·42	18·72
Mean rainfall per wet day	0·45	0·42	0·39	0·27	0·24	0·18	0·24	0·07	0·15	0·16	0·23	0·35			

* Values given are for the period 1911–49 unless otherwise stated. Source of data: Bureau of Meteorology (1956) and daily rainfall records.

hyets run approximately parallel in an east–west direction except where the means are 30 in. or more, in which case the trend is more toward the north-east. Coefficients of variation of annual rainfall are in the order of 30 to 40%, and the average relative variabilities range from 20 to 30%. Variability is lower in the northern part of the area than in the south; but even where least variable, rainfall is less reliable than in most parts of tropical Australia with similar annual means. Since only a very small part of the annual total is received during the dry season, these values effectively represent year-to-year variability of wet-season rainfall.

TABLE 2

PERCENTAGE OF DAYS HAVING RAINFALLS IN EXCESS OF SPECIFIED AMOUNTS AT FOUR STATIONS (DAYS WITHOUT RAIN INCLUDED)

Amount (in.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Beagle Bay						
0·01	38	36	32	9	6	3	3	1	1	2	5	20
0·25	19	22	16	39	2	1	1				2	12
1·00	7	8	6	1	1							4
2·00	2	3	2	1	1							1
4·00		1	1									
						Upper Liveringa						
0·01	37	30	29	7	4	3	2			3	8	23
0·25	19	15	11	2	2	1	1			1	2	10
1·00	6	6	4	1							1	3
2·00	2	2	1									1
						Mt. House						
0·01	39	37	25	8	2	3	2	1		3	12	29
0·25	25	22	15	4	1	2	1			2	5	17
1·00	9	7	4			1					1	4
2·00	1	2	1			1						
						Halls Creek						
0·01	39	35	22	6	4	4	3	1	2	9	27	28
0·25	18	15	8	2	1	1	1		1	2	4	10
1·00	5	4	2									3
2·00	1	1	1									

Mean monthly and seasonal rainfall characteristics for eight stations within, or close to, the area are given in Table 1. These data show that, in general, the wet season begins earlier and finishes earlier in the eastern part of the area than in the west. January is the wettest month over the whole area, but high totals are also recorded in December, February, and March. Rainfall in November and April is

TABLE 3

MEAN NUMBER OF WET PERIODS AND PERCENTAGE OF WET PERIODS WITHIN SPECIFIED LIMITS OF LENGTH

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Beagle Bay						
Mean number of wet periods	5·5	4·3	4·9	1·4	1·0	0·7	0·5	0·3	0·2	0·3	1·0	3·5
Percentage 1 day or less	57	53	51	63	53	61	57	74	85	90	64	60
1–2 days	19	20	28	20	34	29	28	15	15	10	17	20
2–5 days	17	18	17	12	13	10	15	11			16	15
over 5 days	7	9	4	5							3	5
						Upper Liveringa						
Mean number of wet periods	5·7	3·8	4·0	1·2	0·6	0·5	0·3	0·1	0·1	0·5	1·7	4·4
Percentage 1 day or less	63	60	55	67	42	51	49	30	100	51	75	64
1–2 days	17	20	25	8	35	34	40	40		49	15	20
2–5 days	15	14	17	25	23	15	21	30			10	12
over 5 days	5	6	3									4
						Mt. House						
Mean number of wet periods	5·4	4·6	3·9	1·4	0·4	0·5	0·3	0·1	0·1	0·8	2·4	4·9
Percentage 1 day or less	48	45	58	72	65	36	39	77	100	74	71	65
1–2 days	23	31	17	22	16	43	40	23		16	14	13
2–5 days	21	18	17	6	19	15	21			10	15	18
over 5 days	8	6	8			6						4
						Halls Creek						
Mean number of wet periods	4·9	4·4	3·3	1·1	0·7	0·6	0·3	0·1	0·4	1·7	3·4	4·8
Percentage 1 day or less	45	36	49	70	68	35	31	23	75	59	67	76
1–2 days	22	27	24	18	18	53	30	23	25	22	22	3
2–5 days	25	23	24	10	10	12	33	54		19	10	17
over 5 days	8	4	3	2	4		6				1	4

TABLE 4

MEAN TEMPERATURE CONDITIONS AT THREE STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Broome													
Mean max. temp. (°F)	91·3	91·8	93·1	93·3	88·0	82·5	81·8	85·0	88·8	90·5	92·7	93·2	89·3
Mean min. temp. (°F)	79·2	79·1	77·7	71·6	64·8	59·5	57·0	60·0	65·1	72·1	76·7	79·4	70·2
Mean daily temp. range (°F)	12·1	12·7	15·4	21·7	23·2	23·0	24·8	25·0	23·7	18·4	16·0	13·8	19·1
Derby													
Mean max. temp. (°F)	94·0	94·7	94·9	94·6	89·6	85·0	84·2	88·0	92·6	95·7	96·8	96·7	92·2
Mean min. temp. (°F)	79·1	79·0	78·3	72·6	66·6	60·9	58·3	61·5	66·7	73·8	78·5	80·0	71·3
Mean daily temp. range (°F)	14·9	15·7	16·6	22·0	23·0	24·1	25·9	26·5	25·9	21·9	18·3	16·7	20·9
Halls Creek													
Mean max. temp. (°F)	97·6	97·0	95·6	92·3	85·7	80·6	80·1	85·9	92·7	98·3	100·5	99·5	92·2
Mean min. temp. (°F)	75·4	74·2	71·2	63·0	56·0	50·5	47·6	52·1	59·0	69·5	74·2	74·5	64·0
Mean daily temp. range (°F)	22·2	22·8	24·4	29·3	29·7	30·1	32·5	33·8	33·7	28·8	25·3	25·0	28·2

* Source of data: Bureau of Meteorology (1956).

particularly variable because of year-to-year differences in the position and intensity of the major controlling pressure and wind systems. Mean rainfall for the months May to October is less than 0·5 in. at most stations. However, the means in this case have little, if any, significance since individual falls are very sporadic during this period. Over most of this dry period, months without rain occur in at least 50% of all cases. In August and September, rain has been recorded in only 2 or 3 years in 10, and when rain does occur at this time, the falls are frequently less than 0·10 in.

Frequencies of daily rainfalls and wet periods have been determined from daily records of all stations. For this purpose a wet period has been taken as an unbroken sequence of days with recorded rainfall of 0·01 in. or more. Data for four stations are given in Tables 2 and 3. The northern inland and eastern parts of the area receive a high proportion of light daily falls as compared with coastal areas. This is most evident in October and November and is apparently related to the marked increase in convectional rainfall toward the interior at that time. Daily falls in excess of 4·00 in. are very rare at inland stations. Falls of an inch or more occur on about 5 to 10% of all days during January and February over the entire area. The mean number of wet periods during October and November is higher at Mt. House and Halls Creek than at stations in the coastal or south-central areas. This again is apparently related to regional contrasts in the occurrence of early convectional rainfall. During the wet season, the proportion of wet periods over 5 days in length at Upper Liveringa, Fitzroy Crossing, and Margaret River is lower than at other stations. Throughout the area rainfall persistency is greatest in either January or February and least in September.

(*b*) *Temperature*

Temperature records are available only for three stations, Broome, Derby, and Halls Creek. None of these can be regarded as truly representative of the greater central part of the area. However, it may be generally assumed that temperature levels in this area are intermediate between the extremes found in the data for Halls Creek, situated far into the interior, and data for Broome and Derby, which are in coastal situations.

Lowest temperatures occur in July and the highest occur just prior to the onset of the wet season. The somewhat lower temperatures during the wet season are related to the greater cloud cover at that time. This effect is most evident in the daily maxima. Mean temperatures are high throughout the year, remaining above 65°F except in June and July in inland areas. Table 4 shows mean maximum, mean minimum, and mean daily temperature range for the three stations, and in Tables 5 and 6 the percentage of days having maximum and minimum temperatures above and below specified limits respectively is given.

Mean maximum temperatures rise rapidly from August to the end of the dry season. Just prior to the onset of the wet season, daily maxima over 100°F are experienced in about 10% of all cases at Broome, 25% at Derby, and 65% at Halls Creek. As is to be expected, the annual range of maximum temperatures is much less along the coast than it is inland. The median maximum temperatures for January and July at Halls Creek are approximately 100° and 80°F respectively, a difference of 20° F, whereas at the two coastal stations the difference between the median values for these months is less than 10° F. The decline of the maximum temperature, which occurs as a result of increased cloudiness with the onset of the wet season, occurs somewhat earlier at Halls Creek than at the two coastal locations. However, this effect, when it does occur, is much more marked at the coastal stations. Broome and Derby show a drop in mean maximum temperatures of about 2° F in January and a slight rise in March before the decline to winter levels. At Halls Creek no such rise at the end of the wet season is evident. It is notable that the prevailing maximum

TABLE 5

PERCENTAGE OF DAYS WITH MAXIMUM TEMPERATURES ABOVE SPECIFIED LIMITS

Max. Temp. (°F)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Broome (4 yr of records)											
>70			100		99		100	100				
>80	100	100	99	99	94	99	88	96	100	100		100
>90	96	95	82	86	64	50	20	31	53	59	87	94
>100	11	4	11	5					3	15	9	11
	Derby (5 yr of records)											
>70					100	99	99					
>80	99	100	99		98	96	93	100			100	100
>90	87	86	86	95	63	19	16	51	77	97	98	94
>100	9	15	11	12	3			1	13	20	28	18
	Halls Creek (10 yr of records)											
>70	100	100			98	97	96	100	100			
>80	99	98	99	99	88	52	65	91	99	99		100
>90	91	91	88	78	29	2	4	26	75	93	98	93
>100	55	28	17	2					4	36	65	53

temperatures, as well as the minima, are higher during the winter months at the coastal stations than they are at Halls Creek. In July, Broome and Derby experience daily maxima above 90° F in about 18% of the cases examined, whereas at Halls Creek only about 4% of the maxima are above this level at that time.

Mean minimum temperatures show a greater annual range than do the mean maximum temperatures, and there is a greater difference between the levels experienced at coastal and inland stations than in the case of the maxima. The seasonal regimes of mean minimum temperature at Broome and Derby are very similar, ranging from between 55° F and 60° F in July to approximately 79° F in January. At Halls Creek the corresponding range is from 47° F to 75° F. During the winter months, approximately half of the daily minima are below 50° F at Halls Creek, whereas less than 5% are below this level at the coastal stations (Table 6). At Derby and Broome minimum temperatures below 40°F are very exceptional, but at Halls Creek these occur during June, July, and August on about 6, 12, and 4% of the days respectively, and screen temperatures below 35°F occur as well. According to Foley (1945) mild frosts may occur in inland areas at any time from June to August inclusive, but they are distinctly most frequent in July. Frosts are not recorded in

TABLE 6

PERCENTAGE OF DAYS WITH MINIMUM TEMPERATURES BELOW SPECIFIED LIMITS

Min. Temp. (°F)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Broome (4 yr of records)											
<50							3	3				
<60						16	59	56	11			
<70		1	5	22	45	76	98	97	66	24		2
<80	48	39	81	97	99	100			100	100	89	55
<90		100	100									
	Derby (5 yr of records)											
<50					1	1	4					
<60				1	14	41	57	27	5			
<70			1	17	60	88	100	96	59	13	1	
<80	53	54	58	100	100				100	96	67	39
<90	100	100	98								100	100
	Halls Creek (10 yr of records)											
<35						1	1					
<40						6	12	4				
<50				3	17	51	61	42	12	1		
<60		2	2	35	67	88	94	85	46	16		1
<70	12	16	37	69	97	99	100	98	86	49	18	10
<80	77	91	97	100					100	97	75	80
<90	100										100	100

some years and screen temperatures as low as 32°F are rare. With the observed minimum temperatures so distinctly marginal with respect to frost occurrence, it may be expected that at all inland localities the incidence of frost will be very closely related to those local relief conditions which either promote or inhibit an accumulation of cold air near the surface during the period of night-time cooling.

(c) *Humidity*

The onset of the wet season is preceded by an increase in absolute humidity, reflecting large-scale advection from adjacent maritime sources. This normally commences in September and October, two of the driest months of the year. However, the highest absolute humidities are not generally observed until January and February. The lowest absolute humidities are observed in July throughout the area. As is to be expected, absolute humidities are lower at Halls Creek throughout the entire year than at either Broome or Derby. At Halls Creek the annual range is from 16 mg aqueous vapour per litre in January to 6 mg/l in July as compared with approximately 21 mg/l in January to 9 mg/l in July at Broome and Derby.

Relative humidity follows a similar annual course except that there is a secondary peak in the cooler months, particularly at Halls Creek where both minimum and maximum temperatures are much lower. These winter increases do not represent real increases in water vapour content, but merely a reflection of the lower saturation vapour pressures at the lower temperatures which prevail at that time. In Table 7, the average index of mean relative humidity (which can be taken as an approximation of the mean relative humidity) and the mean relative humidity at 3 p.m. are given for the three stations from which data are available. At Halls Creek the average index of relative humidity compares quite closely with the mean 3 p.m. values at Derby, the 3 p.m. relative humidities at Halls Creek being 15–20% lower. Both the average index of relative humidity and the mean 3 p.m. relative humidity are slightly higher at Broome than at Derby throughout the year. This can be related to the slightly lower temperatures at Broome as well as to the more exposed coastal location of that station.

(*d*) *Cloud, Sunshine, and Incoming Radiation*

Mean cloud cover at 9 a.m. and 3 p.m., estimated mean daily duration of sunshine, and estimated mean daily global radiation (solar plus diffuse sky radiation on a horizontal surface) are shown in Table 7 with the mean day lengths at latitude 18°S.

From April to November inclusive, average cloud cover at 9 a.m. is less than two-tenths, August being the month with least cloud. Cloudiness increases gradually from September, reaching a peak in January and February of six- to seven-tenths at Derby and five-tenths at Halls Creek.

Cloudiness at 3 p.m. is considerably greater than at 9 a.m. at Halls Creek, particularly in the months leading up to the wet season. This reflects the gradual build-up of convectional cumulus cloud which is characteristic during the day when the seasonal changes in the pressure and wind systems result in a greater penetration of moist maritime air inland over a heated land surface. At Derby, the difference in cloudiness throughout the day is much less marked. Here mean cloudiness at 9 a.m. does in fact slightly exceed that at 3 p.m. in August and September and also in January and February.

Day length varies throughout the year by about 2 hr, the period from sunrise to sunset being about 13 hr in January and 11 hr in July. In spite of these differences in day length, the mean daily duration of sunshine, estimated from maps published by the Commonwealth Bureau of Meteorology (1954*a*), is about 2 hr longer in July than it is in January. This emphasizes how strongly seasonal differences in cloudiness govern the duration of sunshine within the area.

TABLE 7

MEAN MONTHLY VALUES OF ELEMENTS OTHER THAN RAINFALL AND TEMPERATURE

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Derby												
Average index of relative humidity*	71	71	68	56	49	50	49	51	52	54	60	65
3 p.m. relative humidity (%)	58	57	53	42	40	40	40	38	39	43	50	54
9 a.m. cloudiness† (tenths)	6·5	6·7	4·6	2·7	2·2	2·0	1·6	1·3	1·5	2·2	2·8	5·1
3 p.m. cloudiness (tenths)	6·4	6·3	5·2	3·2	2·6	2·1	1·7	1·1	1·4	2·2	3·5	5·5
Duration of sunshine‡ (hr/day)	7·3	7·4	7·6	9·1	9·0	8·8	9·7	10·0	10·3	10·2	10·1	8·4
Global radiation§ (cal/cm²/day)	373	390	430	504	445	439	456	533	625	631	634	473
Evaporation‖ (in.)	7·2	6·7	6·8	8·0	7·5	6·4	6·7	7·6	8·9	9·6	9·5	8·9
Halls Creek												
Average index of relative humidity	54	54	50	40	41	44	42	39	35	38	38	46
3 p.m. relative humidity (%)	36	36	33	27	29	32	30	26	24	26	28	32
9 a.m. cloudiness (tenths)	5·4	4·7	3·9	2·4	2·0	1·9	1·8	1·3	1·2	2·0	2·8	3·8
3 p.m. cloudiness (tenths)	6·6	5·9	5·5	3·4	2·3	2·0	1·9	1·6	1·9	3·8	5·7	5·5
Duration of sunshine (hr/day)	7·8	7·8	8·1	9·0	9·1	9·0	9·6	9·8	10·3	9·5	9·4	8·3
Global radiation (cal/cm²/day)	416	500	456	504	444	433	442	522	616	596	566	528
Evaporation (in.)	9·2	8·3	8·3	8·6	6·8	5·7	6·0	7·4	9·6	11·2	12·2	11·2
Broome												
Average index of relative humidity	75	76	73	56	54	53	52	54	56	64	66	70
3 p.m. relative humidity (%)	67	67	59	45	44	46	43	42	44	52	57	62
Evaporation (in.)	6·2	5·6	6·0	8·1	6·8	6·0	6·3	6·7	7·7	7·4	7·9	7·7
Mean day length¶ at 18°S. (hr)	13·2	12·8	12·2	11·6	11·2	11·0	11·1	11·5	12·0	12·5	13·0	13·2

* Average index of relative humidity calculated from ratio of mean vapour pressure at 9 a.m. to the saturation vapour pressure at the mean temperature. Source of humidity data: Bureau of Meteorology (1956). † Calculated from daily records. ‡ Estimated from cloud data and day length. After maps of Bureau of Meteorology (1954*a*). § Estimated by method of Black (1956). ‖ Estimated by method of Fitzpatrick (1963). ¶ From tables of Thornthwaite and Mather (1957).

The values for mean daily global radiation shown in Table 7 have been derived by the method of Black (1956), which takes into consideration the observed cloudiness at the station and the rate at which solar energy would be received on a horizontal surface in the absence of the atmosphere. These values can only be regarded as first approximations and must be taken with some reservation since no measurements are available within the area for comparison. However, the general order of magnitude of these estimates is in agreement with mean values observed at Darwin and presented by Loewe (1956). The estimated values for both stations are highest in the pre-wet season period, being somewhat greater than 600 cal/cm^2/day at that time. Lowest estimated global radiation for the year occurs in January for each station. It is of interest that at Derby the estimate for February is not greatly dissimilar to that for January; however, inland at Halls Creek high radiation conditions of 500 cal/cm^2/day return in February after a distinctly lower level during January.

(*e*) *Evaporation*

No evaporation measurements are available, and the lack of instrumental observations of either radiation or duration of sunshine, as well as wind, preclude any useful application of methods of estimation based upon combined energy-balance and aerodynamic principles (e g. Penman 1948). Purely empirical methods which are related to observations from the standard Australian evaporation tank have therefore been called upon. Table 7 gives estimates of evaporation obtained by an empirical method based upon mean maximum temperature, vapour pressure, and day length as described elsewhere by Fitzpatrick (1963). This method has been found to give estimates which are in good agreement with observations from a standard Australian tank at Kimberley Research Station. The monthly values shown in Table 7 are in close agreement with the levels indicated on maps published by the Commonwealth Bureau of Meteorology (1954*b*).

Throughout the area, tank evaporation ranges from approximately 80 to 100 in. per year. The highest evaporation rates occur during the latter part of the dry season, being then about 8 to 10 in. per month at coastal locations and about 12 in. per month in the interior. Evaporation rates during the cool months are about 6 in. per month over the whole of the area. During the wet season, evaporation rates are from 2 to 3 in. per month higher in inland areas than they are along the coast. This can be attributed partly to the higher radiation receipts which result from the lesser amounts of cloud, and partly to the lower absolute humidities which are observed in the interior at that time.

III. Climate and Plant Growth

(*a*) *General Aspects*

Throughout the area, plant growth is strongly regulated by changes in the availability of water. Such control is evident not only inter-seasonally but also within the normal growth period of the wet season when highly variable rainfall accompanies a condition of approximate equality between normal rainfall and evaporation. Temperatures during the months June to August may be low enough at times to suppress growth, but soil moisture reserves at that time have normally already been depleted. The balance between rain-produced increments to the available water within the root zone of the soil and the water extractions resulting from evapotranspiration is thus of fundamental significance in relation to plant growth.

Different species may react distinctively to a particular set of soil water conditions, and the availability of soil moisture to crops or pasture depends upon many interrelated plant and soil factors. Also, the amount of water actually entering the soil is strongly dependent upon the type and condition of the soil, the nature of the cover, the degree of slope, and the intensity of rainfall. It is not possible to give detailed consideration to all of these factors at the scale of regional survey; only a

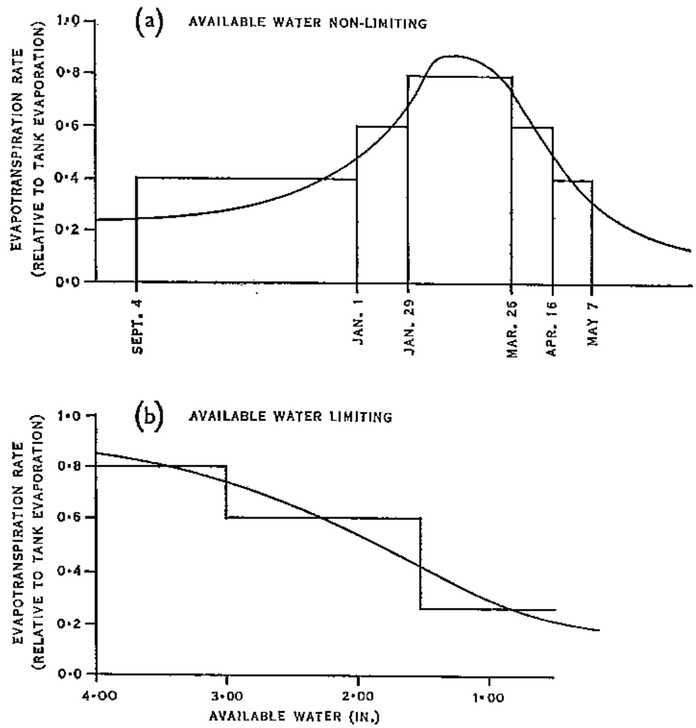

Fig. 3.—(*a*) Diagrammatic interpretation of rate of evapotranspiration of a typical summer-grown crop with available water non-limiting. (*b*) Diagrammatic representation of decline in rate of evapotranspiration with limitation of available water.

generalized assessment of climate in relation to growth can be attempted here. This assessment can be made with the aid of idealized water-usage models which, from experience and theoretical considerations, are appropriate to particular modes of land use. In this analysis, very generalized models for dry-land and irrigated crops and for natural pastures have been used. These cannot be expected to be valid under all circumstances, but should give a more meaningful general interpretation of climate than is possible from simple statistical summaries of the various elements or from even broader assumptions relating to the use of water by crops or pastures.

(*b*) *Dry-land Agriculture*

A method developed by Slatyer (1960) for evaluating the status of the water balance with respect to dry-land agriculture practice is used here. This method has been based upon experience and experimental data obtained with crops grown at Katherine Research Station and gives recognition to those alterations in the crop's water requirements which result from both climatic and plant physiological factors.

Although some differences between the optimum water requirements of different crops seem likely, the method as applied here may be considered generally applicable for crops which might be grown during the wet season without supplementary irrigation. The criteria used by Slatyer have been applied here in unaltered form and are shown diagrammatically in Figure 3. The term "ploughing rains" as used by Slatyer has been replaced by *pre-sowing rains*, since time of ploughing

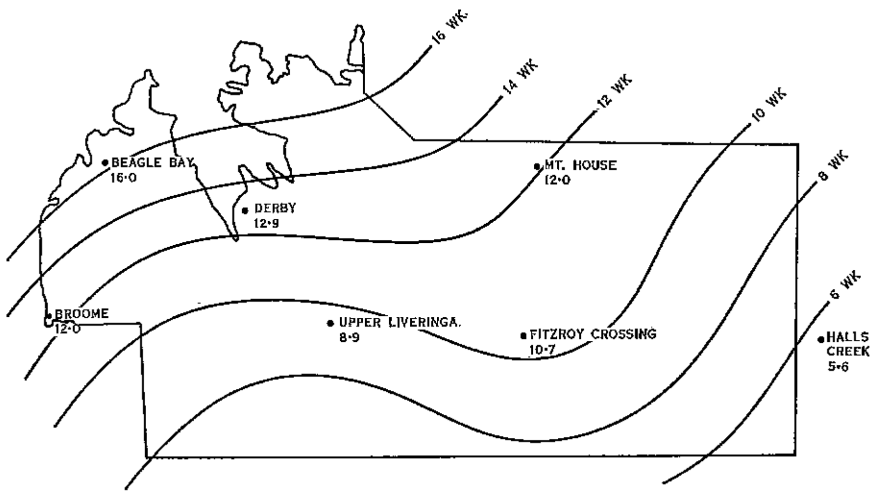

Fig. 4.—Mean length of agricultural period.

is likely to be less dependent upon soil moisture with lighter soils than with the Tippera clay to which the original work applies. Evaporation estimates used in the weekly water balance evaluations were interpolated from monthly levels shown on maps published by the Commonwealth Bureau of Meteorology (1954*b*).

From weekly evaluations made for seven stations over all years with suitable rainfall records, the estimated dates of pre-sowing and sowing rains and the length of the agricultural period were noted for each season. Results of this analysis are given in Table 8, and regional differences in the mean length of the agricultural period are shown in Figure 4.

Estimated mean dates of pre-sowing rains are remarkably uniform over the area as a whole. These occur in either late December or early January. It is of interest that the greatest difference between stations is that which occurs in the comparatively short distance separating the two coastal stations, Beagle Bay and Broome. From the mean dates at these two stations it can be seen that, on the average, the peninsular areas to the north-west which are more exposed to maritime air masses and tropical cyclonic influences receive useful falls nearly a fortnight earlier than the more sheltered areas to the south. Much of this difference can be associated with an apparent skewness in the frequencies of pre-sowing rains at Beagle Bay. One-quarter of these precede December 9, whereas at Broome this proportion is not realized until December 23. The median and third quartile dates

Table 8

PRIMARY CHARACTERISTICS OF THE AGRICULTURAL GROWING PERIOD AT SEVEN STATIONS

	Beagle Bay (50 yr of records)	Broome (48 yr of records)	Derby (26 yr of records)	Upper Liveringa (49 yr of records)	Mt. House (30 yr of records)	Fitzroy Crossing (42 yr of records)	Halls Creek (53 yr of records)
Date of pre-sowing rains							
Mean	Dec. 27	Jan. 7	Jan. 3	Jan. 1	Jan. 3	Dec. 31	Jan. 4
First quartile	Dec. 9	Dec. 23	Dec. 23	Dec. 20	Dec. 22	Dec. 13	Dec. 16
Median	Dec. 31	Jan. 5	Jan. 4	Jan. 2	Dec. 30	Jan. 4	Jan. 6
Third quartile	Jan. 17	Jan. 24	Jan. 12	Jan. 13	Jan. 10	Jan. 14	Jan. 26
No. of years pre-sowing rains did not occur	0	0	0	0	0	0	2
Date of sowing rains							
Mean	Jan. 14	Jan. 21	Jan. 24	Jan. 26	Jan. 14	Jan. 21	Jan. 24
First quartile	Jan. 4	Jan. 8	Dec. 27	Jan. 10	Jan. 4	Dec. 31	Jan. 3
Median	Jan. 13	Jan. 19	Jan. 26	Jan. 26	Jan. 13	Jan. 24	Jan. 24
Third quartile	Feb. 7	Feb. 16	Feb. 7	Feb. 10	Jan. 24	Feb. 5	Feb. 14
No. of years sowing rains did not occur	1	3	2	0	0	1	4
Length of agricultural growing period (wk)							
Mean	16·4	12·1	12·9	8·9	12·0	10·7	5·6
Standard deviation	±8·1	±5·8	±6·3	±5·1	±5·3	±5·4	±3·9
% of years with agricultural growing period $\leqslant$ 4 wk	4	0	0	22	7	12	37
$\leqslant$ 8 wk	17	29	20	51	27	29	86
$\leqslant$ 12 wk	30	62	56	71	50	59	98
$\leqslant$ 16 wk	55	87	88	88	87	93	100
$\leqslant$ 20 wk	70	100	96	100	93	98	100

for the two stations are in closer agreement. Within the periods examined, only at the far inland station, Halls Creek, are there instances of pre-sowing rains failing to occur.

Sowing dates are similarly very uniform within the area. The earliest sowing dates occur at the two northernmost stations, Beagle Bay and Mt. House. In general, the mean sowing dates follow the mean date of pre-sowing rains by 2 to 3 weeks.

At inland stations sowing rains often fail to occur, and it is notable that even under the comparatively high-rainfall conditions at Beagle Bay, there is one instance of sowing rains failing to occur.

Regional differentiation is more marked with respect to growing season length than to date of commencement. A progressive decrease in length of agricultural period from the coast toward the interior is clearly evident in Figure 4.

TABLE 9

COMPARISON OF AGRICULTURAL GROWING PERIOD CHARACTERISTICS AT FITZROY CROSSING WITH THOSE AT KIMBERLEY AND KATHERINE RESEARCH STATIONS

	Fitzroy Crossing	Kimberley Research Station*	Katherine Research Station†
Date of commencement			
Mean	Jan. 21	Dec. 26	Nov. 26
Standard deviation (wk)	3·9	3·0	3·5
Length			
Mean (wk)	10·7	15·5	20·7
Standard deviation (wk)	5·4	4·8	4·1
% of years with growing period < 4 wk	12	6	0
< 8 wk	29	8	0
< 12 wk	59	31	4
< 16 wk	93	65	18
< 20 wk	98	88	46
< 24 wk	100	98	86
Total duration of intra-period water stress			
Mean (wk)	5·5	4·0	2·3
% of years with total duration of intra-period water stress > 2 wk	90	91	57
> 4 wk	77	53	14
> 6 wk	51	19	4
> 8 wk	25	8	0
> 10 wk	4	0	0

* Rainfall data for Ivanhoe, W.A., (1907–45) used prior to the first available records from Kimberley Research Station.

† Rainfall data for Katherine Post Office (1885–1947) used prior to the first available records from Katherine Research Station.

Since a practical basis for sustained agriculture can exist where occasional crop failures and years of low yield occur, it is more relevant to consider the frequencies of the estimated agricultural periods as well as the mean values. From Table 8 it is seen that crops which would require a 12-wk period of active growth to reach a successfully productive stage would experience a premature cessation of growth with the exhaustion of available water held in storage in at least 50% of all years throughout most of the area. The only exception to this occurs in the north-west peninsular areas of higher rainfall. Crops requiring 16 wk would experience premature termination of growth in over 80% of all years throughout the area generally, and in over 50% of all years even in the most favoured areas of higher rainfall.

In Table 9 several characteristics of the estimated agricultural growing period at Fitzroy Crossing are compared with those at Kimberley and Katherine Research Stations. Fitzroy Crossing is given in the comparison because it can be regarded as representative of much of the central portion of the area. Somewhat more favourable climatic conditions can be expected northward and toward the coast and less favourable conditions are apparent southward and toward the interior. For purposes of this comparison, the total duration of intra-period water stress has been examined. This has been taken to include all weeks within a 12-wk interval immediately following the occurrence of sowing rains which have an accumulated deficit (i.e. the amount by which estimated evapotranspiration requirements exceed rainfall) greater than 1·00 in. As well, any weeks during this interval which had no available water have been included, since these may be regarded as the extreme extensions of water stress.

The degree of contrast in the mean length of agricultural growing period at these three locations is considerable. Furthermore, the incidence of intra-period water stress is much higher at Fitzroy Crossing than at either Kimberley or Katherine Research Station. From this it is safe to conclude that any dry-land agricultural practice within the greater part of the area must expect considerably larger proportions of crop failures and generally reduced yields than in areas with more sustained and reliable rainfall to the north and north-east. It would appear that throughout most of the area in only a very small proportion of years could dry-land cropping be practised with any assurance of freedom from serious water stress. It may, however, be practicable to grow certain drought-tolerant crops which could complete their development within short periods in the climatically more favoured north-western parts of the area, assuming that soil and topography are suitable.

(c) *Irrigated Agriculture*

Some aspects of agriculture become less dependent upon climate when irrigation is adopted, but basic water requirements of crops remain strongly linked with climatic factors. The balance between evapotranspiration demands of the crop and the combined additions of water through irrigation and rainfall is of interest in assessing the economics of irrigation practice, in designing water storage and distributional facilities, and in formulating a rational schedule for the application of water to crops.

At Kimberley Research Station field experimental work relating to a variety of crops has been carried out over a number of years, and both wet-season and dry-season crops have been successful with irrigation. These two possibilities are considered here. Results of the analysis may be considered generally applicable to crops with long growth periods such as cotton and safflower. Using a generalized water-usage model, weekly evaluations of the water balance with an assumed irrigation practice have been made for Fitzroy Crossing. Of those stations from which rainfall data are available, Fitzroy Crossing is considered to be most representative of the potentially irrigable land within the area. For comparison, similar evaluations have been made for Kimberley Research Station.

Changes in evapotranspiration rates before sowing and during crop development are assumed to be as indicated by the curve in Figure 5. This curve is used here subject to revision as further experimental data from Kimberley Research Station become available. The curve is similar to that used for dry-land crops but has been modified slightly by steepening the rise of the evapotranspiration rate

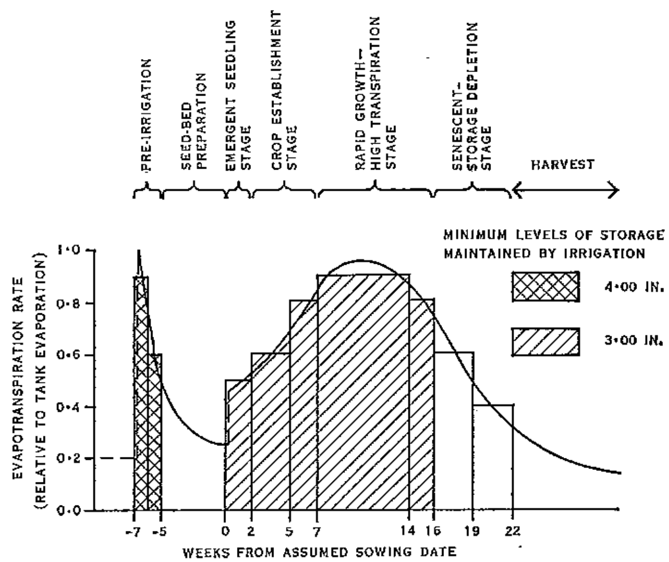

Fig. 5.—Diagrammatic interpretation of rate of evapotranspiration and assumed minimum levels of storage maintained for a typical crop grown under irrigation.

during early growth stages and elevating the maximum rate attained. This is as may be expected with tall crops of high leaf area and considerable aerodynamic roughness. Also high rates of evapotranspiration have been extended over a longer period. This has been done in keeping with an assumed irrigation practice over 16 wk from sowing. No provision is made for reduction of evapotranspiration throughout the irrigated period since available moisture would be kept at a high level. It is assumed that one period of pre-irrigation would be carried out during the seventh and sixth weeks prior to sowing, leaving an intermediate 5-wk interval for seed-bed preparations. As described by Beech (1960) and Thompson (1962) such pre-irrigation has been found advantageous for both wet-season and dry-season crops at Kimberley Research Station. As before, estimated mean weekly tank evaporation has been used for determining actual evapotranspiration requirements from the rates specified in the model.

Weekly irrigation needs of a wet-season crop were calculated by these methods, assuming the crop to have been sown during the last week of November in each year having complete rainfall records. These weekly values were combined for each season, and the mean seasonal irrigation need was determined for each station.

Irrigation of crops during the wet season poses some risk of incurring detrimental excessively wet soil conditions when heavy rains follow closely after an application of irrigation water. To assess this risk, weeks during which the assumed 4 in.

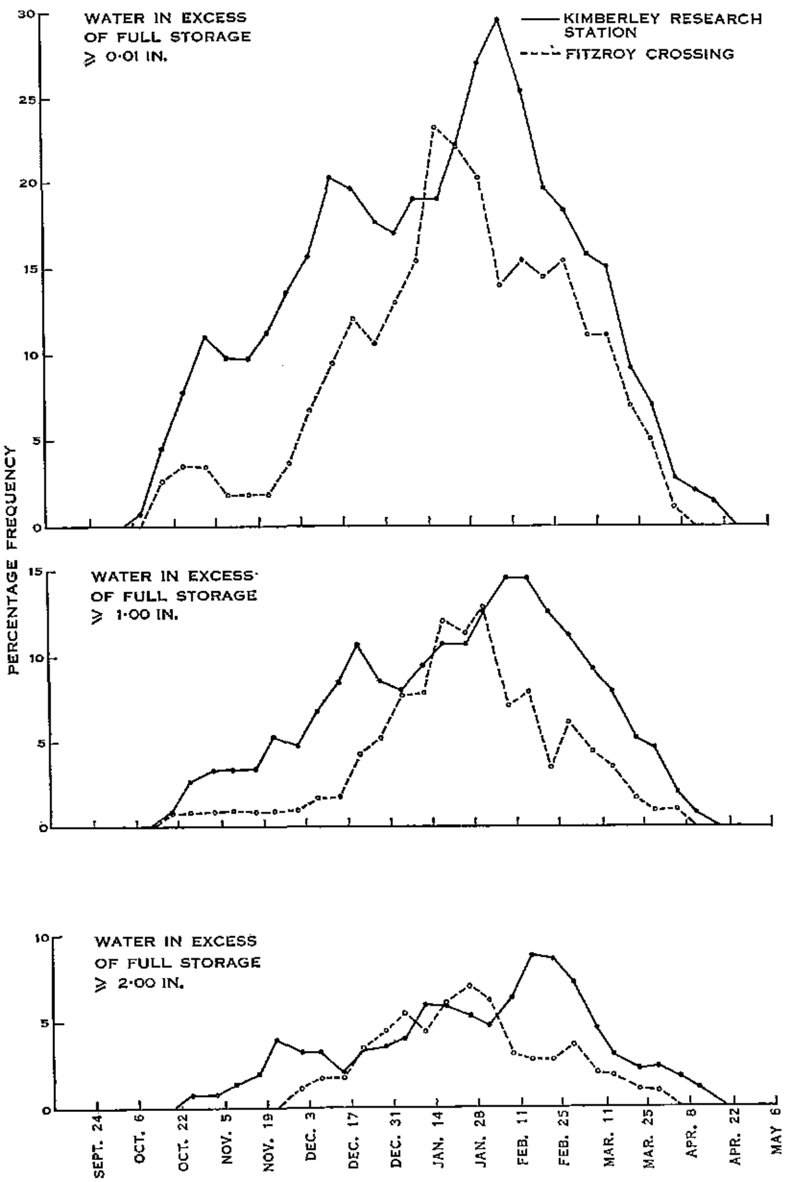

Fig. 6.—Comparison of percentage frequency of weekly intervals having water in excess of full storage at Fitzroy Crossing and Kimberley Research Station.

upper limit of available water was exceeded were identified, and the frequency of weeks having various amounts of water in excess of full storage was determined.

Running three-weekly means of the cumulative percentage frequencies are shown in Figure 6. Seasonal characteristics of irrigation need and water in excess of full storage are summarized in Table 10.

The graphical comparison given in Figure 6 shows that risk of water excess is greatest within a very short period during the wet season at Fitzroy Crossing. Apart from a 5-wk interval between January 1 and February 5, the risk of getting excesses greater than 1·00 in. is apparently only about half as great at Fitzroy Crossing

TABLE 10

WET-SEASON IRRIGATION CHARACTERISTICS AT FITZROY CROSSING AND KIMBERLEY RESEARCH STATION

	Fitzroy Crossing	Kimberley Research Station*
Seasonal irrigation need		
Mean seasonal need (in.)	20·00	16·06
Standard deviation (in.)	3·26	2·83
Highest in one season (in.)	26·68	23·26
Lowest in one season (in.)	12·71	11·41
Mean number of weeks having irrigation need	13·6	11·0
Smallest number of weeks in one season having irrigation need	9 (in 2 cases)	7 (in 2 cases)
Largest number of weeks in one season having irrigation need	17 (in 2 cases)	15 (in 1 case)
Water in excess of full storage		
Mean season total (in.)	3·65	6·90
Mean number of weeks having excess	2·6	3·9
Percentage of seasons with excess	82	100

* Rainfall data for Ivanhoe, W.A., (1907–45) used prior to the first available records from Kimberley Research Station.

as at Kimberley Research Station. Weekly excesses at Kimberley Research Station greater than 1·00 in. between mid December and mid March have occurred in 8–15% of all seasons. For irrigated wet-season crops in the Fitzroy area, it would appear that considerably fewer difficulties due to excessively wet soil can be expected than in the Ord area, assuming similar soil texture and drainage conditions.

For a general assessment of irrigation needs of dry-season crops, it is not necessary to evaluate weekly irrigation needs for individual years. Rainfall during the dry season is persistently meagre and ineffectual, and evaporation over this season does not vary greatly from year to year. Thus dry-season irrigation needs can be expected to vary by only small amounts from one year to another. Accordingly, estimates have been made by applying the water-usage model shown in Figure 5 to a single hypothetical case having no rainfall during the dry season and with an assumed 2·00 in. of available water carried over from the wet season prior to the pre-irrigation period. Sowing during the last week in April has been assumed. A comparison of estimated weekly irrigation needs for Fitzroy Crossing and Kimberley Research Station is given in Figure 7.

Owing to slightly lower evaporation during the winter months at Fitzroy Crossing than at Kimberley Research Station, estimated weekly irrigation needs are lower. The total seasonal irrigation need of a dry-season crop is estimated to be about 25 in. at Fitzroy Crossing and 28 in. at Kimberley Research Station. For

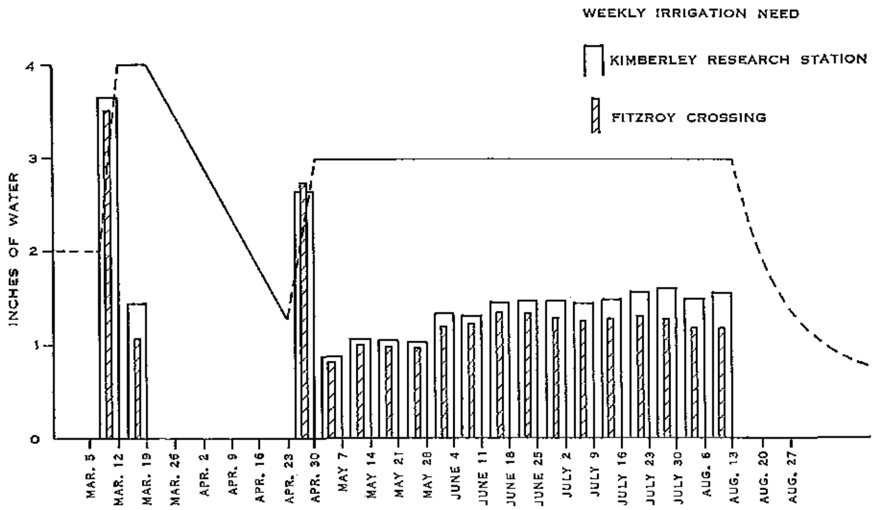

Fig. 7.—Comparison of estimated weekly irrigation needs for a dry-season crop at Fitzroy Crossing and Kimberley Research Station. Curve shows level of available water specified or estimated at the end of each week.

dry-season crops requiring irrigation over longer or shorter periods than that specified in the model used here, an approximation of the total irrigation need can be made by adding or subtracting 1·50 in. of water per week under irrigation.

(*d*) *Pasture*

Assessment of climate in relation to pasture growth is complicated by the varying response of different species within the pasture community to climatic conditions. However, in general, useful growth of pasture within the area is strongly controlled by seasonal changes in available soil moisture.

Dry matter yield data obtained by Slatyer (unpublished) and Norman (unpublished) for native perennial pastures at Katherine, N.T., have been compared with changes in available soil moisture observed by Christian and Slatyer (1958) and estimated from a very simple water-usage model. This model requires that for weeks with combined storage and rainfall in excess of 2·50 in. the rate of evapotranspiration is taken as eight-tenths of the mean tank evaporation of that week, and for weeks with storage plus rainfall less than this amount, the rate is taken as four-tenths. Although further experimental work is needed before yields can be estimated from climatic data with any reasonable accuracy, it is found that the time of commencement and duration of periods of useful pasture growth can be approximated by these methods.

The first occurrence of weekly rainfall in excess of 0·4 times mean tank evaporation is taken as sufficient to initiate useful pasture growth, and this growth is considered to continue until exhaustion of all available water is achieved. In some years, useful pasture growth is terminated early by a failure of rainfall to meet continuing evapotranspiration demands, and often one or more weeks may follow before another period of useful growth commences. In general, the condition of stock is likely to be more closely related to the total duration of useful pasture growth within the season than to the length of one sequence of weeks with continued growth. This total duration has been determined here as the number of weeks during which rainfall plus storage was adequate to meet an evapotranspiration demand of 0·4 times the mean tank evaporation.

TABLE 11

CHARACTERISTICS OF THE PERIOD OF USEFUL PASTURE GROWTH AT SEVEN STATIONS

	Beagle Bay (49 yr of records)	Broome (47 yr of records)	Derby (23 yr of records)	Upper Liveringa (45 yr of records)	Mt. House (28 yr of records)	Fitzroy Crossing (39 yr of records)	Halls Creek (48 yr of records)
Commencement of dominant pasture growth period							
Mean date	Jan. 11	Jan. 3	Jan. 11	Jan. 18	Dec. 28	Jan. 3	Jan. 18
Standard deviation (wk)	3·0	3·0	2·7	3·4	2·0	3·0	4·8
Total duration (wk) of useful pasture growth							
Mean	18·6	16·2	15·8	14·0	16·4	14·7	9·8
Standard deviation	4·4	4·5	4·6	3·9	4·2	3·6	3·7
Total duration (wk) of pasture growth with available water exceeding 2·50 in.							
Mean	9·9	7·3	7·0	5·5	8·3	6·2	4·0
Standard deviation	4·7	3·8	2·7	2·7	3·4	3·8	2·9
% of years with total duration of useful pasture growth							
⩽ 8 wk	0	2	9	11	4	21	38
12 wk	6	21	26	33	11	30	81
16 wk	37	57	46	80	57	41	96
20 wk	63	83	71	96	82	97	100
24 wk	96	98	96	100	96	100	100
28 wk	100	100	100	100	100	100	100

Year-to-year variations in the date of commencement of the dominant growth period are of interest. This date has been identified as the middle of the first week of the longest continuous period of useful growth which occurs each year.

The number of weeks in each year during which storage plus rainfall exceeded 2·50 in. was also readily identifiable and was noted. This may be interpreted generally as that portion of the total duration with available water sufficiently high to preclude any significant water stress.

A summary of weekly evaluations for all stations having more than 20 yr of complete rainfall data is given in Table 11. Regional differences in total duration of useful pasture growth are shown in Figure 8.

The estimated mean total duration of useful pasture growth within the area ranges from approximately 19 wk in the north-western peninsular areas to 10 wk at Halls Creek. As seen from a comparison of Figures 4 and 8, the regional patterns

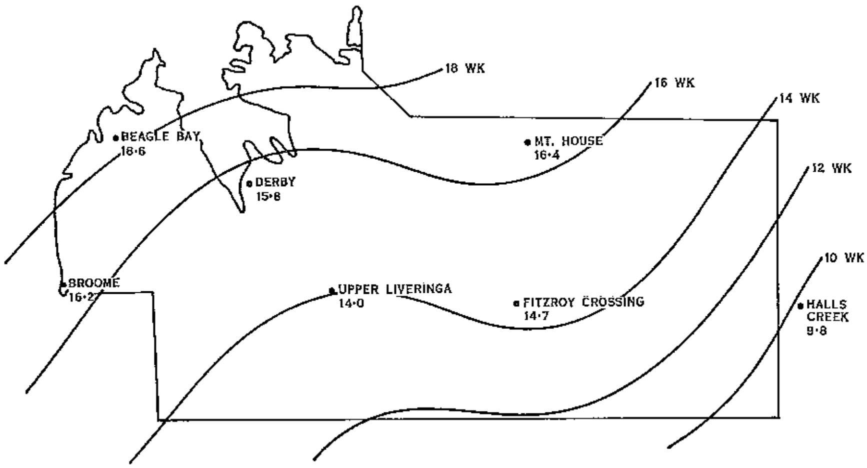

Fig. 8.—Mean total duration (wk) of useful pasture growth.

of the length of agricultural growing period and the total duration of useful pasture growth are very similar. However, the latter are from 2 to 4 wk longer. This is because pastures can quickly utilize even short periods with adequate available water, and useful growth can be interrupted by periods during which the plants are either in a declining state (in terms of total dry matter yield) or in dormancy. The more favoured climatic conditions in the Mt. House area are again evident. Of special interest is an apparent high risk of experiencing a short total duration of useful pasture growth in any one year in the vicinity of Upper Liveringa even with its comparative nearness to the coast. Comparison of the two durations given in Table 11 suggests that for the area as a whole, somewhat less than half of the total duration of useful pasture growth consists of weeks during which some degree of water stress is imposed. The mean date of commencement of the dominant pasture growth period ranges from the last week of December at Mt. House, which is the least variable case, to the third week in January at Halls Creek, which is the most variable case.

Certain seasonal characteristics of the period of useful pasture growth at Mt. House are compared with those at Katherine, N.T., in Table 12. From this it is apparent that although climate–growth characteristics at Mt. House are very favourable in relation to most other parts of the area, these are distinctly inferior to those at Katherine. At Mt. House, the estimated mean duration of useful pasture growth is only about 75% of that at Katherine; the mean date of commencement is about 4 wk later at Mt. House, and the risk of experiencing less than 16 wk duration is about seven times as great as at Katherine. It is notable also that at Mt. House a considerably larger proportion of the estimated total duration of useful pasture growth consists of weeks during which some degree of water stress is likely. The date of commencement of useful pasture growth at Katherine is more variable than at Mt. House. This is apparently related to the greater incidence of early convectional storms in the Katherine area.

TABLE 12

CHARACTERISTICS OF THE PERIOD OF USEFUL PASTURE GROWTH AT MT. HOUSE AND KATHERINE, N.T.

	Mt. House	Katherine*
Commencement of dominant pasture growth period		
Mean date	Dec. 28	Nov. 30
Standard deviation (wk)	2·0	2·7
Total duration (wk) of useful pasture growth		
Mean	16·4	22·5
Standard deviation	4·2	3·9
Total duration (wk) of pasture growth with available water exceeding 2·50 in.		
Mean	8·3	14·6
Standard deviation	3·4	3·9
% of years with total duration of useful pasture growth $\leqslant$ 8 wk	4	0
12 wk	11	1
16 wk	57	8
20 wk	82	25
24 wk	96	69
28 wk	100	97

* Rainfall data for Katherine Post Office (1885–1947) used prior to the first available records from Katherine Research Station.

IV. CLIMATE AND ANIMAL PRODUCTION

Apart from its significance as a control over pasture growth, climate may introduce special problems in animal husbandry. Within the West Kimberley area, two features of climate are of particular interest: (1) the availability of surface run-off which can replenish water supplies at stock watering points, and (2) the incidence of very high temperatures which may adversely affect stock. As a generalized measure of the first of these, weekly amounts of water in excess of full storage were determined from the water balance evaluations which were made in relation to pasture growth.

Seasonal aspects of these are given in Table 13, and the regional pattern of the mean seasonal excesses is shown in Figure 9. The frequency of temperatures above selected levels has been described in Section II(*b*) and is shown in Table 5.

TABLE 13

SEASONAL CHARACTERISTICS OF WATER IN EXCESS OF FULL STORAGE AT SEVEN STATIONS

	Beagle Bay (49 yr of records)	Broome (47 yr of records)	Derby (23 yr of records)	Upper Liveringa (45 yr of records)	Mt. House (28 yr of records)	Fitzroy Crossing (39 yr of records)	Halls Creek (48 yr of records)
Mean seasonal amount of excess (in.)	8·85	4·94	4·83	2·56	2·99	1·81	1·33
No. of weeks with excess per season	3·1	1·7	1·8	1·2	1·8	1·2	0·6
Mean excess per week (only weeks with excess included)	2·85	2·94	2·71	2·22	1·71	1·47	2·21
% of seasons with excess	84	70	78	60	61	59	40
Longest interval between excesses (wk)	148	154	102	205	150	162	202

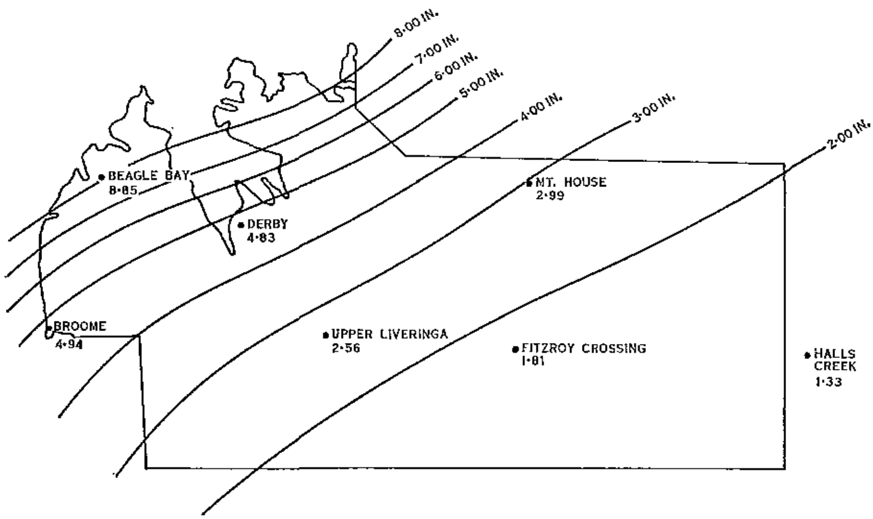

Fig. 9.—Mean seasonal amount of water in excess of full storage.

Owing to the high variability and marginal nature of rainfall during the wet season (in relation to evapotranspiration), long periods without surface run-off do occur frequently throughout the whole of the area. This is particularly so in the southern and western portions. However, from the mean excesses per week it is evident that when excesses do occur, they are generally of substantial amount. The highest weekly excesses are most likely to occur in the last two weeks of January and the first week of February, and excesses of lesser amounts may occur generally between mid December and mid March.

The frequency of daily maximum temperatures over 100° F is high as compared with other parts of northern Australia. The greatest risk of very high temperatures occurs during October and November just prior to the onset of the wet season. However, very high maxima do also occur at times between January and March, particularly at inland localities where the intervals between rainfalls have greater radiation receipts. Very high temperatures occurring just before the wet season are likely to pose the greatest difficulties, since at that time stock may have to travel longer distances to the fewer remaining watering points.

V. Acknowledgments

Assistance of the Commonwealth Bureau of Meteorology in providing notes on general synoptic conditions in the area is greatly appreciated. The authors are grateful to Mr. J. I. Grenot, Applied Science Representative of IBM Australia Pty. Ltd., for his invaluable assistance in preparing a digital computer programme for carrying out the weekly water balance evaluations, and to Professor K. J. Le Couteur, of the Department of Mathematical Physics, Research School of Physical Sciences, Australian National University, for permission to use computer facilities. The assistance of Mrs. A. Komarowski in preparing data for the computer and carrying out a large volume of other computations is gratefully acknowledged.

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PART IV. GEOMORPHOLOGY OF THE WEST KIMBERLEY AREA

By R. L. WRIGHT*

I. INTRODUCTION

The survey area comprises that part of north-western Australia drained by the Fitzroy and Lennard Rivers and their tributaries, together with the peninsulas of Dampier and Yampi. The geology of the area has been described in detail by Guppy *et al.* (1958) and by Veevers and Wells (1961), and reference to structure and lithology in this chapter is based largely on their work.

This account begins with a regional description of the area. Then follows an outline of the evolution of the physical landscape, which forms the framework for the genetic classification of the land systems. The geomorphology of the land systems is then summarized.

II. PHYSICAL REGIONS

The area takes in Fitzroyland and the southern part of the North Kimberley division, first defined by Jutson (1934). These two continental divisions may be divided into "provinces", each with a unity of major relief based on a unity of geological structure. The provinces can be subdivided into "regions" which, although embracing a diversity of rock types, have a unity of relief which is expressive of a unity of physical history (Fig. 10).

(*a*) *North Kimberley Division*

This division consists of the relatively stable Kimberley block (Traves 1955) and comprises Upper Proterozoic quartzite, sandstone, and shale with intrusive rocks of Upper Proterozoic or Lower Cambrian age. Only the southern part of the division is within the survey area. It includes large areas above 2000 ft and forms the divide between drainage south-westwards into Fitzroyland and that flowing north-east to the Timor Sea. As defined here, the division includes Yampi peninsula and the uplands drained by the O'Donnell River, areas which Jutson (1934) included in Fitzroyland. It consists of two provinces.

(i) *Kimberley Plateaux Province.*—This province is formed on subhorizontal or gently dipping rocks and constitutes the core of the North Kimberley division. It consists mainly of high, rugged, quartzite plateaux up to about 2500 ft above sea-level. Only the southern part of this province is included in the survey area and it contains two regions.

(1) *Eastern Plateaux.*—This region lies east of the Hann River and mainly comprises extensive plateaux and broad cuestas capped by massive quartzite and sandstone. Rocky surfaces and high escarpments are characteristic. It includes the main watershed of the division and is drained by the headwaters of the Fitzroy River

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and tributaries of the Traine River on the one hand, and by the northward-flowing headwaters of the Chamberlain and Durack Rivers on the other. Drainage is mainly deeply entrenched in narrow strike valleys and relief is up to 1000 ft.

(2) *Western Plains.*—This region extends west from the Hann River. It includes extensive shale lowlands, with local relief generally less than 30 ft, and comprises the drainage basins of the Adcock River and its tributary the Throssell River. Rocky plateaux with escarpments up to 1000 ft high occur between the two lowlands and also to the west of them. In addition, hilly areas formed on basalt and dolerite occur in the south-east and north-west of the region.

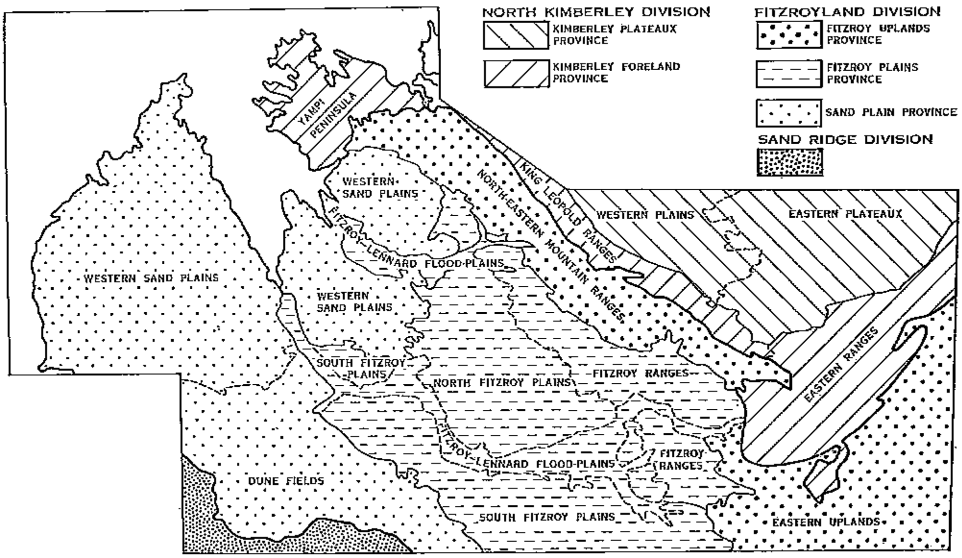

Fig. 10.—Divisions, provinces, and regions.

(ii) *Kimberley Foreland Province.*—This province extends along the western and southern margins of the Kimberley plateaux province and is formed on folded and probably thrust-faulted strata. The underlying resistant and less resistant beds give rise to high, rocky quartzite and sandstone strike ridges and narrow, hilly basalt and dolerite vales. Summits are commonly above 2000 ft and attain 3000 ft. The province is subdivided into three regions with varying complexity and relief.

(1) *Eastern Ranges.*—This is the most complex region. In addition to the characteristic ridge and vale relief, it includes dissected quartzite and sandstone plateaux, and hill tracts and valley plains formed on basalt, gneiss, and schist. Relief is up to 1000 ft. It is drained by part of the Margaret River and its tributary the O'Donnell River, and includes the eastern part of the King Leopold Ranges and the Mueller and Lubbock Ranges.

(2) *King Leopold Ranges.*—This is the least complex region and has the greatest relief, locally attaining 1750 ft. It is in a relatively narrow strike belt, aligned north-west–south-east, in which drainage is strike-aligned and tributary to the Lennard,

Isdell, and Fitzroy Rivers. Drainage gaps are infrequent and the only river cutting through the ranges is the Fitzroy, which does so in the narrowest, south-east part of the region.

(3) *Yampi Peninsula*.—This region mainly comprises rocky plateaux on the axes of anticlines and shallow synclines, with cuestas on the flanks of the folds. Relief is less than in the other regions and does not exceed 500 ft. It also contains low-lying sandy plains, with upstanding hills and ridges which occur in the south of the peninsula. These plains bevel structure and rise gradually inland to the watershed at the heart of the peninsula.

The region has an indented submerged coastline with rocky cliffs several hundred feet high and with numerous small offshore islands.

(*b*) *Fitzroyland Division*

This division comprises the Fitzroy basin, in which a great thickness of Palaeozoic and Mesozoic sediments overlies a Pre-Cambrian basement of crystalline rock. The basement crops out along the north-eastern and eastern margins, where it includes metamorphic rocks. The extreme south-west of the survey area extends slightly beyond the limits of Fitzroyland to include a very small part of the sand ridge division of Jutson (1934). However, because of the small area of this inclusion, its description is included with that of the somewhat similar adjacent part of Fitzroyland.

Fitzroyland division contains three provinces.

(i) *Fitzroy Uplands Province*.—This province includes the highest and most dissected parts of Fitzroyland and is mainly underlain by the crystalline basement. It consists of plateaux, mountain and hill ranges, and valley plains, mainly between 800 and 1500 ft above sea-level. It contains two regions:

(1) *Eastern Uplands*.—This region consists of gently sloping sandy plateaux, hill or mountain tracts, and lower plains. The sandy plateau surfaces extend over all parts of the region and over all rock types, but in tracts dissected below, the other land forms vary with the underlying strata. Low hills and stony plains occur on granite and gneiss which crop out throughout the region, particularly in the north-east. Cuestas up to 350 ft high are formed on quartzite in the centre of the region with valley plains on the intervening shale. Low hills and rocky plateaux, with relief mainly less than 200 ft, are formed on Permian conglomerate and sandstone in the south-west, and mountain ridges and hill ranges with relief up to 500 ft occur on basement metamorphic rocks in the south-east.

This region is drained by the headwaters of Christmas Creek and Margaret River and includes the limit of sea-going drainage, the sand plain to the south-east being the divide beyond which interior drainage commences.

(2) *North-eastern Mountain Ranges*.—This region consists of granite domes, gneiss hills, and schist ridges, with relief of up to 600 ft in a narrow structural belt on the north-east margin of Fitzroyland. Restricted stony plains and undulating terrain occur along the main valleys.

The drainage is strike-directed, tributary to the Barker, Lennard, and Fitzroy Rivers which flow across the belt.

(ii) *Fitzroy Plains Province.*—This province constitutes the greater part of the structural unit of the Fitzroy basin. It is underlain by gently folded sedimentary rocks, mainly of Permian age but ranging from Ordovician to Triassic. Altitudes increase from about 100 ft in the central parts to 800 ft in north-eastern hill ranges, and restricted plateaux exceed 1000 ft above sea-level in the west and south. It contains four regions.

(1) *Fitzroy Ranges.*—This region is a north-west–south-east strike belt consisting of rocky hill ranges and plateaux with narrow bevelled crests. It is mainly underlain by Devonian limestone, sandstone, and shale with dips varying from gentle to steep. Relief is mainly up to 250 ft but rounded conglomerate hills attain 500 ft. Stony plains and extensive alluvial cracking clay plains occur at the foot of the main ranges. Drainage is sparse and strike-controlled, but the Fitzroy River follows an exceptional transverse course across the region.

(2) *North Fitzroy Plains.*—This region consists of sand plain and dune fields underlain mainly by lateritized, interbedded sandstone and shale of Permian and Triassic age. Stony plains on weathered or fresh rock occur in the lower parts to the south and west.

(3) *South Fitzroy Plains.*—This region mainly consists of banded outcrop plains on Permian rocks, with local dune fields. However, the region also includes upstanding rocky plateaux and hill lands with relief of up to 500 ft formed in more resistant Permian sandstone and conglomerate. These comprise the St. George, Poole, Shore, and Grant Ranges.

(4) *Fitzroy–Lennard Flood-plains.*—Flood-plains up to 14 miles wide, with longitudinal gradients between 1 in 2000 and 1 in 4000, occur along the lower and middle course of the Fitzroy and Lennard Rivers and their tributaries. The rivers are seasonal, flowing during the wet season and for a short time afterwards, although scattered pools persist during the dry season. Channels are meandering and anastomosing, commonly up to 40 ft deep and cut in alluvium but locally up to 60 ft deep and incised in bed-rock.

The flood-plains include three main types. The Fitzroy flood-plain upstream from Alexander Island is characterized by broad levees of younger alluvium. Downstream, levees are restricted and back plains of heavy cracking clays are extensive. In addition the region includes older inactive flood-plains of cracking clays, now being marginally dissected. These extend along the lower course of the Lennard River and include Alexander Island on the Fitzroy.

(iii) *Sand Plain Province.*—This province comprises sand plain and dune fields mainly underlain by a Jurassic–Cretaceous sequence of conglomerate, sandstone, and siltstone and by Permian and Triassic sandstone and siltstone. These rocks are lateritized in many areas. It constitutes the western and south-western parts of the survey area and the Dampier peninsula. The province is mainly less than 400 ft above sea-level but altitudes of up to 800 ft are attained in the south.

(1) *Western Sand Plains.*—This region consists of the sand plain of Dampier peninsula and the similar country which extends north and south of the lower Lennard River. It mainly comprises extensive sand plains with no surface drainage, and marginal sand plain and dune fields which generally have integrated drainage

systems. Particularly in the eastern part of Dampier peninsula and flanking the Lennard River, the sand masks a landscape of low plateaux and valley plains, with laterite breakaways in the east. There are broad saline mud flats in the bays and estuaries around the coast.

(2) *Dune Fields.*—This region is in the south-western part of the area. Here, dune fields cover plains on unweathered rock in the north, and a plateau surface (part of the Sand Ridge division) on weathered Jurassic sandstone and siltstone which is 500 ft or so higher to the south. The Edgar Range occurs between these two main areas of dunes and consists of rocky plateaux and hilly terrain with restricted sandy alluvial plains at its foot.

III. Active Land-forming Processes

Under the semi-arid and arid climates which prevail in the survey area, weathering is guided by lithology and detailed rock structures. Rock breakdown, in particular the secondary comminution of rock debris, is very slow. Fine rock waste is removed relatively rapidly but there remains a thin, stony mantle on erosional surfaces.

Hill slopes are characteristically steep, at angles controlled by geological structure, and rectilinear or faceted forms are typical. There is normally a sharp slope break at the hill foot to gently sloping plains or pediments adjusted to sheet-flow.

The stream regime is seasonal. In the uplands of the North Kimberley division, there is high run-off with violent "flash" floods as testified by flood banks in larger streams. The competence of stream-flow is shown by numerous gullies and the work of sheet flooding by the typical occurrence of erosional valley plains.

In the lowlands of Fitzroyland, run-off is low because of gentle slopes and extensive areas of sand cover, and this is reflected in the poorer development of tributary streams. However, in the higher parts heavy storm rains result in "flash" floods, largely as sheet-flow, which deposit their load in aprons and restricted alluvial plains at the hill foot.

For short periods of each year extensive floods occur along the main rivers, fed by tributaries in the North Kimberley division. Little is known of river regime but records indicate that even the prominent levees are topped every few years. The activity of over-bank deposition is indicated by the broad levee zones with stratified alluvia, particularly in the upper sectors. Back plains are more extensive down valley and are areas of quiet deposition masked by the occurrence of relatively mature soils. Towards the end of the dry season the deep main channels and billabongs are occupied only by discontinuous pools which provide an important source of stock water.

Soil erosion by running water occurs mainly in areas of disturbance, particularly on the flood-plains, where scalding and gullying are common, and also locally on texture-contrast soils.

Under the present climate and vegetation cover, aeolian sand surfaces are mainly stable and wind should no longer be an important erosive agent in such areas. Sand movement occurs locally in the extreme south but only during very dry years. Elsewhere, wind erosion is associated with heavy stocking and disturbance and is common on the flood-plain soils and on trampled, powdery soils in limestone areas.

Extensive deposition of marine and estuarine mud and silt has occurred in King Sound and in the Roebuck Plains east of Broome. There is a wide tidal range — up to 36 ft — and extensive mud flats with mangrove fringes and samphire marshes are typical. Estuarine deposition is probably strongly encouraged by the fairly abundant silt transported by the main rivers. Cliffing is mainly restricted to headlands along the indented submerged northern coastline, and the coasts are mainly depositional.

Many of the land forms in the survey area are not being shaped to any significant extent by the processes described, and much of the landscape is inherited and has formed under a different climate from the present. Therefore, the present-day landscape can only be understood in terms of its geomorphic history, which is outlined below.

IV. History of the Physical Landscape

(a) *The Kimberley Surface*

The oldest landscape element is that which is here termed the Kimberley surface. It contains two elements which are altitudinally distinct — the High Kimberley surface in the North Kimberley division, and the Low Kimberley surface mainly in Fitzroyland — and which probably represent distinct cyclic erosion surfaces. For convenience of description the Low Kimberley surface is described first and is progressively traced into the higher level.

In Fitzroyland, the Low Kimberley surface comprises broad, gently sloping plains which bevel the sedimentary rocks and which also extend onto the crystalline rocks further east and north-east. These plains rise gradually from less than 100 ft above sea-level near the coast to between 1300 and 1500 ft at the head of Fitzroy drainage. They also rise across the Fitzroy basin from about 400 ft near the Fitzroy River to between 1100 and 1200 ft in the north-east of Fitzroyland and to between 700 and 900 ft in the south of Fitzroyland.

In the North Kimberley division, the Low Kimberley surface forms dissected plains in the main headwater valleys of the eastern plateaux region. These are mainly between 1000 and 1500 ft above sea-level.

The junction of the Low and the High Kimberley surfaces is marked by the steep escarpment at the southern margin of the King Leopold Ranges. In this region the High Kimberley surface comprises undulating plateaux and accordant, bevelled ridge and cuesta crests, 2000 to 2200 ft above sea-level. Mt. Ord (3070 ft), Mt. Broome (3040 ft), Bold Bluff (2760 ft), and summits in the Durack Range (2500–2850 ft) rise above this level.

The High Kimberley surface is also extensive in the eastern plateaux region and forms undulating or gently sloping quartzite and sandstone plateaux, mainly between 1800 and 2000 ft. However, the surface is more restricted in the western plains region and is preserved only on more resistant quartzite as flat or gently sloping plateau surfaces between 1750 and 2000 ft above sea-level.

The bevelled crests of the Grant Range and parts of the St. George Range stand up to 800 ft above the Low Kimberley surface in the Fitzroy plains province and may represent outliers of the dissected High Kimberley surface. Similarly, bevelled and accordant plateaux, hill, and ridge crests which stand above the Low Kimberley surface in Yampi peninsula and in the eastern uplands region may also have been isolated by dissection of the High Kimberley surface.

Compston (in Prider 1960) has dated the leucite lamproites of the Fitzroy plains province as Jurassic. South-west of Mt. North the Low Kimberley surface lies at about the level of the Jurassic land surface on which lamproites were extruded, and may represent an exhumed part of it. Elsewhere, adjacent to the Low Kimberley surface, the lamproites are intrusive rocks and in these areas, therefore, the Low Kimberley surface must be cut below the level of the Jurassic land surface. The High Kimberley surface may represent an uplifted and degraded part of this Jurassic land surface, the movements possibly occurring in conjunction with the igneous activity that resulted in the intrusion of the lamproites.

At its maximum extent the mid Jurassic to Lower Cretaceous transgressive sea covered most of that part of Fitzroyland south and west of the present lower course of the Fitzroy River (Veevers and Wells 1961). By mid Lower Cretaceous times the sea had withdrawn and with the exception of transgressions in Dampier land towards the end of the Lower Cretaceous and in the mid Tertiary, the area has been land ever since. Thus, the High Kimberley surface possibly may be broadly identified with an uplifted Jurassic land surface and the Low Kimberley surface appears to have been cut from this Jurassic land surface in the north of Fitzroyland and from the emerged Cretaceous sea floor to the south and west. Dissection of the Jurassic plains may have commenced with an uplift during Upper Jurassic and Lower Cretaceous times. During the remainder of the Cretaceous and the early Tertiary, dissection of the Jurassic land surface continued, and much of the Cretaceous and some of the Jurassic sediments were also removed from the emerged Lower Cretaceous sea floor to the south and west. The resultant erosion surface is the Low Kimberley surface.

The High and Low Kimberley surfaces were lateritized to a varying degree, presumably under a humid tropical climate. Crystalline rocks and sandstone and shale in Fitzroyland were weathered to depths of up to 50 ft. Weathering was more selective on the Upper Proterozoic sediments in the North Kimberley division, forming shallow laterites on shale and micaceous sandstone and siliceous duricrusts on some of the quartzites.

Although lateritic weathering profiles occur on both the High and Low Kimberley surfaces and locally on the connecting slopes between them, there is no evidence of separate periods of deep weathering. Lateritization may, in fact, have occurred during any time in the earlier subaerial history of the area, and the occurrence of laterite profiles at different levels may merely be due to the successive achievement of suitable site conditions.

The crest of the Kimberley plateau probably formed a watershed between drainage to the north-east and drainage flowing south-westwards into Fitzroyland. The fact that remnants of the weathered surface slope towards existing rivers indicates that the main elements of the present drainage system already existed on the Kimberley surface by the time of lateritization. Furthermore, lateritized fluviatile gravels flanking the middle sectors of the Fitzroy and Lennard Rivers indicate little subsequent change of course.

(b) Dissection of the Kimberley Surface and the Formation of the Fitzroy Surface

During a subsequent cycle of erosion the Kimberley surface was dissected and a younger, relatively unweathered erosion surface was produced. Because of its extent in Fitzroyland the name Fitzroy surface is suggested for it. Deep weathering had ceased by the time the Fitzroy surface had been formed, and it is interesting that evidence from the Carnarvon basin (J. M. Dickins, personal communication) suggests that deep weathering may have ceased by mid-Tertiary time.

Regional variations in the amount and nature of dissection of the Kimberley surface and the resultant distribution of the Fitzroy surface reflect the influence of three factors — the nature of the initiating uplift, underlying structure and lithology, and the form of the Kimberley surface.

Dissection of the Kimberley surface was probably caused by uplift, possibly part of widespread Upper Miocene earth movements (David 1950). The mode of uplift appears mainly to have been a tilting movement about a coastal hinge line. This led to shallow dissection in coastal areas and to increasing dissection inland.

Thus, the Kimberley surface is extensively preserved near the coast, the main result of the uplift being the formation of broad valleys less than 50 ft deep by the Fraser and lower Lennard Rivers and their tributaries. Shallow dissection is also characteristic along the lower Fitzroy River and its tributaries. Eastwards dissection increases up to 300 ft and the Low Kimberley surface has been almost entirely destroyed and replaced by the Fitzroy surface in the east and north-east of the Fitzroy plains province. Dissection attains 500 ft in the eastern uplands region and the Fitzroy surface forms the floors of deeply entrenched valleys on the resistant sandstone and metamorphic rocks of the central and south-eastern parts of the region, and broad valley plains on other rocks.

The movements may also have included cross-warping along an axis parallel to and a little north of the Fitzroy River, which elevated the Kimberley plateau and the southern margins of Fitzroyland relative to the central part of the Fitzroy basin. That such warping has taken place is evidenced by the base of Jurassic lamproite extrusions at Mt. North in the Fitzroy plains province being about 400 ft below the present level of Jurassic rocks in the upwarped Edgar Range to the south. Such postulated movements would reconcile the relatively shallow dissection along the axis of the basin, where remnants of the Low Kimberley surface are preserved in a belt extending north-west from Alexander Island in the Fitzroy River flood-plain to the coast, with deep dissection and extensive destruction of the Low Kimberley surface along the margins of the basin.

The plains of the Fitzroy surface transgress up to 8 miles into the crystalline rocks of the north-eastern mountain ranges. Elsewhere in this region, on the flank of the postulated cross warp, dissection is up to 600 ft, forming closely spaced steep-sided mountains and ridges with the Fitzroy surface occurring as restricted gently sloping valley floors.

The pattern of destruction of the Kimberley surface shows a close adjustment to structure and lithology. Thus, the presence of weaker rocks has enabled the Fitzroy surface to develop, even in headwater areas. The broad shale plains of the western plains region and the plains formed by the removal of weathered crystalline rocks in the eastern uplands are examples. However, maximum development of the Fitzroy surface was on the relatively weak, weathered Permian and Triassic interbedded sandstone and shale in Fitzroyland. Here, south of the Fitzroy River, the Low Kimberley surface has been almost entirely destroyed and the younger planation comprises outcrop and sand-covered plains up to 70 miles in extent. The distribution of these plains suggests that during this cycle the lower Fitzroy River flowed west to Roebuck Bay. This line is marked by a broad depression in which the Fitzroy surface was cut, and this is consistent with the stratigraphic evidence for an earlier westward course of the Fitzroy, described by Brunnschweiler (1957).

The formation of the Fitzroy surface made little headway in the massive subhorizontal quartzite and sandstone of the North Kimberley division, and narrow, deeply entrenched valleys were the main result of this cycle of erosion. On dipping rocks of varying resistance in the Kimberley foreland province, however, the weaker shales and basaltic rocks were eroded and narrow strike vales have been formed.

The form of the Kimberley surface also influenced its subsequent dissection during the Fitzroy cycle. The higher-standing High Kimberley surface was more strongly dissected than the Low Kimberley surface. In the North Kimberley division, deep incision of the rivers occurred on the divides of the High Kimberley surface in the eastern plateaux region, isolating rocky plateaux up to 1000 ft high, whereas the Low Kimberley surface in the broad intervening headwater valleys was only moderately dissected to form undulating or hilly terrain in which the weathered surface survives on many interfluve crests. The Fitzroy surface consists of restricted lower plains.

In Fitzroyland, outliers of the High Kimberley surface on the crests of the Grant and St. George Ranges were also strongly dissected by vertical stream incision. However, on the Low Kimberley surface, dissection was shallower but more extensive, forming the broad plains of the Fitzroy surface.

(*c*) *Dissection of the Fitzroy Surface*

Subsequent dissection of the Fitzroy surface is likely to have been caused by uplift which may have been part of the late-Pliocene movements recorded elsewhere in Australia. Dissection was only slight near the coast but extended throughout the area and reached headwaters in the eastern uplands and the North Kimberley division. The initiating uplift, therefore, may have been a reactivation of the earlier Tertiary movements and may have consisted of a tilting about a coastal hinge line.

These movements may have encouraged a tributary of the Lennard, then flowing across King Sound, to cut back and capture the Fitzroy to divert this river northwards. This part of the river's course is narrowly flanked by remnants of the Low Kimberley surface but not by the outcrop plains of the Fitzroy cycle.

The incision of the lower Lennard was slight and is partly concealed by more recent aggradation, but the Fitzroy surface was fairly closely dissected up to about 20 ft along the Fraser River and in the Tarraji basin in the north. Further inland, however, dissection was stronger and the Fitzroy River is entrenched up to about 50 ft into the Fitzroy surface between Mt. Anderson and Myroodah homestead and up to about 100 ft between Myroodah and Noonkanbah homesteads. This dissection reached headwater areas in the Fitzroy Ranges where the limestone plains and undulating terrain of the Fitzroy surface were dissected up to 30 ft. Similarly, valley plains and their marginal pediments were dissected up to 30 ft in the eastern uplands and the Kimberley plateaux.

(d) *Alluvial Deposition*

Subsequently the climate became drier. This led to the formation of flood-plains along the main rivers and to extensive alluviation marginal to upland areas in Fitzroyland. Flood-plain deposition has continued, perhaps in phases, to the present day. The oldest deposits are preserved as plains generally above the level of present floods and are being marginally dissected. In the southern parts of Fitzroyland, sandy aprons and plains formed downslope from the Grant, Poole, and Edgar Ranges, and trunk drainage lines were choked. North of the Fitzroy, plains of fine-textured calcareous alluvium formed downslope from the limestone ranges. These consisted of aprons or broad valley plains such as those flanking Brooking Creek, tributary to the Fitzroy, and Chestnut Creek, tributary to the Lennard. More restricted loamy alluvial plains and drainage floors formed below breakaways in the north Fitzroy plains region.

(e) *Aeolian Sand Movement*

Increasing aridity led to widespread aeolian sand movement in Fitzroyland. Sand plain was mainly developed on weathered remnants of the Kimberley surface whilst dune fields formed in dissected tracts or on the Fitzroy surface to the south. The direction of sand movement, as indicated by dune alignment and elongation, was to the west or slightly north of west.

It is likely that surface drainage was never wholly obliterated during the arid phase. The main rivers, fed by large catchments in the uplands to the north, seem certain to have persisted and flood-plain deposition would have continued in their lower sectors. It is also possible that surface drainage was maintained in the upper sectors of the alluvial plains in Fitzroyland, although wind action became general downslope.

(f) *Climatic Amelioration*

A change to more humid conditions caused the reactivation of drainage in those areas to the south and west where sand movement had been greatest, and led to the stabilization of sand by vegetation. Erosion has not been great during this recent phase. Channels are often only shallowly incised into the sand surfaces. Furthermore, sand plain extends to the foot of escarpments in many areas. There has, however, been some redistribution of aeolian sands by sheet floods at the foot of the ranges south of the Fitzroy, and younger alluvium has been deposited.

Climatic amelioration appears to have been accompanied by a eustatic rise of sea-level post-dating the formation of the sand plain and dune fields. This produced the indented submerged coastline of Yampi peninsula. Elsewhere, relief in coastal areas was slight and the rise of sea-level flooded broad shallow valleys to form King

Sound and numerous bays around Dampier peninsula. Aggradation followed and mud flats formed in the bays and estuaries. These flats extend for short distances into the swales of the adjacent dune fields.

The fact that the saline coastal flats of the Roebuck plains lie above high tides may indicate a more recent slight fall in sea-level.

V. Geomorphology of the Land Systems

The foregoing denudation chronology provides a framework for a classification of the land systems. A major break within this classification is that between erosional and depositional surfaces. The erosional land systems are classified according to whether they form part of, or have been produced by dissection of, either the Kimberley surface or the Fitzroy surface. In this way the relationships of inherited land forms and weathering profiles to their soil and vegetation cover are made clear. The Kimberley surface is considered an entity, and land system boundaries transgress the break between the High and Low Kimberley surfaces.

The depositional land systems are divided into alluvial, aeolian, and estuarine types.

(*a*) *Land Systems Forming Part of the Kimberley Surface*

These land systems consist of gently sloping plains on weathered rock, with patchy mantles of aeolian sands.

Gidgia land system occurs on lateritized granitic rocks and forms divides at the head of the Margaret River in the eastern uplands region.

Mamilu land system is underlain by lateritized micaceous sandstone, siltstone, and shale, and occurs in the north Fitzroy plains region.

(*b*) *Land Systems Formed by Dissection of the Kimberley Surface*

These land systems are classified according to land form and listed according to amount of relief. Those with greatest relief include remnants of both the High and Low Kimberley surfaces, whereas the lower relief categories include remnants of the Low Kimberley surface only. They occur mainly in the north and east of the area.

(i) *Plateaux and Mountain Ranges*.—These land systems, which are mainly underlain by resistant quartzite and sandstone, comprise the strongest relief in the area. They are inaccessible and are characterized by high escarpments, deep gorges, steep rocky slopes, and relief ranging between 350 ft and 1750 ft. They form major drainage divides.

Precipice land system contains the strongest relief in the area and is a complex of plateaux, mountain ranges, broad cuestas, and hill lands. It occurs extensively in the North Kimberley division.

Clifton land system has more uniform, slightly less strong relief and consists of plateaux with closely spaced narrow and deeply entrenched valleys. Its chief occurrence is in the western plains region of the Kimberley plateaux province.

St. George land system comprises less extensive, more dissected plateaux with marginal hill tracts and with sand plain in the main valley floors. It occurs in the south Fitzroy plains region.

Forrest land system consists of strike ridges with intervening hilly vales. It occurs in the Kimberley foreland province.

Lubbock land system consists of cuestas and benched steep-sided ridges and plateaux. It mainly occurs in the eastern ranges of the Kimberley foreland province.

Dockrell land system comprises closely spaced strike ridges and stony valley plains formed on a variety of metamorphic rocks, and occurs in the eastern uplands.

Mandeville land system consists of broad strike ridges with sandy lowlands. It is restricted to Yampi peninsula.

Margaret land system is partly underlain by weaker rocks and lower slopes, and outcrop plains form more than half of the land system. The uplands include plateaux, ridges, and cuestas. It mainly occurs in the eastern uplands but also forms the Shore Ranges in the south Fitzroy plains.

(ii) *Hill Lands*.—The land systems of this group consist of hill lands in which relief mainly ranges between 100 ft and 300 ft but locally attains 600 ft. Hills constitute up to two-thirds of their total areas with undulating lowlands forming the remainder. Remnants of the Low Kimberley surface survive as bevelled or locally laterite-capped crests. Rocky, stony surfaces are general. These land systems occur in tributary headwater areas in Fitzroyland.

Burramundi land system mainly consists of rounded hills and undulating terrain formed on conglomerate. It occurs chiefly in the Fitzroy Ranges.

Bohemia land system consists of plateaux and hill tracts formed on weathered sandstone and sandy siltstone. Laterite summit remnants are unusually extensive, constituting one-quarter of the total area. It occurs mainly in the eastern uplands and also in the dune fields region.

Rose land system is characterized by closely spaced granite domes and it occurs mainly in the north-eastern mountain ranges.

Windjana land system consists of limestone ranges in narrow strike belts in the Fitzroy Ranges.

Reeves land system consists of sand plain with scattered hills and minor plateaux formed on sandstone and quartzite. It occurs in Dampier peninsula.

Koongie land system contains unusually extensive laterite-capped plateaux formed on granite–gneiss–schist complexes. It is distinguished from Bohemia land system by less relief and by differences of land form which are related to differences in rock type. It occurs in the eastern uplands.

(iii) *Undulating Terrain*.—The three land systems in this group are characterized by gently sloping or rounded interfluves, which carry shallow laterites, and by stony lower slopes and scattered low hills. Relief is mainly less than 100 ft. They occur in headwater areas of the North Kimberley division and Fitzroyland.

Fork land system is formed on quartzite, sandstone, and shale, and stony surfaces constitute two-thirds of the total area. It occurs in the eastern plateaux region.

Tableland land system is formed on shale with some interbedded sandstone. One-third of the land system consists of laterite remnants. It occurs in the eastern plateaux.

Ruby land system is formed on granite and metamorphic rocks and is distinguished by extensive laterite remnants and by sand plain. It is confined to the eastern uplands region.

(iv) *Plains*.—The three land systems in this group consist of gently sloping upland plains in which cracking clays cover about two-fifths of the area. Relief is mainly less than 10 ft but the first land system includes broad valleys entrenched up to 100 ft.

Leopold land system comprises cracking clay plains with stony, stripped margins and with entrenched valleys characterized by much limestone outcrop. It occupies watershed areas in the Fitzroy Ranges.

Oscar land system comprises less extensive cracking clay plains interspersed with limestone outcrop plains and low hills. It is contiguous with Leopold land system in watershed areas in the Fitzroy Ranges.

Gladstone land system consists of cracking clay plains separated by broad gently sloping sandy interfluves and is formed on shale and sandstone. It occurs in the eastern plateaux region.

(*c*) *Land Systems Eroded below the Kimberley Surface*

Mountains and hills with relief between 300 and 600 ft constitute up to two-thirds of the area of this group of land systems, in which the Low Kimberley surface is indicated only by local summit accordance. Hill slopes are steep and surfaces are rocky. These land systems form the greater part of the north-eastern mountain ranges and have scattered occurrences in the eastern uplands and in the North Kimberley division.

Richenda land system consists of closely spaced, steep-sided mountains formed on granite–gneiss complexes, schist, and other metamorphic rocks.

Amy land system consists mainly of massive granite domes with intervening alluvial flats. The alluvial flats together with hill-foot slopes comprise more than half the total area.

Looingnin land system consists of mountains and hills on basalt and dolerite with scattered quartzite ridges. It mainly occurs flanking major drainage lines in the Kimberley ranges and the eastern plateaux.

(*d*) *Land Systems formed by Partial Dissection of the Fitzroy Surface*

These land systems consist of gently undulating terrain and plains which are generally cut well below the level of the Kimberley surface, although locally they have been formed merely by the stripping away of the weathering mantle, as in parts of the Fitzroy plains. They occur on a wide range of rock types and outcrop and stony surfaces are general. They are particularly extensive in the Fitzroy plains province but have a wide distribution flanking the main rivers and form valley plains in head-water areas.

(i) *Undulating Terrain*.—The land systems in this group have relief less than 30 ft but include scattered hills mainly less than 100 ft high. Differences between the land systems appear to be related to differences in rock type. They occur in tributary headwater areas of Fitzroyland and the North Kimberley division.

Tarraji land system has scattered, high, steep-sided granite domes. It occurs in the north-west and lowest part of the north-eastern mountain ranges.

O'Donnell land system is differentiated from Tarraji land system by lower, less numerous hills, by extensive stony surfaces, and by restricted cracking clay plains. It is formed on granite, gneiss, and metamorphic rocks and occurs at the foot of mountain and hill belts in the eastern uplands.

Pigeon land system consists of extensive valley plains, mainly in the Fitzroy uplands province, formed on granite, gneiss, and metamorphic rocks.

Neillabublica land system, formed on limestone, is distinguished by low, gently sloping, stony interfluves, alluvial plains of cracking clays, and restricted sandy aprons. It occurs in the Fitzroy Ranges fringing the hill lands.

Glenroy land system, formed on shale, is distinguished by broad alluvial drainage floors. It is extensive in the western plains region of the North Kimberley division.

(ii) *Plains*.—These land systems consist of gently sloping outcrop plains, with scattered low hills and ridges, and are mainly formed on interbedded sandstone, siltstone, and shale. They occur mainly in the Fitzroy plains province.

Myroodah land system is characterized by strike-aligned scalded flats. It is the most extensive land system in the group and constitutes a large part of the south Fitzroy plains.

Cowendyne land system is formed on basalt and dolerite, which give rise to cracking clay plains. It occurs mainly in the western plains region of the North Kimberley division but there are scattered occurrences as narrow valley floors in the Kimberley foreland province.

Egan land system is characterized by low lateritic rises, formed by the stripping away of the earlier weathering mantle. It is contiguous with shallowly dissected parts of the Low Kimberley surface in the north Fitzroy plains.

Duffer land system consists of plains of residual cracking clays in the north Fitzroy plains.

(*e*) *Alluvial Plains*

These land systems consist of tributary alluvial plains, stable flood-plains, and younger active flood-plains, and they are confined to the Fitzroy plains province. The deposits range from sand to silt and include much fine-textured calcareous material.

(i) *Tributary Alluvial Plains*.—These land systems consist of alluvial plains and minor colluvial aprons lying mainly on the Fitzroy surface in the Fitzroy plains province. They vary with the nature of the parent material. They are characterized by a sparse pattern of subparallel drainage and by gradients mainly less than 1 in 500. Extensive areas are subject to diffuse sheet flooding.

Fossil land system consists of cracking clay plains formed of fine-textured calcareous deposits from the limestone Fitzroy ranges.

Coonangoody land system consists of sandy plains, locally re-sorted by wind, derived from sandstone and conglomerate uplands in the south Fitzroy plains. It contains broad through-going trunk drainage floors.

Calwynyardah land system comprises loamy alluvial plains with extensive scalded tracts and occurs downslope from the dissected margins of the lateritized Low Kimberley surface in the north Fitzroy plains. It includes the backing breakaways.

(ii) *Stable Flood-plains.*—The two land systems in this group consist of older flood-plains flanking the main rivers, but lying mainly above the level of present floods, and being marginally dissected.

Alexander land system is the more extensive and consists of stable cracking clay plains along the lower Lennard River and includes Alexander Island on the Fitzroy River.

Chestnut land system comprises sandy plains up to 30 ft above the active flood-plains. It has restricted occurrences along the lower course of Christmas Creek.

(iii) *Active Flood-plains.*—These land systems are the active flood-plains of the Fitzroy and Lennard Rivers. They comprise levees of stratified, commonly micaceous deposits which are mainly fine-textured but which range from sand to silt, and back plains characterized by dark cracking clays.

Djada land system is distinguished by extensive back plains which constitute half the land system. It forms much of the Fitzroy flood-plains.

Gogo land system is distinguished by broad levees which form two-thirds of the total area. It occurs chiefly along the Fitzroy River up-stream from Alexander Island, and also in the lower sectors of the Fitzroy and Lennard Rivers.

(*f*) *Sand Plain and Dune Fields*

Gently sloping or undulating sand plain with dune fields covers one-quarter of the survey area. Dunes are linear, trending approximately east–west, and are particularly extensive overlying the outcrop plains of the Fitzroy surface. Surfaces are generally stabilized by vegetation.

(i) *Sand Plain and Dune Fields with Little Organized Drainage.*—Surface drainage is here restricted to local run-on from adjacent hill tracts or to minor ill-defined drainage floors in areas of thin sand cover. These land systems overlie extensive plains of the Low Kimberley and Fitzroy surfaces and occur in the north Fitzroy plains and in higher parts of the sand plain province.

Yeeda land system consists of gently sloping or broadly undulating sand plain. It is most extensive in Dampier peninsula.

Camelgooda land system comprises the dune fields which constitute much of the dune fields region and which have scattered occurrences in the sand plain region and in the north and south Fitzroy plains regions.

Luluigui land system consists of sand plain and dune fields with extensive areas of thin sand cover or bare, stony surfaces.

(ii) *Sand Plain and Dune Fields with Through-going Drainage.*—These areas have a sparse to moderately dense system of branching drainage in broad shallow valleys entrenched in the Low Kimberley and Fitzroy surfaces. Relief is mainly less than 50 ft. They occur at a lower elevation than those of the previous group and are extensive in coastal areas of the sand plain province and adjacent to the lower Fitzroy and lower Lennard Rivers.

Sisters land system consists of low sandy plateaux, with marginal laterite exposures, and lower sand plain surfaces. It is extensive adjacent to the lower Lennard River and south of the Robinson River.

Lowangan land system consists of sandy divides with lower sand plain and restricted alluvial plains in the lowest sectors. Lowangan land system occurs in the Fraser River drainage basin.

Wanganut land system is the most extensive and consists of sand plain with dunes in shallow valleys tributary to the coast in the sand plain province.

Fraser land system consists of sand plain with irregular dunes in which areas of thin sand cover and outcrop constitute one-sixth of the total area. It occurs in the Fraser River drainage basin.

(g) *Saline Coastal Flats*

The two land systems in this group consist of saline estuarine and littoral deposits which occur in estuaries and bays around the coast. Outer mangrove fringes, bare mud flats, and slightly higher samphire flats are general.

Carpentaria land system consists of tidal flats in which bare mud surfaces constitute two-fifths of the total area.

Roebuck land system is distinguished by broad grass plains with a dense pattern of branching drainage at the landward margins. Since the land system is mainly above the level of high tides, bare mud flats form only one-twentieth of the area. It comprises the Roebuck plains east of Broome.

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PART V. SOILS OF THE WEST KIMBERLEY AREA

By G. K. RUTHERFORD*

I. INTRODUCTION

Although the present climate is semi-arid, many of the soils are moderately to strongly leached. This is due in part to the preservation of soils formed in the past, probably within erosional cycles, or the formation of soils on deeply weathered or redistributed products of earlier erosion cycles, and in part to the occurrence of sedimentary rocks containing only minor amounts of weatherable minerals.

Wright (Part IV) has defined a number of land surfaces and it appears that some clear relationships exist between the soils and these surfaces. Within each of these land surfaces there are specific relationships between soil and parent material (Table 14).

Skeletal soils dominate the rugged and undulating parts of the landscape formed by the dissection of the Kimberley and Fitzroy surfaces. At least one-third of the soils of the area are skeletal soils. Brown soils of light texture are the next most extensive soils and are formed mainly on sand plains and dune fields. They may occur also on remnants of the Kimberley surface and plateaux formed by dissection of this surface. These soils occupy about one-quarter of the survey area. Red earths constitute about one-eighth of the survey area and commonly occur on remnants of the Kimberley surface and on hills and undulating terrain formed by the dissection of this surface. These soils are also important on sand plains and dune fields. Yellow earths occur most commonly on alluvial plains, sand plains, and plains formed by the dissection of the Kimberley and Fitzroy surfaces.

Cracking clays are the dominant soils on alluvial plains and are important also on plains formed by the dissection of the Kimberley and Fitzroy surfaces, particularly those associated with limestone and basalt. These potentially important agricultural soils occupy about one-tenth of the area. Red-brown earths are most commonly developed from calcareous fine-grained sedimentary rocks and occur on pediment slopes of mountain ranges formed by the dissection of the Kimberley and Fitzroy surfaces. They occur also on plains formed by the dissection of the latter surface. Solonetzic soils are mainly developed on pediment slopes of hills formed by the dissection of the Kimberley and Fitzroy surfaces. They are usually associated with acid igneous and metamorphic rocks.

Alluvial soils are an important element in some alluvial plains but they occur to a limited extent among stream and river channels throughout the area. Saline soils, saline muds, and beach dunes are the dominant soil types in the coastal parts.

Most of the soils show very poor structural development in the surface and the fine-textured soils display a strong tendency to form sealed surfaces, except the self-mulching cracking clays which show typical angular blocky structure and are

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TABLE 14

SUMMARY OF THE RELATIONSHIPS BETWEEN GREAT SOIL GROUPS AND LAND SYSTEMS

		Land System	Great Soil Groups*													
			Red Earths		Yellow Earths	Brown Soils of Light Texture	Calcareous Earths	Cracking Clays	Red-brown Earths	Solonetzic Soils	Meadow Podzolics	Skeletal Soils			Alluvial Soils	Miscellaneous
			Frayne	Others								Walsh	Oscar	Others		
Forming part of the Kimberley surface	Plains on weathered rock	Gidgia		*D*										m		
		Mamilu		m	S	S								m		
Formed by dissection of the Kimberley surface	Plateaux and mountain ranges	Precipice		m	m					m				*D*		
		Clifton				m								*D*		
		St. George			m	S				m				*D*		
		Forrest	m		m			m				m		S		
		Lubbock		m	m				m					*D*		
		Dockrell							S	m				*D*		
		Mandeville			m	S				m	m			S		
		Margaret			S				m					*D*	m	
	Hill lands	Burramundi		m	m									*D*	m	
		Bohemia		m		m			m					*D*	m	
		Rose		m		m				S				*D*		
		Windjana						m					*D*			
		Reeves		*D*	m									S		
		Koongie		m				m	m					*D*		
	Undulating terrain	Fork			S									*D*	m	
		Tableland			m	m		m						*D*		
		Ruby		*D*		m			m	m				S		
	Plains	Leopold					m	*D*						m		
		Oscar						S					m	S		
		Gladstone			*D*			S								

Eroded below the Kimberley surface	Mountain and hill ranges	Richenda								m				*D*	m	
		Amy				m				S				S		
		Looingnin		S	m			m				m		*D*		
Formed by partial dissection of the Fitzroy surface	Undulating terrain	Tarraji			m		S			S				S	m	
		O'Donnell			m			m	S	m				*D*	m	
		Pigeon							m					*D*		
		Neillabublica					m	S					*D*	m		
		Glenroy			S			m						*D*	m	
	Plains	Myroodah		S		m		m	S				m	m		
		Cowendyne	S					S				m	m		m	
		Egan		m	*D*	m		m		m						
		Duffer			m			*D*								
Comprising alluvial plains	Tributary alluvial plains	Fossil			m		m	*D*								
		Coonangoody			*D*	m				m				m	m	
		Calwynyardah		m	*D*				m	m				m		
	Stable flood-plains	Alexander				m		*D*		m					m	m
		Chestnut		*D*										m		
	Active flood-plains	Djada						*D*							m	m
		Gogo						*D*							S	m
Comprising sand plain and dune fields	With little organized drainage	Yeeda		m	m	*D*			m							m
		Camelgooda		S	m	*D*								m		
		Luluigui		*D*		m			m					m		
	With through-going drainage	Sisters		m	S	S				m				S		
		Lowangan		S										S		m
		Wanganut		S	S	S				m						m
		Fraser		S	S	m								m		
Formed on saline coastal flats		Carpentaria			m										m	*D*
		Roebuck													S	*D*

* *D*, soils occupying more than 50% of the area of the land system; S, soils occupying between 50% and 20% of the area of the land system; m, soils occupying less than 20% of the area of the land system.

locally associated with a gilgai microrelief. Some of the soils, particularly the red-brown earths, solonetzic soils, and cracking clays with crusty surfaces, are very prone to degradation when the vegetative cover is partly or wholly removed and many parts of the area are characterized by large bare scalds. Stony pavements are found on many soils, particularly where the parent material is shaly in nature. Most steep to moderate slopes have shallow skeletal soils and outcrop and deep soils are uncommon on slopes greater than 5°.

Bulk soil samples were collected in the field and selected subsamples were analysed by the Royal Tropical Institute, Amsterdam, Holland. Full details of these are available on application to the Division of Land Research and Regional Survey.

The results of these analyses together with the results of analyses from similar soils from the East Kimberleys and Northern Territory give some general information on the chemical and physical characteristics of these soils.

The reaction varies from slightly acid to moderately alkaline but the chemical fertility of these soils is generally poor. Total C and N are generally low, indicating the small reserves of organic matter. Available phosphorus is low, though the mean figure for total phosphorus (0·05%) is higher than the Australian average as computed by Wild (1958). With the exception of the cracking clays and calcareous earths the results of the analyses indicate that the soils are moderately to strongly leached.

The red earths are generally slightly acid to neutral. Significantly higher amounts of exchangeable cations and available phosphorus and wider C/N ratios occur with those formed from basic igneous rocks than with those formed on other rocks and on sand plains.

Only limited information is available for the yellow earths and this and data from other areas indicate that they are similar but slightly more leached than the red earths. The brown soils of light texture are more leached and have less available nutrients than the red and yellow earths.

The calcareous earths are characterized by the high amounts of carbonate concretions and the dominance of calcium on the exchange complex. They are alkaline and have considerable amounts of available phosphorus.

The cracking clays consist predominantly of illite and montmorillonite clays and are mildly alkaline with high exchange capacities. The exchange complex is dominated by calcium and magnesium and moderate amounts of available phosphorus are usually but not invariably present.

Red-brown earths and the solonetzic soils have fairly strongly leached, slightly acid topsoils, with rather low amounts of soluble salts, over alkaline subsoils. The subsoils of the solonetzic soils are invariably hard although some are coarse-textured and their exchange complex is dominated by sodium. The subsoils of the red-brown earths have more clay and their exchange complex is dominated by calcium ions.

The alluvial soils are generally neutral to mildly alkaline with calcium ions dominating the exchange complex and are moderately well supplied with available phosphate.

TABLE 15

GREAT SOIL GROUPS AND SOIL FAMILIES RECOGNIZED IN THE WEST KIMBERLEY AREA COMPARED WITH NEAREST UNITED STATES DEPARTMENT OF AGRICULTURE (1960) CLASSIFICATION

Classification Used in this Report		U.S.D.A. Classification	
Great Soil Group	Family	Order	Lower Category
Red earths	Yabbagoddy Tippera Frayne Walsh	Alfisols (7·0)	Orthic Ultustalfs (7·440) Orthic Ultustalfs (7·440) Orthic Rhodustalfs (7·430) Lithic Rhodustalfs (7·43–R)
Yellow earths	Tableland Elliott	Alfisols (7·0)	Orthic Ultustalfs (7·440) Orthic Ultustalfs (7·440)
Brown soils of light texture	Cockatoo Pago Kalyeeda	Entisols (1·0)	Oxic Psammustents (1·31–9) Oxic Psammustents (1·31–9) Oxic Psammustents (1·31–9)
Calcareous earths	Neillabublica Oscar	Aridisols (4·0)	Orthic Calcorthids (4·130) Lithic Calcorthids (4·13–R)
Cracking clays	Cununurra Myroodah Wonardo Cherrabun	Vertisols (2·0)	Entic Grumaquerts (2·11–1) Orthic Mazaquerts (2·120) Orthic Grumusterts (2·210) Orthic Mazusterts (2·220)
	Brownish juvenile cracking clays	Entisols (1·0)	Vertic Hapludents (1·43–2)
Red-brown earths	Moonah	Aridisols (4·0)	Orthic Haplargids (4·210)
Solonetzic soils	Tarraji Jurgurra Hooper	Aridisols (4·0)	Orthic Natrargids (4·230) Orthic Natrargids (4·230) Orthic Natrargids (4·230)
Alluvial soils	Robinson Fitzroy	Entisols (1·0)	Orthic Hapludents (1·430) Orthic Hapludents (1·430)
Shallow soils and rock outcrop	Lithic soils Skeletal soils		
Miscellaneous soils	Salt flat soils Medium-textured samphire soils	Entisols (1·0)	Haplaquents (1·14) Haplaquents (1·14)
	Fine-textured samphire soils	Vertisols (2·0)	Natrargidic Mazusterts (2·22–4·23)
	Dark saline muds Beach dune complex Billabong floor soils	Entisols (1·0)	Hyaraquents (1·13) Orthic Orthopsamments (1·22) Orthic Haplaquents (1·140)

II. Classification of the Soils

For the purpose of this report and in order to provide a system of classification which is easily comprehensible and which does not differ radically from traditional Australian systems, great soil groups similar to those outlined by Stephens (1956) have been employed. The unit of classification is the soil family and use is made of soil families which have been described for adjacent areas (Stewart 1954, 1956). Additional families have been named and described where necessary and where observations are adequate.

The Liveringa area has been studied and mapped in detail by Churchward and Bettenay (1962). None of the soil series names employed by them has been used. Their Camballin and Lanlacatta series are included in the Cununurra and Wonardo families respectively, the Josceline and Bylina series in the Moonah family, the Liveringa series in the brownish juvenile cracking clays, and the spinifex series in the Elliott family. A list of soil families used in this report compared with the nearest U.S.D.A. classification (United States Department of Agriculture 1960) is contained in Table 15.

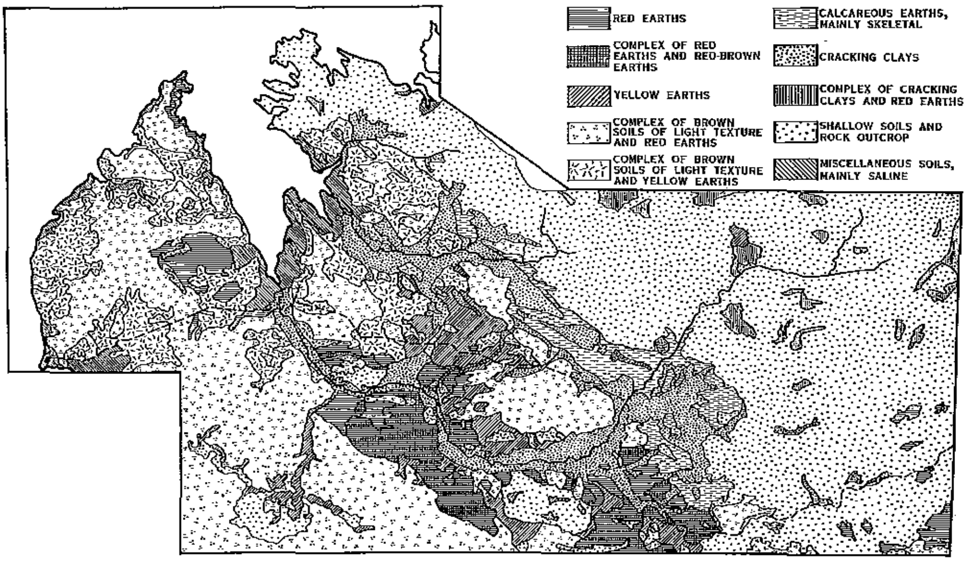

Fig. 11.—Distribution of the main soil groups.

III. Description of the Soils

The broad distribution of the main soils is shown in Figure 11 and on an inset on the land system map. More detailed distribution can be obtained from the land system descriptions and map.

(a) *Red Earths*

Red earths have gradational profiles in which the dark or reddish surface horizons merge into redder loamy or clayey subsoils. They are apedal in both surface and subsoil, and the soil fragments are dull and entirely without shiny faces and are porous and earthy. They are well drained, and are friable when moist and hard to very hard when dry except when very sandy. They are weakly acid to neutral throughout the profile, and soluble salt content and available phosphorus are invariably low.

Soils of the Yabbagoddy and Tippera families dominate the remnants of the Kimberley surface and also occur on younger surfaces on a wide range of sedimentary or alluvial parent materials. They have few or no weatherable minerals, the exchange capacity of their clay, which is mainly kaolin with minor amounts of illite, is low, and their native pastures are considered to be of low nutritive value. They occupy about 6000 sq miles and are important in the Camelgooda, Chestnut, Fraser, Gidgia, Reeves, and Ruby land systems.

Soils of the Walsh and Frayne families are associated only with basic igneous parent materials. They have significant amounts of weatherable minerals in the soil, the exchange capacity of their clay minerals, which are predominantly illite, is high, and their native pastures are of higher nutritive value apparently because of greater soil fertility.

(1) *Yabbagoddy family* has sandy surface horizons merging to red-coloured sandy loam to sandy clay loam at 3 ft. They commonly occur in interdune corridors and on sand plains, on quartzites and sandstones, and also on Permian sediments. They may overlie laterite or have lateritic concretions in the profile.

(2) *Tippera family* has sandy, loamy, or clayey surface horizons merging gradually to red-coloured clay subsoils. Some profiles have low amounts of ferruginous concretions throughout and some overlie laterite.

(3) *Frayne family* has loamy and clayey surface horizons merging gradually to dark reddish or dusky red clay subsoil. Some surface horizons have low amounts of weatherable dark minerals and basic igneous rock pseudomorph fragments which increase in number with depth. The zone of primary rock weathering is usually below 24 in. These soils are important only in the Cowendyne land system, and occupy only about 400 sq miles.

(4) *Walsh family* has reddish, gritty, clayey, shallow surface horizons high in weatherable minerals and rock and rock pseudomorph fragments which merge to the zone of weathering basalt at less than 18 in. They are restricted mostly to Forrest land system and occupy only about 200 sq miles.

(*b*) *Yellow Earths*

The yellow earths are closely related to the red earths in profile morphology, topographic situation, and parent material except that their surface horizons are brownish and subsoils are yellow-coloured with mottling, and they usually have higher amounts of manganiferous concretions.

The fundamental geochemical difference between the two groups of soils is probably the nature and the state of hydration and oxidation of the iron oxides. Yellow earths always occur relatively downslope from the red earths, and they appear to be an imperfectly drained equivalent of the red earths. Yellow earths do not always occur in association with red earths and in fact they occur over wide areas without any red earths.

Melaleuca sp. often occurs on yellow earths and is commonly a useful indicator for them.

Yellow earths were not observed over volcanic rocks or limestone, but are formed on a wide array of sedimentary and alluvial parent materials. The only apparent consequence of lithological differences in parent rock seems to be that micaceous sandstones, siltstones, and mudstones produce finer-textured profiles than other rocks.

The yellow earths are common on the remnants of the Kimberley surface but are developed only in the north-east on the plains and undulating terrain formed by the dissection of this surface. Considerable areas are developed on plains which are part of the Fitzroy surface in the centre of the area and in interdune areas mainly in the western part. Minor areas are developed on alluvial plains adjacent to the major rivers and in the dune fields of the central part. They are important in Calwynyardah, Coonangoody, Egan, and Mamilu land systems, and occupy about 4000 sq miles.

(5) *Tableland family* has brownish sandy to loamy surface horizons merging to yellow-coloured sandy loam to sandy clay loam subsoil at 3 ft. They occur commonly over Upper Proterozoic sandstones and on the outwash material from other sandstones and quartzites. They are also found in the lower sites and interdune areas in the pindan area and in sand plains. They are commonly associated with laterite or lateritic gravels.

(6) *Elliott family* has brownish sandy, loamy, or clayey surface horizons merging gradually to yellow-coloured clay subsoils. They sometimes have mottled subsoils with manganiferous concretions and are commonly associated with laterite and lateritic gravels. They are common over Permian sediments, particularly finer-textured siltstones, mudstones, and shales.

(*c*) *Brown Soils of Light Texture*

These soils usually have a brown sand or sandy loam topsoil with little apparent organic matter. This merges gradually with the brownish grey, brownish yellow, yellow, or red subsoil which is sand to clayey sand to at least 3 ft and commonly to more than 6 ft. They contain virtually no weatherable minerals or lime, the soil mass being composed mainly of quartz sand and kaolin. The reaction of the surface horizons is usually weakly acid and becomes neutral with depth, and both soluble salt content and phosphate content are very low. Thus, they are coarse-textured equivalents of the red and yellow earths.

These soils occur in extensive tracts of sand plain and sand dune country in the western and central parts of the area where they are commonly derived from aeolian material. They are minor in the soil pattern of the remainder of the area with the exception of some pockets derived from quartzitic parent materials in the mountain ranges formed by the dissection of the Kimberley surface. Some minor areas occur on pediments from hill lands formed by dissection of the Fitzroy surface, in particular those which are formed from acidic igneous rocks. They are also of minor extent on alluvial plains. They are important in Camelgooda, Wanganut, and Yeeda land systems and occupy about 10,000 sq miles.

(7) *Cockatoo family* has sandy to loamy sandy texture to at least 3 ft and the subsoil is red. These are most common on the dune crests of the south-west and west although they also occur *in situ* over quartzites and quartzitic sandstones.

(8) *Pago family* has sandy to loamy sandy texture to at least 3 ft and the subsoil is yellow. They are commonly free of rock fragments. They have a limited distribution, and were observed virtually only on outwash fans from quartzitic hills in the King Leopold Ranges.

(9) *Kalyeeda family* has sandy to sandy loam textures to at least 3 ft and the subsoil is brownish grey to brownish yellow in colour. It is not common but occurs in association with hard laterite and also in certain interdune areas.

(*d*) *Calcareous Earths*

Calcareous earths are characterized by moderate to high amounts of amorphous calcium carbonate throughout the weakly developed profile, which is usually shallow. The dark grey or brown surface horizons merge to brownish, greyish, and sometimes reddish subsoils. The texture ranges from silty and sandy loam in the surface horizons to silty clay and clay subsoils, although loamy subsoils occur. They have very weakly developed structural units in the surface soil and become apedal in the subsoil, the soil fragments being entirely without shiny faces, and are porous and powdery, well drained, and friable when moist and hard when dry. The surface horizon is neutral to weakly alkaline and the subsoil is alkaline in reaction. The soluble salt content and available phosphorus are invariably low whilst the total phosphorus content is relatively high. The clay material is predominantly illitic. They may be considered as the arid equivalents of the rendzinas.

These soils are most commonly developed on the low rises on limestone pediments, where they are shallow, while the shallow depressions have cracking clay soils. As the pediment slope declines and the outwash plain is approached, the proportion of calcareous earths decreases and that of cracking clay increases. Calcareous earths also occur as minor shallow pockets on limestone plateaux and outcrop. Only one plain of significant extent with deep calcareous earths was observed.

Where calcareous earths are formed from very calcareous siltstones and shales the surface is nearly completely covered with a strew of hard flat ferruginized rock fragments.

These soils are minor in the soil pattern of the area. They are dominant only on the upper parts of the pediments from limestone ranges which form part of the Fitzroy surface and extend in a north-west–south-east belt across the area. Minor occurrences on plains formed on limestone by the dissection of the Kimberley surface were also observed.

These soils are mostly associated with *Triodia wiseana* to the exclusion of other spinifex species and most other grasses, and shrubs and trees. Termitaria are characteristically absent.

Two families have been distinguished based on depth to rock.

(10) *Neillabublica family* has calcareous brownish loamy neutral to weakly alkaline surface horizons which merge gradually to greyish or brownish clayey subsoils. It overlies limestone at depths greater than 15 in. The surface horizons contain high amounts of calcium carbonate concretions which increase in number with depth. They are of only minor importance in the Fossil and Neillabublica land systems, and occupy less than 200 sq miles.

(11) *Oscar family* has shallow dark brown or dark reddish brown loamy to clayey calcareous soils with high amounts of calcium carbonate concretions and with limestone parent material within 15 in. of the surface. They are important in the Neillabublica and Windjana land systems and occupy about 2000 sq miles.

(*e*) *Cracking Clays*

These soils are known in the area as "black soils", "black soil plains", and "cracking clays". They are similar to swelling clays variously named in other countries.

They are typically A–C type profiles in which the clay content is 35% or more but which vary in colour, structure, depth of cracking, and degree of self-mulching. The clay material is mainly illitic or montmorillonitic. The colour of the solum is generally nearly uniform throughout the profile except for difference due to moisture content. It ranges from black and dark grey to grey-brown, brown, yellow-brown, olive, and reddish. The surface horizons vary from strongly self-mulching to crusty but with depth the structure rapidly coarsens and becomes massive. In prolonged periods of dry weather the whole soil profile is traversed by a pattern of nearly vertical cracks which vary in depth and width. Seasonal rainfall is adequate to saturate the soil with subsequent swelling and closing of cracks. Calcium carbonate, gypsum, or manganiferous concretions occur throughout some profiles. The soils are weakly to strongly alkaline.

Cracking clays are formed from four major types of parent materials—alluvium, limestones and highly calcareous sediments, shales, and basic volcanic rocks—and a well-defined topographic succession through one or more soils to cracking clays occurs on each of these.

The alluvial succession is characteristic of the flood-plains of the major rivers of the area, notably the Fitzroy River. The river levees are composed of more or less fresh, mainly fine-textured, often micaceous alluvium which with increasing distance from the levees gives rise to soils with more marked grumusolic characteristics. Stratification disappears and structure gradually appears and increases in development.

Limestones and highly calcareous sediments weather to give a succession of cut pediments with outcrop, skeletal calcareous earths, and local pockets of cracking clays which merge into extensive cracking clay plains.

Red earths and red-brown earths develop *in situ* from shales on shale colluvium on the higher sites and give place at lower elevations or in depressions to cracking clays which may form small plains. In flat areas cracking clays form directly from the shale parent material.

In the volcanic succession outcrops of basic igneous rocks in the higher parts of the terrain merge into red earths on the pediment slopes with minor areas of cracking clays on benches or gentle rises. These in turn merge into small plains of cracking clays formed on the outwash colluvium. Cracking clays also form directly from basic igneous rocks.

A very close association commonly occurs between yellow earths and cracking clays where both soils are developed on calcareous shales. Minor areas of cracking clays occur on very calcareous Permian mudstones and siltstones and on small remnants of the older Kimberley land surface.

Cracking clays mainly of the Cununurra and Wonardo families occur as plains derived from highly calcareous sediments by the dissection of the Kimberley and Fitzroy surfaces and they also occur on the Fitzroy surface.

Four families and one group of juvenile cracking clay soils have been distinguished. The basis of the differentiation of the soil families is on colour and degree of self-mulching in accordance with that suggested by the U.S.D.A. (United States Department of Agriculture 1960) classification. All four families are a common and significant part of most of the alluvial plains of the area.

There are about 4000 sq miles of cracking clays in the area. They are important in the Alexander, Djada, Fossil, and Gogo alluvial land systems and in the Leopold, Gladstone, and Windjana land systems formed on limestone, and the Cowendyne land system on basalt.

(12) *Cununurra family* is dark grey to black heavy clays with strongly self-mulching surface horizons and with deep wide cracks when dry. Carbonate and manganiferous concretions occur throughout some profiles but gypsum is comparatively rare or absent. In some the deeper horizons are diffusely mottled and some have strong linear gilgai microrelief.

(13) *Myroodah family* is dark grey to black and grey-brown heavy clays but with crusty non-mulching and weakly cracking surface horizons which are commonly severely scalded. These overlie moist, dark grey to black and olive, commonly mottled, horizons. Manganiferous concretions occur throughout the profile whilst calcium carbonate concretions are rare and gypsum is usually absent. Incipient low gilgais have formed in some places.

(14) *Wonardo family* is grey-brown, brown, olive, yellow-brown, and reddish brown strongly self-mulching and moderately cracking clays. Fine carbonate and manganiferous concretions occur throughout some profiles. The surface structure is strongly developed granular to subangular blocky which becomes massive with depth. Where gilgais are present the puff is commonly better structured than the depression and has lime concretions to the surface.

(15) *Cherrabun family* is poorly structured, commonly strongly scalded reddish to dark brown, yellow-brown to olive heavy clay. Minor amounts of fine carbonate and manganiferous concretions occur throughout some profiles. Colour changes little down the profile and the weakly-structured surface horizons become very coarsely structured at shallow depth and the width of the cracks in the subsoil is much less than in the other families. Gilgais are mostly poorly developed or absent.

(16) *Brownish juvenile cracking clays* are soils which do not preserve enough of the characteristics of alluvial soils to include them in that group but which have not developed the mulching and cracking properties of the grumusols. They have silty loam to silty clay loam surface horizons which are commonly micaceous and which become finer textured with depth although sandy lenses are common. The surface is incipiently self-mulching and exhibits strong tendencies to seal hard. In some places the surface layers show evidence of stratification whilst in some the middle horizons exhibit reasonably well-developed structural units. Broad, irregular, shallow cracking patterns occur. These soils occupy extensive areas of the flood-plain of the Fitzroy River.

(*f*) *Red-brown Earths*

The topsoil of the red-brown earths is invariably reddish in colour, its texture varies from sandy to sandy clay loam although loamy textures are most common, and it is poorly structured to structureless. There is an abrupt change to the subsoil, which is finer-textured than the topsoil and is mostly a clay, its colour being always brighter and redder than the topsoil. The structure of the subsoil horizons varies somewhat according to texture but for clay it is usually strongly prismatic with marked transverse cracking which gradually becomes angular blocky to structureless with depth. Carbonate and manganiferous concretions and weathering rock fragments are common in the lower parts of some profiles. The reaction in the topsoil is slightly acid to neutral and becomes markedly alkaline in the subsoil.

These soils are characteristically developed over Permian and Triassic shales and interbedded mudstones. They also occur in the north-eastern part of the area on Elgie shales interbedded with Wharton sandstones and in these sites the subsoils are usually coarser-textured. They are most common on slopes and pediments formed by the dissection of the Kimberley surface, particularly those formed on fine-textured, calcareous rocks in the centre and south of the area.

They occupy a very minor part of the soils of the south-east and were seldom recorded in other parts of the area. They are prominent only in the Myroodah land system and occupy about 2000 sq miles. Only one family has been recognized.

(17) *Moonah family* has brown to reddish brown, sandy, loose surface horizons over red-brown to red and bright red, hard sandy clay loam to clay subsoils, some of which exhibit well-developed angular blocky structure. The surface horizons are slightly acid to neutral in reaction, which becomes strongly alkaline in the subsoil. The exchangeable metal cations are dominated by calcium, and sodium is usually very low.

(*g*) *Solonetzic Soils*

The solonetzic soils of the area are most closely related to soils which elsewhere in Australia have been called solodized solonetz soils. Like the red-brown earths, they have abrupt and marked texture and consistence changes between the surface and subsoil.

They have loose, dark grey-brown, pale to dark brown, yellow-brown, olive, and reddish sandy or loamy topsoils over hard, grey-brown, olive-brown, dark brown, pale to dark reddish brown, and yellowish red loamy or clayey subsoils, some of which show columnar or angular blocky structure. The top of some of the subsoil is bleached. The topsoils are slightly acid to neutral and the subsoils are weakly to moderately alkaline. The soluble salt content is very low in the topsoil and becomes moderately low to low in the subsoil. Available phosphorus is generally low throughout the profile. Either illitic or kaolinitic clays dominate the clay fraction.

A characteristic usually associated with these soils is a well-developed columnar structure in the subsoil, but in this area the columnar structure is confined to some of the fine-textured subsoils. Some of these soils show evidence of waterlogging, such as manganiferous stainings and concretions and mottles either in the topsoil or throughout the profile.

Solonetzic soils are formed on the colluvial outwash from granitic and gneissic rocks, sandstone, and shale and on alluvium. They were also observed on sites which suggest that they were forming directly from shales and granites.

They occur on only about 1000 sq miles of the area but occupy characteristic sites. They are most commonly developed on pediments formed by the dissection of the Kimberley and Fitzroy surfaces in the north-east and central parts of the area and are uncommon on alluvial plains. They are important in the Amy land system, and are minor elements in Rose and Tarraji land systems.

Three soil families are distinguished based on the texture of the subsoil together with the presence or absence of columnar structure.

(18) *Tarraji family* has very loose, dark grey-brown to yellow-brown, sandy, strongly leached, slightly acid topsoils over hard to very hard, grey-brown to reddish brown sandy or loamy neutral to moderately alkaline subsoils. The family is not common and occurs always in association with highly quartzitic igneous and sedimentary rocks.

(19) *Jurgurra family* has loose sandy and loamy yellow-brown and reddish brown topsoils over hard, brown and reddish brown sandy clay loam to clay subsoils which show well-developed columnar structure. The family is common on the outwash colluvium from Lamboo rocks in the north and north-west of the area. It is also a common feature of the soils under the laterite breakaway ridges in association with old land surfaces particularly where the laterite is formed over fine-grained sedimentary rocks.

(20) *Hooper family* has loose, dark grey-brown, pale brown to brown, yellow-brown, and olive, neutral topsoils (some weakly structured) over hard, reddish brown, yellow-brown, and brown clay subsoils which have weak to strong angular blocky structure. Mottling and manganiferous stainings and concretions are common.

(*h*) *Alluvial Soils*

Alluvial soils are restricted to alluvium so young that soil-forming processes other than organic matter accumulation have had little effect and thus genetically related horizons have not developed.

These soils exhibit a considerable range in colour and texture both within the profile and from one site to another. They have dark yellow-brown to brown and dark brown, dark reddish brown, and black, weakly to moderately structured, sandy to clayey topsoils some of which are stratified and which merge to reddish, yellowish, greyish and dark brown, yellow-red, and black loamy to clayey intermediate horizons which become dark reddish and greyish brown and black and mainly clayey with depth. Biologic influences such as the action of worms are common in the surface horizons. The upper parts of the profile are mostly loose to slightly hard but some become very hard with depth. The soils are generally slightly to moderately micaceous. The topsoils are slightly acid to neutral and the reaction generally becomes more alkaline with depth although acid subsoils were recorded. Mottles and manganiferous concretions occur throughout some profiles.

Alluvial soils are very seldom observed as other than narrow strips along the river and stream courses. The greatest development is along the levee crests of the Fitzroy, Robinson, and Lennard Rivers. They are important only in the Gogo land system and occupy less than 1000 sq miles.

Two soil families have been differentiated on the texture of the subsoil.

(21) *Robinson family* has dark reddish, yellowish, and greyish brown, brown and black, mainly silty and loamy topsoils which merge through dark reddish and greyish brown, dark brown, and yellow-red, mainly loamy intermediate horizons to dark brown and dark reddish and yellowish brown loamy subsoil horizons which are commonly very micaceous, hard, and sometimes comparatively impermeable.

(22) *Fitzroy family* has variable but mainly dark yellowish, greyish, and reddish brown, brown, and black silty and clayey surface horizons which merge through dark reddish, yellowish, and greyish brown, dark brown, olive, grey, and black clayey intermediate horizons to dark reddish and greyish brown, dark brown, very dark grey, reddish brown, and black clayey subsoil horizons. The topsoil horizons are soft and weakly to strongly structured whilst deeper horizons are slightly hard to very hard and apedal. Some show stratification in the upper horizons but with increasing distance from the levee crests they tend to become more homogeneous and show a transition to grumusolic characteristics.

(*i*) *Shallow Soils and Rock Outcrop*

Shallow soils and rock outcrop comprise the most extensive group of soils in the area (approximately 14,000 sq miles). They are dominant on nearly all areas formed by the dissection of the Kimberley and Fitzroy surfaces with the exception of the plains. They are also the dominant soil on hills and mountain ranges eroded below the Kimberley surface, i.e. virtually the whole of the terrain to the east of the north-west–south-east trending King Leopold Range is dominated by them. There are also considerable areas in the southern, central, and south-eastern parts of the west Kimberleys.

Two families have been created already for shallow soils of pastoral importance (Oscar and Walsh families) but families are not defined for other skeletal soils.

(23) *Lithic phase soils* are those which have horizons characteristic of the upper layers of the family described, the profile being cut off by bed-rock or dominated by parent rock fragments at depths of not more than 20 in. The term is used adjectivally, for example Tippera family — lithic phase (2, 23).

(24) *Skeletal soils* are essentially stony or gravelly soils showing no profile development other than organic matter accumulation in the surface horizon. They are generally less than 10 in. deep and interspersed between rock outcrop.

Their nature is largely determined by the parent rock. Skeletal soils formed from acid igneous rocks are marked by outcrop, bare boulders, and pockets of gritty sand with weathering rock fragments. Sandstones and quartzites produce rough bouldery hills with small pockets of sandy soils whilst skeletal soils from fine-textured metamorphic rocks have outcrop and angular fragmentary gravels with a loamy matrix. Soils formed from conglomerates and tillites are characterized by rounded boulders with very little soil material.

They are the dominant soil of 20 land systems.

(*j*) *Miscellaneous Soils*

A number of soils on which only scanty information was collected have been given only descriptive names. They occur in the littoral parts of the area and occupy about 2000 sq miles, being the major soil group in Carpentaria and Roebuck land systems.

(25) *Salt flat soils* occur on estuarine alluvia that are subject to flooding only by a combination of high stream flow and high tide. They are fine-textured, dark, saline clays some of which are very weakly structured and which merge to a massive, mottled commonly light-coloured clay with shell fragments. They support a characteristic vegetation of *Sporobolus virginicus*. They are well developed in the Roebuck plains near Broome and occur in minor pockets further north along the coast, particularly on Oobagooma station.

(26) *Medium-textured samphire soils* have brownish loamy surfaces merging to saline, mottled, sandy clay loam subsoils with shell fragments. These are non-tidal and support a low samphire vegetation.

(27) *Fine-textured samphire soils* have a thin salt crust over light grey calcareous saline clay which merges to light-coloured, weakly-structured calcareous saline clay which becomes massive with depth. There is commonly a thin salt crust along ped surfaces. The surface salt crust is very liable to wind erosion and broad saline scalds are commonly formed. These soils support a characteristic bush samphire vegetation.

(28) *Dark saline muds* are deep, permanently wet, saline clays which are either bare or support mangrove communities. They occur on the tidal flats and are subject to varying degrees of intertidal exposure.

(29) *Beach dune complex* consists of the following components:

Foremost or "white dunes" with deep loose light calcareous loamy sand containing high amounts of fine shell fragments.

Stable vegetated back dunes with deep, loose light brown to light yellowish brown loamy sand with some indurated secondary calcareous layers.

Intermediate areas with swale floors with dark grey-brown loamy sands and indurated calcareous layers.

(30) *Billabong floor soils* are brownish grey to dark yellowish brown silty mottled clays. An irregular blocky 2 in. surface cracking is commonly developed. These are found under fresh and brackish water and are commonly dry at least part of the year.

IV. Agricultural Characteristics of the Main Great Soil Groups

With the exception of a minor area devoted to rice-growing near Liveringa, the soils of the area are entirely used for producing grass for grazing by sheep or cattle. As in the future some of the soils may be used for irrigation or dry-land farming, brief comments are made on some of their important known features.

(a) *Red Earths*

The red earths are all well-drained soils and are moderately to rapidly permeable.

Intensive experimental agriculture has been carried out on medium-textured soils of the Tippera family at Katherine Research Station, Northern Territory. From experience there it is likely that medium-textured earths in the West Kimberley area will show the following characteristics:

They will be markedly deficient in phosphate and it is likely that few or no other nutrient elements will give significant response except nitrogen on non-legumes.

Their available water range is likely to be narrow (at Katherine it is only about 6% throughout the profile).

Their surface soil will break down rapidly under rainfall impact and the crust formed on drying would cause problems in seedling emergence.

The soil probably sets so hard that dry ploughing will be impracticable.

They are moderately permeable and appear to be suitable for flood and furrow irrigation if water is available.

Some experimental work has also been done on sandy soils of the Tippera family (called Blain sand) at Katherine Research Station. The major differences from the medium-textured soils are that the sandier soils respond to light falls of rain, are much easier to plough and cultivate, and, as they are rapidly permeable, could probably only be irrigated by sprays. The ploughed surface soil is likely to be unstable to rain and would erode in intensive storms. Phosphate deficiency would probably be marked also in these soils. Even though their range of available moisture is probably less than in the medium-textured soils, their greater permeability would permit greater water storage at depth and thus they could be expected to carry deep-rooted crops later into the dry season.

The Yabbagoddy soils are likely to be similar to sandy-surface Tippera soils especially with respect to water-holding capacity. Both are attractive agricultural soils and generally occur on very gentle slopes.

The red earths formed on volcanic rocks, i.e. Walsh and Frayne families, contain more weatherable minerals, have higher exchange capacities, and almost certainly would have a wider range of available moisture. Because of the greater nutritive value of their pastures these soils are believed to be more fertile. In most other ways they are likely to be similar to medium-textured Tippera soils. However, they generally occur on steeper slopes with a greater erosion hazard. Also, their distribution is patchy and they frequently have stones on the surface and are, therefore, not likely to be suitable for arable agriculture.

Roads formed on the red earths tend to have firm stable surfaces. Catchment dams may be successfully established in the more clayey phases, especially if they can be trampled by stock.

(b) *Yellow Earths*

The yellow earths are similar to the red earths except that they are significantly less permeable. They are easily waterlogged and become "spewy"; animals may get bogged and the soils may become impassable for motor vehicles and agricultural equipment. Crops which are sensitive to this condition would be susceptible to damage. Trampling when half wet tends to consolidate the surface and seed emergence is considerably reduced.

Owing to the loamy nature of their topsoils the yellow earths are particularly prone to erosion, especially when the vegetative cover is depleted or removed. When very dry, powdering of the surface leads to erosion by wind and water.

These soils have been cultivated at Katherine Research Station, Northern Territory, where they were very "boggy" during the first year of cultivation but seem to have settled down in later years.

They are used with success for earth dams, and in fact many of the dams used for water-spreading at Calwynyardah have been formed on these soils. They appear to be used with equal success as watering dams around bores. Because of their "boggy" nature they are not suitable for ordinary road construction.

(*c*) *Brown Soils of Light Texture*

Some success has been achieved in growing certain crops on soils of the Cockatoo family at Kimberley Research Station, Western Australia. Because of their porous nature, these soils are not liable to erosion and the water penetrates rapidly where the vegetation has not been disturbed, but observation at Kimberley Research Station indicates that erosion of ploughed ground could be appreciable.

These soils have low nutrient status and the available moisture range is low so that they are susceptible to drought and would be of limited use.

(*d*) *Calcareous Earths*

The variation in depth exhibited by these soils together with the presence of concretions and rock fragments presents cultivation hazards. They are prone to water erosion when the surface vegetation is reduced; grey and white scalds are a common feature where they are developed on pediments.

Pedologically these soils are only slightly weathered and leached and thus they are probably moderately fertile with reasonable water-holding capacity. The large amounts of Ca^{++} in the soil matrix and in concretionary material may cause calcium-induced deficiencies in any other than the natural vegetation which is dominated by the unpalatable *Triodia wiseana*. The erosion hazard and the strong tendency to sealing of the silty surface horizons would make plant establishment difficult.

(*e*) *Cracking Clays*

These soils are probably the backbone of agricultural potential and present land use in the area.

(i) *Cununurra and Wonardo Families.*—The intensive pattern of deep cracking makes these soils highly permeable when dry but they are very slowly permeable when wet. Experience at Kimberley Research Station indicates that water-logging on the Cununurra family will affect susceptible crops. They are plastic and sticky when wet and cultivation during the wet season is difficult. The phosphate status is low but limited analytical data indicate that they may be moderately well supplied with most other plant nutrient elements. Experience with rice-growing at Liveringa shows that they are favourable soils to handle and that a good seed bed can be prepared.

As they are quickly dispersed in water they are very prone to "run" and are not suited to earthworks for anti-erosion purposes. Earth tanks are very impermeable. Soil erosion even on very gently sloping ground could be a major problem when these soils are ploughed.

These soils occur on pediment slopes and flood-plains but only those on flood-plains are liable to flooding, the exception being Alexander Island.

(ii) *Myroodah Family.*—The soils of this family have a very limited distribution in the area. They are commonly inundated for considerably longer periods than other cracking clays. They are non-self-mulching and seal hard, which, together with their position in broad drainage lines, makes them poorly suited to agriculture.

(iii) *Cherrabun Family.*—These soils are weakly self-mulching and exhibit weakly-developed cracking and are very subject to erosion. An incipient thin crust forms on the eroded surface which on drying tramples to a fine dust and which is easily removed by wind and light showers of rain. Apart from this hazard they appear to have similar agricultural properties to the Wonardo family but the red colour may indicate better drainage. Considerable areas of this soil are susceptible to flooding.

(iv) *Brownish Juvenile Cracking Clays.*—These exhibit properties of both alluvial soils and cracking clays. They occur only in areas which are susceptible to flooding. They can be cultivated to produce good seed beds but this is offset by the tendency to disperse on wetting and seal on drying.

(*f*) *Red-brown Earths*

These soils appear reasonably permeable and well drained. The topsoil sets hard on drying and the short period between wetting and drying allows little time for cultivation. They are rather prone to scalding and large erosion scars are common.

There are few, if any, extensive areas which could be cultivated and in general these soils are not commandable by water and occur on pediment slopes which would also present a considerable erosion hazard. Similar soils have been successfully irrigated in southern Australia, where the good water-holding properties have been exploited.

(*g*) *Solonetzic Soils*

These soils have loose, commonly powdery topsoils over tough intractable clay subsoils of low permeability which restrict the roots of plants. The topsoils are unstable to water and they crust and erode rapidly. Depletion of the native vegetation and subsequent erosion and removal of the topsoil with exposure of the subsoil horizon have formed large bare scalds which are very characteristic. Seed germination in these scalds is very difficult owing to the strong crusting.

These soils are only a minor element in the area and support only very inferior pastures. Most of the area occupied by them has been extensively degraded.

(h) *Alluvial Soils*

These soils are probably the most naturally fertile soils in the area. Morphologically they are variable but are deep and vary from permeable to slowly permeable. They seem to have better water-holding properties than other soils. The surface soils are usually moderately to well structured and they should be easy to plough and a good seed bed could be prepared.

Large areas are liable to frequent and deep flooding which would limit their agricultural use. Although commonly overgrazed they do not show scalding and other effects of erosion. This is probably due to their youthfulness and lack of profile differentiation. These soils most commonly occur in irregular broken topography associated with river levees.

There is very little to differentiate agriculturally the two families of alluvial soils. The coarser-textured Robinson family is most common on the levee crests and generally on less broken areas which are also less liable to flooding than the fine-textured Fitzroy family.

(i) *Skeletal Soils*

These are thin soils and generally liable to severe erosion. They are frequently so stony that no agriculture is possible.

(j) *Miscellaneous Soils*

Salt flat and samphire soils are too saline and too poorly drained for cultivation.

Beach dunes are too droughty and would drift if cleared.

V. Assessment of the Soils for Irrigation

Brief comments will be made here on the soils occurring in those land systems which could in the foreseeable future be considered as likely areas for irrigation.

(a) *Alexander, Djada, and Gogo Land Systems*

These land systems are comprised of similar land forms which vary in proportion within the different land systems. The major land forms concerned are:

(1) Levee back slopes which have soils of the Cherrabun family. These soils are moderately well-drained clayey soils with poor surface structure and tend to crust strongly causing problems in seedling establishment and emergence. They are also very prone to erosion and scalding. Most of the area occupied by them would be liable to deep flooding, and is traversed by many minor channels.

(2) Levee crests which have mainly loamy and clayey alluvial soils of the Fitzroy family with minor amounts of finer-textured soils of the Robinson family. These soils have satisfactory surface characteristics but some appear to have impeded drainage in the subsoil. Generally they occur in the least flooded part of the land system and some areas will be above flood level. They have a slightly irregular and sometimes transverse distribution and are broken by occasional depressions and distributaries.

(3) Back plains have soils of the Cununurra and Wonardo families. These heavy clay soils with well-structured self-mulching surfaces are satisfactory for irrigation but problems arising from waterlogging may be encountered. They occur on long gentle slopes and are liable to flooding. They are traversed by a number of broad shallow depressions.

(4) Depressions have soils of the Myroodah family. These are shallow, broad, natural drainage-ways which have deep heavy clay soils with non-self-mulching poorly-structured surfaces. They are flooded for a longer period of time than the other soils in this group of the land systems and are not suitable for agriculture.

(5) Minor channels and billabongs have silty to heavy intractable clays which are flooded for much of the year and are wholly unsuited for agriculture.

The Alexander land system consists of 73% of cracking clay plain with mainly soils of the Cununurra family and levee back slopes with soils of the Cherrabun family constituting 16% of the land system. Minor channels and billabongs are less than 5% and depressions with soils of the Myroodah family are virtually absent.

The Djada land system consists of 46% of back plain with soils of the Cununurra and Wonardo families almost evenly distributed. Levee back slopes with soils of the Cherrabun family occupy about 25% and the levee crests with soils of the Fitzroy family occupy less than 10%. Minor channels and billabongs and depressions which are unsuited to agriculture together occupy almost 20% of the land system.

The Gogo land system has almost half its area occupied by levee back slopes with soils of the Cherrabun family. Levee crests with mainly soils of the Fitzroy family and minor amounts of the Robinson family constitute about 20% of the total area. The back plains with approximately equal amounts of soils of the Wonardo and Cununurra families occupy 11% of the land system and are traversed by a large number of depressions with soils of the Myroodah family. Minor channels and billabongs constitute about 11% of the total area and are commonest in the levee crest area.

(*b*) *Fossil Land System*

Soils of the Cununurra family constitute about 95% of the total area of this land system. Approximately 12% of this occurs in broad drainage zones which are liable to flooding. The remaining 83% occurs contiguously on pediments from limestone ranges. It would be difficult to command these latter soils with water but there would be no flood hazard so that it would be very desirable to be able to irrigate them.

The dark-coloured strongly self-mulching heavy cracking clays of the Cununurra family would be very satisfactory soils for irrigation but may present problems associated with waterlogging.

(*c*) *Chestnut Land System*

Because of elevation and distance from water it would be difficult to irrigate the soils of this land system. However, the dominant soil has been irrigated with success in other parts of northern Australia.

Plains dominated by soils of the Tippera family constitute 85% of the land system. Gentle erosional slopes with soils of the Yabbagoddy family and some outcrop constitute the remaining part of the land system.

Both the Yabbagoddy and Tippera soil families are attractive agricultural soils which may be deficient in phosphate but should be well supplied with other nutrients. Soils of the Tippera family tend to crust after rain and thus present problems of seedling emergence but should otherwise have favourable physical properties. They would be well suited to flood and furrow irrigation. Soils of Yabbagoddy family are coarser-textured and should respond to light falls of rain and be relatively easy to plough and cultivate. They could probably only be irrigated by sprays. In this land system both soil families occur on gentle slopes so that the erosion hazard should be minimal.

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PART VI. VEGETATION AND PASTURES OF THE WEST KIMBERLEY AREA

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I. INTRODUCTION

The area falls within Gardner's (1942) Northern province but, occupying the southerly part of it, lacks, except for a few species (*Eucalyptus miniata, E. phoenicea, E. alba, E. collina,* and several others) in the most northerly part, the higher-rainfall elements characteristic of the adjacent North Kimberley area (Speck 1960). Monsoon forests described for northern Australia by Christian and Stewart (1953) contain many rain-forest elements but occur only as fringing communities along the main stream lines. Monsoon woodlands, characterized by deciduous elements, are much more widespread and comprise two alliances although they are limited to special types of habitat. Gardner (1942) suggests that these elements give the vegetation of the province a distinctive character. Such species as *Adansonia gregorii* (baobab or bottle-tree), *Cochlospermum fraseri, Bauhinia cunninghamii,* and *Terminalia* spp. certainly do that. The impression of the importance of these elements is accentuated because, as individual species, their range is much greater than the communities they characterize. However, this distinctive feature should not be over-emphasized because various *Eucalyptus* spp. characterize the upper storeys of most of the major communities.

(*a*) *Plants and the Environment*

The area lies in a region of semi-arid and arid monsoonal climates with distinct wet and dry seasons (Part III). The wet season, which extends from December to March, is followed by a long dry season, April to November, during which practically no rain falls. These annual droughts have exerted a selective influence in the evolution of the vegetation.

The sharp decrease of rainfall from 40 in. in the north-west to 16 in. in the south-east is associated with comparable changes in vegetation structure and floristics. Forests occur only on the deep sands in the higher-rainfall areas and as fringes along the major stream lines. Sclerophyllous woodlands with moderately dense shrub layers and ground storeys characterized by *Plectrachne pungens* (curly spinifex) and annual sorghum are predominant to the north of the King Leopold Ranges. To the south of these ranges the tree layer is more open and grassy ground storeys are better developed. Further to the south the tree layer is still more open and stunted until in the most southerly parts, on the borders of the Eremean province, the vegetation is characterized by spinifex with sparse stunted trees and shrubs (spinifex steppe). Thus the survey area may be considered as a broad ecotone joining the Northern and Eremean provinces, having many elements of both.

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Within this general control of vegetation by climate soils exert an influence on the floristics and structure of many plant communities. In the North and West Kimberley areas, volcanic country with similar soils, over a wide rainfall range (25–40 in.), is characterized by the same tree and ground-storey species. Similarly there is a striking correlation between the distribution of the spinifex, *Triodia wiseana*, and areas of calcareous influence. Many other examples could be cited. Although the cases just mentioned appear to have a distribution that is influenced by the chemical properties of soils, Perry and Lazarides (1962) have pointed out that the most important soil characteristics in relation to species distribution are those which control the amount and availability of the water supply, and thus the physical properties and depth of soil in many cases exert a greater influence on plants than their chemical properties.

(*b*) *Plant Types*

Only those species adapted to persistence through or evasion of the annual dry periods have been successful in coping with the environment. During the wet season, moisture is abundant, temperatures are high, and growth is rapid. The growing season is short. When moisture is no longer available growth ceases and plants dry off or become dormant. Species are adapted to the long dry periods rather than to the full utilization of moisture available during the wet season (Christian and Slatyer 1958). Perry (1960) has pointed out, and it is obvious in the following paragraphs, that in many cases ability to persist through the dry season is inversely related to pastoral value, and the most firmly established species are often of little or no use. These same species are also the strongest competitors of better-quality plants which may be introduced.

A natural grouping of plants according to their means of survival through the long dry period (Perry 1960) has been used.

(i) *Perennial Drought-resisting Species*.—This group includes species in which the vegetative parts remain alive and green through the dry periods. During this period growth is suspended, but it is resumed under favourable conditions. Plants which have developed this drought resistance commonly are tough, lignified, or highly sclerophyllous, which influences their pastoral value. The majority are trees and shrubs including *Eucalyptus* spp. and *Acacia* spp. Also included are a number of top-feed or browse species including *Ventilago viminalis*, *Atalaya hemiglauca*, and *Carissa lanceolata*. The most extensive species are sclerophyllous hummock-forming grasses collectively referred to as spinifex (*Triodia* spp. and *Plectrachne* spp.). Other representatives of this group include the halophytic, succulent sub-shrubs (samphire) restricted in this area to the coastal fringe.

(ii) *Perennial Drought-evading Species*.—These comprise perennial species in which the leaves, at least, are dead during the drought periods and which thus evade rather than resist the unfavourable season. Growth is resumed from vegetative buds. Included in this group are the deciduous trees and shrubs and those perennial herbaceous plants in which the aerial parts die each season but which are capable of new growth from perennating buds with the next favourable season. Although deciduous trees and shrubs are numerous in the area, pastorally the most important species of this group are the perennial grasses. Growth is rapid and the plants are nutritious and palatable during the wet season, but during the long dry season (the plant nutrients having been translocated to the lower parts of the plant or even underground) the fodder consists almost entirely of dry mature pasturage of low nutritive value.

The most important species include the Mitchell grasses (*Astrebla* spp.), ribbon grass (*Chrysopogon* spp.), blue grass (*Dichanthium fecundum*), perennial sorghum (*Sorghum plumosum*), white grass (*Sehima nervosum*), and many others.

(iii) *Annual Drought-evading Plants.*—Vegetative growth of the plants in this group takes place only in the short wet season. Seeds germinate quickly, growth is rapid, and with the onset of water stress they die. Seed production is large and commences at an early stage in the favourable season ensuring that adequate seed reserves of the various species are replenished should the season be very short. If the fall of rain is enough to produce a longer favourable period the plants continue to grow and to produce more flowers and seeds.

The chief components of this group of plants are described in the following parts of this report as short grasses. These species (*Enneapogon* spp. and species of *Aristida, Chloris, Sporobolus,* and many others) are either true annuals or behave as annuals in this climate. Although these plants occur in greater or lesser abundance in almost every community, they characterize the ground storeys of comparatively few communities and most of these, although widely distributed, are not extensive. Spinifex commonly is also present either as scattered clumps or as larger patches forming a complex.

The annual *Sorghum* spp. occur as tall coarse grasses up to 5 ft high and are widespread in the higher-rainfall parts of the area.

(*c*) *Relation between Upper and Lower Storeys*

The independence of ground-storey and upper-storey communities has already been pointed out by Perry (1960). For example, in this survey area a very widespread upper-storey community characterized by *Eucalyptus brevifolia* has six different ground storeys. One of these ground storeys (*Plectrachne pungens*) occurs with 12 upper-storey communities. Other examples are given in Table 16. Because of this complexity the 46 upper-storey communities and 21 ground-storey communities have been described separately. In the description that follows the upper-storey communities have been numbered 1–46, and the lower-storey communities 47–66.

The 46 upper-storey communities, which approximate associations or closely related groups of associations, have been arranged in a hierarchy of 15 alliances (Beadle and Costin 1952) and two groups of fringing communities. Of these upper-storey communities, three only (Table 16) consistently lack ground storeys. These comprise the three mangrove communities which grow from tidal muds which completely lack any other macroscopic plant forms. Nine ground storeys lacking tree layers (grasslands) occur on three very different habitats, cracking clay plains, stony plains with areas of shallow skeletal soils and outcrop, and a group of saline habitats. These all have in common long periods each year when the amount of water available to plants would be extremely low.

TABLE 16

COMBINATIONS OF UPPER STOREYS AND GROUND STOREYS

Upper Storey	Ground Storey																					
	(47) *Astrebla* spp.	(48) *Chrysopogon* spp.–*Dichanthium fecundum*	(49) *Chrysopogon* spp.	(50) Frontage grass	(51) Fringing grass	(52) *Sehima nervosum*–*Sorghum* spp.	(53) *Sehima nervosum*–*Dichanthium fecundum*	(54) *Plectrachne pungens*	(55) *Triodia pungens*	(56) *Plectrachne pungens*–*Chrysopogon* spp.	(57) *Triodia intermedia*	(58) *Triodia wiseana*	(59) *Triodia inutilis*	(60) *Plectrachne bynoei*	(61) *Enneapogon* spp.	(62) *Aristida hygrometrica*	(63) *Aristida browniana*	(64) *Sporobolus virginicus*	(65) *Xerochloa* spp.	(66) Samphire	(67) Beach dune communities	Nil
(1) *E. brevifolia*			●	●				●			●	●	●		●							
(2) *E. brevifolia*–*E. pruinosa*											●											
(3) *E. brevifolia*–*E. perfoliata*								●														
(4) *E. brevifolia*–*E. collina*								●														
(5) *E. brevifolia*–*Eucalyptus* sp. (Lazarides 6413)–*E. ferruginea*								●														
(6) *E. collina*–*E. dichromophloia*								●														
(7) *E. phoenicea*–*E. ferruginea*								●														
(8) *E. dichromophloia*			●					●	●			●										
(9) *E. dichromophloia*–*E. argillacea*			●									●										
(10) *E. dichromophloia*–*E. zygophylla*–*Acacia* spp.										●												
(11) *E. dichromophloia*–*E. perfoliata*										●												
(12) *E. dichromophloia*–*E. grandifolia*			●																			
(13) *E. confertiflora*										●												
(14) *E. tectifica*			●			●		●								●						
(15) *E. tectifica*–*E. dichromophloia*							●															
(16) *E. tectifica*–*E. perfoliata*								●			●											
(17) *E. perfoliata*–*Acacia impressa*											●											
(18) *E. argillacea*			●																			
(19) *E. argillacea*–*E. microtheca*			●																			
(20) *E. microtheca*		●	●						●													
(21) *E. microtheca*–*E. papuana*										●												
(22) *E. papuana*				●												●						
(23) *E. papuana*–*E. alba*				●																		
(24) *E. alba*–*E. microtheca*				●																		
(25) *E. polycarpa*																●						
(26) *E. polycarpa*–*Melaleuca viridiflora*										●												
(27) *E. polycarpa*–*E. grandifolia*				●																		
(28) *E. miniata*–*E. perfoliata*										●												
(29) *E. miniata*–*E. polycarpa*			●																			
(30) *Adansonia gregorii*												●										
(31) *Adansonia gregorii*–*E. perfoliata*										●												
(32) *E. perfoliata*–*Adansonia gregorii*–*E. dichromophloia*														●								
(33) *Adansonia gregorii*–*Terminalia platyphylla*				●												●						
(34) *Grevillea striata*			●					●	●													
(35) *Melaleuca acacioides*			●																●			
(36) *Melaleuca* spp.								●														
(37) *Bauhinia cunninghamii*		●	●																			
(38) *Bauhinia cunninghamii*–*Ventilago viminalis*								●	●								●					
(39) *Bauhinia cunninghamii*–*Tristania suaveolens*				●																		
(40) *E. camaldulensis*				●	●																	
(41) *E. camaldulensis*–*Melaleuca* spp.				●	●																	
(42) *E. camaldulensis*–*Terminalia platyphylla*				●	●																	
(43) *Terminalia platyphylla*				●	●																	
(44) *Bruguiera conjugata* (tall mangrove)																						●
(45) *Ceriops tagal* (medium-height mangrove)																						●
(46) Low mangrove community																						●
Nil	●	●	●						●		●	●						●		●	●	

II. Description of Upper Storeys

(*a*) Eucalyptus brevifolia *Alliance*

Eucalyptus brevifolia (snappy gum), as a stunted tree 10–15 ft high, characterizes the tree layer of a group of low, open, grassy woodland communities widely distributed over a range of habitats throughout the eastern and south-eastern parts of the area. In the lower-rainfall parts of its distribution other low trees and shrubs (*Grevillea striata*, *Acacia* spp., *Cochlospermum fraseri*, and *Carissa lanceolata*) form a sparse lower layer or are absent, but are more numerous towards the higher-rainfall margins. Except for small areas, where *E. pruinosa* is co-dominant, *E. brevifolia* tends to form pure stands in the drier parts of its range but in the wetter parts several other eucalypts occur in the tree layer. Seven ground-storey communities were recorded in the *E. brevifolia* alliance. *Plectrachne pungens* characterizes the higher-rainfall parts but there is much greater variety in the ground storeys in the drier areas. Eight communities are described within this alliance.

(1) E. brevifolia *Community*.—The seven ground storeys mentioned above all occur in this community and because these are accompanied by other differences each combination has been briefly described below.

(1*a*) *E. brevifolia* with *Triodia intermedia* (57) ground storey forms low and very open woodlands. Although *E. brevifolia* commonly forms pure stands, in places *E. dichromophloia* is sparsely present. Shrubs are scattered or absent. This combination is distributed throughout south-eastern parts of the area. It occurs in a wide range of habitats in Ruby, Dockrell, Koongie, Margaret, and Gidgia land systems, in the lower-rainfall parts of the Lubbock and Burramundi land systems, and locally in the Bohemia and Rose land systems.

(1*b*) *E. brevifolia* with *Triodia inutilis* (59) ground storey is characterized by a particularly open and stunted tree layer and shrubs are extremely sparse. It occurs only in the extreme east of the area on the rocky hills and ridges of Dockrell and Koongie land systems and on the stripped margins of Gidgia land system. It is known to have a wider distribution in the adjacent Ord–Victoria area (Perry 1956).

(1*c*) *E. brevifolia* with *Triodia wiseana* (58) ground storey occurs as extremely open woodlands and is very similar to 1*a* but differs mainly in that the ground storey is characterized by *Triodia wiseana* and grades into spinifex grassland. The community is widespread throughout the areas of calcareous influence though it is not extensive. It occurs locally in Neillabublica land system and in minor calcareous habitats of the Lubbock and Bohemia land systems.

(1*d*) *E. brevifolia* with *Plectrachne pungens* (54) ground storey is somewhat variable in structure but commonly occurs as open woodland with moderately dense shrub layer. It occurs on a wide range of habitats (20–40 in. rainfall) in Tableland, Glenroy, Precipice, Lubbock, and Forrest land systems, in restricted habitats in Looingnin land system, and in the higher-rainfall parts of Burramundi, Koongie, and Gidgia land systems.

(1*e*) *E. brevifolia* with *Chrysopogon* spp. (49) ground storey has an open tree layer with *E. dichromophloia* and *Bauhinia cunninghamii* sparsely present. A patchy shrub layer (*Melaleuca minutifolia*, *Carissa lanceolata*, *Dodonaea* spp., and *Cochlo-*

spermum fraseri), 4–8 ft high, is commonly present. It commonly occurs on the interfluves and slopes of Glenroy, Gladstone, and Koongie land systems, and on the drainage floors of Tableland and Ruby land systems.

(1*f*) *E. brevifolia* with *Enneapogon* spp. and other short grass (61) ground storey forms low open woodland resembling 1*e* but differs in that the tall perennial grasses are absent or greatly reduced and various short grasses, mostly *Enneapogon* spp., characterize the ground storey.

Distribution was recorded for the interfluves and hill slopes of O'Donnell, Koongie, and Rose land systems.

(1*g*) *E. brevifolia* with frontage grass (50) ground storey has a restricted distribution in the south-eastern, low-rainfall parts of the area. Here the typical dense fringing woodlands and forests are commonly absent from all except the major streams and the *E. brevifolia* communities of the neighbouring slopes extend to the stream lines with an increase in the density of the tree layer and changes in the floristics and density of the ground storeys. The characteristic grasses are *Heteropogon contortus* and a number of other perennial frontage grasses. This community occurs along the smaller stream lines of Gidgia, Koongie, and probably Ruby land systems.

(2) E. brevifolia–E. pruinosa *Community*.—This community very closely resembles community 1*a*, except that *E. pruinosa* also is characteristic of the tree layer. Distribution is restricted to small areas in Bohemia, Margaret, and probably Ruby land systems. These are the only recorded occurrences of *E. pruinosa* in the area.

(3) E. brevifolia–E. perfoliata *Community*.—Except for the addition of *E. perfoliata* to the tree layer this community closely resembles 1*d* in both structure and floristics but is much more restricted in distribution. The ground storey is characterized by *Plectrachne pungens* (54), and it occurs on summit remnants and lower slopes of Clifton land system, the quartzite ridges and rocky hill slopes of Forrest, Richenda, Pigeon, and Rose land systems, and the lower slopes of Sisters land system.

(4) E. brevifolia–E. collina *Community*.—Although *E. collina* is widespread in the higher-rainfall areas to the north (Speck 1960), within the survey area it occurs in restricted habitats in association with *E. brevifolia* and *E. dichromophloia*. Except for the addition of *E. collina* to the tree layer this community closely resembles 1*d* in structure and floristics. It also has affinities with 6.

It was observed on the rocky surfaces and plateau summits of Clifton, Forrest, Lubbock, and Precipice land systems.

(5) E. brevifolia–Eucalyptus *Sp*. (*Lazarides* 6413)–E. ferruginea *Community*.—The two eucalypts here associated with *E. brevifolia* have a wider distribution in the adjacent higher-rainfall parts to the north (Speck 1960). The community commonly occurs as a scrubby woodland but in places approaches the density of an open forest. Other small trees (*Brachychiton* sp. and *Gardenia* sp.) are common. The shrub layer (*Grevillea* spp., *Acacia tumida*, and *A. sericata*) is denser than is common for the area. Although *Plectrachne pungens* (54) characterizes the ground storey, it is more open than is usual and annual *Sorghum* spp., *Aristida hygrometrica*, *Eriachne obtusa*, and other short grasses are present in variable amounts. The community was observed only on the broad stable surfaces of Tableland land system in the extreme north of the area.

(*b*) Eucalyptus collina–E. dichromophloia *Alliance*

These open woodlands are widespread on the rugged sandstone and quartzite country of the North Kimberley area (Speck 1960) and are restricted to the most northerly parts of this survey area. One community only has been described.

(6) E. collina–E. dichromophloia *Community*.—The tree layer (15–25 ft high) is open. The shrub layer (*Grevillea refracta*, *Acacia tumida*, *Cochlospermum fraseri*, and *Persoonia falcata*) is patchy and of moderate density. The ground layer is characterized by *Plectrachne pungens* (54) with variable amounts of annual sorghum. This community is restricted to the rocky plateau surfaces of the Clifton, Lubbock, and Forrest land systems.

(*c*) Eucalyptus phoenicea–E. ferruginea *Alliance*

This alliance is also characteristic of the central and southern parts of the North Kimberley area (Speck 1960), where it occurs on sandy and skeletal soil as woodland or open low scrub forest. With some reduction of density it extends into the extreme north of this area. One community only has been described.

(7) E. phoenicea–E. ferruginea *Community*.—The tree layer (15–30 ft high) of this woodland is characterized by these two eucalypts. Apart from the difference of species in the tree layer this community, in structure and floristics, closely resembles community 5. It is restricted to the stable surfaces and rocky slopes of Tableland and Fork land systems.

(*d*) Eucalyptus dichromophloia *Alliance*

E. dichromophloia characterizes the tree layer (10–25 ft high) of open grassy woodlands in a wide range of habitats throughout the area. Although it commonly forms extensive almost pure stands, it also associates with a number of other tree species. Six communities have been described.

(8) E. dichromophloia *Community*.—Four different ground storeys were observed with this community, and because of this and associated differences these combinations are described below.

(8*a*) *E. dichromophloia* with *Triodia wiseana* (58) ground storey has a very open tree layer and grades into grassland with scattered trees. Except on the most rocky parts shrubs are almost entirely absent. The ground storey is characterized by the calciphilous hard spinifex, *Triodia wiseana*.

The community is widespread on areas of calcareous influence on the hills, slopes, and interfluves of Windjana, Fossil, Leopold, Neillabublica, and Oscar land systems, less widely on the plains in Myroodah land system and hill slopes of Richenda, Gladstone, and Koongie land systems.

(8*b*) *E. dichromophloia* with *Triodia pungens* (55) ground storey occurs as low woodland with an open tree layer and a sparse, discontinuous distribution of smaller trees (*Hakea arborescens*, *H. lorea*, and *Eucalyptus grandifolia*). Shrubs, 4–8 ft high, (*Carissa lanceolata*, *Atalaya hemiglauca*, *Acacia holosericea*, *A. pachycarpa*, and *Grevillea* spp.) are present but not abundant. This woodland is best developed in the more favoured habitats of the lower-rainfall (16–22 in.) parts in the south of the area.

It was recorded on the plains, slopes, and interfluves of Chestnut, Luluigui, and Pigeon land systems and on the summit remnants of the Calwynyardah and Mamilu land systems.

(8*c*) *E. dichromophloia* with *Plectrachne pungens* (54) ground storey occurs as woodlands characterized by *E. dichromophloia* with several other trees (*E. brevifolia, Atalaya hemiglauca, Ventilago viminalis, Gyrocarpus americanus,* and *Erythrophloeum chlorostachys*) having a scattered occurrence. Shrubs, particularly *Melaleuca minutifolia, Carissa lanceolata,* and *Acacia* spp. are present but not abundant.

It was recorded on the plains of Chestnut land system and on the swales and sand plains of Camelgooda land system, lower slopes and interfluves of Pigeon land system, drainage floors of Burramundi land system, and, in higher-rainfall (20–40 in.) areas, the quartzite ridges of Forrest land system.

(8*d*) *E. dichromophloia* with *Chrysopogon* spp. ground storey occurs as very open woodland and grades into grassland with scattered trees. The associated trees are similar to community 8*c*. Shrubs (*Carissa lanceolata, Notoxylinon australe, Dolichandrone heterophylla, Grevillea* spp., and *Acacia* spp.) are sparingly present.

The community was observed over a wide range of habitats in Egan, Koongie, Neillabublica, Pigeon, Ruby, Gogo, and Tarraji land systems.

(9) E. dichromophloia–E. argillacea *Community.*—This is very similar to the previous one except for the addition of *E. argillacea* to the tree layer. Two different ground storeys were observed.

(9*a*) *E. dichromophloia–E. argillacea* with *Triodia wiseana* (58) ground storey structurally and floristically is similar to 8*a* but more restricted in distribution. It was observed on calcareous habitats in Fossil, Neillabublica, and Windjana land systems.

(9*b*) *E. dichromophloia–E. argillacea* with *Chrysopogon* spp. (49) ground storey structurally and floristically, except for the addition of *E. argillacea*, closely resembles 8*d*. It also has minor amounts of *Sehima nervosum, Dichanthium fecundum,* and scattered clumps of *Plectrachne pungens* as well as the usual assemblage of short grasses. The observed distribution included the lower slopes in Amy and Tarraji land systems, alluvial aprons in Burramundi land system, and interfluves of Neillabublica land system.

(10) E. dichromophloia–E. zygophylla–Acacia *Spp. Community.*—This community is representative of pindan-form vegetation. The tree layer consists of stunted eucalypts, 15–25 ft high, of open woodland density. Although this layer is characterized by *E. dichromophloia* and *E. zygophylla*, a number of other trees (*E. grandifolia, Bauhinia cunninghamii, Grevillea* spp., and *Erythrophloeum chlorostachys*) are less regularly present. One of the most distinguishing features of pindan vegetation is the prominent tall shrub layer. This layer in places is quite dense and in patches almost thicket-like and is characterized by *Acacia holosericea, A. sericata,* and other *Acacia* spp. Many other shrubs (*Atalaya hemiglauca, Hakea* spp., *Grevillea* spp., *Dolichandrone heterophylla, Persoonia falcata,* and *Bauhinia cunninghamii*) also occur. The low shrub layer is relatively poor and generally consists of many species from the upper shrub layer as well as *Carissa lanceolata, Crotalaria cunninghamii, Newcastlia* spp., and *Sida* spp. The ground storey is characterized by a complex of

Chrysopogon spp. and *Plectrachne pungens* (56). It is apparently influenced by the dense upper layers and remains very open. Forbs have a seasonal abundance.

This community is characteristic of the sand plains and dune fields of Camelgooda, Yeeda, Wanganut, Sisters, Luluigui, Reeves, and Mamilu land systems and occurs locally in a number of others.

(11) E. dichromophloia–E. perfoliata *Community*.—This community has some of the qualities of 10, but is more stunted and, although *Acacia* species are present, the tall dense shrub layer is only of local importance. The tree layer (10–20 ft high) of this low scrubby woodland is characterized by *E. perfoliata*, which gives the community an "orchard" appearance, although *E. dichromophloia* is also present. Many of the tall shrubs (*Bauhinia cunninghamii*, *Hakea* spp., *Grevillea* spp., *Dolichandrone heterophylla*, and *Cochlospermum fraseri*) extend into the upper layer. The low shrub layer is variable but commonly sparse. The ground storey is characterized by a complex of *Chrysopogon pallidus* and *Plectrachne pungens* (56).

The community is important on the marginal sand plains of Yeeda land system and also occurs in Pigeon, Egan, Sisters, and St. George land systems.

(12) E. dichromophloia–E. grandifolia *Community*.—This open grassy woodland differs from 8*d* mainly in the addition of *E. grandifolia* to the tree layer. The ground storey is characterized by *Chrysopogon* spp. (49).

Recorded distribution includes parts of Camelgooda, Duffer, Egan, Fraser, Koongie, Luluigui, Ruby, and Wanganut land systems.

(13) Eucalyptus confertiflora *Community*.—Structurally and floristically this community closely resembles 10 except that *E. confertiflora* is the characteristic tree of the upper layer. It is pindan form of vegetation. Although only recorded for Reeves land system (20–30 in. rainfall), it is probably much more widespread than this in the western sand plain country.

(*e*) Eucalyptus tectifica *Alliance*

The grey box, *E. tectifica*, characterizes this alliance, which is restricted to the central and northern higher-rainfall parts of the area and generally forms open grassy woodlands.

(14) E. tectifica *Community*.—Although *E. tectifica* characterizes the open tree layer, several other trees are sparsely present. Four different ground storeys occur within the range of the community.

(14*a*) *E. tectifica* with *Sehima nervosum–Sorghum* spp. (52) ground storey is characteristic of the extensive red earth soils of the volcanic country of the North Kimberley area (Speck 1960) and is largely restricted to similar habitats in the higher-rainfall parts of the West Kimberley area. The open tree layer of this grassy woodland is commonly monospecific. The shrub layer (*Cochlospermum fraseri*, *Gyrocarpus americanus*, *Adansonia gregorii*, *Terminalia canescens*, *Dolichandrone heterophylla*, and *Atalaya hemiglauca*) is sparse. It occurs on the hills, slopes, and plains of Cowendyne, Forrest, Looingnin, and Precipice land systems and is a minor element in the higher-rainfall (20–40 in.) parts of Amy, Richenda, and O'Donnell land systems.

(14*b*) *E. tectifica* with *Chrysopogon* spp. (49) ground storey occurs as open grassy woodlands characterized by *E. tectifica* with a number of other trees (*E. dichromophloia, E. grandifolia, E. polycarpa, Adansonia gregorii*, and *Bauhinia cunninghamii*) sparsely present in places. The shrub layer is moderately dense, but patchy.

The community was recorded on the hills, slopes, and cracking clay plains and alluvial floors of Richenda, Amy, O'Donnell, Rose, and Tarraji land systems as well as lower sand plain and shallow valleys in Yeeda, Wanganut, and St. George land systems.

(14*c*) *E. tectifica* with *Plectrachne pungens* (54) ground storey closely resembles 14*b* but the ground storey is characterized by *Plectrachne pungens*, with *Chrysopogon* spp. and other tall perennial grasses sparsely represented.

It occurs on parts of the sand plain of Yeeda and Lowangan land systems, and on low-lying sand plain and lower slopes of Amy, Rose, and Richenda land systems.

(14*d*) *E. tectifica* with *Aristida hygrometrica* (62) ground storey occurs naturally as a minor element in a number of sites. The area covered by it increases with overstocking and with the practice of burning. This community differs from others of the alliance chiefly in the paucity or absence of tall perennial grass and is characterized by *Aristida hygrometrica* and other short grasses. The community was observed on the drainage floors of Cowendyne land system, swales and low-lying sand plain of Wanganut land system, and the rocky surfaces of Tableland land system.

(15) E. tectifica–E. dichromophloia *Community*.—This open grassy woodland is closely related to 14*a*. It differs in that *E. dichromophloia* occurs in the tree layer and the grassy ground storey is much richer floristically. It is characterized by *Sehima nervosum* and *Dichanthium fecundum* (53) and a rich assortment of other perennial grasses. Short grasses are sparse. Distribution is restricted to the lower slopes and drainage floors of volcanic country in Cowendyne, Looingnin, Forrest, and Precipice land systems.

(16) E. tectifica–E. perfoliata *Community*.—Commonly associated with lateritic surfaces is a depauperate woodland the tree layer of which is characterized by *E. tectifica* and *E. perfoliata*. Other stunted trees (*E. jensenii, E. confertiflora*) are sparsely present in some places. A number of tall shrubs (*Acacia impressa, Acacia* spp., *Dolichandrone heterophylla, Erythrophloeum chlorostachys, Grevillea* sp., and *Petalostigma quadriloculare*) also extend into the tree layer. The prominent shrub layer is distinguished by *Acacia* spp., chiefly *A. impressa*. Other shrubs (*Grevillea pyramidalis, Carissa lanceolata, Scaevola* sp., and *Atalaya hemiglauca*) are moderately abundant but patchy. The ground storey is variable, but in the higher-rainfall (25–35 in.) parts is commonly characterized by *Plectrachne pungens* (54) with variable amounts of annual sorghum. Towards the lower-rainfall (20 in.) parts *Triodia intermedia* (57) occurs more frequently. Distribution was recorded for lateritic surfaces and rocky hill slopes in O'Donnell, Rose, Pigeon, Richenda, and Calwynyardah land systems.

(17) E. perfoliata–Acacia impressa *Community*.—This community structurally, floristically, and in habitat closely resembles 16, and may be considered as a low-

rainfall (16–25 in.) variant of it. The community is more depauperate. The tree layer distinguished by *E. perfoliata* is more stunted and the Acacias are even more prominent.

The ground storey is characterized by *Triodia intermedia* (57) although *Chrysopogon* spp., *Plectrachne pungens*, and *Triodia pungens*, as well as a range of short grass, are sparsely present in places.

The community is widespread on the lateritic surfaces of Egan, Mamilu, Koongie, St. George, and lower-rainfall parts of Sisters land systems.

(*f*) Eucalyptus argillacea *Alliance*

E. argillacea closely resembles *E. tectifica* and there is some overlapping of their environmental tolerances. *E. argillacea* extends further to the south than was recorded for *E. tectifica.* Two communities have been described.

(18) Eucalyptus argillacea *Community*.—This grassy woodland closely resembles 14*b* except that the open tree layer (25–30 ft high) is characterized by *E. argillacea,* the moderately dense shrub layer contains more *Acacia* spp., and the grassy ground storey is characterized by *Chrysopogon* spp. (49) but has a poorer assortment of other tall perennial grasses and extends further to the lower-rainfall (20–25 in.) areas.

The community was recorded for the lower slopes of Amy, Richenda, and Rose land systems and the shallow valley depressions of the Yeeda land system.

(19) Eucalyptus argillacea–E. microtheca *Community*.—Associated with some alluvial soils and yellow earths of the outer flood-plains or outer channel areas *E. microtheca* and *E. argillacea* form an open tree layer to grassy woodlands with a well-developed ground storey of *Chrysopogon* spp. (49), with occasional clumps of spinifex (*Plectrachne pungens*) and variable amounts of annual sorghum.

Although the observed distribution was limited to Glenroy and Sisters land systems it probably has a wider range.

(*g*) Eucalyptus microtheca *Alliance*

E. microtheca (coolibah) is widely distributed throughout the flood-plains of the area and does not appear to extend beyond environments which at some time are flooded. Two communities have been described.

(20) E. microtheca *Community*.—The tree layer (20–35 ft high) of this open grassy woodland is monospecific. The rounded crowns and widely-spaced trees give the community a distinctive appearance. Shrubs (*Melaleuca* sp., *Carissa lanceolata, Acacia victoriae, Bauhinia cunninghamii*) occur in patches or are extremely sparse. Three different ground storeys corresponding to slight differences of habitat have been described.

(20*a*) *E. microtheca* with *Chrysopogon* spp. (49) ground storey occurs as an open woodland, distinguished by a well-developed, almost pure stand of *Chrysopogon* spp. Short grasses are sparse and forbs are few.

Distribution is widespread on the fine-textured soils in Alexander, Djada, Gogo, Mandeville, and Coonangoody land systems.

(20*b*) *E. microtheca* with *Chrysopogon* spp.–*Dichanthium fecundum* (48) ground storey. This community differs from 20*a* mainly in that dominance of the tall grass layer is shared by *Chrysopogon* spp. and *Dichanthium fecundum*, with a rich assortment of other perennials. The tree layer is very open and the community grades into grassland.

Distribution is limited to the cracking clay soils of the flood-plains of Alexander, Djada, and Gogo land systems.

(20*c*) *E. microtheca* with *Triodia pungens* (55) ground storey. The spinifex ground layer distinguishes this community from the rest of the group. Observation by residents and correlation with habitat suggest that although this community occurs naturally upon the higher and stable parts of the flood-plain it encroaches upon the habitats of 20*a* and 20*b* following over-grazing.

Distribution is limited to fringes of minor channels and billabongs and higher fringes to flood-plains of Alexander, Djada, and Gogo land systems and pans and depressions of Luluigui and Myroodah land systems.

(21) E. microtheca–E. papuana *Community*.—The tree layer (20-35 ft high) of these woodlands comprises *E. microtheca* and *E. papuana*. The tall shrub layer is variable but is dense in patches, and consists mainly of *Acacia* spp. of the adjoining pindan. The tall grass layer also resembles pindan and consists of a complex of *Plectrachne pungens* and *Chrysopogon* spp. (56). Short grasses are sparse or absent.

Observed distribution was limited to the low-lying swales where dune fields approach the coast in Wanganut land system and in some pans and depressions in the Camelgooda land system.

(*h*) Eucalyptus papuana *Alliance*

E. papuana, in the survey area, is almost entirely restricted to alluvial soils of the levee crests and parts of the levee back slopes and similar habitats throughout the extensive flood-plains of the area. Three communities have been described.

(22) E. papuana *Community*.—*E. papuana* characterizes the upper tree layer (30–40 ft) of this grassy woodland and except for an occasional *Adansonia gregorii* or *E. polycarpa* forms almost pure stands. *Bauhinia cunninghamii* commonly occurs as a smaller tree. The shrub layer (*Bauhinia cunninghamii*, *Carissa lanceolata*, *Grevillea striata*, and *Acacia* spp.) is patchy or sparse. Two ground storeys have been described.

(22*a*) *E. papuana* with ground storey of frontage grass (50) is extremely varied from place to place but consists typically of a rich assortment of tall perennial frontage grasses including *Chrysopogon* spp., *Heteropogon contortus*, and *Dichanthium fecundum*. This community occurs on the levee crests and levee back slopes of Gogo, Djada, and Alexander land systems and on drainage floors of a number of others throughout the area.

(22*b*) *E. papuana* with *Aristida hygrometrica* and other short grasses (62) ground storey occurs as a grassy woodland very closely resembling 22*a* but lacks the tall perennial grass layer. It is characterized by *A. hygrometrica* and other short grasses (62). It is extensive on the restricted sandy levees of the North Kimberley area (Speck 1960) but in the West Kimberley area the community occurs naturally only on the more sandy parts of the levees, and extends by over-grazing at the expense of 22*a*. It occurs as a minor community in a number of land systems throughout the area.

(23) E. papuana–E. alba *Community*.—The presence of *E. alba* in the tree layer (30–40 ft) of this grassy woodland is the only significant thing that distinguishes this from 22*a*. It is restricted to levee crests and similar alluvial sites of Djada, Gogo, Sisters, and Tarraji land systems.

(24) E. alba–E. microtheca *Community*.—The tree layer (30–40 ft) of this grassy woodland is characterized by *E. alba* and *E. microtheca*. In other respects it also resembles 22*a*. It occurs on levee back slopes in the higher-rainfall (30–40 in.) parts of Djada, Gogo, and Sisters land systems.

(*i*) Eucalyptus polycarpa *Alliance*

E. polycarpa is widespread in the higher-rainfall parts of the area but is restricted to special, commonly moister, habitats. Three communities have been described.

(25) E. polycarpa *Community*.—Although the tree layer of this woodland (30–50 ft high) is characterized by *E. polycarpa*, several other trees (*Eucalyptus* sp. Lazarides 6413, *E. ferruginea*, and *E. camaldulensis*) sporadically occur. A lower tree layer, 10–15 ft high (*Brachychiton* sp., *Grevillea pteridifolia*, *Persoonia falcata*, *Planchonia careya*, and *Melaleuca* sp.), is commonly present. Shrubs, mostly smaller bushes of the same species, are sparingly represented. Tall and medium-height perennial grasses are patchy or absent and the ground storey is characterized by *Aristida hygrometrica* with an assortment of other short grass species (62). Recorded distribution is restricted to the shallow valleys and drainage floors of Fork, Precipice, Glenroy, Wanganut, and Tableland land systems.

(26) E. polycarpa–Melaleuca viridiflora *Community*.—*E. polycarpa* characterizes the open tree layer (25–50 ft) of this woodland although other trees (*E. confertiflora*, *Adansonia gregorii*, and *Bauhinia cunninghamii*) are sparsely represented. A definite, but patchy, low tree–tall shrub layer formed by *Melaleuca viridiflora* commonly is quite dense. The ground storey is commonly sparse and is characterized by tussocks of *Plectrachne pungens* and *Chrysopogon* spp. (56).

Distribution is restricted to the pans and depressions and ill-drained areas within the pindan country of Yeeda, Wanganut, Sisters, and Mandeville land systems in the higher-rainfall areas (25–40 in.).

(27) E. polycarpa–E. grandifolia *Community*.—The upper tree layer (20–30 ft high) of this woodland is characterized by *E. polycarpa* and *E. grandifolia*. A smaller tree layer, 10–20 ft high (*Terminalia canescens*, *Melaleuca minutifolia*, and *Dolichandrone heterophylla*), is commonly present. The shrub layer (*Carissa lanceolata* and *Atalaya hemiglauca*) is sparse.

The ground storey is characterized by an assortment of perennial frontage grasses (50). Observed distribution is restricted to the alluvial flats of Glenroy and Tableland land systems.

(*j*) Eucalyptus miniata *Alliance*

E. miniata, commonly in association with *E. tetrodonta,* is extensive on the sandstone and quartzite country of the North Kimberley area (Speck 1960) and other high-rainfall parts of northern Australia (Perry 1956; Christian and Stewart 1953). *E. tetrodonta* does not extend as far west and south as the West Kimberleys. *E. miniata* was observed only on the deep sands in the north-western higher-rainfall parts of the area, where it might be considered as a high-rainfall variant of pindan into which it grades to the south. Two communities have been described.

(28) E. miniata–E. perfoliata *Community.*—The structure of this community is commonly woodland but in places approaches the density of open forest. Its tall tree layer (40–50 ft) is characterized by *E. miniata.* Other trees (*E. tectifica* and *E. confertiflora*) slightly lower are sparsely present in some places. A definite smaller tree layer (15–25 ft) characterized by *E. perfoliata* but with a number of other trees (*Bauhinia cunninghamii, Persoonia falcata, Adansonia gregorii, Buchanania obovata, Terminalia canescens, Erythrophloeum chlorostachys,* and *Grevillea* spp.) is a characteristic feature. *Acacia tumida, Dodonaea* sp., *Petalostigma quadriloculare, Cochlospermum fraseri,* and *Grevillea* spp. form a prominent but patchy shrub layer reminiscent of pindan. The grassy ground storey is characterized by *Plectrachne pungens* and *Chrysopogon* spp. (56) and variable amounts of annual sorghum. Short grasses and forbs are sparsely present.

The community is restricted to the deep sands, sand plains, and dune fields, and other minor habitats of Yeeda, Mandeville, and Wanganut land systems in the higher-rainfall parts (25–40 in.) of the area.

(29) Eucalyptus miniata–E. polycarpa *Community.*—This community is a variant of 28 and is characteristic of the shallow valleys and depressions within the boundaries of community 28. The main differences are that *E. polycarpa* also occurs in the tall tree layer, and the ground storey is distinguished by *Chrysopogon* spp. (49).

Distribution is limited to these special moister habitats in the land systems as given for 28.

(*k*) Adansonia gregorii *Alliance*

Adansonia gregorii (baobab or bottle tree) is extremely widespread throughout the area on a wide range of habitats, forming a minor element in many communities. Its distinctive form makes it conspicuous wherever it occurs. It is, however, in comparatively few places that it merits recognition as a community dominant. Four communities have been described.

(30) Adansonia gregorii *Community.*—Although this community in many respects resembles 31, there are some important differences. *Adansonia gregorii* characterizes an extremely open tree layer (15–35 ft), other trees are commonly absent. The shrub layer though floristically rich is scattered and restricted to pockets of soil and cracks and crevices where it attains a foothold. The common species of this distinctive layer are *Cochlospermum fraseri, Ficus opposita, Terminalia* sp., *Wrightia* sp., *Celtis philippensis, Sarcostemma australe,* and *Santalum* sp.

The ground storey comprises tussocks of *Triodia wiseana* (58) and other sparse grasses. Forbs (*Achyranthes aspera, Portulaca* sp., *Indigofera linifolia*, and *Cleome viscosa*) are plentiful.

Distribution is restricted to the rugged limestone country on Neillabublica, Windjana, and Oscar land systems.

(31) Adansonia gregorii–E. perfoliata *Community*.—The tree layer (25–40 ft) of this community is characterized by *Adansonia gregorii* and is very open. *Bauhinia cunninghamii, Ventilago viminalis*, and scattered, stunted eucalypts (*E. grandifolia* and *E. dichromophloia*) are sparsely present. A smaller tree layer (10–20 ft) is distinctive and is characterized by *E. perfoliata*. Other small trees (*Atalaya hemiglauca, Hakea* spp., *Terminalia canescens*, and *Acacia tumida*) are also present. Smaller bushes of the same species form a moderately dense but patchy shrub layer.

The grassy ground storey is characterized by *Plectrachne pungens* and *Chrysopogon* spp. (56) and varying amounts of annual sorghum. Short grasses are sparse and there is considerable bare ground.

Distribution was observed over a wide range of habitats, commonly stony, in Clifton, Fraser, Luluigui, Mamilu, Sisters, Reeves, Yeeda, and St. George land systems.

(32) E. perfoliata–Adansonia gregorii–E. dichromophloia *Community*.—Associated with granite domes and tors and some quartz ridges occurs a distinctive community characterized by scattered trees (*E. perfoliata, E. dichromophloia, Adansonia gregorii*, and less prominently *Gyrocarpus americanus, Bauhinia cunninghamii*, and *Petalostigma quadriloculare*) growing where they can get a place on their rocky habitat. The sporadic shrub layer (*Cochlospermum fraseri, Brachychiton* sp., *Terminalia ferdinandiana, Gardenia* spp., *Buchanania obovata*, and *Ficus* spp.) also consists of a rich and distinctive assortment of species.

This distinctive site provides the restricted habitat of *Plectrachne bynoei* (60), which characterizes the ground storey.

Distribution is widespread, but restricted to these special habitats in Amy, Rose, Tarraji, Richenda, and Mandeville land systems.

(33) Adansonia gregorii–Terminalia platyphylla *Community*.—Some of the smaller non-permanent streams and associated drainage floors are fringed with *Adansonia gregorii*, which, although it commonly forms an extremely open tree layer (20–35 ft), here is comparatively dense and gives a very distinctive appearance to the community. Associated trees are *Terminalia platyphylla, Brachychiton diversifolium*, and *Tristania suaveolens*. The community commonly remains very open and shrubs are scattered.

The ground storey is variable, sparse, and patchy but commonly characterized by *Heteropogon contortus* and an assortment of perennial frontage grasses (50). In some patches *Aristida hygrometrica* and other short grasses (62) are predominant.

Recorded distribution includes the channels and drainage floors of Amy, Pigeon, Richenda, Rose, Burramundi, Tableland, Myroodah, and Gladstone land systems.

(*l*) Grevillea striata *Alliance*

Grevillea striata is extremely widespread throughout the area, and occurs as a minor element in many communities outside the alliance which it characterizes. It is more prevalent on the fine-textured yellow and red earths of the central and southern parts of the area. One community only has been described.

(34) Grevillea striata *Community*.—*Grevillea striata* as a tall shrub or small tree characterizes the upper layer (10–20 ft) of this community. This layer may be open or quite dense and distribution is commonly patchy, forming thickets in low-lying areas. The layer may be monospecific or other stunted trees (*Adansonia gregorii*, *E. dichromophloia*, and *E. perfoliata*) or tall shrubs (*Bauhinia cunninghamii*, *Hakea arborescens*, *H. lorea*, *Atalaya hemiglauca*, and *Acacia* spp.) may be sparsely represented. Smaller shrubs are also scattered. Three different ground storeys were recorded for this community.

(34*a*) *Grevillea striata* with *Chrysopogon* spp. (49) ground storey occurs commonly as a widely distributed, low open woodland. Except where the tree layer is dense the tall grass layer characterized by *Chrysopogon* spp. is well developed.

Distribution is chiefly upon the fine-textured yellow and red earth soils of the alluvial plains of Calwynyardah, Myroodah, Luluigui, Margaret, Sisters, Lowangan, and Mamilu land systems and upon the low-lying sand plain in the Camelgooda and Fraser land systems and in the depressions of the Coonangoody land system.

(34*b*) *Grevillea striata* with *Triodia pungens* (55) ground storey closely resembles 34*a* except that the ground storey is characterized by *Triodia pungens*.

Although, as a minor community, it has a widespread distribution in the central and southern parts of the area, it is most prominent and widespread along and to the south of the Fitzroy River and is an important community on the alluvial plains of Calwynyardah, Chestnut, Luluigui, and Myroodah land systems, the swales and low-lying sand plain on Camelgooda, the drainage floors of Coonangoody, and the back plains of Djada land systems.

(34*c*) *Grevillea striata* with *Plectrachne pungens* (54) ground storey also closely resembles 34*a* and 34*b* except that *Plectrachne pungens* characterizes the grass layer of this combination.

Distribution is restricted to the lower slopes, alluvial plains, and scalded tracts of Calwynyardah and Myroodah land systems.

(*m*) Melaleuca acacioides *Alliance*

This alliance consists of a group of coastal communities characterized by *Melaleuca acacioides*. One of the more important communities with several different ground storeys has been described.

(35) Melaleuca acacioides *Community*.—This species characterizes the upper layer (15–40 ft) of this community. It is extremely variable in height and density, ranging from scattered trees to dense thickets. Other trees (*E. polycarpa*, *E. papuana*) are rare. Shrubs (*Acacia* spp. and *Pandanus* sp.) are scattered or absent. The grass layers are inconstant both in density and composition but in general fall into two kinds of ground storey.

(35*a*) *Melaleuca acacioides* with *Chrysopogon* spp. (49) ground storey has a grass layer characterized by *Chrysopogon* spp. which is never very dense. Other perennials (*Dichanthium fecundum*, *Sehima nervosum*, or isolated clumps of spinifex) are sparsely represented in places. The short grass layer commonly resembles the ground storey of 35*b*.

This community characterizes the slightly saline upper parts of Carpentaria land system.

(35*b*) *Melaleuca acacioides* with *Xerochloa* spp. (65) ground storey differs from 35*a* mainly in absence of the tall perennial grasses. The ground storey is limited to short grass–forb elements and is characterized by *Xerochloa barbata* and *X. imberbis* and a number of short grasses including patches of *Aristida hygrometrica* and *Sporobolus virginicus*.

Distribution is restricted to the upper slightly saline parts of Carpentaria land system.

(*n*) Melaleuca *Spp. Alliance*

The group of *Melaleuca* communities that occur in numerous small habitats throughout the area is composed of species different from those of the coastal fringe. One community only has been described.

(36) Melaleuca *Spp. Community*.—The upper layer (15–20 ft) of this community is characterized by *Melaleuca minutifolia* and an undescribed *Melaleuca* sp. It occupies a wide range of habitats all having the common feature of retarded drainage. Other small or stunted trees (*E. brevifolia*, *E. polycarpa*, *Hakea* sp., and *Bauhinia cunninghamii*) are sparsely present in places. Shrubs are sparse or absent.

Although *Plectrachne pungens* (54) characterizes the ground storey, *Chrysopogon* spp. are also present in many places.

The recorded distribution includes these special habitats in Fork, Tableland, Camelgooda, Wanganut, Yeeda, Amy, Richenda, and Calwynyardah land systems.

(*o*) Bauhinia cunninghamii *Alliance*

Bauhinia cunninghamii is extremely widespread. Very few communities occur in which it is not represented as either a small tree or shrub but it is in comparatively few places that it is the characteristic tree. Three communities have been described and two of these occur with several different ground storeys.

(37) Bauhinia cunninghamii *Community*.—The tree layer (15–25 ft) of these low woodlands is characterized by *Bauhinia cunninghamii*. It occurs over a range of habitats and the associated trees, shrubs, and grasses vary accordingly.

(37*a*) *Bauhinia cunninghamii* community with *Chrysopogon* spp.–*Dichanthium fecundum* (48) ground storey is characteristic of the minor stream lines of the cracking clay plains and becomes very open where they extend onto the plains. Other trees (*Atalaya hemiglauca*, *Dolichandrone heterophylla*, *Terminalia volucris*, and *Ventilago viminalis*) are patchy and sparse. The sparse shrub layer is commonly characterized by *Acacia suberosa*, *Carissa lanceolata*, and bushes of the tree species. The ground storey characterized by *Chryosopogon* and *Dichanthium* spp. is floristically rich, tall, and dense.

It occurs in the Fossil, Leopold, Neillabublica, Windjana, Duffer, Forrest, Oscar, and Margaret land systems.

(37*b*) *Bauhinia cunninghamii* with *Chrysopogon* spp. (49) ground storey occurs on scalded cracking clay plains where the shrub layers resemble 37*a* but it is also widespread on yellow earths and fine-textured red earths where it shows affinities with 34*a*.

The ground storey in both cases is characterized by *Chrysopogon* spp., which in places is quite dense although scalding is extensive.

The community occurs on the scalded plains of Egan, Mamilu, Myroodah, Fraser, Luluigui, Camelgooda, and Sisters land systems.

(38) Bauhinia cunninghamii–Ventilago viminalis *Community*.—The tree layer (15–25 ft) of this low open woodland is characterized by *Bauhinia cunninghamii* and *Ventilago viminalis*, and several other small trees (*Dolichandrone heterophylla*, *Atalaya hemiglauca*, and *Acacia* spp.) are commonly present. Shrubs are scattered. It is restricted to a range of sandy habitats in the sand plains and dune fields. Three different ground storeys were observed with this community, with little or no change in the upper layers.

(38*a*) *Bauhinia cunninghamii–Ventilago viminalis* with *Plectrachne pungens* (54) ground storey is restricted to sandy habitats. Although the ground storey is characterized by *Plectrachne pungens* (54), *Eriachne obtusa* and *Aristida hygrometrica* are commonly present as a short grass layer.

The community occurs on the dunes of Wanganut and Camelgooda land systems and on the lateritic crests of the Bohemia land system.

(38*b*) *Bauhinia cunninghamii–Ventilago viminalis* with *Triodia pungens* (55) ground storey is significantly different only in that *Triodia pungens* characterizes the ground storey and that it is more common in the southern parts of the area. Distribution was recorded for dune fields of Camelgooda, Wanganut, and Luluigui land systems.

(38*c*) *Bauhinia cunninghamii–Ventilago viminalis* with *Aristida browniana* (63) ground storey is pindan-form vegetation. It differs from the other pindan communities in that the stunted eucalypts are absent. As with other pindan communities the prominent tall shrub layer is distinguished by *Acacia* spp. (mainly *Acacia tumida*). Other shrubs include *Acacia impressa*, *Hakea arborescens*, *H. macrocarpa*, *H. lorea*, *Dolichandrone heterophylla*, *Ehretia* sp., *Capparis* sp., and *Atalaya hemiglauca*.

The ground storey has patches of pindan grasses (*Chrysopogon* spp.–*Plectrachne pungens* (56)) but is commonly characterized by *Aristida browniana* and other short grasses. There is considerable bare sand.

Observed distribution includes minor parts of Fossil land system and red sandy soils of sand plain and dune fields (particularly dune crests) of Camelgooda, Fraser, Wanganut, Luluigui, and Coonangoody land systems.

(39) Bauhinia cunninghamii–Tristania suaveolens *Community*.—Along some of the smaller non-permanent streams of Burramundi, Forrest, Fraser, Lowangan, Margaret, Neillabublica, Oscar, Windjana, and Gladstone land systems, *Bauhinia cunninghamii* and *Tristania suaveolens* characterize the upper layer (15–30 ft) of a fringing community. Sparse *Adansonia gregorii* and *Terminalia platyphylla* trees are locally present. The community is open and the perennial frontage grasses (50) are patchy.

(*p*) Eucalyptus camaldulensis–Terminalia platyphylla *Fringing Communities*

This group of communities forms fringing communities along most of the stream lines throughout the area. In density they range from open woodland to forest. Four communities have been described.

(40) E. camaldulensis *Community*.—Along many of the non-permanently-flowing streams *E. camaldulensis* characterizes the open tree layer (25–35 ft) of a fringing community. Other trees (*Terminalia platyphylla* and *Tristania suaveolens*) are scattered or absent. The shrub layer also is sparse, but the ground storey of perennial frontage grasses (50) is dense but patchy. As well as these, tall coarse fringing grasses (*Arundinella nepalensis, Cyperus* sp., *Imperata cylindrica* var. *major*, and *Chloris acicularis*) (51) commonly form a patchy, discontinuous fringe to the channel. Distribution is widespread throughout the area.

(41) E. camaldulensis–Melaleuca *Spp. Community*.—This is a similar community to 40 and is also restricted to small streams in which water is available for longer periods throughout the year. Although characterized by *E. camaldulensis*, it has a pronounced smaller tree layer distinguished by *Melaleuca argentea* and *M. bracteata*. Other trees (*Ficus coronulata, F. racemosa, Tristania suaveolens*, and *Brachychiton* sp.) are sparsely represented. Tall shrubs (*Planchonia careya, Terminalia volucris, Acacia* spp., and *Pandanus* sp.) occur in a discontinuous layer. As well as patches of perennial frontage grasses (50) other tall coarse fringing grasses (*Coelorhachis rottboellioides, Arundinella nepalensis*, and *Imperata cylindrica* var. *major*) (51) occur in pockets along the channel banks. Distribution is widespread throughout the area.

(42) E. camaldulensis–Terminalia platyphylla *Community*.—*E. camaldulensis* and *Terminalia platyphylla* characterize the tree layer (40–60 ft) of the fringing forests and woodlands along the main rivers of the area. Other trees (*Ficus coronulata, F. racemosa, Tristania suaveolens, Nauclea orientalis, Adansonia gregorii*, and *E. polycarpa*) are commonly present. Many smaller trees (*Melaleuca* spp., *Bauhinia cunninghamii, Acacia* spp., *Brachychiton* spp., *Planchonia careya*, and *Pandanus* sp.) assist in forming a more or less dense fringe to the channel. The ground storey is characterized by patches of perennial frontage grasses (50) and pockets of tall coarse grasses (*Coelorhachis rottboellioides, Arundinella nepalensis*, and *Imperata cylindrica* var. *major*) (51) occur in pockets or as fringes at the water's edge.

(43) Terminalia platyphylla *Community*.—Associated with the smaller permanent or near-permanent streams in the higher-rainfall (25–40 in.) parts is a fringing community characterized by *Terminalia platyphylla*, and *E. camaldulensis* is absent. Other associated trees and grasses are similar to 42.

(*q*) *Mangrove Communities*

Limited information only is available for these communities. Three species (*Ceriops tagal, Bruguiera exaristata*, and *Lumnitzera racemosa*) were observed and these appeared to correlate with mangrove communities of different structure and height, although considerable mixing of the species in the two taller communities possibly occurs. They are accessible only at low tide and the deep muds in which they grow are almost impossible to negotiate, therefore it is not known if the species distribution given below is constant.

(44) *Tall Mangrove Community*.—This is the tallest mangrove community (10–25 ft) and is invariably the outermost with minimum period of inter-tidal exposure. It typically consists of a single dense tree layer with canopies mingling. Where observed, this layer appeared to be characterized by *Ceriops tagal* with some intermingling by *Bruguiera exaristata*. Although the deep tidal muds support an abundant fauna, no other plants were observed.

(45) *Medium-height Mangrove Community*.—These mangroves (6–10 ft) also form a dense community immediately landwards from the taller community. *Bruguiera exaristata* appears to characterize the layer but *Ceriops tagal* is also present. No other plants were observed.

(46) *Low Mangrove Community*.—This low mangrove community (3–6 ft) is the most extensive and widespread and is the most tolerant of inter-tidal exposure although it was not observed anywhere above the high-water mark. The community is underlain by bare mud.

III. Ground-storey Attributes

Twenty-one different ground storeys have been recognized. A few of these occur only as grasslands, some as grasslands and as grassy ground storeys to woodlands, and others only as grassy ground storeys to one or more tree communities (Table 16). These ground-storey communities comprise reasonably consistent assemblages of plants, are characterized by one or more species, and are, in this report, synonymous with pasture types.

In the higher-rainfall parts of Australia, pastures generally comprise only the ground storeys of the vegetation communities. Under arid conditions many of the trees and shrubs are also grazed by stock, particularly during the unfavourable season when the ground storeys are in a state of low productivity. The native pastures of the West Kimberley area have developed under an average rainfall of 15–40 in. and in many respects have affinities with those of both arid and higher-rainfall parts of northern Australia. The grassy ground storeys resemble those of higher-rainfall, tropical Australia, but like pastures of an arid environment many of the trees and shrubs are also grazed by stock. The main characteristics of these ground storeys have been summarized in Table 17.

On a regional basis, the top-feed plants range from low to moderate in palatability and provide a subsistence diet for stock. They are generally utilized as supplementary forage and are particularly valuable where pastures are of poor quality and in periods of drought when pasture productivity has ceased. However, a number of species appear to be palatable to the grazing animal even under normal conditions. These are *Bauhinia cunninghamii*, *Acacia suberosa*, *A. farnesiana*, *Dolichandrone heterophylla*, *Carissa lanceolata*, and *Ventilago viminalis*. Some can be toxic to stock at certain periods of growth, e.g. *Atalaya hemiglauca* during flowering. Others such as *Grevillea striata*, *Planchonia careya*, and *Acacia victoriae* are browsed only under extremely adverse conditions.

TABLE 17

MAIN CHARACTERISTICS OF THE GROUND STOREYS (PASTURE TYPES)

Pasture Type (Ground-storey Community)	Top Feed	Remarks
Astrebla spp. (Mitchell grass)	Moderate: *Bauhinia*, *Acacia suberosa*, *A. farnesiana*, *Carissa lanceolata*, *Atalaya hemiglauca*, *Dolichandrone heterophylla*	Capable of fattening stock. High stocking rates. Inaccessible during wet season
Chrysopogon spp.–*Dichanthium fecundum*	Moderate: *Bauhinia*, *Acacia suberosa*, *A. farnesiana*, *Carissa lanceolata*, *Atalaya hemiglauca*, *Dolichandrone heterophylla*	Highly regarded. Subjected to heavy grazing. Large areas scalded and degraded. Parts inaccessible during wet season
Chrysopogon spp.	On frontage similar to above. Elsewhere *Grevillea striata*, *Bauhinia cunninghamii*, *Melaleuca* sp.	Moderately high stable stocking rate. High proportion of palatable components
Frontage grass	Good	High fodder production, palatable and nutritious. High stocking rate. Susceptible to degradation under heavy grazing
Fringing grass	Variable	Unattractive to stock
Sehima nervosum–*Sorghum* spp.	Sparse: *Cochlospermum fraseri*, *Dolichandrone heterophylla*, *Atalaya hemiglauca*	Generally unattractive to stock, but utilized in association with better pastures
Sehima nervosum–*Dichanthium fecundum*	Sparse: *Cochlospermum fraseri*, *Dolichandrone heterophylla*, *Atalaya hemiglauca*	Moderate carrying capacity
Plectrachne pungens	Negligible	Low but stable carrying capacity. Drought reserve
Triodia pungens	Moderate: *Bauhinia cunninghamii*, *Grevillea striata*, *Atalaya hemiglauca*, *Carissa lanceolata*	Good subsistence fodder, low but stable carrying capacity
Plectrachne pungens–*Chrysopogon* spp.	Poor to moderate	Low carrying capacity. Good seasonal fodder when adjacent to frontage pastures or waters
Triodia intermedia	Poor	Unpalatable to stock. Very low carrying capacity. Drought reserve
Triodia wiseana	Poor or absent	Low palatability and low nutritive value. Some utilization in association with better pastures

TABLE 17 (*Continued*)

Pasture Type (Ground-storey Community)	Top Feed	Remarks
Triodia inutilis	Absent	Little palatable fodder. Extremely low carrying capacity
Plectrachne bynoei	Present, but inaccessible	Inaccessible, extremely low carrying capacity
Enneapogon spp. and other short grasses	Sparse	Palatable and nutritive. Good fodder for some months after rain but degenerates in long dry periods
Aristida hygrometrica	Sparse	Unpalatable except for short periods after rain. Low carrying capacity. Grass seeds may cause sheep mortality
Aristida browniana	Moderate to good: *Bauhinia cunninghamii* and *Ventilago viminalis*	Palatable for some months after rain, but of low value because sporadic in distribution
Sporobolus virginicus	Absent	Capable of fattening stock, readily grazed at all stages. Good carrying capacity
Xerochloa spp.	Sparse	Highly palatable and nutritious for short periods after rain. Fodder production ceases under drought conditions. Susceptible to degradation
Samphire	Absent	Samphire not grazed. Some fodder from associated plants during favourable season
Beach dune	Sparse	Low fodder production, low carrying capacity

Unlike adjoining areas to the south and south-east, there is little or no winter rainfall with its subsequent response of useful forbs. During the lengthy rainless periods between successive wet seasons, pasture productivity is almost nil and the quality of existing fodder is low. Palatable short-lived plants, though generally lacking in the area, occur with summer rainfall and are available for brief periods of one month to six weeks. They are the more nutritious components of the natural pastures and comprise annual and ephemeral grasses, a few sedges, and mainly leguminous or succulent forbs. Noteworthy species of this group include *Dactyloctenium radulans*, *Fimbristylis dichotoma*, *Portulaca* spp., *Trianthema* spp., *Ptilotus* spp., and *Sesbania* spp.

In cattle-producing parts of the area, the native pastures are suitable mainly for breeding purposes. There are also limited areas which produce pastures sufficiently nutritious for the fattening of cattle. However, these conditions apply only during the growing season. For most of the dry season stock either barely maintain or lose weight depending on the quality of the pasture types and severity of the season. Under extremely adverse conditions stock mortalities occur, but are usually less frequent where drought-resisting spinifex types are available.

Because the characteristic plants are with few exceptions grasses, the pasture types fall fairly readily into two broad groups based firstly on height and secondly on the method of surviving the unfavourable period. The taller grasses are mostly perennial and may be classified as drought evading and drought resisting (Perry 1960; Perry and Lazarides 1962). The latter are represented entirely by sclerophyllous grasses and can be subdivided into hard and soft spinifex types.

The short pastures form a less well-defined group comprising plants of varied life form. They are characterized by both perennial and annual drought-evading grasses, and to a lesser extent by succulent, drought-resisting shrubs or undershrubs. However, the group is not well developed in the area and is satisfactorily subdivided into saline-tolerant pastures and upland types.

IV. Ground-storey Descriptions

(a) *Ground Storeys (Pasture Types) Characterized by Grasses of Tall to Medium Height*

On the method of survival of the unfavourable period these have been subdivided into two groups.

(i) *Ground Storeys Characterized by Drought-evading Species.*—The predominant plants in these types are perennial tussock grasses represented by *Astrebla* spp., *Chrysopogon* spp., *Dichanthium* spp., *Bothriochloa* spp., *Sorghum plumosum*, and *Eulalia fulva*. The characteristic features of the pastures are their rich floristic composition and their high fodder production, which includes a relatively high proportion of forbs and top feed. In favourable periods, the better types are nutritious enough to fatten stock. With the onset of dry conditions, they rapidly deteriorate in palatability and nutritive value until finally little more than roughage remains. Nevertheless, for most of the time these pastures are an important source of fodder and in general, they carry most of the stock in the area. Their distribution is correlated with heavy clay soils such as dark cracking clays and yellow earths, and alluvial cracking clays. They are widely distributed but dominate the broad flood-plains.

The numbers used to designate these ground-storey communities are continous with those used for the upper storeys.

(47) Astrebla *Spp. (Mitchell Grass) Ground Storey.*—This is characteristic of the extensive cracking clay plains throughout the area. The soils typically have gilgai microrelief and this influences the structure of the community.

Tussocky perennial grasses, 2–4 ft high, form a moderately dense, tall grass layer distinguished by *Astrebla squarrosa* (bull Mitchell), *A. pectinata* (barley Mitchell), and *A. elymoides* (weeping Mitchell), and occupy the inter-gilgai areas. *Chrysopogon* spp., *Sehima nervosum*, and *Aristida latifolia* are commonly present and in places *Chrysopogon* spp. are locally dominant. The shorter grasses (*Dichanthium fecundum*, *Brachyachne convergens*, *Panicum decompositum*, *P. whitei*, and *Iseilema* spp.) characterize the gilgais. The community is further enriched by annuals and forbs including a number of leguminous species of *Moghania*, *Rhynchosia*, and *Neptunia*. It commonly occurs as a grassland with, locally, sparse trees (*Bauhinia cunninghamii* and *Eucalyptus microtheca*), and shrubs (*Acacia suberosa*, *A. farnesiana*, *Carissa lanceolata*, *Atalaya hemiglauca*, and *Dolichandrone heterophylla*), commonly scattered, are in places quite numerous.

As a pasture type the community is floristically rich and many of the constituents are highly palatable. Associated trees and shrubs are browsed as top feed. Because of their well-balanced composition, the pastures are attractive to grazing animals. They are favourably regarded by pastoralists as their high level of productivity is conducive to high stock-carrying rates. The community is confined to the mature cracking clay soils of the flood-plains of Alexander, Djada, and Gogo land systems, the broad outwash plains of limestone country (Fossil, Oscar, Neillabublica, Duffer, and Windjana land systems), and areas of other cracking clay soils throughout O'Donnell and Gladstone land systems. It does not occur on cracking clays on volcanic country.

(48) Chrysopogon *Spp.*–Dichanthium fecundum (*Ribbon Grass–Blue Grass*) *Ground Storey*.—Structurally and floristically this closely resembles 47, except for the absence of *Astrebla* spp. and the presence locally of a greater range of tall to medium-height tussocky perennial grasses (*Eulalia fulva*, *Sorghum plumosum*, *Dichanthium superciliatum*, *Bothriochloa ewartiana*, and *Heteropogon contortus*). There is also a greater variety of species in the lower layer. Of its numerous components *Dichanthium fecundum* and *Chrysopogon* spp. are predominant. The lower layer (12–18 in. high) commonly is well developed and comprises shorter perennial and annual grasses and a wide selection of plants of varied habit and life form. Representative species in this layer include *Iseilema* spp., *Brachyachne convergens*, *Eriachne glauca*, *Eragrostis setifolia*, *Echinochloa colonum*, *Paspalidium rarum*, *Xerochloa laniflora*, *Dactyloctenium radulans*, *Polycarpaea* spp., *Ipomoea* spp., *Desmodium* spp., *Boerhaavia diffusa*, and many others including the succulents *Calandrina* and *Portulaca* spp.

The community occurs extensively as a grassland with sparse trees and shrubs (*Bauhinia cunninghamii*, *Terminalia volucris*, *Atalaya hemiglauca*, *Acacia farnesiana*, *A. suberosa*, *A. victoriae*, and *Carissa lanceolata*) and as a ground storey to open woodlands of *Bauhinia cunninghamii* (37), *Eucalyptus microtheca* (20), and *E. tectifica–E. dichromophloia* (15).

As a pasture type this community has many of the qualities of community 47. The predominant grasses are of moderate palatability and nutritive value. Several of the associated grasses and forbs are short-lived but nevertheless important as they comprise the more nutritious components. Among the more valuable of these are the succulents.

With a readily available supply of water, these flood-plain pastures are highly favoured areas as little development is necessary for their utilization. For this reason also, they are attractive to stock and subjected to heavy grazing. Because of flooding and their boggy nature they cannot be utilized during the wet season.

Not only does this community occur on the cracking clay soils throughout the area but it occurs in a much wider range of habitats including drainage floors, pans and depressions, and numerous minor habitats. It is a major community on the flood-plains of Djada and Gogo land systems and the cracking clay plains of Cowendyne and Looingnin and is important in Alexander, Fossil, Leopold, Duffer, Oscar, and Gladstone land systems. It occurs as a minor element in O'Donnell and Koongie land systems, in the floors of Richenda, Glenroy, and Myroodah land systems, and in pans and depressions in Yeeda and Wanganut land systems.

(49) Chrysopogon *Spp.* (*Ribbon Grass*) *Ground Storey*.—This is characterized by species which are extremely widespread throughout the area and are represented in most ground-storey communities. The communities characterized by *Chrysopogon* spp. are also extensive and widespread. The tall perennial grass layer (3–5 ft) is distinguished by *Chrysopogon latifolius* (ribbon grass) and *C. fallax* (golden spear grass). The community structurally and floristically resembles 48 but lacks *Dichanthium fecundum* and many of the short grasses (*Brachyachne convergens, Iseilema* spp.) typical of that community. Other tall to medium-height perennial grasses (*Aristida latifolia, A. inaequiglumis, Sehima nervosum,* and annual sorghum) are locally important and clumps of spinifex are present in places. The community is quite dense or open according to the varied environmental factors or grazing. As a pasture type this community where it occurs on the flood-plains resembles 48. The dominant *Chrysopogon* species are hardy perennial grasses forming small tussocks of basal vegetative tillers and elongated flowering culms up to 5 ft high. They have vigorous, fibrous root systems which rapidly regenerate after rainfall and which probably contribute to the drought-resistant and grazing-tolerant qualities of the species. Plants are regarded as palatable when young and have moderate nutritive value. Many of the associated upper-storey plants are suitable as top feed. In general, *Chrysopogon* spp. pastures contain a high proportion of palatable components and have a moderately high and fairly stable stocking rate.

The community is important on the less mature cracking clay areas. In these areas it commonly occurs as grassland or grassland with sparse trees and shrubs and has a similar land system distribution to community 48. It is also extensive and widespread on red and yellow earths of the central and southern parts of the area, where it characteristically occurs as a ground storey to low open woodlands of *Grevillea striata, Bauhinia cunninghamii, Melaleuca acacioides,* and a number of eucalypts (Table 16). It is a major community in Calwynyardah, Myroodah, and Luluigui land systems. It occurs in similar habitats in Margaret, Sisters, Lowangan, and Mamilu land systems, in low-lying sand plain in Camelgooda and Fraser land systems, in the depressions of Coonangoody land system, and on numerous minor habitats throughout the area.

(50) *Frontage Grass Ground Storey*.—This characterizes the levees of the major rivers and commonly occurs associated with watercourses throughout the area. Characteristic plants comprise coarse, perennial, tall to medium-height tussock grasses among which *Dichanthium* spp. and *Chrysopogon* spp. are predominant and *Sorghum plumosum, Themeda australis, Bothriochloa intermedia,* and *Heteropogon contortus* are of local importance. Although variable in floristics and structure the community is one of the richest of the area and contains many of the elements of the flood-plain which it commonly adjoins. In structure the ground storeys comprise

two well-defined layers of plants consisting of perennial grasses and under-shrubs over 5½ ft high in one, and numerous perennial, annual, and ephemeral grasses and forbs up to 2 ft high in the other. Associated vegetation comprises the *Eucalyptus papuana* woodland (22–24) and other communities (Table 16).

A variant of this ground storey is found as an under-storey to the channel fringing communities (39–43), where it is commonly more open and discontinuous and contains some species not common in the rest of its distribution. It is bounded on the channel side by fringing grass (51).

As a pasture type this community is regarded favourably, as a major proportion of its constituents are palatable and nutritious. Also, because of the varied composition and high fodder production, it has a high stock-carrying capacity which, under normal conditions, can be maintained for the greater part of the year.

In most parts, surface water is generally available in the nearby channels. Thus, river frontages are naturally favoured areas of grazing animals and are subjected to high stock concentrations for long periods. Furthermore, because of their higher topographic situation, they can be utilized sooner after flooding than adjacent flood-plain pastures. This grazing takes place during the critical period of initial growth prior to flowering and seeding and may lead to interference with the natural regeneration of the pasture. Because of these factors, frontage pastures are highly susceptible to severe degradation in areas where stocking is uncontrolled.

Areas of occurrence are usually narrow and linear. They are extensive in Gogo land system, important in the Djada and Alexander land systems, and occur as a minor element in numerous other land systems.

(51) *Fringing Grass Ground Storey*.—This is associated with the *E. camaldulensis* alliance. It is restricted to the channel margins and consists of very tall, coarse perennial grasses (*Coelorhachis rottboellioides*, *Arundinella nepalensis*, and *Imperata cylindrica* var. *major*) in dense stands forming a discontinuous fringe at the water's edge.

As a pasture type this fringing community is relatively unimportant.

The favourable water relations existing in these situations are conducive in places to the growth of robust, perennial grasses. These are often shrubby in habit with cane-like culms and rank foliage and may produce tussocks up to 6 ft high and almost as wide. They are not attractive to stock and are generally neglected in favour of adjacent frontage and flood-plain pastures.

Fringing grasses occur mainly in the Gogo, Djada, and Alexander land systems.

(52) Sehima nervosum–Sorghum *Spp.* (*White Grass–Annual Sorghum*) *Ground Storey*.—This is characterized by *Sehima nervosum*, a wiry tufted perennial with culms reaching 3–4 ft at maturity, and annual sorghums (*Sorghum australiense* and *S. stipoideum*). The sorghums are erratically distributed and in places form dense stands. They are rapidly growing plants which produce small tufts of one to two flowering culms up to 10 ft high. Associated plants include other tall perennials (*Sorghum plumosum*, *Heteropogon contortus*, *Cymbopogon bombycinus*, and *Aristida pruinosa*) and a well-developed layer of shorter grasses (*Eriachne glauca*, *Panicum*

delicatum, *Enneapogon polyphyllus*, and *Brachyachne convergens*). Forbs are abundant and include species of *Tephrosia*, *Corchorus*, *Dicliptera*, *Cleome*, *Heliotropium*, *Polycarpaea*, and *Borreria*.

The shrub layer (*Cochlospermum fraseri*, *Grevillea mimosoides*, *Terminalia canescens*, *Dolichandrone heterophylla*, and *Atalaya hemiglauca*) is sparse.

As a pasture type this community is not highly regarded because of the lack of palatable components and top feed. Of the dominant grasses, white grass is largely neglected by stock and except for a brief initial period, the annual sorghums are virtually worthless for grazing (Arndt and Norman 1959). Though associated grasses and forbs are common, the majority of these are also normally ignored by stock.

The community occurs as a ground storey to *Eucalyptus tectifica* woodlands (14*a*) and characterizes the shallow, skeletal soils of the gently undulating to hilly volcanic country of Cowendyne, Forrest, Looingnin, and Precipice land systems and is a minor element in the higher-rainfall parts of Richenda and O'Donnell land systems.

Downslope on the deeper red earth soils this community is continuous with the *Sehima–Dichanthium* ground storey (53).

(53) Sehima nervosum–Dichanthium fecundum (*White Grass–Blue Grass*) *Ground Storey*.—Commonly this occurs downslope from 52. *Sehima nervosum* and *Dichanthium fecundum* characterize the ground storey of the *E. tectifica–E. dichromophloia* woodland. It is similar to 52 but commonly lacks the annual sorghum species and has a richer assortment of perennial grasses (*Dichanthium fecundum*, *Sorghum plumosum*, *Chrysopogon* spp., *Heteropogon contortus*, *Aristida pruinosa*, *A. inaequiglumis*, and *Themeda australis*) and shorter grasses (*Brachyachne convergens*, *Enneapogon polyphyllus*, *E. glabre*, *E. purpurascens*, *Eriachne obtusa*, *Boerhaavia diffusa*, *Sporobolus australasicus*, *Aristida hygrometrica*). Forbs are numerous and include species of *Tephrosia*, *Corchorus*, *Dicliptera*, *Cleome*, *Heliotropium*, *Polycarpaea*, *Pterocaulon*, *Euphorbia*, and *Borreria*. The shrub layer (*Planchonia careya*, *Grevillea mimosoides*, *Bauhinia cunninghamii*, *Atalaya hemiglauca*, and *Acacia* spp.) is sparse.

As a pasture type, though closely related to 52, these pastures are much more valuable. They lack many of the worthless components and contain a relatively high proportion of grasses, forbs, shrubs, and trees which are moderately to highly palatable. Also, they are readily available to stock. The proximity of this richer pasture to 52, into which it blends, leads to some utilization of the poorer community. In general, pastures of volcanic country are heavily utilized and are highly regarded as stock-producing areas. Both of these types have marked affinities with the pastures of the volcanic country of the North Kimberleys (Lazarides 1960), where they are more extensive.

Distribution is restricted to the lower slopes, valleys, and cracking clay plains of the volcanic country in Cowendyne, Looingnin, Forrest, and Precipice land systems in the northern part of the area.

(ii) *Ground Storeys Characterized by Drought-resisting Sclerophyllous Grasses*.—The major under-storey components of these communities comprise a group of drought-resistant, strongly lignified grasses (Burbidge 1945, 1946), widely known as spinifex (*Triodia* spp. and *Plectrachne* spp.). These are characteristic plants of arid regions of Australia and in the West Kimberleys thrive under the prevailing conditions of high temperatures, brief wet seasons, and prolonged dry periods. In general, they produce low-quality fodder for short periods after rainfall when available new growth is relatively palatable. Normally, their utilization is largely dependent upon associated plants, including top feed and adjacent pastures. Those species which inhabit the lower-rainfall parts are particularly coarse and virtually worthless for grazing. Others grow under comparatively high-rainfall conditions or in better-watered habitats and are more palatable. They are valuable as drought reserves and have a low but stable stocking rate which may exceed that of better pastures under extremely adverse conditions.

On the basis of palatability and other plant qualities, these communities are arranged into hard and soft spinifex types. The first three ground storeys (54–56) are in the latter category. The characteristic grasses of this group are comparatively more palatable probably because of a smaller amount of lignified tissue in their leaves (Burbidge 1946). The leaves and stems are commonly coated with a resinous exudation. The next four ground storeys (57–60) are classified as hard spinifex. These are the most highly lignified of the spinifex species, have a low palatability and nutritive value, and, except when young, are grazed only under extreme conditions.

(54) Plectrachne pungens (*Curly Spinifex*) *Ground Storey*.—This is characterized by *Plectrachne pungens*, which in the Kimberleys is probably the most widespread grass in areas receiving a mean annual rainfall of more than 20 in. Ground storeys characterized by it are particularly extensive in the northern half of the area. They occur in diminishing proportions toward the south, and are absent only in the drier, south-eastern corner where hard spinifex communities predominate. The community is also an important element in the ground storey of the vast pindan areas in the west. It occurs in a wide range of habitats, but is most common on sandstone and quartzite country.

Plectrachne pungens grows in straggly tussocks up to 3 ft wide with vegetative tillers usually less than 2 ft high and flowering culms attaining 3 ft. Commonly in rugged habitats the community is seasonally characterized by patchy, dense stands of annual sorghum up to 6 ft high. Associated perennials, though rare, include *Aristida pruinosa* and *A. inaequiglumis*. The tussock interspaces, usually bare in the dry season, carry in favourable periods a sparse cover of annuals and ephemerals (*Brachyachne convergens*, *Enneapogon* spp., *Fimbristylis dichotoma*, *Polycarpaea* spp., and *Gomphrena* spp.). The associated shrub layer is sparse to moderate in density and varies with the habitat.

As a pasture type this widespread ground storey is of low value and a fairly high proportion of it is not utilized for grazing because of the inaccessible topography on which it occurs. Accessible areas are grazed in association with better adjoining pastures. Palatable components of the pasture comprise the dominant grass, a number of annual and ephemeral forbs and grasses, and top feed in negligible quantities. In general, the type has a low stocking rate which, because of its drought-resisting components, does not fluctuate greatly with seasons. It may exceed that of normally better pastures during long drought periods.

The distribution of this community is chiefly with *E. brevifolia* and *E. dichromophloia* communities but was observed with 12 different upper storeys (Table 16). It is represented in many land systems but is a major element in the vegetation of Precipice, Clifton, Richenda, Lubbock, Rose, Fork, Mamilu, and in the higher-rainfall parts of Gidgia land systems. It is an important element in many other land systems in the higher-rainfall parts of the area.

(55) Triodia pungens (*Gummy Spinifex*) *Ground Storey.*—This is characterized by *Triodia pungens*, which is widespread throughout the area but commonly as a minor constituent of other communities. It is relatively unimportant to the north of the King Leopold Ranges. It is mainly in the drier south and south-east that it characterizes the ground storeys of communities. These ground storeys are sporadic in occurrence, restricted in distribution, and selective of environment. They are best developed in situations with favourable water relations such as alluvial drainage floors, though these may occur in areas having a low annual rainfall. Individual communities are commonly small in extent and confined to fringes of pans, depressions, flood-plains, and swales, and lower slopes of dunes. They occur on a wide range of soil types ranging from coarse sands to heavy clays. It occurs as grasslands with sparse trees and shrubs (*Grevillea striata, Bauhinia cunninghamii, Adansonia gregorii, Atalaya hemiglauca, Carissa lanceolata*, and *Acacia* spp.) and as ground storey to open woodlands of *E. microtheca* (20) and *Bauhinia cunninghamii–Ventilago viminalis* (38). Other associated plants vary with habitat and the degree of selective grazing that has taken place.

As a pasture type it has moderate to good forage value as fodder components occur in the shrub and tree storeys as well as in the ground storeys. It is generally grazed by stock at all stages of growth but young material and inflorescences are more favoured. Though palatability decreases with maturity, the plants remain green and are utilized as subsistence fodder. A characteristic feature of the species is the presence of a resinous exudation on leaves and culms. Those forms with excessive resinous coatings tend to be less attractive to stock.

Although fairly extensive areas occur in Chestnut, Myroodah, Calwynyardah, and Luluigui land systems, it is only in Chestnut land system that it occurs as a major ground storey. It also occurs in Egan, Camelgooda, Coonangoody, and similar land systems.

(56) Plectrachne pungens–Chrysopogon *Spp.* (*Curly Spinifex–Ribbon Grass*) *Ground Storey.*—This is associated with low scrubby woodland vegetation locally referred to as pindan. This formation is characteristic of the sand plain and dune fields which are extensive in the western and south-western parts of the West Kimberley area. The ground storeys comprise a mixture of sclerophyllous and herbaceous plants characterized by *Plectrachne pungens* (curly spinifex) and *Chrysopogon pallidus* (ribbon grass), which occur as a complex. Annual sorghums (*Sorghum australiense* and *S. stipoideum*) are commonly associated constituents and in many parts are seasonally dominant. A poorly defined lower layer carries sparse *Aristida browniana, A. hygrometrica, Eriachne ciliata, E. obtusa, Eragrostis eriopoda, Panicum* spp., and a seasonal abundance of annual grasses and forbs, including sedges and succulents, among them *Perotis rara, Portulaca* spp., *Fimbristylis dichotoma*, and *Polycarpaea* spp.

This ground storey is described with six different upper tree layers (Table 16) but the most characteristic and widespread of these is the *E. dichromophloia–E. zygophylla–Acacia* spp. community (10). The shrub layers of this community are commonly dense but patchy, and richness and density of the ground-storey elements are inversely proportional to that of the upper layers.

As a pasture type this community has in general a low carrying capacity. The more nutritious components of this pasture comprise the short-lived plants of the community and include a number of grasses and forbs, including sedges and succulents. These are abundant as a low layer 9–18 in. high for short periods after rainfall and small falls are sufficient for their rapid regeneration. The predominant perennials on the other hand are less palatable and are grazed mainly in unfavourable periods when the short-lived constituents are absent. Because of the variation in structure of the associated upper storeys, this pasture varies considerably in degree of utilization and in general value, e.g. communities with dense *Acacia* scrub or those with well-developed shrub layers carry sparse pastures containing fewer nutritious components and more of the worthless annual sorghum. Resultant low stocking rates combined with reduced accessibility, shortage of water, and stock management difficulties because of the density of the vegetation, are deterrent factors in the development of these areas for grazing. However, where adjacent to frontage country they are extensively utilized during the wet season because of the general inaccessibility of the flood-plains during that period.

Yeeda, Camelgooda, Luluigui, Wanganut, Sisters, Reeves, and Mamilu land systems contain major proportions of this ground storey but it also occurs as a minor element in many others.

(57) Triodia intermedia (*Lobed Spinifex*) *Ground Storey*.—This is extremely widespread either as a ground storey to low open woodlands (1, 2, 16, and 17) or as a spinifex grassland over a wide range of habitats. It is predominant in lower-rainfall parts (less than 20 in.) and is characteristic of extensive tracts of country in the southern half of the area, particularly toward the east. Rainfall appears to be a major factor in determining its distribution. For example, sites similar to those dominated by this community in the lower-rainfall areas are occupied by a softer spinifex species (*Plectrachne pungens*) in higher-rainfall areas. Within climatic limits it is tolerant to a wide range of physical conditions and it occurs on topography ranging from gently undulating plains to strongly dissected inaccessible country.

The community consists of tussocks usually less than 2 ft wide and up to 3 ft high (including flowering culms) and having extensive, almost bare, inter-tussock areas. There are few associated grasses (*Enneapogon polyphyllus, Aristida hygrometrica*, and *Eriachne obtusa*) and forbs are confined largely to favourable situations such as shallow drainage lines. Under optimum conditions the community carries a sparse cover of ephemerals. The shrub layer (*Carissa lanceolata* and *Acacia farnesiana*) is sparse.

As a pasture type this community is extremely poor. The predominant species is a plant of extremely low fodder quality. The remaining components, though somewhat more palatable, occur sparsely only during favourable periods and add but little to the value of the pasture. Browse plants are almost wholly absent. Generally, pastures are unpalatable to stock but are less so when young. Consequently, firing to promote new growth and encourage utilization is a regular management practice. Even so, they provide only subsistence fodder and are used mainly as drought reserves.

Distribution is widespread in Myroodah, Luluigui, Ruby, Dockrell, Koongie, and Margaret land systems and in the lower-rainfall parts of Gidgia, Lubbock, Richenda, and Burramundi land systems and locally in Bohemia and Rose land systems.

(58) Triodia wiseana (*Limestone Spinifex*) *Ground Storey*.—Characteristically this occurs in areas of calcareous influence. This particularly coarse species is highly lignified and has extremely pungent leaves. It forms compact bushy tussocks up to 6 ft high and similar width. Individual communities in favourable habitats commonly consist of very dense, almost continuous stands which are largely impenetrable to stock. Tussock interspaces are small and therefore associated grasses are sparse or absent. Where the spinifex is more open, annual grasses and forbs are seasonally present.

Limestone spinifex has a very low palatability and a low nutritive value because of its general coarseness. Commonly, it forms fairly extensive, dense monospecific pastures which are largely inaccessible to stock. Better examples of the type are found on undulating terrain where top-feed plants are usually present and the spinifex is sufficiently open to allow the growth of more palatable grasses and forbs in the interspaces. Even so, such areas are rarely utilized under normal conditions unless better-quality pastures are available nearby to support stock for most of the time.

Distribution is restricted to limestone country of Windjana, Oscar, Neillabublica, Fossil, and Leopold land systems.

(59) Triodia inutilis (*Hairy Spinifex*) *Ground Storey*.—Commonly this is confined to the extreme south-eastern corner of the area. It occurs on granitic outcrops and on skeletal soils over metamorphosed rocks. These occurrences represent the western limit of the species range and are erratic in distribution, very minor in area, and restricted to the upper slopes and ridges and low hills.

The layer is very open and consists of perennial tussocks up to 4 ft high and 2 ft wide. There is considerable mixing of this species with *Triodia intermedia*. Other grass and forbs are sparse. The only associated tree layer is characterized by *E. brevifolia* (16).

As a pasture type this community is insignificant. Though perhaps not as highly lignified as other representatives in the hard spinifex group, this grass is no more valuable as fodder. It characterizes a pasture comprising a mixture of associated grasses, forbs, and shrubs, but yielding little palatable fodder.

Distribution is restricted to rocky hills and ridges of Dockrell and Koongie land systems and stripped margins of Gidgia land system.

(60) Plectrachne bynoei (*One-awned Spinifex*) *Ground Storey*.—This is scattered throughout northern and eastern parts of the area. It occurs as a minor but distinctive community on granite tors and domes and some quartzitic hills. The dominant species is a coarse tussocky perennial with long, resinous, shiny green blades. It forms tussocks up to 5 ft high (including inflorescences) and up to $2\frac{1}{2}$ ft in diameter.

This and other associated tall grasses (*Cymbopogon procerus*, annual sorghum, and *Heteropogon contortus*) grow in the cracks and crevices of this rocky habitat or wherever there are small pockets of soil. Short grasses and forbs (*Enneapogon polyphyllus*, *Eriachne ciliata*, *E. mucronata*, *Fimbristylis dichotoma*, and *Portulaca filifolia*) are sparse and patchy.

This community occurs as a ground storey to open woodlands characterized by *E. perfoliata*, *Adansonia gregorii*, and *E. dichromophloia* (32). The sporadic shrub layer (*Cochlospermum fraseri*, *Brachychiton* sp., *Terminalia ferdinandiana*, *Gardenia* spp., *Buchanania obovata*, and *Ficus* spp.) also consists of a rich and distinctive assortment of species.

Because of its scattered distribution in minor inaccessible habitats, as well as its small total area, this community is unimportant as a pasture.

Distribution is widespread but restricted to these small special habitats in Amy, Rose, Tarraji, Richenda, and Mandeville land systems.

(b) Ground Storeys Characterized by Short Grasses and Succulents

This group of ground storeys has a range of life form including characteristic species which may be classified as perennial drought-evading species, ephemeral drought-evading species, and drought-resistant species. It is convenient for the purposes of this report to subdivide them on habitat into two subgroups.

(i) *Upland Ground-storey Communities*.—The chief components of these types are low grasses of short duration and a few forbs represented mainly by species of *Enneapogon*, *Aristida*, *Chloris*, *Sporobolus*, and *Fimbristylis*. These are highly regarded for their palatability and nutritive value (Perry 1960). With the onset of the wet season they make rapid growth and during the summer months repeated responses to successive falls are common. Consequently, under favourable conditions these pastures are among the first to be grazed and heavy concentration of stock on the new growth is a characteristic feature of their utilization pattern. They have the effect of raising the carrying capacity of adjoining pastures but lack the bulk necessary for the maintenance of grazing animals over long periods and are susceptible to heavy grazing.

(61) Enneapogon *Spp. and Other Short Grasses Ground Storey*.—This is most extensive in lower-rainfall parts but there are also smaller, widely distributed occurrences in a range of environments. The chief components are low grasses characterized by *Enneapogon* spp. and species of *Aristida*, *Chloris*, *Sporobolus*, *Fimbristylis*, and many others. These form a well-developed layer commonly less than 18 in. high. Tall perennials are scattered or absent and tussocks or small clumps of curly spinifex have a scattered distribution. The upper storey is characterized by low widely-spaced *E. brevifolia*. Shrubs are extremely scattered or absent.

This is the most valuable of the upland short types as the majority of the components are highly palatable. Also, the predominant grasses commonly behave as short-lived perennials rather than annuals and thus provide fodder for relatively longer periods. Nevertheless, the quality of the pasture varies considerably because of the wide range of environments in which it occurs and the degree of utilization is largely dependent upon the quality of associated pastures, general accessibility, and watering points.

This ground storey occurs as a major community on the interfluves and hill slopes of O'Donnell, Koongie, and Rose land systems.

(62) Aristida hygrometrica (*Kerosene Grass*) *Ground Storey*.—Commonly this occurs on the more sandy levee soils scattered over a wide range of environments as a very mixed, short to medium-height, ground-storey community. The chief components are ephemeral, annual, or short-lived perennial grasses. It is commonly characterized by *Aristida hygrometrica*, a slender wiry annual, which rapidly dries out, producing coarse spear-like seeds. Also represented are species of *Setaria, Schizachyrium, Eriachne, Thaumastochloa, Eragrostis, Panicum, Fimbristylis, Ectrosia*, and *Perotis*. Forbs, including *Gomphrena* spp. and *Polycarpaea* spp., are commonly present. Taller perennials such as *Chrysopogon* sp., *Aristida* spp., *Heteropogon contortus*, and *Eulalia fulva* are sparse.

Associated upper storeys are characterized by *E. papuana* (22*b*), *E. polycarpa* (25), and less commonly *E. tectifica* (14*d*).

As a pasture type this community is not highly regarded. Though rich floristically, it comprises mainly slender ephemerals which lack the bulk necessary to support grazing animals for prolonged periods. Where they are subject to relatively intensive grazing because of the proximity of water, communities are readily denuded of ground-storey vegetation. Of the major components, the predominant *Aristida* species and many of the others are normally ignored by stock. The main source of fodder is provided by associated forbs, top-feed plants where they occur, and the few perennial grasses, though these are sometimes too coarse to be of much value. In sheep country the spear-like seeds may cause sheep mortality.

Although its distribution is widespread, nowhere is it extensive. It occurs as a minor community of the sandy levees and drainage floors of the Tableland, Fork, Glenroy, Wanganut, and Cowendyne land systems.

(63) Aristida browniana *Ground Storey*.—This is associated with the sandy crests of dunes and resembles 62. It differs in that *Aristida browniana* is the characteristic species and the associated species are not so numerous and varied. Other species commonly present include *Aristida hygrometrica, Eriachne obtusa, Perotis rara*, and *Enneapogon polyphyllus*. Forbs and shrubs resemble those of the adjacent pindan. The associated upper storey is characterized by *Bauhinia cunninghamii* and *Ventilago viminalis* (38*c*).

As a pasture type, though resembling the former in structure and floristics, this is much more valuable, as the predominant species and a number of the other grasses are moderately to highly palatable. Where occurrences are fairly extensive, they have the effect of increasing the stocking rate of adjoining pindan pastures. Generally, however, these pastures are limited in extent, small in total area, and briefly seasonal in duration.

The community is restricted to dune crests and similar sandy habitats in Camelgooda, Fraser, Wanganut, and Coonangoody land systems.

(ii) *Coastal* (*Halophytic*) *Communities*.—These are the only pastures in the area in which semi-succulent shrubs as well as grasses are characteristic. The shrubs (*Arthrocnemum* spp. and *Sesuvium portulacastrum*) do not appear to be grazed, but the grasses (*Sporobolus virginicus* and *Xerochloa* spp.) are regarded as valuable fodder. The types are confined to littoral parts and are generally small in area.

(64) Sporobolus virginicus (*Salt-water Couch*) *Ground Storey*.—This is characterized by *Sporobolus virginicus*, which is widespread throughout the coastal area commonly as a minor element in the ground storey. However, in the extreme south of the area, on the old tidal flats now above high-water mark, it forms extensive pastures. Other occurrences are restricted to small isolated patches throughout the coastal belt but particularly in the north.

The dominant species, *Sporobolus virginicus*, forms a dense grassland pasture 6–12 in. high. Associated plants are largely absent, except for occasional clumps of samphire from the adjacent community. Also *Bassia* spp., *Eragrostis falcata*, and in shallow drainage lines *Dichanthium fecundum* and *Salsola kali* occur in places.

As a pasture type this community is highly regarded.

Salt-water couch is readily grazed at all stages. Its pastures are utilized as stock-fattening areas and are grazed in preference to other halophytic pastures and adjoining pindan types.

It is the major community of Roebuck land system.

(65) Xerochloa *Spp.* (*Rice Grass*) *Ground Storey*.—Commonly this occurs in areas situated on the margins of saline influence and characterizes the narrow transitional zone between the salt-water couch and pindan communities. In the central position of the coastal belt it also occurs as marginal to the bare extensive saline plains and extends into the swales of the adjacent dune fields. The characteristic species, *Xerochloa barbata* and *Xerochloa imberbis*, generally behave as short-lived perennials, but the majority of associated plants are ephemerals. Scattered tussocks of *Chrysopogon* spp. and *Sporobolus virginicus* are commonly the only other perennials. The upper storey is characterized by *Melaleuca acacioides* (35) but *Bauhinia cunninghamii*, *Atalaya hemiglauca*, and *Carissa lanceolata* are sparsely present.

As pastures, they yield highly palatable and nutritious fodder for short periods immediately after rains, but production ceases under dry conditions. Their utilization under the present management regime follows a characteristic pattern in which grazing stock concentrate heavily on the pastures with the onset of seasonal rains and remain until all available fodder is exhausted before moving to less palatable perennial pastures. Consequently, without vegetation cover for long periods, these areas are susceptible to erosion and scalding is a common feature.

The associated upper storey includes small quantities of top-feed species in some parts. Under extreme conditions, the major tree species is also browsed by stock.

Distribution is restricted to Carpentaria land system.

(66) *Samphire Communities*.—These communities are characterized by drought-resistant succulent plants.

The coastal belt of country which constitutes Carpentaria land system comprises a number of environments among which the beach dunes, the saline plains with their sandy upper margins, and tidal mud flats are distinctive. Of these only the saline plains with their sandy margins and to a lesser extent the beach dunes are suitable for grazing purposes.

The saline plains carry dense stands of samphire (*Arthrocnemum halocnemoides*, *A. leiostachyum*, and *Sesuvium portulacastrum*), which are succulent shrubs or under-shrubs from 2½ to 4 ft high. Associated plants normally are rare or absent, but ephemeral grasses and forbs are present in the wet season. In places species of the adjoining *Sporobolus virginicus* or *Xerochloa* spp. communities are present.

As a pasture type this is the only community in the area characterized by succulent shrubs or under-shrubs. For the greater part of the year, these are probably grazed in association with nearby salt-water couch and rice grass pastures, but during the wet season, when associated plants on which stock may graze are undoubtedly present, it comprises a much more attractive pasture.

Distribution is restricted to Carpentaria land system.

(67) *Beach Dune Ground-Storey Communities*.—These communities occupy the series of beach dunes which have a discontinuous distribution along the coastal belt and contain a number of related habitats. A generalized description only can be given here. The ground storey commonly is characterized by *Spinifex longifolius* and other perennial tussock grasses. In favourable periods a number of forbs such as *Ptilotus exaltatus*, *Salsola kali*, *Crotalaria cunninghamii*, and *Euphorbia* spp. also occur. Over-shrubs, mainly *Acacia* spp., have a scattered distribution and trees (*Terminalia* sp., *Santalum* sp., and *Ficus opposita*) are sparse or occur in clumps in the more sheltered parts. As a pasture type this is the least valuable of the halophytic pastures owing mainly to the lack of palatable components. However, the type varies considerably in floristic composition and accessibility and in some parts a number of useful plants occur in favourable periods.

Distribution is restricted to Carpentaria land system.

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PART VII. THE PASTURE LANDS OF THE WEST KIMBERLEY AREA

By N. H. Speck,* K. Fitzgerald,† and R. A. Perry*

I. Introduction

Meigs (1953) classifies the southern half of the West Kimberley area as arid and the northern half as semi-arid. He defines arid areas as "those in which rainfall on a given piece of land is not adequate for crop production" and semi-arid lands as those in which "rainfall is sufficient for certain types of crops". Thus, according to Meigs, rainfall in the area is inadequate or marginal for dry-land cropping. Over much of the area, and particularly the higher-rainfall parts, the topography is too rough and the soils too shallow and stony for cropping. The area is distant from centres of population and costs of production and marketing are high. The combination of these factors virtually limits dry-land land use to the grazing of natural pastures. The area has this in common with most of northern Australia.

About one-third of the area is virtually useless for grazing and nearly half carries poor pastures. Good pastures are restricted to about 5300 sq miles.

II. Stock Population in Relation to Grazing Pressure on Pasture Lands

Most of northern Australia has been grazed on an extensive system for 70 to 100 years. With the exception of areas near waters, the pastures have withstood grazing fairly well, and most areas are nearly as productive as ever. Flood-plain and frontage country tend to be the most susceptible to damage (Perry 1960) and to have the longest history of grazing. The better pastures of the West Kimberley area mostly consist of such country and pasture degradation is worse than the average for northern Australia. The location of the main stock route along the Fitzroy frontage has aggravated pasture degeneration.

The high grazing pressure in the area compared with that of most other parts of northern Australia can be gauged from the following figures. The 1960 cattle population in the surveyed area was 278,000 (Part VIII)‡. The peak numbers occurred in 1917, when the cattle population was 413,000§. In addition the sheep population was 184,000§ (31,000 cattle equivalents) in 1917 and 200,000|| (33,000 cattle equivalents) in 1960, making the total stock carried in the area 444,000 cattle equivalents in 1917 and 311,000 cattle equivalents in 1960.

These animal populations constitute a heavy grazing pressure on all types of country in the area. Although it has not been possible to assign actual carrying capacities to the pasture types or pasture lands, the various pasture lands can be rated in four classes, viz. very poor to useless, poor, moderate, and good (Table 18).

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† Department of Agriculture, Western Australia.

‡ Obtained by summing the population of the properties.

§ Statistical Register of Western Australia for 1917–18.

|| Obtained by summing the population of the properties.

TABLE 18
CHARACTERISTICS OF THE PASTURE LANDS

Pasture Land	Area (sq miles)	Pastoral Value	Description	Major Pasture Types	Land Systems
Mitchell grass country					
Mitchell grass	2000	Good	Grasslands on dark cracking clay soils on stable flood-plains and plains on shale and limestone	Mitchell grass, and ribbon grass–blue grass	Alexander, Fossil, Leopold, Duffer, Gladstone
Mitchell grass–ribbon grass	2200	Good	Grasslands and grassy woodlands on active flood-plains and levee zones; juvenile cracking clays and levee soils	Ribbon grass–blue grass, Mitchell grass	Djada, Gogo
Mitchell grass–spinifex	1100	Good	Grasslands on cracking clay plains; spinifex on limestone outcrop areas	Mitchell grass, ribbon grass–blue grass, limestone spinifex	Oscar, Neillabublica
Ribbon grass country					
Ribbon grass	1100	Moderate to good	Beefwood and *Bauhinia* sp. grassy woodlands; yellow earths on alluvial plain and undulating country	Ribbon grass, ribbon grass–blue grass	Egan, Calwynyardah
Volcanic country					
White grass–annual sorghum	3200	Moderate	Grassy woodlands on basalt hills and undulating country with stony red earths; grasslands on cracking clay plains	White grass–*Sorghum* spp., ribbon grass–blue grass	Cowendyne, Looingnin, Forrest
Coastal country					
Salt-water couch	200	Moderate	Grasslands on saline depositional plains above tide level	Salt-water couch (*Sporobolus virginicus*)	Roebuck

Littoral	1200	Poor to moderate	Scattered pastures on sandy coastal margins, saline flats, bare mud flats; occasional dunes	Ribbon grass, rice grass, samphire	Carpentaria
			Pindan country		
Pindan	12,200	Poor	Low open scrubby woodlands with tall *Acacia* shrub layer on sand plain and dune fields	Curly spinifex–ribbon grass	Yeeda, Camelgooda, Luluigui
Pindan–ribbon grass	3300	Poor	Low open scrubby woodlands and grassy woodlands on sand plain and dune fields with through-going drainage	Curly spinifex–ribbon grass, ribbon grass	Wanganut, Sisters, Lowangan, Fraser, Reeves, Mandeville
			Spinifex country		
Spinifex–short grass	4700	Poor to moderate	Low open woodlands on mainly hilly to undulating country over crystalline rocks or shale–sandstone	*Enneapogon* spp.–short grass, curly spinifex	O'Donnell, Coonangoody, Koongie, Amy, Pigeon, Tarraji
Soft spinifex	200	Poor	Grasslands and very open woodlands; stable alluvial plains adjacent to flood-plains	Gummy spinifex (*Triodia pungens*)	Chestnut
Curly spinifex	2200	Poor	High- or low-level plains on quartzite, sandstone, and shale	Curly spinifex	Gidgia, Fork, Mamilu, Glenroy, Tableland
Hard spinifex	4000	Very poor	Stony hills and plains on wide range of rocks	Winged spinifex (*Triodia intermedia*)	Burramundi, Bohemia, Margaret, Ruby, Myroodah
			Inaccessible country		
Inaccessible	10,700	Very poor to useless	Mostly hilly to mountainous, steeply dissected country, including limestone ranges	Curly spinifex (*Plectrachne pungens*), winged spinifex (*Triodia intermedia*), limestone spinifex (*Triodia wiseana*)	Precipice, Clifton, Richenda, Lubbock, Rose, Dockrell, St. George, Windjana

By assigning various arbitrary ratios of stocking rates to the classes, the stocking rates necessary to carry the stock populations can be estimated from equations. For example, for the ratio 1 : 2 : 6 : 20 if the stocking rate of the very poor to useless country is x, then the rates for poor, moderate, and good country are $2x$, $6x$, and $20x$ respectively. The sum of the products of these rates by their respective areas can be equated

TABLE 19

STOCKING RATES (CATTLE/SQ MILE) FOR VARIOUS CLASSES OF COUNTRY AND VARIOUS RATIOS OF STOCKING RATES

Ratio of Stocking Rates	Class of Country: Very Poor–Useless (14,700 sq miles)	Poor (22,600 sq miles)	Moderate (5700 sq miles)	Good (5300 sq miles)
1917 (Stock population = 444,000 cattle equivalents)				
0:4: 8:20	0	7·3	14·6	36·7
0:4:12:20	0	6·7	20·2	33·6
0:2: 6:20	0	4·8	14·3	47·8
1:2: 6:20	2·2	4·4	13·3	44·4
1:3: 6:20	2·0	6·0	11·9	39·8
2:4: 8:20	3·3	6·6	13·1	32·8
2:4:12:20	3·0	6·0	18·1	30·2
1960 (Stock population = 311,000 cattle equivalents)				
0:4: 8:20	0	5·1	10·3	25·7
0:4:12:20	0	4·7	14·1	23·5
0:2: 6:20	0	3·4	10·1	33·5
1:2: 6:20	1·6	3·1	9·3	31·0
1:3: 6:20	1·4	4·2	8·4	28·0
2:4: 8:20	2·3	4·6	9·2	22·9
2:4:12:20	2·1	4·2	12·7	21·1

to the total stock population. Thus for the above ratio in 1917 the equation is

$$14{,}700x+(22{,}600\times 2x)+(5700\times 6x)+(5300\times 20x)=444{,}000,$$

$$\text{i.e. } x=2\cdot 22,$$

which means that the stocking rates of the various classes of country are 2·2, 4·4, 13·3, and 44·4 cattle/sq mile respectively. Table 19 shows the stocking rates of each of the four classes of country for various assumed ratios of carrying capacities. In three of the ratios the poorest country is rated as zero carrying capacity, in two ratios as one-twentieth as good as the best country, and in two as one-tenth as good. The poor and moderate country are assigned various intermediate values.

For the three ratios in which the poorest country is given zero value the lowest stocking rate for the best country is with the 0 : 4 : 12 : 20 ratio (23·5 cattle/sq mile in 1960* and 33·6 in 1917). With this ratio the stocking rates for poor and moderate country are unrealistically high. For the ratios in which the poorest country is one-tenth as good as the best country the calculated stocking rates for the good country in 1960 are only slightly above normal northern Australian standards but the stocking rates for the poorest country are unrealistically high, especially as much of it is undeveloped. In 1960 probably the most realistic ratio for the three poorer classes of country is 1 : 3 : 6 : 20, with which the stocking rate for good country is 28 cattle/sq mile or 50% above normal northern Australian standards.

With this ratio the stocking rate for good country in 1917 would have been 39·8 cattle/sq mile. Since in 1917 less of the very poor and poor country was developed than in 1960 the 0 : 2 : 6 : 20 ratio probably is more realistic and with this the stocking rate for good country would have been 47·8 cattle/sq mile.

These figures are very conservative in that they are calculated on the basis that all the pastures are within walking distance of water — actually Thomas (Part VIII) states that 7000 sq miles of the area is unoccupied and that of the nominally occupied cattle country, only 23,300 sq miles is effectively productive. Also experience has shown that estimates for statistical purposes normally are lower than cattle actually on the properties. The high populations of wallabies, donkeys, and scrub animals further increase grazing pressure.

Irrespective of the system of pasture management, with such heavy grazing pressure in the past it is not surprising that the pastures degenerated and generally are in poorer condition now than those of most other parts of northern Australia. In the circumstances, present stocking rates should be lower than, rather than higher than, normal for other parts of northern Australia if the downward trend in condition is to be halted.

III. Seasonal Cycle of Pasture Growth and Nutrition

Pasture growth is limited to the short wet season. Even during this period the pastures have only a moderate protein status, but with ample forage available stock gain weight. During the dry season animals are dependent on dry standing forage (the evergreen spinifex is mostly unattractive and top feed is scanty) which has a low or very low nutritive value and animals lose weight. The main period of stress for animals is the late dry season when total forage is low, of poor quality, and relatively distant from water. Also stock are probably uncomfortable under the high temperatures at this time of the year and forage less.

During the late dry season the nutritive value of the evergreen grasses (spinifex), though low, may be as high as that of the better pastures. For this reason soft spinifex species are commonly considered as drought reserves.

* In other parts of northern Australia, country similar to that classed as good has remained in a fairly stable condition under stocking rates of 15–20 cattle/sq mile run on similar open-range conditions. Comparable stocking rates for moderate, poor, and very poor to useless country are 10, 0–4, and 0–2 respectively (Perry 1960).

The late dry season is the critical period of the year for the pastoral industry and the stocking rate for the whole year is determined by the stocking rate at this time. This is an important aspect when considering the possibilities of pasture improvement — it is of no use introducing plants which improve pasture production only during the wet and early dry season. To be effective, pasture improvement must result in improved animal nutrition in the late dry season.

The critical period for pastures is the early growing season when the plants, particularly drought-evading ones, are dependent on reserves established in the previous season.

IV. The Pastoral Industry

The present pattern of land use is that the area near the lower Fitzroy River is used for sheep-grazing and the rest of the area for cattle-grazing. Thomas (Part VIII) states that the area carries 27% of the beef cattle and 1·2% of the sheep in Western Australia.

Sheep-grazing requires more intensive development than cattle-grazing and the sheep properties are relatively well watered and well fenced. The seasonal grazing system of grazing pindan pastures during the wet season and frontage pastures during the dry season has been dictated by the danger of flooding on the frontage country.

In common with most of northern Australia, cattle are grazed on an extensive scale and cattle properties have limited fencing and widely-spaced waters. Capital investment is thus much lower on cattle properties than on sheep properties. Under present conditions return on capital is higher with cattle.

The cattle population was highest in 1917 and fell fairly steadily from then until the early 1950s (Part VIII). It has steadily risen since. The sheep population has shown two peaks, the first between about 1900 and 1910 and the second between 1935 and 1945.

V. Pasture Management

The natural pastures were, before the introduction of the white man's grazing animals, in dynamic equilibrium with their environment, which included relatively light grazing pressure from the natural herbivorous animals such as wallabies and kangaroos. While there have been drought periods and also wet periods in the 80 years of occupation, there is no reason to believe that the climate is drier now than before settlement and undoubtedly the major change in the pasture environment has been the introduction of large numbers of grazing animals. The objective of pasture management is the achievement of a new equilibrium in the animal–pasture ecosystem consistent with maximum sustained productivity from the grazing animals.

(a) *Management Systems*

Near Port Hedland (in the north-west division of Western Australia) it has been demonstrated (Nunn and Suijdendorp 1954) that a system of deferred grazing (deferred for two successive years in six) has improved the condition of, and production from, soft spinifex pastures. In these pastures only a small proportion of the plants are palatable to stock, the spinifex which comprises the bulk of the vegetation being unattractive. Under continuous grazing the palatable elements are destroyed and the carrying capacity reduced. It is logical to expect that the deferred grazing system advocated by Nunn and Suijdendorp could be used to advantage in those parts of the West Kimberley area where the pastures are similar in type to those of the experimental area, i.e. where forage plants constitute a small proportion of the vegetation. This would include the pindan pastures, which occupy about one-third of the area, and spinifex pastures.

In the absence of trials it is not safe to recommend the system for the better pastures, where forage plants constitute a high proportion of the vegetation. The general experience with Mitchell grass pastures in northern Australia is that continuous grazing does not harm them provided that stocking rates are conservative.

Because of the fairly low production per unit area the grazing industry is likely to remain of an extensive, rather than intensive, nature. Within this framework the logical recommendations for management are:

(1) Conservative stocking rates.
(2) Better distribution of stock (more waters, some possibly of only short duration after rain).
(3) Control of unproductive animals (donkeys, wallabies, wild cattle).
(4) More efficient animal production (enough fences to permit herd management for maximum production from the animals being carried).

(*b*) *Pasture Burning*

Spinifex is regularly burnt to remove harsh unpalatable growth. Mostly it is burnt in the wet season, or in the mustering season soon after. This routine is followed from fear of fires getting out of control in other seasons.

During and shortly after the wet season, fires are comparatively cool. They do not kill old spinifex tussocks but do kill many useful grasses and grass seeds. Spinifex regeneration is rapid. Wet-season fires also favour the establishment of scrubby wattle (*Acacia* spp.). Thus, spinifex and pindan pastures are best burnt in the late dry season. Extreme care is necessary to control fires at this time.

Late dry-season fires kill the spinifex tussocks but by this time many grass seeds are buried and are not harmed. The regeneration of spinifex from seeds is slow and more palatable species are able to compete for several years.

Where pastures composed of drought-evading perennial grasses are burnt to remove accumulated old growth, it is also best done in the late dry season. Burning during the wet or early dry season destroys more plant nutrients and kills more seed. These pastures should not be burnt more frequently than at about 4-year intervals.

(*c*) *Pasture Improvement*

Reseeding of pastures is costly and is probably uneconomic where plant production per unit area and the chances of successful establishment are low. The economics of reseeding may be more favourable in the higher-rainfall parts and with plants which spread naturally from established nuclei. In all instances reseeded areas need to be protected from grazing animals until the new pasture is well established.

Water-spreading — the spreading of run-off water over flat country — is a useful method of increasing plant production. However, unless the site is especially suitable, the cost of earthworks compared with extra production is likely to be prohibitive.

With both reseeding and water-spreading the costs of the operations should be related to the economics of the industry. In special cases uneconomic operations may be necessary to halt the spread of pasture degeneration or soil erosion.

VI. Pasture Lands

The pasture types (ground storeys) described in Part VI are not mapped at the scale of the survey but each land system contains a definite pattern of them. By grouping land systems which have similar patterns of pasture types, 14 pasture lands have been established. These are grouped on the basis of broad similarity into seven types of country, namely, Mitchell grass country, ribbon grass country, volcanic country, coastal country, pindan country, spinifex country, and inaccessible country (Table 18).

(a) *Mitchell Grass Country*

(i) *Mitchell Grass Pasture Land*

(1) *Area.*—2000 sq miles.

(2) *Location.*—This land occurs in a wide belt aligned north-west–south-east through the centre of the area.

(3) *Environment.*—It comprises stable flood-plains and other gently sloping, dark cracking clay plains, mostly alluvial in origin, but also associated with Devonian limestone and Permian shale, limestone, and sandstone. Gilgai microrelief is common and limestone outcrops occur in some parts. Rainfall decreases towards the south-east (30 in. to 15 in.).

(4) *Composition.*—Although characterized by the Mitchell grass pasture type (47) with its three Mitchell grass species and rich assortment of other grasses, several other types are present. Commonly forming a mosaic with Mitchell grass is ribbon grass–blue grass pasture type (48), which also has a range of other grasses including Flinders grass. There appears to be considerable fluctuation in the respective areas occupied by these two types dependent upon the season and grazing management or condition. Minor components include the frontage pasture type (50) associated with the main stream lines and limestone spinifex pasture type (58) on the rocky outcrops. Scattered patchy shrubs and a very open tree layer are common. Many of these species are palatable and provide moderate amounts of top feed.

(5) *Pastoral Value.*—These pastures, with their wealth of perennial and annual grasses and scattered top feed, provide some of the most valuable grazing in the area. They have the highest carrying capacity and are favourably regarded by pastoralists.

(6) *Reaction to Grazing, and Management.*—The cracking clay plains, especially those on alluvium, are boggy or flooded during the wet season and stock normally do not graze them. Sheep are moved from cracking clay soil paddocks before the wet season and returned after it.

In general, these pastures show comparatively little degradation and the only badly affected areas are associated with stock routes and marginal areas. Normally degradation is limited to the prominence of bull Mitchell grass and feathertop (*Aristida latifolia*) but on some areas on limestone, for example north of Leopold Downs, the perennial grasses have been replaced by annual species such as *Brachyachne* and *Enneapogon*.

The making of bush hay from these pastures generally is not profitable because of the short period available for cutting, the low yield and poor quality of the product, and the damage, caused by the uneven microrelief, to machinery.

(ii) *Mitchell Grass–Ribbon Grass Pasture Land*

(1) *Area.*—2200 sq miles.

(2) *Location.*—This pasture land is associated with the flood-plains of the main streams through the centre of the area.

(3) *Environment.*—It comprises the active flood-plains of the main rivers of the area and is referred to locally as "frontage" or "flood-plain country". It includes loamy silty soils of the levee crests, the finer-textured soils of the levee back slopes, and the various cracking clay soils of the back plains which are commonly quite extensive. Gilgais, depressions, billabongs, and tributary channels are common features within the flood-plain. Because it contains a high proportion of cracking clay soils the outermost parts are inaccessible during the wet season.

(4) *Composition.*—Although ribbon grass–blue grass pasture type (48) characterizes the pasture land, extensive areas of Mitchell grass pasture type (47) occur on the dark cracking clay soils. However, over large areas the soils are less stable and on these the grasslands readily deteriorate to annual *Portulaca* spp. and rice grass (*Xerochloa* sp.), or the ground becomes completely bare and scalded as a result of poor seasons or bad management. Under natural conditions scattered or patchy shrubs and a very open, scattered tree layer form discontinuous upper layers and provide moderate amounts of top feed.

The loamy soils of the levee zone, which in parts is quite extensive, carry a grassy woodland with frontage pasture type (50). These contain perennial, annual, and ephemeral grasses and forbs as well as edible and inedible trees and shrubs.

(5) *Pastoral Value.*—These were some of the best pastures in the area, and on many stations still provide the most valuable grazing.

(6) *Reaction to Grazing, and Management.*—Heavy grazing has caused extensive pasture degradation. In many places blue grass has disappeared but a good cover of Mitchell grasses, ribbon grass, Flinders grasses, and rice grass (*Xerochloa* sp.) remains in some areas. Elsewhere the perennial grass cover has been destroyed (or reduced to scattered remnants) and replaced by annual plants. Of these pigweed (*Portulaca* sp.) and miniature pigweed (*Trianthema* sp.) are highly regarded by

graziers. They provide good grazing during and shortly after the wet season but dry off rapidly and blow away, leaving the ground bare. Extensive clay pans occur along both sides of Christmas Creek and the Fitzroy River. They have formed under the combined action of heavy grazing, excessive trampling, and wind and water erosion on soils which show solonetzic tendencies.

On the sheep stations, sheep are moved from the flood-plain areas during the wet season but the large population of wallabies remains. Even with extensive flooding, wallabies only move to the edge of the flooded zone. The cattle stations have few fences and cattle are free to graze the flood-plains yearlong. They voluntarily leave the flood-plains during floods.

For most of the distance between Fitzroy Crossing and Derby the stock route traverses this pasture land and has contributed to pasture degradation and erosion.

(iii) *Mitchell Grass–Spinifex Pasture Land*

(1) *Area.*—1100 sq miles.

(2) *Location.*—This pasture land is associated with a narrow belt of limestone country aligned north-west and south-east through the centre of the area.

(3) *Environment.*—It is formed over limestone, calcareous sandstone, siltstone, and shale. The terrain is gently undulating with broad, dark cracking clay plains and spinifex plains with limestone outcrop. Low rounded hills and cuestas are common, though a minor feature. Apart from the dark self-mulching cracking clay soils of the plains, the soils are dark brown to reddish brown loams and clays, mostly calcareous. Shallow skeletal soils dominate the hills and rocky slopes. Rainfall decreases towards the south-east from 30 in. to 18 in.

(4) *Composition.*—Grasslands consisting of Mitchell grass (47) and ribbon grass–blue grass (48) pasture types characterize the plains with dark self-mulching, cracking clay soils and there is little or no top feed.

The rugged hills with limestone outcrop carry few useful pasture plants, being mostly sparsely covered with spinifex and occasional trees and shrubs, but sandy aprons and plains adjacent to the hills carry grassy woodlands with better pastures (49). Where these areas are transitional to the plains the pastures contain many of the elements of the cracking clay plains. On the outcrop plains the harsh spinifex pasture type (10) dominates both the grasslands and the open bloodwood and box woodlands.

(5) *Pastoral Value.*—The cracking clay plains and the grassy woodlands are the most productive, though valuable grazing is afforded by the drainage floors and some parts of the plains with outcrop where the spinifex is more open.

(6) *Reaction to Grazing, and Management.*—The pasture land has been grazed only by cattle. Erosion is confined to minor areas near watering points. Pasture degradation is more widespread, particularly in the transitional area between the cracking clay plains and the low limestone ridges and plains with outcrop. The mixed Mitchell grass, ribbon grass, and blue grass pastures of the cracking clay plains show little pasture degradation. In some areas spinifex has replaced more palatable species.

(b) *Ribbon Grass Country*

(i) *Ribbon Grass Pasture Land*

(1) *Area.*—1100 sq miles.

(2) *Location.*—This pasture land is restricted to the centre of the area, mainly to the north of the Fitzroy River.

(3) *Environment.*—Gently sloping alluvial and outcrop plains, sand plain islands, restricted cracking clay plains, and low lateritized plateau remnants form the main elements of this land. The soils are varied but the most characteristic are yellowish clayey soils. These become "spewy" when wet but most parts are accessible throughout the year.

(4) *Composition.*—The alluvial plains with yellow earth soils are characterized by ribbon grass pastures with some areas of ribbon grass–blue grass. Less extensive are Mitchell grass pastures (47) on cracking clay plains, pindan pasture (56) on sand plain "islands", and spinifex grasslands (57) on the plateau remnants.

(5) *Pastoral Value.*—This class of country is well developed on Calwynyardah, Noonkanbah, Blina, and Ellendale stations. Large numbers of sheep have been carried on these properties. Production is largely dependent on management.

(6) *Reaction to Grazing, and Management.*—Most parts have been grazed by sheep, small areas by cattle. In both, grazing has been heavy and pasture degradation is extensive.

The degree and nature of the degradation depend on the type of country. The spinifex country is not grazed and remains little changed. In many places the perennial drought-evading grasses on the yellow earths have been replaced by spinifex, wire grass (*Eriachne obtusa*), and other inferior species, and bare ground is common. Fine stands of blue grass, white grass, panic, and three-awn remain on flooded country.

(c) *Volcanic Country*

(i) *White Grass–Annual Sorghum Pasture Land*

(1) *Area.*—3200 sq miles.

(2) *Location.*—This pasture land is restricted to the north of the King Leopold Ranges and to the Yampi peninsula.

(3) *Environment.*—It is characterized by volcanic rocks and consists of hilly and gently undulating country with red earths and skeletal red earths and broad plains with cracking clay soils. It includes some rugged quartzite and sandstone country with broad valleys formed on basalts and dolerites. With the exception of the quartzite and sandstone country it is generally accessible although some of it is isolated geographically. It occurs mainly in the northern part of the area.

(4) *Composition.*—With the exception of the cracking clay plains, which carry grasslands (ribbon grass–blue grass (48)), the vegetation consists of open grassy woodlands. The red earths and the skeletal red earths carry a well-developed grassy understorey of white grass (*Sehima nervosum*) and *Sorghum* spp. (52) with an open tree layer of grey box (*E. tectifica*). The lower slopes and valley floors are character-

ized by white grass–blue grass pastures (53). The sandstone country carries an open woodland with curly spinifex under-storey (54). The larger stream lines commonly have dense fringing communities with restricted frontage and fringing pasture types (50 and 51).

(5) *Pastoral Value.*—This country is continuous with the volcanic country of the North Kimberley area where it was rated as of moderate value (Speck *et al.* 1960). White grass, which is prominent in the common white grass–annual sorghum pasture type, is unpalatable but is associated with minor amounts of plumed sorghum (*Sorghum plumosum*) which remains palatable for most of the year. The pastoral value is enhanced by the scattered small areas of the white grass–blue grass and ribbon grass–blue grass pasture types.

(6) *Reaction to Grazing, and Management.*—The pastures show little degradation except near waters. Because of the difficult terrain and the scattered distribution of the better pasture types the extensive open-range system of grazing is not likely to be changed.

(*d*) *Coastal Country*

(i) *Salt-water Couch Pasture Land*

(1) *Area.*—200 sq miles.

(2) *Location.*—This land is restricted to a single locality near Broome.

(3) *Environment.*—It includes broad depositional saline plains above the high tides, traversed by a close network of channels, with samphire flats, and bare mud flats with mangrove fringes seawards. The soils generally are brownish and greyish calcareous saline loams and clays and dark saline muds.

(4) *Composition.*—Salt-water couch occurs as almost pure stands on the plains although species of *Bassia* and *Eragrostis* occur. Blue grass (*Dichanthium fecundum*) and roly-poly (*Salsola kali*) occur as minor elements in the shallow depressions of the drainage lines. Extensive samphire communities commonly occur between these pastures and bare saline muds, seawards.

The transitional zone from the plains to the pindan commonly carries a rice grass (*Xerochloa* sp.) pasture type (65).

The plains are usually devoid of trees except on the fringes. Paperbark (*Melaleuca acacioides*) is the main tree, with *Bauhinia*, *Atalaya*, and *Carissa* occurring as minor elements, particularly on the edge of the pindan. All four species provide useful top feed although *Melaleuca* is only eaten under extreme conditions.

(5) *Pastoral Value.*—Salt-water couch is an extremely hardy, perennial short grass, providing useful grazing at all stages of growth. Even when it is closely cropped, all types of stock appear to relish it. The blue grasses of the many shallow drainage lines add to the value of this land. *Bassia* and *Eragrostis* are both eaten but are of minor importance. Rice grass (*Xerochloa* sp.) acts as a short-lived perennial and provides good grazing immediately after the rainy season but it matures rapidly and quickly loses its feeding value. In some places rice grass has been cut and baled for hay; the product is quite good.

(6) *Reaction to Grazing, and Management.*—Pasture degradation is severe along the fringes and much scalding has occurred.

(ii) *Littoral Pasture Land*

(1) *Area.*—1200 sq miles.

(2) *Location.*—This extends along most of the coastline. It is particularly extensive around King Sound but is poorly developed on the hilly coastline of Yampi peninsula.

(3) *Environment.*—It consists of coastal flats, saline littoral flats, sand dunes, and shallow tidal inlets.

(4) *Composition.*—The vegetation is extremely complex and varied. Paperbark thickets fringe the mouths of the creeks and the edges of the saline flats, and are scattered over the lower rises. These commonly have a ribbon grass pasture type (49). Samphire pasture type (66) is common on the extensive saline plains which in many places extend seawards as broad, bare, mud flats fringed by mangroves. Rice grass (65) occurs between the ribbon grass and samphire pasture types. The pastures of the beach dunes (67) are a minor element.

(5) *Pastoral Value.*—Although apparently favoured by stock the value of these lands is doubtful, extremely variable, and dependent largely upon the nature of the adjoining country. Fresh water is not commonly obtainable on the plains.

(6) *Reaction to Grazing, and Management.*—Near Broome much of the country near watering points and on the edges of the plain is denuded.

(*e*) *Pindan Country*

(i) *Pindan Pasture Land*

(1) *Area.*—12,200 sq miles.

(2) *Location.*—This pasture land is referred to locally as pindan. It dominates the south-west and is widely distributed in the central and western parts of the area.

(3) *Environment.*—Extensive sand plains with fixed dunes, swales, pans, and depressions and some stony surfaces comprise this pasture land. The complex of sandy soils forming this group is characterized by a lack of organized drainage. Excess water is generally held in sheets or interdune flats or depressions, areas which are usually marked by paperbark (*Melaleuca* spp.) communities and occasionally fringed by coolibahs (*E. microtheca*). The soils and relief are such that the country is accessible throughout the year. Average annual rainfall decreases from 35 in. to 15 in. from north to south.

(4) *Composition.*—The term pindan is applied rather loosely to country with a vegetation cover of low scrubby woodlands with a tree layer of stunted bloodwoods (*E. dichromophloia*), *Bauhinia* sp., ironwood, and paperbarks. *Acacia* spp. form a prominent tall shrub layer with curly spinifex–ribbon grass pasture type (56). In the lowest-rainfall parts the vegetation becomes more stunted, the eucalypt tree layer sparse or absent, and the formation degenerates to an *Acacia* scrub. In the highest-rainfall parts the tree species are different and taller, the vegetation approaches the structure of a forest, and annual sorghum is more prominent and consistent in the ground layer.

(5) *Pastoral Value.*—This country has only a low carrying capacity and large areas have not been grazed because of lack of established waters. Most of the developed areas are adjacent to frontage country where it provides useful grazing during the wet season when the frontage areas are flooded or boggy.

Ribbon grass and curly spinifex are the two most useful grasses, the former provides green forage shortly after storms and the latter is a useful drought reserve. The annual sugar grass (*Sorghum stipoideum*) is relished by stock. Young green wire grasses (*Eragrostis* spp. and *Eriachne* spp.) are grazed by sheep, but mature plants are unattractive. Many of the short-lived grasses and forbs, scattered throughout the pastures, are palatable and nutritious.

Supplejack (*Ventilago viminalis*), konkerberry (*Carissa lanceolata*), and *Bauhinia cunninghamii* are the most useful top-feed species.

(6) *Reaction to Grazing, and Management.*—On the cattle stations the country has few improvements and open-range grazing applies, but the sheep properties are well fenced and watered and the pindan is used for wet-season grazing. Continued wet-season grazing has resulted in depletion of the better pasture species and their replacement by inferior ones. Corkscrew (*Aristida hygrometrica*) is rapidly spreading.

The practice of wet-season burning has assisted the degradation by destroying grass seeds and seedlings. Fire also assists the germination of *Acacia* seed.

On similar country in the Port Hedland district a system of deferred grazing (Nunn and Suijdendorp 1954) has improved the pastures and production from them.

(ii) *Pindan–Ribbon Grass Pasture Land*

(1) *Area.*—3300 sq miles.

(2) *Location.*—This kind of pindan country is restricted to the western parts of the area and is widely distributed in the Dampier peninsula and in the country to the east of King Sound.

(3) *Environment.*—It consists of extensive sand plains with dunes, swales, pans, and depressions but differs from the previous pasture land in having through drainage and lower valley floors characterized by yellow clayey soils. It also has more extensive rocky outcrop areas, low rocky hills, and in the Mandeville land system, rocky mountainous ridges in the sand plain. Soils of the sand plain are mostly deep red sands with lateritic gravels common on the crests and lower slopes of the ridges. Average annual rainfall decreases from 35 in. to 22 in. from north to south.

(4) *Composition.*—Vegetatively this country is similar to the undissected pindan country with similar increase to forest structure in the higher-rainfall parts. It differs in having lower valley plains with grassy woodlands of coolibah, beefwood, and *Bauhinia.* The ground storey of these grassy woodlands comprises ribbon grass pasture type (49).

(5) *Pastoral Value.*—The grazing potential is slightly better than that of the previous pasture land because of the grassy woodlands and the more numerous natural waters.

(6) *Reaction to Grazing, and Management.*—This pasture land does not include any sheep properties but otherwise its reaction to grazing is similar to that of the other pindan country.

(*f*) *Spinifex Country*

(i) *Spinifex–Short Grass Pasture Land*

(1) *Area.*—4700 sq miles.

(2) *Location.*—Of the land systems in this pasture land only Coonangoody occurs in the south of the area.

(3) *Environment.*—The pasture land includes a wide range of topography, including hilly to mountainous country with massive granite domes and outcrop with wide alluvial plains, undulating country with scattered rocky hills and granite domes, low lateritic plateaux with stripped zones and breakaways, undulating country on sandstones, and broad alluvial plains. Minor cracking clay plains occur throughout. The soils are variable but generally consistent in pattern, with shallow reddish skeletal soils occurring on the hills and ridges and the deeper reddish or yellowish sandy soils on the lower slopes and sand plains. The drainage floors, alluvial areas, and depressions usually have greyish sandy soils over a tough clayey subsoil. Gravelly soils and rock outcrop are a common feature of the slopes.

(4) *Composition.*—The vegetation comprises very open low grassy woodlands with *Enneapogon* spp. and other short grasses (61) characterizing the ground storey. Clumps and patches of curly spinifex pasture type (54) occur throughout the short grass pastures and dominate the skeletal soils of the hills and ridges with hard spinifex pasture type (57) on less favoured sites. Ribbon grass (49) is associated with the shallow valleys and drainage floors, and Mitchell grass (47) and ribbon grass–blue grass (48) are associated with the cracking clay plains. Top feed is not well developed.

(5) *Pastoral Value.*—The pastures are useful but of low carrying capacity. The ephemerals, annuals, and short-lived perennials provide plenty of succulent feed during the wet season but soft spinifex provides the bulk of the feed for the rest of the year.

(6) *Reaction to Grazing, and Management.*—Pasture deterioration is most marked on the fine-textured soils carrying ribbon grass, where bare patches are common.

(ii) *Soft Spinifex Pasture Land*

(1) *Area.*—200 sq miles.

(2) *Location.*—This pasture land is restricted to the central southern portions of the area near Fitzroy River and Christmas Creek.

(3) *Environment.*—The pasture land consists of stable alluvial plains adjacent to, and mainly above, the active flood-plains. The soils are mainly deep reddish sands and loams with finer textures near the active flood-plains.

(4) *Composition.*—Soft spinifex (*Triodia pungens* and *Plectrachne pungens*) characterizes this land. Other grasses are scanty. The tree layer of bloodwoods, beefwoods, and *Bauhinia* sp. is in most cases extremely sparse. It is probable that ribbon grass and wire grass and other palatable grasses were much more abundant in the original vegetation and that, with heavy grazing, spinifex has extended its area until it dominates these lands.

(5) *Pastoral Value.*—The soft spinifex species are highly regarded by pastoralists as a drought reserve fodder but the pastures have a low carrying capacity.

(6) *Reaction to Grazing, and Management.*—The pastures have been degraded severely and the more palatable grasses have disappeared.

(iii) *Curly Spinifex Pasture Land*

(1) *Area.*—2200 sq miles.

(2) *Location.*—This has a scattered distribution throughout the central and northern parts of the area.

(3) *Environment.*—The pasture land consists of plains and sand plains, broad stripped surfaces formed over lateritized granitic rocks, and rocky undulating upland plains over quartzite, sandstone, and siltstone. The soils range from deep, red sands to red and yellow sandy loams with extensive areas of gravelly and skeletal soils.

(4) *Composition.*—Low woodland with moderate to sparse shrub layers and curly spinifex pasture type (54) are characteristic. In the lower-rainfall parts spinifex (pasture types 57 and 60) occupies the less favourable sites. Ribbon grass pasture type (49) occurs as a minor element on the sand plain and valley floors.

(5) *Pastoral Value.*—This pasture land has a low carrying capacity but is useful in association with better country. There is a paucity of top feed, *Bauhinia cunninghamii* and beefwood (*Grevillea striata*) occurring only as a very minor element on the stable plains. Curly spinifex, which is the most widely distributed species, is eaten by stock when better grasses are not available and is regarded by pastoralists as a dry-season reserve fodder.

(6) *Reaction to Grazing, and Management.*—Pasture degradation is not obvious. In pockets of alluvial soil some replacement of ribbon grass by curly spinifex has occurred.

The pasture is of a similar type to that near Port Hedland on which Nunn and Suijdendorp (1954) demonstrated the value of deferred grazing.

The spinifex stands are burnt regularly to provide fresh green regrowth. This is only possible every 4 or 5 years.

(iv) *Hard Spinifex Pasture Land*

(1) *Area.*—4000 sq miles.

(2) *Location.*—This pasture land mainly occurs in the southern and south-eastern parts of the area.

(3) *Environment.*—It includes extensive often scalded plains with ferruginized outcrop, and commonly with light pebble strew, undulating and hilly to mountainous sandstone country with lateritic remnants and extensive shaly lower slopes, and sand plain islands. The soils are extremely variable but mainly reddish, shallow, skeletal sandy and loamy soils. The rainfall is low and unreliable.

(4) *Composition.*—The vegetation ranges from low open woodlands with spinifex understorey to spinifex grasslands with sparse trees and shrubs. Winged spinifex pasture type (57) is dominant except for minor occurrences of ribbon grass (49) in valleys and depressions, curly spinifex (54) and ribbon grass–curly spinifex (56) on sand plain islands, and gummy spinifex (55) in more favoured habitats.

Top feed is scanty — beefwood (*Grevillea striata*) is the main species, but is eaten only as a last resort. Konkerberry and mimosa (*Acacia farnesiana*) occasionally occur along the stream lines. The former is browsed by sheep and the latter is highly regarded by cattlemen as a drought reserve.

(5) *Pastoral Value*.—At best this is low-carrying country providing a subsistence diet. Small inclusions of better pastures are responsible for any value it has.

(6) *Reaction to Grazing, and Management*.—Pasture management has been on an extensive scale and is likely to remain so.

Spinifex is burnt regularly to promote fresh young growth. In most cases it has been done during and shortly after the wet season, at which time it destroys many of the more palatable plants.

(g) *Inaccessible Country*

(i) *Inaccessible Pasture Land*

(1) *Area*.—10,700 sq miles.

(2) *Location*.—Except for two small areas including the St. George and Mt. Anderson–Grant Ranges, this pasture land occurs to the north of the King Leopold Ranges.

(3) *Environment*.—The rugged mountain ranges, elevated plateaux, steep hills, and associated valleys have a complex geological pattern with quartzites, sandstones, shales, slates, schists, basalt, dolerite, and limestone. It is mostly rough, inaccessible, unproductive, and undeveloped. Soils are varied but characteristically skeletal with extensive outcrop.

(4) *Composition*.—Most of the lands are within the higher-rainfall area and the vegetation of these parts is an open woodland with moderate shrub layer and grassy ground storey of curly spinifex pasture type (54). In the lower-rainfall parts the vegetation is more stunted and open and the grass layer is hard spinifex (pasture types 54, 57, 58, 59). Grasses other than spinifex are poorly represented. Edible top feed is also scanty.

(5) *Pastoral Value*.—Only where these lands are adjacent to better country is utilization possible. They are more likely to have a nuisance value. They are generally well watered and therefore provide a hideout for scrub bulls, increasing the difficulty of herd management and mustering. At best it will remain extremely poor pastoral country.

(6) *Reaction to Grazing, and Management*.—Much of the area is unstocked and there is little or no evidence of pasture degradation or denudation except in isolated, restricted areas adjacent to watering points.

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PART VIII. THE PASTORAL INDUSTRIES OF THE WEST KIMBERLEY AREA

By F. THOMAS*

I. INTRODUCTION

Permanent successful occupation of the West Kimberleys was effected in the early 1880s by woolgrowers from the south-west of Western Australia, who brought with them the traditional paddocking method of the sheepmen. They were followed shortly by open-range cattlemen who had, in the main, overlanded their cattle from Queensland. Although there has been an appreciable adjustment of boundaries from first settlement to the present day, the two industries with their generally differing systems of husbandry still persist as separate entities. The open-range methods proved the more easily adaptable to local conditions, but this process of adaptation did not eliminate entirely the Western Australian grazing tradition (Bolton 1954).

Of the West Kimberleys, Despeisseis (1911) wrote, "Under the present system of land tenure . . . the vast areas given up to grazing are worked with the minimum number of station hands. This is particularly true of the cattle-raising country . . ., where the stock is held along river frontages or crowd surface water pools and lagoons.

"On the sheep stations more hands are employed as the country is fenced, windmills must be attended to, mustering is more frequent, and shearing necessitates the collecting together and handling of each individual sheep on the station . . .".

Reference to more recent publications (Fyfe 1940; Fletcher 1954; Kelly and Williams 1953; Beattie 1956) and observation of the area indicate that, with few exceptions, production practices today have not changed greatly from the time of Despeisseis.

(a) *Land Use*

The area surveyed in 1959 comprises approximately 47,000 sq miles. It supports a major regional beef-cattle industry and a minor wool-producing sheep industry, carrying about 27% of all beef cattle in Western Australia and 1·2% of the sheep in the State. Of the total area, about 70% is devoted to beef-cattle production and 12% to wool production. About 18% of the area is unoccupied or used for non-commercial purposes (e.g. missions). Agriculture is at present limited to 20,000 ac on the flood-plain of the lower Fitzroy River; part of this area is used for the production of irrigated rice, safflower, and sudan grass hay. Urban, industrial, or other forms of land use are negligible.

The boundaries of areas of present land use are shown in Figure 12.

(i) *Sheep Country*.—Sheep country, about 6000 sq miles, comprises the central part of the Fitzroy flood-plain (Mitchell grass–ribbon grass pasture land) and the

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plains immediately to the north (ribbon grass, pindan, and locally hard spinifex pasture lands). The location of the sheep industry has a historical basis in that the early settlers had occupied this area before the arrival of the cattlemen. Consolidation of the sheep-producing area into a cohesive locality in the lower-rainfall areas was dictated by considerations of flock protection (from depredations of dogs and wild aborigines) and disease.

Sheep areas include land removed from the frontage plains and some sand plain because of early legislation which stipulated a depth of holding equal to three times the length of frontage occupied.

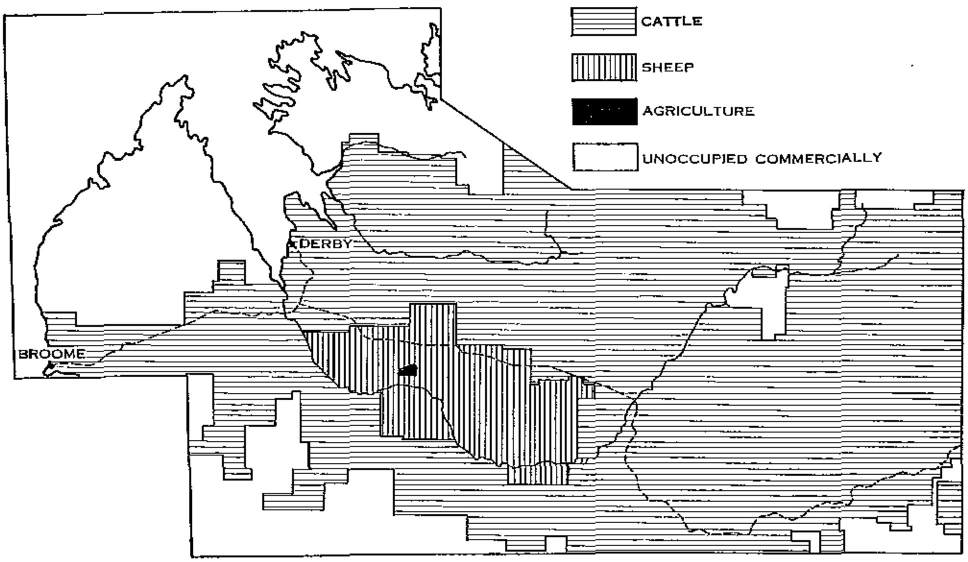

Fig. 12.—Present land use.

In comparison with the cattle-producing areas, the sheep properties contained in the north Fitzroy plains and Fitzroy flood-plains are highly improved. Boundaries are enclosed, while internally most of the area is subdivided into paddocks on roughly a 4-mile grid basis. Made waters are numerous. The stocking rate is about 26 per sq mile or 1 sheep to 25 ac. The variation in stocking rates between properties appears to be more a function of management than of environment. It is pertinent that, in spite of very substantial investment in sheep property improvement, the total sheep population at March 31, 1961, was about 145,000 head, the lowest level since the mid 1920s.

(ii) *Cattle Country*.—The remainder of the area, which is mostly unsuitable for sheep, is occupied by cattle holdings, except where shortage of water or inaccessibility prevents expansion of livestock enterprises. The total extent of the cattle holdings is at present approximately 34,000 sq miles. Although nominally occupied, substantial areas of rugged country (inaccessible pasture land), amounting to about 10,700 sq miles, reduce the effectively productive cattle area to about 23,300 sq miles.

Most of the inaccessible land is in the north-east of the survey area and serves as the catchment for the main drainage systems. It is largely north of the King Leopold Ranges and uplands in the south-east of the area.

The average cattle stocking rate for the 40 main cattle leases in the survey area was about 8·2 beasts per sq mile, but there was a very wide range of from 2·4 beasts to 17·9 beasts per sq mile. As management and production practices throughout the area were relatively uniform and as stations were stocked to their normal "safe" capacity, it is evident that environment exerts a strong influence in the variation of land use intensity as judged by the stocking rate.

Over much of the area, topography has a limiting influence on stocking rate. Thus in the Kimberley plateau province (Part IV) are areas which have average stocking rates of about 5 beasts per sq mile ranging from nil to about 8·8 beasts. These areas of strong relief occupy the greater part of the north, north-east, and east of the West Kimberleys and have a poor system of communications. Although most parts have rainfall of from 25 to 30 in. per annum, soils are skeletal and apart from favoured valley bottoms, which carry white grass–blue grass and plumed sorghum, the main vegetation is curly spinifex. There is an abundance of surface waters, which makes husbandry difficult, and unbranded cattle exist in considerable numbers. Although the limestone ranges and plateaux of Fitzroy Ranges limit locally the intensity of land use, there are extensive areas of Mitchell grass associated with them. These, together with numerous springs and natural waters found in these limestone formations, result in a fairly high stocking rate which is currently about 7·5 beasts per sq mile with a range from 4·3 to 12. On the north Fitzroy plains and Fitzroy–Lennard flood-plains the stocking rate on cattle properties ranges from 8 beasts per sq mile to about 18 per sq mile with much higher densities in bullock paddocks.

(iii) *Unoccupied Country*.—The remaining, unoccupied, portion of the area is about 7000 sq miles in extent. This comprises the Yampi peninsula and the major part of the sand plain or pindan (pindan and pindan–ribbon grass pasture lands) which constitutes the south-western part of the area and most of the Dampier peninsula. Settlement of these areas has been attempted, but most efforts ended in failure and abandonment. Lack of surface water, dense *Acacia* cover, and inaccessibility are major reasons for lack of settlement and these problems are further aggravated by heavy infestation of tick and buffalo fly in the higher-rainfall areas of the Dampier and Yampi peninsulas.

II. The Cattle Industry

(*a*) *General*

The West Kimberley survey area includes portions of the statistical districts of Broome, West Kimberley, and Halls Creek. The total present cattle population is approximately 278,000 head. As no long-term statistical data exist for the survey area as such, much of the description which follows will refer to the statistical districts of Broome and West Kimberley, collectively called the West Kimberleys. The West Kimberleys at present carries about 205,000 head of cattle and the physical and land-use characteristics of the area are such that inferences drawn from West Kimberleys data will be generally applicable to the survey area as a whole.

(b) The Cattle Population

The West Kimberleys cattle industry, judged by its cattle population, had not progressed over the years since its establishment. From the mid 1880s until 1913 the growth of herd numbers was continuous and by 1917 the population had reached a peak of over 400,000 head (Fig. 13). There was a very rapid decline to below 300,000 head by 1920. The decline continued until 1954, when the cattle population, of about 153,000, was at its lowest point. From 1954 to 1959 there was a strong recovery to 209,000 head, and although in 1960 the total cattle population stood at 205,000 there are indications that conditions are favourable for further progress.

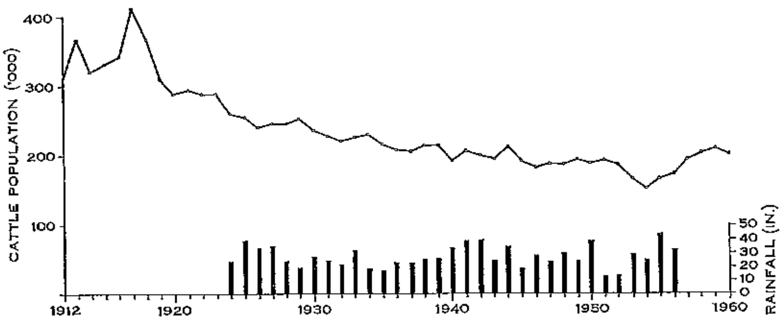

Fig. 13.—Cattle population of the West Kimberleys, 1912–60, and mean annual rainfall at Mt. House.

(c) Breeds

The cattle of the area are predominantly Shorthorns, which on the whole appear suited to the variety of conditions encountered in the area. Herefords occur on one station while at least two stations have initiated experiments to introduce zebu blood into their herds.

Limited progress has been made in the field of upgrading, but the influence of fresh blood is not marked except in the immediate vicinity of the homesteads of the station concerned, where close control of improved herds is exercised. On a regional basis the improvement of herd quality by breeding is likely to be very slow and difficult without substantial investment by graziers for the purposes of herd control.

(d) Lease and Property Size

Of the 40 leases (or portions of leases) contained in the survey area, most are relatively large, the average size being about 940 sq miles (range 90–1700). Table 20 gives a frequency distribution of individual leases according to size.

The relatively strong central tendency of the frequency distribution shows that 74% of leases lie within the range 500 to 1500 sq miles, thus the average of 940 sq miles is typical. The leases do not compare in size with many of the leases in the Northern Territory and Queensland, but there is a closer resemblance if subdivision of the cattle area is considered on an ownership basis. One aggregation of leases with common ownership and centralized general management amounts to about 6000 sq miles. Although this is the largest aggregation in the West Kimberleys, amalgamation of two or more leases under single ownership is common, so that the 40 leases contained in the area resolve themselves into 18 ownership groupings as shown in Table 21.

TABLE 20
FREQUENCY DISTRIBUTION OF CATTLE LEASES BY SIZE

Size of Lease (sq miles)	Frequency (no. of leases)	Total Area (sq miles)	% of Total Cattle Area
0–500	8	3050	8·1
501–1000	19	15,320	40·9
1001–1500	9	12,500	33·4
1501–2000	4	6600	17·6
Total	40	37,470	100·0

Size of ownership groupings reflects more closely the status of cattle stations as production units than does the size of lease. Thus the most frequent property size is from 1000 to 4000 sq miles, 11 such stations occupying about 67% of the total area of 37,470 sq miles*. Although numerically important, properties below 1000 sq miles account for only 6·6% of the area, while stations above 4000 sq miles, although only two in number, comprise about 26% of the total area.

TABLE 21
FREQUENCY DISTRIBUTION OF CATTLE PROPERTIES BY SIZE

Size of Property (sq miles)	Frequency (no. of properties)	Total Area (sq miles)	% of Total Cattle Area
0–1000	5	2460	6·6
1001–2000	5	7600	20·3
2001–3000	3	7560	20·2
3001–4000	3	9800	26·2
4001–5000	1	4150	11·1
5001–6000	1	5900	15·6
Total	18	37,470	100·0

(*e*) *Stocking Rates*

Over the whole survey area, property stocking rates vary from 2·4 beasts per sq mile in the mountainous areas of the north-east to 13·6 beasts per sq mile on stations occupying parts of the Fitzroy valley. The average is 8·2 beasts per sq mile.

* The discrepancy which exists between the figure of 37,740 sq miles and the 34,000 sq miles mentioned previously as being the total cattle country in the survey area, arises from the fact that in the tables, the whole area of the property was included for stations that were only partly included in the survey area.

Within properties, stocking rates vary from no cattle at all on inaccessible or waterless portions to the very high (but uncalculated) rates on frontage bullock paddocks. The variation in the distribution of stocking rates on a lease and property is shown in Table 22.

Scatter diagrams relating property size to stocking rate show no significant correlation. The position in the West Kimberleys cattle industry thus differs from that in most of Queensland and the Northern Territory, where large size is usually associated with the more extensive use and small properties with higher stocking rates and production. There are historical and economic explanations for this situation. Marginal areas were ignored by the original cattlemen and later arrivals filled in the unoccupied remainder of the country. Although many of the smaller

TABLE 22

FREQUENCY DISTRIBUTION OF CATTLE LEASES AND PROPERTIES BY STOCKING RATES

Stocking Rate (beasts per sq mile)	No. of Leases	% of Leases	No. of Properties	% of Properties
0–3·0	1	2·5	1	5·6
3·1–6·0	11	27·5	3	16·6
6·1–9·0	14	35·0	8	44·4
9·1–12·0	8	20·0	3	16·7
12·1–15·0	5	12·5	3	16·7
15·1–18·0	1	2·5	—	—
Total	40	100·0	18	100·0

leases were absorbed in time, some small properties still exist, but none of these enjoys both a favourable location and environment. Such being the case, size of holdings related to the stocking rate is not significant in the present circumstances.

(f) *Management and Effects of Management*

Descriptions of the management of northern cattle properties have been given by Beattie (1954, 1956), Kelly (1952), Kelly and Williams (1953), and others. This section is more concerned with the effects of management than with the systems themselves.

Cattle property management in the West Kimberleys has evolved to suit the prevailing conditions and the result is the open-range system of production, with complete dependence on the natural vegetation for cattle feed. Management practices are influenced by a variety of factors including, on the physical side, environment and, on the non-physical side, such things as tenure, lease conditions, ownership, labour, finance and investment, communications, transport, markets, prices, costs, technical knowledge, ability, and producers' choice of system.

The long-term application of open-range management methods has given the West Kimberleys cattle industry several well-defined characteristics, some of which are described by Perry (1960) in relation to cattle production in the Northern Territory and by Anon. (1961*b*) relating to the Northern Territory and north Queensland. Some characteristics of low stocking rates have already been discussed, others include high herd numbers per property, high total investment per property (mainly in cattle) but low investment per square mile, especially in fixed improvements, low operating costs per beast, and a small labour force per beast or unit area. There is generally a low proportion of breeding to non-breeding animals combined with high mortality of breeders, uncontrolled mating, little or no segregation of various classes of cattle, and low branding and turn-off rates. Mustering difficulties exist so that unbranded and entire male cattle are numerous.

Table 23 shows that the total breeding herd is only 44·6% of the total herd. If young maiden heifers (although included in the breeding herd and accessible to the bulls) are excluded from the effective breeding herd as being too young and small,

TABLE 23

ESTIMATED COMPOSITION OF HERDS IN WEST KIMBERLEYS, MARCH 31, 1960*

Class of Cattle	Number	% of Total Herd	
Cows + heifers, 2 yr and over	69,101	33·7	44·6
Heifers, 1–2 yr	22,274	10·9	
Bulls, 1 yr and over	5148	2·5	
Heifer calves, less than 1 yr	23,446	11·4	21·8
Bull calves, less than 1 yr	21,338	10·4	
Bullocks, 1–2 yr	20,271	9·9	31·1
Bullocks, 2–3 yr	19,866	9·7	
Bullocks, 3–4 yr†	19,866	9·7	
Speyed and culled cows‡	4052	2·0	
Total	204,965	100·0	

* Derived from Statistical Register of Western Australia, 1959–60, for statistical districts of Broome and West Kimberley. The table assumes 5% mortality in calves and 2% in bullocks.

† For sale annually.

‡ Part for sale annually.

then the figure is 33·7%. This is due to the generally advanced age of cattle turn-off. Herd bulls approximate to 6·5% of the total breeding herd. This percentage should be adequate but it is not known to what extent the scattered nature of open-range breeding or inter-bull competition limits the effectiveness of herd bulls. The relatively low calf drop may be mostly related to the proportion of bulls to breeders, but this aspect needs investigation. The branding rate, according to the statistics, is about 49%. Even if the young heifers are excluded from the breeding herd numbers, the branding rate would be only about 63%. It is not known to what extent calf mortality or cow infertility contributes to the low branding rate. In a sample census in the nearby East Kimberley region Ritson and Norman (1961) found a generally similar herd composition, the main differences being that the proportion of bulls 1 year and over was nearly twice as high as, and the proportion of bullocks and speyed cows somewhat lower than, that in the West Kimberleys.

The turn-off of marketable cattle from the West Kimberleys from 1949 to 1958 was less than 10% of total herds and averaged about 18,000 head. In 1959, turn-off rose atypically to some 30,000, an increase of 12,000 per annum, under the influence of the U.S. trade. In 1960, the turn-off had returned to about 20,700 head. The low percentage turn-off, mainly a function of the advanced age of marketable bullocks, is due partly to slow growth rates and the necessity to have strong cattle to stand up to droving. Official statistics indicate that as a result of the Air Beef Scheme (Anon. 1955) and the development since 1952 of road transport for marketing, the age of turn-off has been reduced from about 5 years and over to 3–4 years and the proportion of followers has dropped from about 41·5% of the herd in 1948 to 31% in 1960. This is discussed under the heading of the development of the cattle industry.

Apart from the low branding rate, the most adverse feature of the open-range system of management is the high loss due to mortality in breeders, mainly old cows and first-calf heifers. This is estimated to amount to about 18,000 head per annum.

(*g*) *Production and Marketing*

Production and marketing of cattle in the West Kimberleys have been strongly influenced by environment, markets, communication, transport facilities, and quarantine restrictions.

Because of distance to fattening areas in the south-west of Western Australia and in eastern and southern Australia, the difficulties of overland communication and lack of transport, and the costs and wastage involved and the limitations imposed on movement by quarantine restrictions, the West Kimberleys has never had an external outlet for store cattle. In consequence, and because favoured areas along the river frontages made useful bullock-finishing paddocks, the cattle industry of the West Kimberleys has evolved a local system of integration between breeding and fattening country for the main purpose of slaughter cattle production. Often the whole production process is completed on one station, but with aggregation of holdings it is common to find one lease acting as the breeding paddock for another under the same ownership.

Although some live shipments have been made to Singapore, Hong Kong, and the Philippines and in 1959 to north Queensland for processing and re-export to the U.S.A., the main traditional market has been Perth, to which live cattle are consigned by ship via Derby and Fremantle for slaughter and metropolitan consumption. Bolton (1954) credits Alexander Forrest with pioneering the Perth market with a shipment of 15 head which grossed £12 a head in Perth in 1890. Prices paid for "prime average bullocks, weight over 750 lb" delivered at Derby ranged from £5 in 1895 to £5 15*s* in 1898. In 1896, 3017 cattle were sent from Derby and by the turn of the century this had risen to about 6600 head. From 1949 to 1960, exports via Derby to Fremantle averaged 8815 head with a range from 5593 in 1953 to 14,000 in 1959.

Expansion of this trade was limited by the availability of shipping space, but apart from occasional mobs, droving of West Kimberley cattle to the south-west did not develop because of quarantine restrictions and the physical difficulties involved. The introduction of the State Shipping Service in pre-1914 years helped to increase the capacity of shipping to Fremantle and assisted smaller producers to get rid of their turn-off. Thus to a large extent the prosperity of the West Kimberleys has been governed by the price of cattle in the Perth market.

In 1929 an outbreak of pleuropneumonia stopped the sporadic droving to the south-west and the effects of the depression lowered the Fremantle cattle price to about £9 per head in 1931.

In 1941, the meatworks built at Broome provided an additional outlet for West Kimberley cattle, mainly for export, while in 1949 a private abattoir was established at Glenroy in an attempt to remove some of the disabilities of isolation and so provide an outlet for cattle stations north of the King Leopold Ranges (Anon. 1955). These facilities placed the West Kimberleys in the most favourable marketing position since the start of the cattle industry, and from 1949 to 1960 an average of about 19,000 cattle was disposed of annually through the main outlets provided by Perth, Broome, and the Air Beef Scheme at Glenroy, though shortage of coastal shipping still remained a factor which limited access to the metropolitan market.

TABLE 24
APPARENT CAPACITY OF WEST KIMBERLEY OUTLETS (1962)

Outlet	Cattle
Broome works	12,000
Air Beef	5000
State shipping service	7000
Other ships	5500
Total capacity	29,500

Table 24 shows the apparent 1962 annual capacity of West Kimberley outlets. By 1963 the total outlet capacity should rise to 31,300 by the addition of another ship by the Western Australian Government to service the coastal trade in live cattle to Fremantle. When plans for a new West Kimberley deep-sea port reach fruition, and if a new meatworks is developed in conjunction with this port, the cattle industry, provided it takes full advantage of these and other current developments in roads and road transport, could effect a substantial and permanent recovery.

Except for the exceptionally high turn-off of about 30,000 head of cattle in 1959 (when additional outside shipping was available), production from West Kimberley herds has seldom exceeded 10% of total herd numbers, being 10·1% in 1960. As there was a considerable variation in actual numbers and in prices paid for cattle, the gross value of production and hence producer income showed some variation also. Although both Perth and export cattle prices rose consistently and steeply from 1949 to 1961 (Anon. 1962), 1962 prices showed a sharp drop.

The gross value of production of the West Kimberley cattle industry, based on Perth sales, is shown in Table 25. Net of marketing and transport charges, the present on-station value of the average annual turn-off (20,000) from the West Kimberleys is estimated to be approximately £510,000 (or £25·5 per head).

Methods of marketing and sale vary. Droving as a marketing method except for stations adjacent to Broome, Derby, and Glenroy, has been replaced by road transport, for which the standard charge for the area is about 30*s* per head per 100 miles. Cattle sold to Broome meatworks are paid for on a weight and grade basis, to Glenroy on a per head basis, while cattle may be sold by the vendor at Robbs Jetty by auction or sold delivered to ships at Derby on a per lb liveweight basis. Except for returns from Glenroy, where prices appear to be arbitrarily depressed, net returns from the other outlets are fairly comparable although generally greater from Perth sales.

TABLE 25

ESTIMATED GROSS VALUE OF WEST KIMBERLEY CATTLE OUTPUT, 1949–50 TO 1961–62

Year	Price for 100 lb Dressed Weight (*s*)	Av. Value per Head (£)*	Total Turn-off (Head)	Approximate Gross Value of Production (£)
1949–50	97	29·1	16,948	493,200
1950–51	113	33·9	19,790	670,800
1951–52	140	42·0	20,421	357,700
1952–53	154	46·2	19,236	888,700
1953–54	171	51·3	15,379	788,900
1954–55	164	49·2	17,520	861,200
1955–56	163	48·9	16,818	822,400
1956–57	174	47·9	17,652	845,500
1957–58	168	46·2	16,573	765,700
1958–59	173	47·6	18,459	878,600
1959–60	194	53·3	30,142	1,606,600
1960–61	208	57·2	20,701	1,184,100
1961–62	145†	39·9	22,000‡	877,800

* Based on average of 600 lb carcass weight to 1956, thereafter 550 lb.

† Robbs Jetty sales 1962.

‡ Estimated.

In the event of the construction of a new meatworks at the deep-sea port site, which might reduce or end the wasteful live cattle trade to Fremantle by subsidized State ships, prices would tend to even out and bear a close relationship to export parity prices.

(*h*) *Development of the Cattle Industry*

Although water, pastures, and a market are the basic requirements of cattle-raising (Patterson 1960), many other things are needed to ensure a stable industry capable of economically utilizing the biological potential of a region. For example, in the West Kimberleys the introduction of an air beef scheme in 1949 and of road transport in 1952 has resulted in a change in herd composition (Table 26) due to the reduction in age of turn-off from 5 years to about 3–4 years. Both the proportion and numbers of breeding cows have risen and although the branding rate has only slightly improved (43·4% in 1948 to 49% in 1960) the total annual calf drop is now more than 10,000 above that of 1948. The effect on turn-off is clearly demonstrated by the main stations supplying cattle to Air Beef. Prior to 1949 their average turn-off was 6·1% of total herds but in subsequent years it rose to 11·6%.

TABLE 26
HERD COMPOSITION, WEST KIMBERLEYS, 1948 AND 1960*

Class of Cattle	1948		1960	
	Number	%	Number	%
Cows and heifers, 1 yr and over	73,288	39·6	91,375	44·6
Heifer calves	15,733	8·5	23,446	11·4
Bull calves	16,044	8·7	21,338	10·4
Bulls	3068	1·7	5148	2·5
Other	76,990	41·5	63,658	31·1
Total	185,123	100·0	204,965	100·0

* Source: Statistical Registers of Western Australia.

Although the West Kimberley cattle numbers have declined in the long term, the short-term trend from 1949 to 1960 has been upward. On the basis of this trend the 1970 cattle population could be about 213,000 with a turn-off of about 35,000 (Table 27). These figures are based on the assumptions of a three-year-old turn-off, the present branding rate (49%), and mortality rates of 5% in calves and 2% in bullocks. On this basis the breeding herd in 1970 could constitute about 50% of the total herd, the percentage of followers would be about 24%, and about 23,000 bullocks, 2000 culls and speys, and about 10,000 culled surplus females should be available for market. This would still allow about 15,000 females a year for replacements to the breeding herd.

TABLE 27
ESTIMATED COMPOSITION OF WEST KIMBERLEY HERDS, 1970

Class of Cattle	Number	% of Total Herd
Cows and heifers, 1 yr and over	105,000	49·3
Heifer calves, less than 1 yr*	26,900	12·6
Bull calves, less than 1 yr	24,600	11·6
Bulls, 1 yr and over	6000	2·9
Bullocks, 2 yr old	23,300	10·9
Bullocks, 3 yr old†	23,100	10·8
Speys and culled cows‡	4100	1·9
Total, West Kimberleys	213,000	100·0

* Usually for herd replacement.

† For sale annually.

‡ Half for sale annually.

The cattle industry of the West Kimberleys owes much to Government action in the field of investment. Accounts of public expenditure in the West Kimberleys alone are not available, but some details presented by the Bureau of Agricultural Economics (Anon. 1961*c*) indicate the substantial amounts expended on development of the north-west, much of it to the direct advantage of West Kimberley producers. Items include the subsidy paid by loss reimbursement to the State Shipping Line, the waiving of loan interest on the Broome meatworks, Air Beef subsidy, assistance on a £ for £ basis for station water development, improvement of stock route facilities, very marked improvements in the Great Northern Road and the construction of a new road from Derby to Mt. House, and in other directions not so apparent. In addition, a deep-sea port, further slaughtering facilities, and an increase in shipping capacity are contemplated.

It is evident that, in order to take full advantage of this developmental expenditure, there should be some response by pastoralists themselves. It has been shown that the provision of roads and market outlets has had a marked influence both on the marketing method and age of turn-off with resulting changes in herd composition which should lead to greater output in the future.

Significant advances might be made in the West Kimberleys merely by the practical application by the industry itself of some of the elementary principles of good husbandry, but it is unlikely that this would be possible without more enlightened management and an appreciably higher level of investment and development on existing holdings. Alternatively, a more intensive utilization of holdings which are now excessively large might be indicated.

Aspects which demand attention are the high mortality among breeders, the low branding percentage, the rehabilitation of over-utilized pastures to restore carrying capacity, and control of pests and predators.

Although the Government, in addition to direct public expenditure, has sought to encourage station development and increased production by measures such as high depreciation allowances, zonal taxation concessions, etc., the level of private station investment during the 1959 survey did not appear to be high.

Because of the very high and fixed-cost nature of improvements such as buildings, yards, fencing, and water supplies and the fact that these facilities are specific to the cattle enterprise, having no alternative productive uses, it is likely that producers' attitudes to further investment will be cautious.

Accordingly, the confidence with which producers view the profitability of future markets will continue to be of more importance in determining future developments in the cattle industry than the wish to maximize or improve production.

III. The Sheep Industry

(*a*) *General*

The West Kimberleys at present support about 1·2% of the sheep population of Western Australia. In 1960 it produced 1,500,000 lb of greasy wool worth about £354,000*.

* Based on an average Western Australian price for greasy wool of 59·6*d* per lb in 1960.

(*b*) *The Sheep Population*

Sheep population figures from 1890 to 1961 (Fig. 14) illustrate the erratic nature of the sheep industry in the West Kimberleys. In 1883 there were eight sheep stations on the Fitzroy, Meda, and Lennard Rivers, but by 1886 the Fitzroy valley alone contained the consolidated sheep industry, which was organized on a system of shepherding on natural pastures and using natural waters. Shepherding gradually

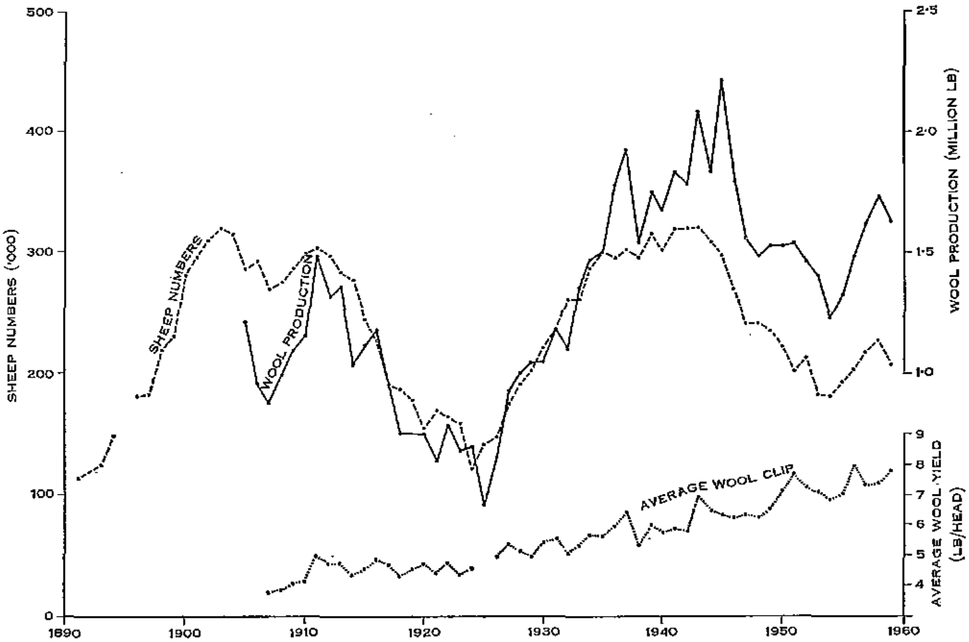

Fig. 14.—Sheep population and wool production of the West Kimberley area, 1890–1959.

evolved into paddocking for the control of the sheep and the industry assumed settled permanent characteristics. Four population phases are apparent:

(1) 1880s–1903.—Stocking the virgin frontage country, numbers rose to over 300,000.

(2) 1903–1925.—Over-utilization of natural frontage grassland, numbers fell to 144,000.

(3) 1925–1943.—Provision of made waters on pindan, fencing and stocking to capacity, numbers rose to 321,000.

(4) 1943–1961.—Over-utilization of both frontage and pindan, numbers fell to 184,000.

(*c*) *The Sheep*

The type of sheep run are small-framed, plain-bodied Merinos with an open, fine fleece. The wool is predominantly 64s or finer in quality, fair length only, light in condition, with seed in skirtings and some discolouration in evidence. A proportion shows serious "canary" stain (Anon. 1951). Most of the females are locally bred, although the industry tends to be a net importer for flock maintenance and replacement after seasons or periods of excessive flock losses. Rams are generally imported from southern studs and as such are subject to the stresses of adaptation to the environment.

(d) *Property Size and Stocking Rate*

The eight sheep properties in the West Kimberleys range in size from 80,000 ac to about 1,000,000 ac, the average being about 460,000. The frequency distribution shown in Table 28 indicates a wide deviation from the mean. The four stations below 300,000 ac in size account for 20·1% of the total sheep area and 25·6% of the total sheep while the four above 300,000 ac together occupy 79·9% of the area but carry only 74·4% of the sheep.

TABLE 28

SIZE OF SHEEP STATIONS, STOCKING RATE, AND PRODUCTION, WEST KIMBERLEYS, 1961

Station Size ('000 ac)	No. of Proper-ties	Total Area ('000 ac)	% of Total Sheep Area	No. of Sheep in Class ('000)	% of Total Sheep	Stocking Rate (ac/sheep)	% of Annual Total Clip	% Lamb Drop*
<100	1	80	2·2	5·5	3·8	14·5	3·9	30
101–200	2	350	9·6	24·0	16·6	14·6	19·4	60
201–300	1	300	8·3	7·5	5·2	40·0	4·3	30
301–400	—	—	—	—	—	—	—	—
401–500	2	900	24·8	30·0	20·6	30·0	20·6	30
>500	2	2000	55·1	78·0	53·8	25·6	51·8	30
Total	8	3630	100·0	145·0	100·0	25·0	100·0	—

* Data collected by author during 1959 field season.

No marked statistical correlation exists between the size of individual stations and stocking rate, although it is apparent that the three stations below 200,000 ac have almost twice the average density of stocking of the five stations larger than 200,000 ac (one sheep to 14·6 ac compared with one to 27·7 ac). Production from the two stations in the size group 101,000 to 200,000 ac is noteworthy.

The Kimberley Development Committee considered (Anon. 1951) that several of the large stations, although well managed, were well above optimum size. Even though the largest stations are well improved and operate on an out-camp basis, this does not appear to be an effective substitute for individual management of smaller properties under resident ownership.

(e) *Management*

Sheep and grazing management are influenced by both tradition and environment. The alternate use of frontage and pindan is dictated by the risk of flood on the frontages and the damage from corkscrew grass seed on the pindan. Sheep are moved from the frontage towards the end of the dry season (October). Lambs are weaned at this time and rams joined in early December. Shearing takes place at the end of the wet season (March to early April), after which at least the breeding flocks are transferred to the frontage country where the lambs are dropped (Anon. 1951).

The sheep properties are well fenced and watered (fences generally run north–south, east–west on a 4-mile grid). Return to capital is high (Anon. 1957) but has fluctuated widely under the dual influences of price variability and output instability, and has been achieved at the expense of the carrying capacity.

The performance of the West Kimberley flocks compares very unfavourably with that of Western Australia and Australia (Table 29). However, the best-managed station has a lamb marking rate of 60% and a wool clip per head of 8–8·5 lb, which is comparable with the average for Western Australia.

TABLE 29

FLOCK COMPOSITION AND PERFORMANCE IN THE WEST KIMBERLEYS, WESTERN AUSTRALIA, AND AUSTRALIA, MARCH 1960*

Type of Sheep	West Kimberleys		Western Australia	Australia
	Number (head)	% of Flock	% of Flock	% of Flock
Rams	4059	2·1	1·3	1·2
Ewes, breeding	90,185	47·5	43·3	44·1
Ewes, other	6600	3·5	6·1	6·0
Wethers	69,587	36·7	29·8	27·7
Lambs and hoggets	19,365	10·2	19·5	21·0
Total	189,798	100·0	100·0	100·0
Lambs marked, 1959 ('000)	25		4190	44,150
Ewes mated ('000)	96		6506	61,196
% Lambs marked	25·9		64·4	72·2
Average fleece cut (lb)	7·3		8·8	9·0

* Sources: Statistical Register of Western Australia, 1962; Statistical Handbook, Bureau of Agricultural Economics, 1961.

Wallaby infestations are a problem. These pests not only directly influence the sheep stocking rate by their depredations and adversely influence the precarious balance of sheep survival, but also frustrate attempts at range rehabilitation either by deferred grazing or by the introduction of sown species.

(*f*) *Production*

Wool production from the West Kimberleys has varied with the sheep population (Fig. 14). As all suitable sheep are shorn annually, there are (unlike the cattle industry) no "hidden" reserves to draw on in response to any sudden rise in wool price. Management has exerted a major influence in the variation of flock numbers while climate (mainly rainfall) has short-term effects both on numbers and on fleece weight yields. Thus, despite the gradual improvement of wool yield per sheep to the present clip of about 7½ lb, this has eased only slightly the violence of fluctuations in total production, which have been responsible, with varying prices, for a state of chronic income instability.

Because of high mortality and low lamb marking percentages, the industry has found it necessary to retain not only its annual increase but also sheep which

TABLE 30

SHEEP SHORN, AVERAGE CLIP, WOOL CLIP, AND ESTIMATED GROSS INCOME, WEST KIMBERLEYS, 1939–40 TO 1959–60*

Year	No. Sheep Shorn ('000)	Av. Clip (lb/head)	Total Clip ('000 lb)	Av. W.A. Greasy Price (*d*/lb)	Est. Gross Income (£'000)	Index of Income
1939–40	291·5	5·8	1685	12·89	90·5	100
1940–41	315·0	5·9	1850	13·36	103·0	114
1941–42	307·2	5·9	1798	12·99	97·3	108
1942–43	297·4	7·0	2094	15·12	131·9	146
1943–44	283·7	6·5	1843	15·11	116·0	128
1944–45	306·0	7·2	2214	15·21	140·3	155
1945–46	280·5	6·3	1780	15·44	114·5	127
1946–47	245·4	6·4	1564	23·97	156·2	173
1947–48	236·9	6·3	1497	39·23	244·7	270
1948–49	233·4	6·6	1530	48·34	308·2	341
1949–50	214·8	7·2	1536	61·56	394·0	435
1950–51	197·3	7·8	1541	137·67	883·4	976
1951–52	199·9	7·3	1461	66·15	402·7	445
1952–53	197·3	7·2	1417	75·99	448·7	496
1953–54	179·1	6·9	1231	77·68	398·4	440
1954–55	190·6	7·1	1348	66·87	375·6	415
1955–56	190·3	8·0	1528	56·73	361·2	399
1956–57	221·0	7·4	1643	73·92	506·0	559
1957–58	231·7	7·5	1739	60·39	437·6	484
1958–59	206·4	7·9	1629	45·70	310·2	343
1959–60	201·2	7·3	1476	56·60	348·1	385
1960–61	n.a.	n.a.	n.a.	48·77	n.a.	n.a.

* Sources: Statistical Register of Western Australia 1939–40 to 1955–60; Statistical Handbook, Bureau of Agricultural Economics, 1961.

would normally be culled or cast for age in order to maintain flock numbers and hence its clip. Because of this, except for a few sporadic exports of sheep, no reliable additional income from the sale of sheep for slaughter could be expected. Production is therefore very inelastic.

Table 30 provides details of production and estimated gross income to the industry since 1939–40. With a drop in the average Western Australian price in 1961 to 48·77*d* per lb for greasy wool, and with reduced flock numbers, the position of the West Kimberleys sheep industry does not look promising. A further drop in price could result in serious economic consequences, especially in the light of rising costs and increased capitalization during years of high wool prices.

Economic data available at present are insufficient to evaluate these consequences but they could lead to the elimination of the one attractive feature of the industry, namely a high return to capital. Whereas the wool industry of Australia has been able to meet the cost/price squeeze to some extent by greater production, the West Kimberleys have been unable to stabilize station income even by these means. Production has in fact dropped with prices while costs have risen considerably. Total production and marketing costs per lb of West Kimberleys wool have risen from 8·2*d* in 1939 (Fyfe 1940) to about 38*d* in 1958 (K. Fitzgerald, personal communication), an almost five-fold increase without a commensurate stable increase in price.

(*g*) *Development of the Sheep Industry*

The Kimberley Development Committee (Anon. 1951) considered that wool-growing in the area would expand at the expense of cattle-growing. The very reverse transpired. Wool prices fell from 138*d* per lb in 1951 to 66*d* in 1952 and now stand at about 50*d*, while the value of beef has risen from 113*s* per 100 lb dressed weight in 1951 to an estimated 145*s* in 1962 with much higher values in the intervening years. One of the large sheep stations has in consequence begun to develop cattle as a separate enterprise on the property in order to offset its diminishing income from sheep. A wholesale swing to cattle by the industry is not expected because the improvements specific to sheep are not necessarily suited to cattle production, nor is the sheepman generally well disposed towards cattle.

TABLE 31

ESTIMATED NET INCOME PER 1000 ACRES FOR SHEEP AND CATTLE, WEST KIMBERLEYS, 1961–62

Item	Sheep	Cattle
Animals* (number)	40	12–5
Output per annum	300 lb wool†	1·25 beasts‡
Gross value of output	£62·5§	£50·0‖
Production and marketing cost	£47·5¶	£30·0**
Net income	£15·0	£20·0

* Average stocking rates for the area: 1 sheep to 25 ac, 8 cattle/sq mile.

† Average fleece weight 7·5 lb.

‡ Turn-off 10%.

§ Estimated average Western Australian price per lb greasy wool: 50*d*.

‖ Estimated average Perth price for 550 lb dressed-weight beast: £40.

¶ Estimated cost per lb: 38*d*.

** Production cost for 3-yr old: £10; cost of marketing at Perth: £14.

In Table 31 the estimated present position of the net earning capacity of sheep as opposed to cattle is compared. The figures presented for cattle output are conservative, since it has been shown that annual turn-off is likely to increase to about

16% of total herd. In addition it must be remembered that the country occupied by sheep is capable of stocking rates in excess of the average of eight beasts to the mile shown in the example.

One further point which should be borne in mind is the effect of any expansion of agriculture in the Fitzroy valley. While resumption of frontage country for agricultural purposes would no doubt adversely affect the traditional method of bullock production, it would not have the same deleterious effect as it would on the sheep industry, which is at present rigidly dependent on the frontage for its production processes.

The problems facing the sheep industry are mainly technical and managerial. The area is environmentally capable of achieving lamb drops of 60% and average clips of at least 8 lb per head under modified systems of management. With the increased use of road trains for the marketing of cattle, the frontage country, which has hitherto formed the stock route, should recover to some extent its carrying capacity. Whether management can respond by increasing production without raising costs is something which cannot be predicted.

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PART IX. AGRICULTURAL POTENTIAL OF THE WEST KIMBERLEY AREA

By J. J. BASINSKI*

I. INTRODUCTION

The objective of the following broad discussion of agricultural potential is to put the apparent potential in perspective and to provide material for consideration concerning further investigations. Attention is paid mainly to the possibilities offered and the limitations imposed by the physical and biotic environment described in earlier Parts. These controlling factors are more permanent than economic conditions, which determine the immediate possibilities of development but which have to be re-examined more frequently.

The environment of the area imposes considerable restrictions on agricultural potential. This, coupled with geographical remoteness from the more developed parts of the country and a climate unattractive for white settlement, makes conditions in the area relatively unfavourable for agricultural development. As a result, early attempts to establish commercial farming were few and short-lived. The recent irrigation project at Camballin, on the lower Fitzroy River, has encountered considerable difficulties in water control, in finding suitable crops and varieties, and in combating weeds and birds. The amount of experimental work carried out in the area is very limited. Consequently, there is little local information to assist agricultural assessment, which has therefore to be based on data acquired elsewhere. Research results from Kimberley Research Station on the Ord River and Katherine Research Station in the Northern Territory are of particular relevance, but caution must be exercised in applying them to the West Kimberley area because of significant differences in environmental conditions.

II. RAIN-GROWN CROPS

The amount, seasonal distribution, and reliability of rainfall are the main factors limiting the possibilities of non-irrigated crop production in the area. These possibilities can be conveniently reviewed in relation to three somewhat arbitrary rainfall zones; areas with more than 30 in. mean annual rainfall, areas with rainfall between 20 in. and 30 in., and areas with rainfall below 20 in.

The area with a mean annual rainfall of 30 in. and above appears to be restricted to the Yampi peninsula. Rainfall statistics for the area are not available, but according to Christian and Stewart (unpublished data) the agricultural growing season at Oobagooma is only slightly shorter than that at Katherine and may be somewhat more reliable. Thus, from a climatic point of view, agricultural production using crops found successful at Katherine Research Station would be possible. However, rugged terrain, inaccessibility, and shallow infertile soils preclude any consideration of agriculture over most of the Yampi peninsula. The only areas where topography and soils might permit crop production are the levees of the Robinson and lower

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Tarraji Rivers in the Djada land system and parts of the Fossil land system north of Oobagooma. The former are reputed to be periodically flooded. The latter are characterized by heavy cracking clay soils, which have proved marginal for rain-grown crops under similar rainfall conditions at the Kimberley Research Station. However, it may be possible to produce, on a limited scale, short-season fodder crops such as bulrush millet, sorghum, and quick-maturing legumes. These could be of value as supplementary feed for horses and stud stock if and when the local cattle industry reaches a more advanced stage of development.

In the 20–30-in. rainfall zone the average length of the estimated agricultural growing season ranges from 11 to 13 wk, compared with 15·5 wk at Kimberley Research Station and nearly 21 wk at Katherine Research Station (Table 9). In a considerable proportion of years the season is much shorter (Table 8). Moreover, drought conditions occur relatively frequently within the growing season. Consequently the moisture regime imposes severe limitations on the possibilities of rain-grown crop production. In other parts of the world, crops such as sorghum, millets, sesame, and quick-maturing pulses are grown under comparable climatic conditions. In the West Kimberleys, however, remoteness from sources of supply and markets and the need to apply phosphatic and, on some soils, possibly potash fertilizers present additional obstacles. The prospects for rain-grown crops appear therefore to be confined to their production as feed for valuable stock. In this context they may merit some investigation in order to determine whether they could compete with imported feeds.

Although in parts of Africa and Asia crops are produced in areas with less than 20-in. rainfall, under Australian socio-economic conditions there are no prospects of rain-grown crop production in the driest zone of the area except in areas receiving appreciable run-on, where some fodder production for local use may prove possible.

III. Irrigation Possibilities

(*a*) *Water Resources**

(i) *Underground Water*.—As far as is known at present, there are no major underground water resources which could be utilized for irrigation. Data from the existing bores indicate that, in general, the aquifers are relatively deep and their yields low. In three bores sunk recently near Broome, water was found at 100–200 ft and test yields were of the order of 15,000 gal per hour. Without more information on the extent of the aquifer tapped and its recharge, it is impossible to assess its irrigation potential, which is unlikely, however, to be of more than minor local importance.

(ii) *Rivers*.—Surface streams provide the main potential source of irrigation water. Of these, the Fitzroy, Margaret, and Lennard Rivers are the only ones which offer possibilities of development on an appreciable scale. Knowledge of the hydrological characteristics of these rivers and of the detailed topography of their basins is still limited, so that irrigation potential can be discussed only in general terms.

* The numerical data in this section have been kindly provided by the officers of the Western Australian Government.

The mean annual discharge of the Fitzroy River at Fitzroy Crossing (from the Fitzroy–Margaret catchment area of 13,200 sq miles) is estimated at 1·6 million ac ft. The annual discharge of the Lennard River at Windjana Gorge (from a catchment area of 2500 sq miles) is estimated at 0·4 million ac ft. By comparison the annual discharge of the Ord River at Kununurra is 2 million ac ft.

As could be expected from rainfall characteristics (Part III) the flow of the rivers, even in the lower reaches, varies considerably from year to year. It is virtually restricted to the wet season and consists of a series of spates alternating with very low discharges. The two typical flow hydrographs in Figure 15 illustrate the rapid rise and equally rapid fall of the Fitzroy River discharge at Fitzroy Crossing. In terms of river height the variations are also considerable. Since 1957, when measurements began, the maximum stage recorded has been 37·7 ft, corresponding to a discharge of 180,000 cusecs. Because of their torrential character, without storage works the rivers are a very unreliable source of irrigation water. They also expose the more easily commandable lands adjoining them to flooding.

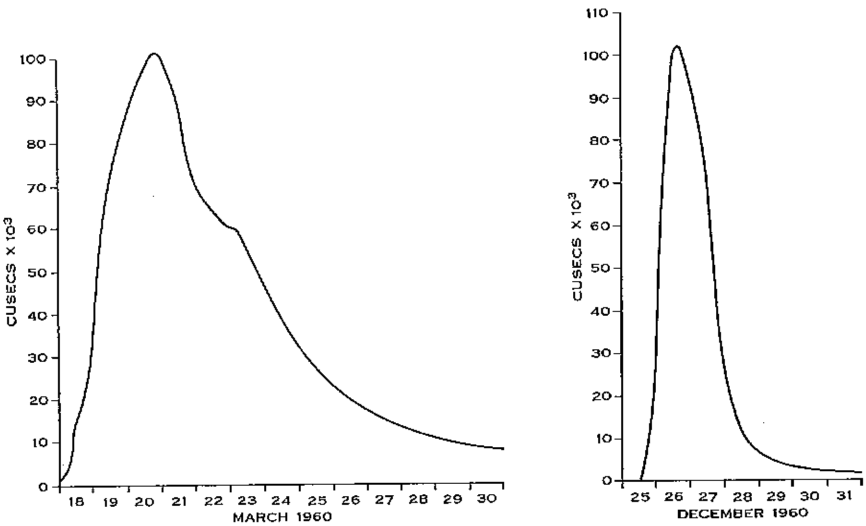

Fig. 15.—Typical flood hydrographs of Fitzroy River at Fitzroy Crossing (1960).

The existence of several apparently excellent dam sites on the Fitzroy, Margaret, and Lennard Rivers offers possibilities of large-scale flow control. Some of these sites are currently under study by engineers of the Western Australian Government. Dimond Gorge on the Fitzroy River would provide a reservoir with an active storage capacity of 3·5 million ac ft and a safe annual off-take of 0·75 million ac ft. On the Margaret River a dam near Mt. Ball could store some 0·5 million ac ft. The safe annual off-take has not yet been determined, but the size of the catchment and its rainfall suggest that it may be of the order of 0·4 million ac ft. On the Lennard River investigations are insufficiently well advanced even for preliminary storage and controlled flow estimates.

Without more detailed topographical surveys and more river height records the effect of storage reservoirs on flood hazard cannot be properly assessed. However, it is possible that the extent and frequency of flooding could be appreciably reduced.

The amount of silt carried by rivers, which would affect storage reservoirs and other irrigation works, appears to be moderate. In samples collected at Fitzroy Crossing in 1960, with flows ranging from 17,000 to 69,000 cusecs, the maximum silt content was less than 0·2% and the average 0·09% by weight.

(b) *Improved Utilization of Water Resources*

The degree of possible improvement in the utilization of water resources may range in intensity and cost from better use of natural flooding to an orthodox irrigation system involving a high degree of water control.

(i) *Natural Flooding*.—Most of Djada land system, the lower parts of Gogo land system, and parts of Alexander, Fossil, and other land systems adjoining major streams are subject to seasonal flooding. These flood-prone areas carry Mitchell grass and blue grass–ribbon grass pastures, which are the most productive of the area. Some of these have been over-grazed and show signs of deterioration (Part VII). Careful pasture management, with particular attention to rates of stocking and time of grazing, can therefore be regarded as a major step in the improved utilization of naturally flooded areas. Further improvement may be possible through the introduction of new species, especially flood-tolerant legumes. Success, however, is likely to be dependent on prior correction of the phosphate deficiencies common in local soils (Part V). In view of year-to-year variations in the extent and intensity of natural flooding, and hence in the productivity of riverine pastures, fodder conservation may provide another means of increasing production.

Improved utilization of natural flooding does not necessarily involve engineering works. On the smaller streams it may be possible to extend flooding, and to make it more reliable, by relatively simple and inexpensive earth works. This has been tried with some success at Calwynyardah station. However, on the major rivers the works required would be substantial and costly, and it is doubtful whether they would be economically justified.

(ii) *Controlled Flooding*.—Provision of storage reservoirs would permit regulation of the extent, duration, depth, and, what is most important, the time of flooding. Without more knowledge of the effect of flooding on natural and improved pastures the best methods of flood control and their benefits cannot be estimated. Particularly the value of out-of-season "flash" floods merits investigation. Apart from dam construction costs, flood regulation would involve a minimum of capital investment in engineering works. It is possible, however, that the improvement in productivity of the riverine pastures would be insufficient to justify the cost of the necessary storage reservoirs.

It has been suggested that in areas where natural flooding is relatively frequent, but is neither too deep nor too destructive to engineering works, the degree of flood regulation necessary for rice production could be achieved by supplementary pumping.

This system has been tried at Camballin, where considerable problems have been encountered in controlling natural flooding. As a result the system has been changed to orthodox irrigation during the season when there is little natural flood danger.

(iii) *Orthodox Irrigation.*—On the engineering side, this system of development of water resources involves not only the provision of storage reservoirs but also proper reticulation installations, including weirs or pumping units and distributory channels, a drainage network, and in many areas flood-protection works. Thus it requires considerable capital investment in addition to that of dam construction. It therefore demands intensive land use, but offers possibilities for a wide range of crops and for irrigated pastures.

There are areas, described below, with topography and soils suitable for irrigation and free from flood hazards. However, in some of these commandability by gravity or low-lift pump irrigation is doubtful. Until further survey work and engineering investigations are carried out these doubts cannot be resolved. Unfortunately, most of the more easily commandable areas appear to be liable to flooding and show broken microrelief, which would increase the costs of water application. Many of them may be difficult to protect against floods. However, where the flood hazard to engineering works is not great they could be used for dry-season cropping.

With similar environmental conditions and similar economic limitations imposed by geographical location, intensive irrigation farming in the West Kimberleys is likely to be similar to that being evolved on the Ord River. Experimental experience gained in the latter area at the Kimberley Research Station should be largely applicable to local conditions, although this would have to be confirmed by local experiment.

(*c*) *Possible Crops*

(i) *Cotton.*—Results achieved with cotton at the Kimberley Research Station are promising (Thomson and Basinski 1962). The average yield for three seasons, 1959–61, is 2200 lb seed cotton per acre. The lower rainfall in the West Kimberleys should be advantageous to irrigated cotton-growing. It is likely to present less serious drainage problems and to simplify control of weeds and pests. Because of lower winter temperatures, successful cotton-growing in the dry season is even less likely in the West Kimberley area than on the Ord, where experiments have shown that to achieve satisfactory results cotton should be planted between November and early March. This eliminates cotton as a possible crop in areas liable to flooding, unless protection can be provided. As in the Ord area, insect pests may prove to be a major limiting factor. In a preliminary trial at Camballin, a regularly sprayed crop yielded 1800 lb seed cotton per acre and the yield of an unsprayed crop was 450 lb per acre.

(ii) *Oil Crops.*—Recent experimental yields of dry-season oil crops at the Kimberley Research Station are of the order of 3000 lb/ac for safflower and 2000 lb/ac for linseed. Promising results have also been obtained in initial trials with oil-seed *Brassica* crops. It is evident from research at the Station that the relatively restricted planting period is one of the most important factors affecting production of these crops (Beech and Norman 1963). The dry season is likely to be longer under West Kimberley conditions, and earlier planting may be feasible in view of a lighter March and April rainfall. What could be more important, late planting in June and early July might also give satisfactory results because the cool winter season is approximately a month longer in this area than on the Ord. The lower winter temperatures could in addition prove favourable to yield and oil content.

The summer oil crops, soya beans, sesame, and castor, have proved less successful under Ord valley conditions; they have suffered from drainage deficiencies and from severe insect pest damage. They would, however, merit trial under the drier conditions of the West Kimberleys. On lighter soils, where digging should not be difficult, irrigated peanuts would be worth trying. Yields of over 3000 lb/ac were achieved with this crop in early experiments at the Kimberley Research Station.

(iii) *Rice.*—This crop has been grown at Camballin on the lower Fitzroy for a number of years, with results ranging from failure to yields of 1½ tons of paddy per acre. In contrast to the Ord area, no major stem-border damage has been recorded. Some experimental work on time of planting for a number of varieties has been carried out. It has been shown that, as on the Ord, *indica* varieties are better suited to the wet summer season and *japonica* varieties to the dry winter season. Sub-*japonica* varieties of American origin give the most satisfactory results with mid or late wet season planting. No really satisfactory variety for March or April planting (i.e. when the flood danger has largely passed but water supplies are still comparatively plentiful) has yet been found. As on the Ord, nitrogen nutrition is likely to prove the key to major yield increases.

(iv) *Other Cash Crops.*—Tobacco may prove a suitable crop for the infertile light soils of the pindan country. Even with the recent fall in prices the crop is likely to justify costs of the pump irrigation which might be necessary to command these soils.

Encouraging results have been obtained with sugar-cane at the Kimberley Research Station. The average annual yield of plant crops and up to three ratoons for the best varieties has ranged from 30 to 40 tons of cane per acre. There is no apparent reason why sugar-cane should not perform equally well in the West Kimberleys, providing market conditions justify production.

Experience in the Ord valley indicates that summer-grown sorghum and winter-grown wheat should prove satisfactory, although at present prices they might not be as economic as cash crops. On the lighter levee soils, production of a range of tropical and subtropical fruit crops should also be possible.

(v) *Fodder Crops.*—Animal industry is, and will remain, the main form of production in the area. At present it provides practically no outlet for fodder crops, and methods of husbandry would have to be revolutionized before an appreciable demand for these crops was created.

Results at the Kimberley Research Station indicate that the growth of tropical fodder legumes and graminaceous crops during the winter season is slow. On the other hand, lucerne does not survive the wet summer season. No satisfactory fodder crop for the dry season has yet been found, although *Brassica* spp. show promise provided nitrogen is adequate. Research on fodder crops has lately been intensified and the results are likely to be applicable to West Kimberley conditions.

IV. Major Potential Irrigation Areas

(a) *Margaret River Area*

The area extends from the Margaret (Macdonald) Gorge — a possible dam site — to the Gogo homestead some 8 miles below Fitzroy Crossing. It includes lands mapped as the Djada, Gogo, Fossil, and Alexander land systems. On the basis of irrigation potential and problems it can be classified into three land types.

(1) Flood-plains, which include the Djada land system and lower parts of the Gogo land system. Liability to seasonal flooding is the main factor limiting suitability for irrigation. It may be possible to protect at least some parts by closing the gaps in river levee banks. This, however, has to be confirmed by further engineering investigations. Clayey soils, and uneven microrelief caused by numerous stream lines and depressions, would make water reticulation and drainage difficult.

In view of these obstacles, pasture improvement based on controlled flooding would appear to be the most promising approach to the better utilization of this land type, which is estimated to cover approximately 60,000 ac.

(2) Levee lands of the Gogo land system, which adjoin the Margaret and Fitzroy Rivers in a belt seldom more than 2 miles wide. Although most of the levee lands are not prone to flooding, it is reputed that those in the Fitzroy Crossing–Gogo homestead section are subject to intermittent floods. The levee belt is broken in several places by drainage channels and depressions. This would complicate the reticulation layout and thus increase the cost of irrigation. Even within the larger levee blocks microrelief is often uneven and land levelling would be essential. The levee soils vary in texture but are generally well drained, and should prove suitable for a wide range of crops. Except in the immediate vicinity of the rivers and major streams the land is lightly timbered and clearing costs should not be high. The area of levee lands is estimated at 68,000 ac. Until more data on flood risks and commandability of different parts are available the actual proportion of usable land cannot be determined. It may, however, be as little as one-quarter.

(3) Black soil plains of the Fossil and Alexander land systems. This type of land offers the main possibilities for irrigation development in this area. Most of the black soil plains are flat and water reticulation would be simple. The slopes, mainly of the order of 1 : 500, are suitable for both reticulation and drainage. The occurrence of gilgais would necessitate some land levelling. There are, however, more dissected parts of the plains, found mainly in the vicinity of major streams (e.g. Mt. Pierre Creek, Baobab Creek, Brooking Creek), which show uneven relief and are also subject to flooding. The heavy cracking clay soils of the Cununurra and Wonardo families should be suitable for a range of crops, although they present tillage and waterlogging problems and would require careful husbandry. Clearance of the grasslands and open grassy woodlands characteristic of this type of land should be easy and cheap.

Without more information on the general levels of the plains and the amount of water available from the Margaret River the extent of the possible irrigation area cannot be assessed. Parts of the area may not be economically commandable from the Margaret storage. Moreover, the quantity of water available from storage may be inadequate for the full development of all suitable land in the area. The possibility of using Fitzroy waters is at present under engineering study. The area on both banks of the river between the Margaret Gorge and Gogo homestead, approximately 15 miles wide, was surveyed by Christian and Stewart (1952, unpublished data), who estimated the acreage of black soil plains suitable for irrigation at 100,000 ac, with a further 17,000 ac of land liable to flooding and with uneven topography. Appreciable areas of Fossil land system were excluded from this investigation.

(*b*) *Fitzroy River Area*

The area extends from the Gogo homestead to the Fitzroy River mouth. From the viewpoint of irrigation development, an area mapped as Alexander land system (mostly on Alexander Island but extending over the Forrest anabranch near Quanbun) is of particular interest. A more detailed topographic and soil survey of this land is required to confirm its suitability for irrigation. Field data from the present survey and examination of air photographs indicate that the area is nearly flat, so there would be no major topographic difficulties in providing reticulation and drainage works. The soils, which belong to Cununurra family, are suitable for a wider range of crops in spite of their physical limitations. Open grassland vegetation with sparse trees and shrubs presents no major clearance problems.

However, the area is liable to flooding. An aerial survey on February 13, 1962, showed a major part of the area to be under shallow flooding, estimated at 12 to 18 in. deep. The maximum river stage recorded on the Fitzroy Crossing gauge at the time of survey was 38 ft 9 in. It is considered that a flood of this magnitude has an estimated 5-yr recurrence interval. Floods up to 2 ft higher can be expected. Local rainfall (0·89 in. at Cherrabun and 2·36 in. at Quanbun during the week preceding the aerial survey) contributed little to the flooding, which was caused mainly, if not entirely, by heavy falls in the higher parts of the catchment. It is thought that a barrage near Alligator Hill, together with a system of levee banks, could provide the required flood protection and, in addition, gravity irrigation for the area.

Between Alexander Island and the river mouth the more easily commandable lands belong almost entirely to the Djada and Gogo land systems. Uneven topography and many flood hazards limit the irrigation potential of these areas, though there are isolated areas of levee lands which are not liable to flooding. Although the aggregate area of these is appreciable, individually they are not large enough to justify the major structures which would be necessary to provide gravity irrigation. Most of these areas are frequently isolated by floods during the wet season, and hence their use for summer or perennial crop production would be further complicated by inaccessibility. In special circumstances their use for the production of dry-season fodder crops, pump irrigated, might be justified. In the more distant future, given favourable market conditions, they could be used for the production of such crops as tobacco, fruit, and vegetables.

As in the Margaret River area, controlled flooding combined with pasture improvement appears to offer the best prospects for the development of flood-prone lands. The areas which are at once sufficiently level, not flooded too deeply, and large enough to justify installation of the pumping equipment necessary for rice production and dry-season irrigation appear to be confined to the vicinity of Camballin, where development is already in progress.

Parts of the pindan country included in Camelgooda and Calwynyardah land systems may be commandable at a reasonable cost by a low-lift pump or even by gravity irrigation. Because of high soil permeability, special irrigation equipment such as sprinklers or perforated pipes would be necessary. The inherently low fertility of the soil would have to be improved for most crops. Both these factors would increase production costs. Nevertheless, the possibilities of producing tobacco, fruit, and in special conditions even field crops (e.g. oil seeds) cannot be completely discounted.

There is a small area east of the river mouth mapped as Alexander land system. This may be suitable for irrigation. However, it adjoins the tidal reach of the river, and saline irrigation water might be a problem.

(c) *Lennard River Area*

The area extends from the Napier Range to the tidal delta and includes Djada, Fossil, Gogo, and Alexander land systems.

The levee lands of Djada land system are generally narrow, and towards the junction of Lennard and Barker Rivers are much broken by stream lines and flood-plain deposits. However, just below Windjana Gorge there is a broad levee covering nearly 4000 acres, presenting no major problems of water reticulation and with soils suitable for a large range of crops. It is reputed to be not subject to flooding.

The areas of black soil plains of Fossil land system found on both banks of the Lennard below the Windjana Gorge are probably the most promising for irrigation. The south-western part of the larger area on the south bank is, however, dissected by numerous channels and depressions associated with Mt. North Creek, which would hinder water reticulation.

There are also substantial areas of black soil plains of Fossil land system, adjoining the Barker River and extending towards the Hawkstone Creek, which would be worth considering for irrigation if water were available from either the Lennard or its tributaries.

The uneven terrain of Gogo land system and its partial liability to flooding make it unsuitable for large-scale orthodox irrigation development, and increased productivity would mainly depend on controlled flooding and pasture improvement. This obviously does not exclude the possibility of small-scale irrigation on the levee lands.

The areas of Alexander land system along the Lennard River are probably mainly above flood level. A large proportion of them is, however, dissected by stream lines which would create reticulation problems. A topographic survey would be essential to determine the irrigation potential of these apparently otherwise suitable lands.

(d) *Other Areas*

There are undoubtedly limited areas of irrigable land along the upper reaches of the Fitzroy, Margaret, and Lennard Rivers and their tributaries, and also along the Robinson River, where an area of black soil plain of the Fossil land system on the southern bank appears to be promising. However, the provision of adequate and sufficiently reliable water supplies presents a considerable obstacle to their development.

V. Future Research

Because of environmental similarities, research results from the Kimberley Research Station should be largely applicable to the West Kimberley area. Nevertheless, this would have to be confirmed by local investigations. For this purpose a research substation in the vicinity of Fitzroy Crossing would be desirable. The urgency of its establishment would be governed by general development plans for the area, which may be affected by the progress of the Ord project. However, it is important for agricultural studies to be coordinated with engineering investigations. Insufficient agricultural information may delay or affect the success of development projects considered possible by engineers.

Problems of the improved utilization of flooded lands are not included in Kimberley Research Station work, and research at the substation could be largely oriented towards them. In addition, some work could be undertaken on better use of the inland pastures.

VI. References

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Thomson, N. J., and Basinski, J. J. (1962).—Cotton in the Ord valley of northern Australia. *Emp. Cott. Gr. Rev.* **39**: 81–92.

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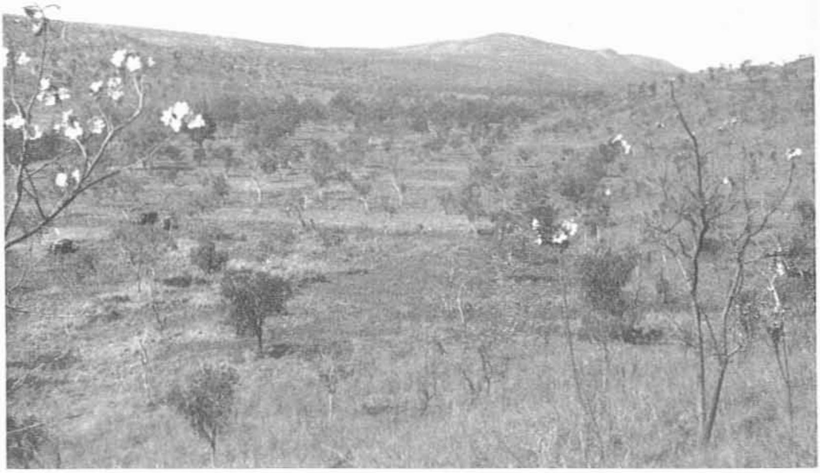

Fig. 1.—The basic mapping unit used is the land system (an area or group of areas throughout which there is a recurring pattern of topography, soils, and vegetation). The Looingnin land system comprises 6 units: (1) basalt hills, (2) quartzite ridges, (3) lower slopes, (4) cracking clay plains (restricted), (5) drainage floors, (6) channels. It is characterized by shallow red basaltic soils with outcrop and open grey-box grassy woodlands with white grass–annual sorghum; also cracking clays with ribbon grass–blue grass. It has a moderate pastoral value.

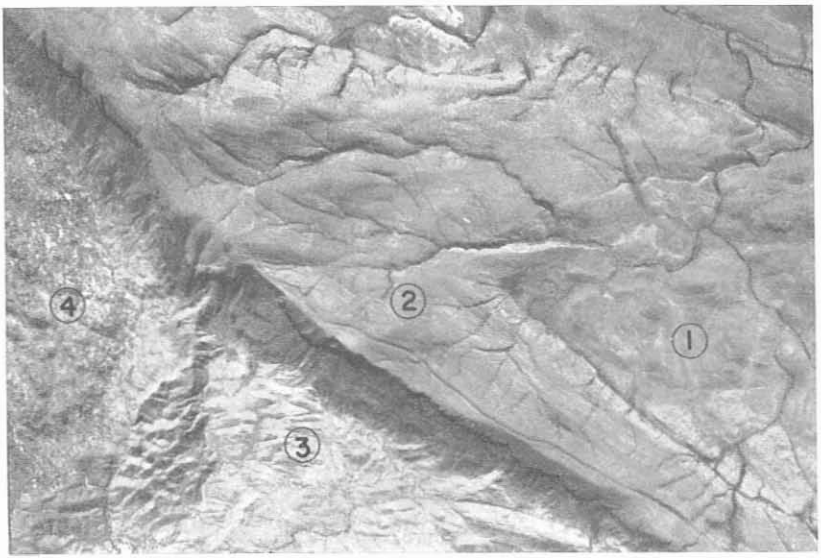

Fig. 2.—The method of survey is based on the assumption that the pattern of topography, soils, and vegetation of each land system is expressed on the air-photos by a distinctive pattern. This aerial view shows four patterns: (1) basalt mountains and hills of Looingnin land system (Plate 1, Fig. 1), (2) inaccessible quartzite mountains and plateaux of Precipice land system (Plate 2, Fig. 1), (3) mountainous country on crystalline rocks of Richenda land system (Plate 6, Fig. 2), and (4) granite domes with intervening alluvial flats of Amy land system.

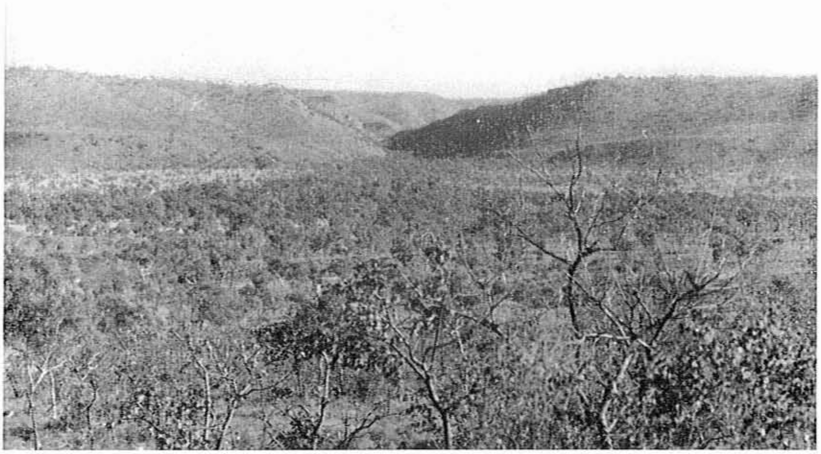

Fig. 1.—The area is divided into two major topographic divisions: Fitzroyland division and the southern part of the North Kimberley division. The oldest landscape element, the Kimberley surface, has two parts, the High Kimberley surface (skyline) is mainly immaturely dissected quartzite plateaux, the Low Kimberley surface is seen as rock-cut platforms below skyline. The erosional land systems are classified according to whether they form a part of, or have been produced by dissection of, either the Kimberley surface or the Fitzroy surface. In this way the relationships of inherited land forms and weathering profiles to their soil and vegetation cover are made clear. The skyline ranges are typical of the Precipice land system.

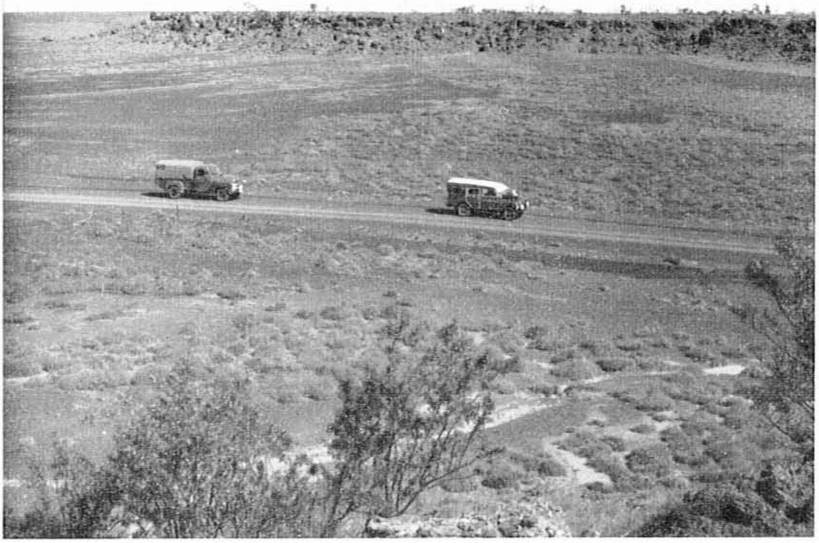

Fig. 2.—The Low Kimberley surface (with lateritic breakaway seen on the skyline) comprises the partially dissected plains of Fitzroyland division. The Fitzroy plains occur downslope. The Margaret land system (illustrated) is formed by dissection of the Low Kimberley surface and is part of hard spinifex pasture land. Similar pasture lands have been grouped into types of country.

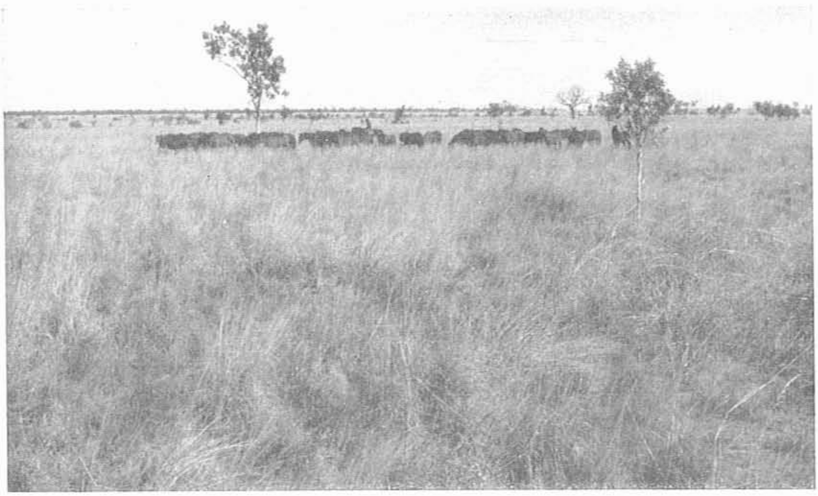

Fig. 1.—Mitchell grass country occurs on the flood-plains of the major stream lines and on the cracking clay plains associated with limestone and shale. It is characterized by a complex of Mitchell grass, ribbon grass–blue grass, and frontage grass pastures, with some spinifex in one of the pasture lands. Plants grow rapidly during the wet season but dry off quickly in the dry season leaving the grazing animal dependent on dry standing fodder for most of the year. Nevertheless, the wealth of perennial and annual grasses, and scattered top feed, provide a balanced diet that has been rated as good pasture. These pastures, because of abundant waters, were the first to be utilized and have carried the major proportion of stock ever since. The horses, in the charge of a stockman, are a part of a mustering plant.

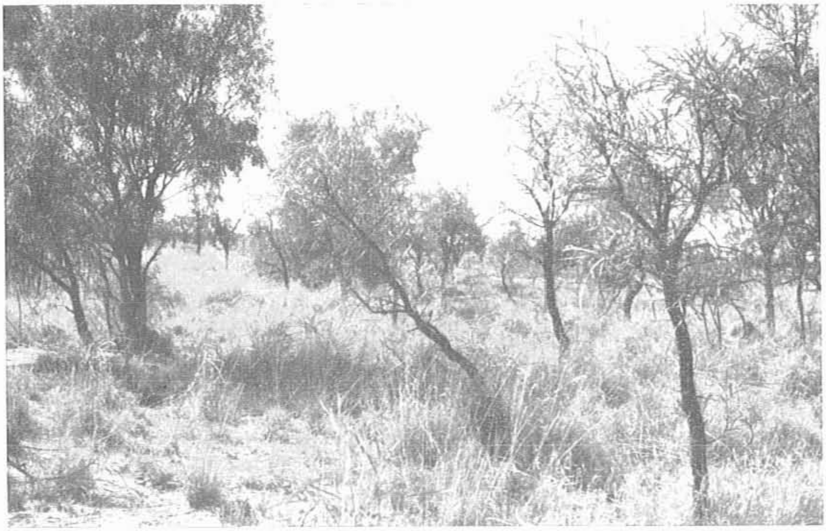

Fig. 2.—Ribbon grass country occurs on gently sloping alluvial and outcrop plains with yellowish loamy soils. It is characterized by ribbon grass (*Chrysopogon* spp.) associated with many other perennial and annual grasses including many commonly associated with the cracking clay plains. This country is rated as moderate pasture land. It has carried large numbers of sheep and many parts have been excessively grazed, producing severe degeneration.

Fig. 1.—Volcanic country covers a wide topographic range including basalt hills, undulating country, and cracking clay plains. Although characterized by the unpalatable white grass (*Sehima nervosum*) (illustrated), its value is increased by other grasses including the blue grasses and plumed sorghum. The extensive cracking clay plains are characterized by ribbon grass–blue grass pastures. Volcanic country is rated as moderate pasture land.

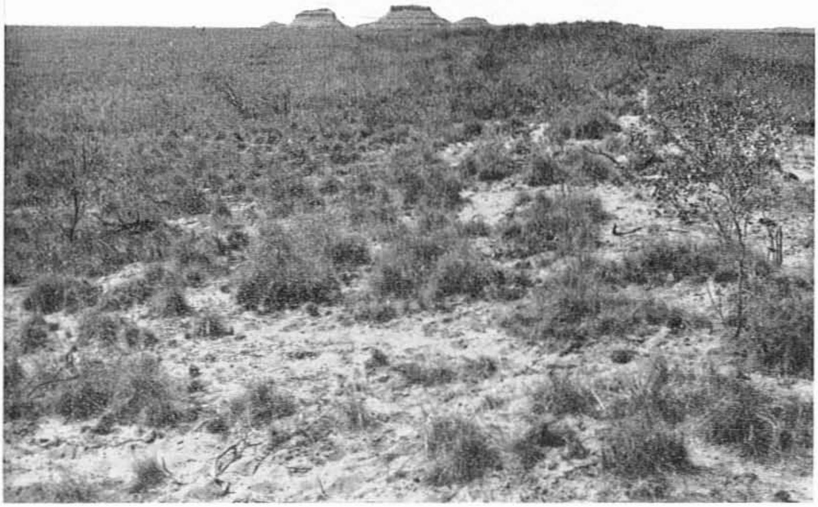

Fig. 2.—The term pindan is locally applied, rather loosely, to country with a range of reddish sandy soils carrying a characteristic vegetation cover of low scrubby woodlands with an open tree layer of stunted bloodwoods, *Bauhinia* sp., ironwood, and paperbarks. *Acacia* spp. form a prominent tall shrub layer with curly spinifex–ribbon grass. In the drier parts (illustrated) the tree layer is absent while in higher-rainfall parts it grades into tall woodland. This is useful country where it is adjacent to better country providing wet-season grazing when stock are moved from frontage country because of danger of flooding and bogginess of soils.

Fig. 1.—Spinifex country (not including inaccessible country) occupies approximately one-quarter of the area. Of the four pasture lands the spinifex–short grass pasture land (illustrated) is the most valuable, being rated as of poor to moderate value. It comprises a complex of curly spinifex and short grasses as well as inclusions of many other pasture types in restricted habitats.

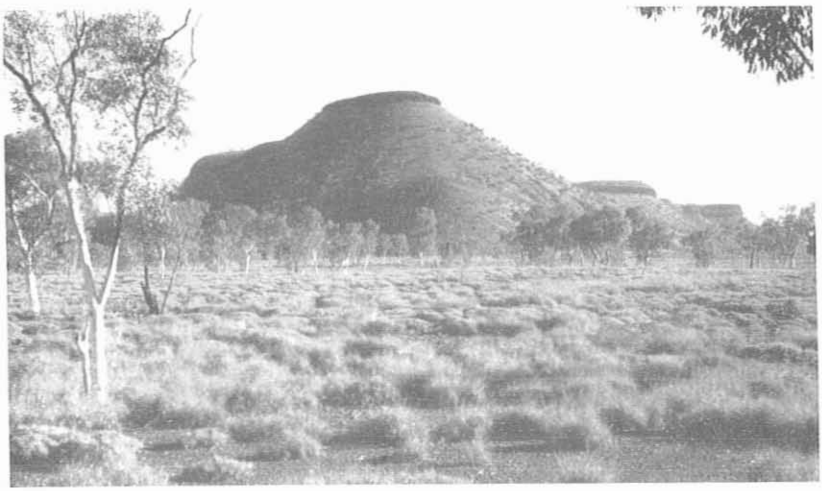

Fig. 2.—Curly spinifex pasture land is characterized by curly spinifex. In the higher-rainfall parts associated grasses include *Sorghum* spp. and in the lower-rainfall parts the less favourable sites are occupied by hard spinifex. Ribbon grass and other better grasses occur on valley floors and other favourable sites. There is little or no top feed. This land provides a subsistence diet and drought reserve but has a low carrying capacity. Its value is higher where adjacent to better country. Inaccessible country is shown on the skyline.

Fig. 1.—Hard spinifex lands are very extensive in the drier parts of the area (under 20 in. rainfall). The soils are extremely varied but mainly reddish, shallow, skeletal, or sandy. Pastoral value is very low and depends on small inclusions of better pasture types along the stream lines and other favoured sites and on the few other plants that grow in the inter-tussock spaces. It is unlikely that pasture improvement would be economic. Inaccessible country is shown on the skyline.

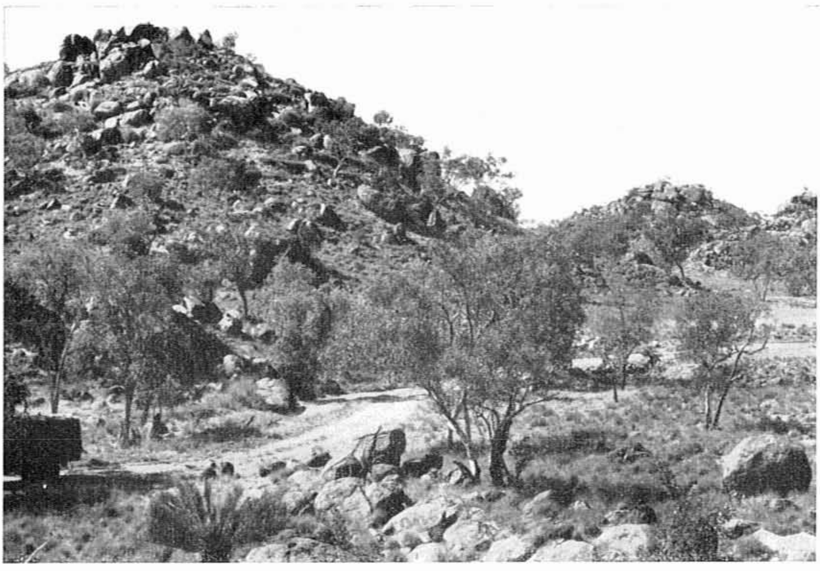

Fig. 2.—Inaccessible country occupies about one-quarter of the area and includes rugged mountain ranges, elevated plateaux, and rocky steep hills, on a wide range of rock types. It is largely inaccessible to stock and extremely difficult to muster. It is characterized by various spinifex pasture types. Parts adjacent to better country may be utilized but it also has a nuisance value as it is commonly well watered and provides a hide-out for scrub bulls. It is useless pastorally.

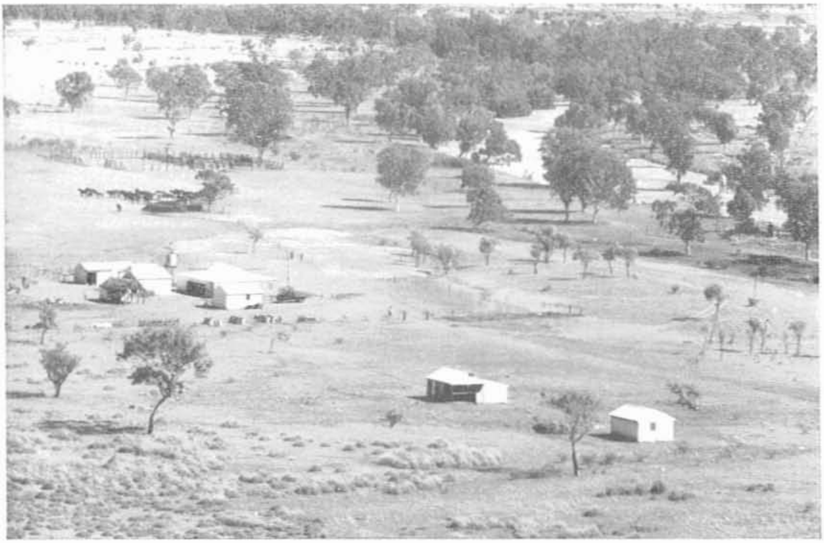

Fig. 1.—Cattle-grazing is the most important industry in the area although sheep occupy a large portion of the Fitzroy flood-plains (Mitchell grass country) and the Fitzroy plains to the north (mainly ribbon grass and pindan country), in the central part of the area. Many of the stations are more than a million acres in area and the station homesteads (illustrated) are many miles apart.

Fig. 2.—There was rapid build-up of stock numbers from 1885 to 1912, when a run of bad seasons and deteriorated pastures produced a rapid decline which continued to about 1950. Continuous heavy grazing and excessive trampling have combined to produce extensive tracts of country as illustrated.

Fig. 1.—Since settlement, wallabies have increased to plague proportions, and on many stations outnumber the stock. Not only are they able to compete favourably for the choicest grazing with domestic animals but during the dry periods they do extensive permanent damage to the grasses by digging out the nutritious roots and rhizomes of perennial grasses. Donkeys also, no longer used for transport, have increased to tens of thousands.

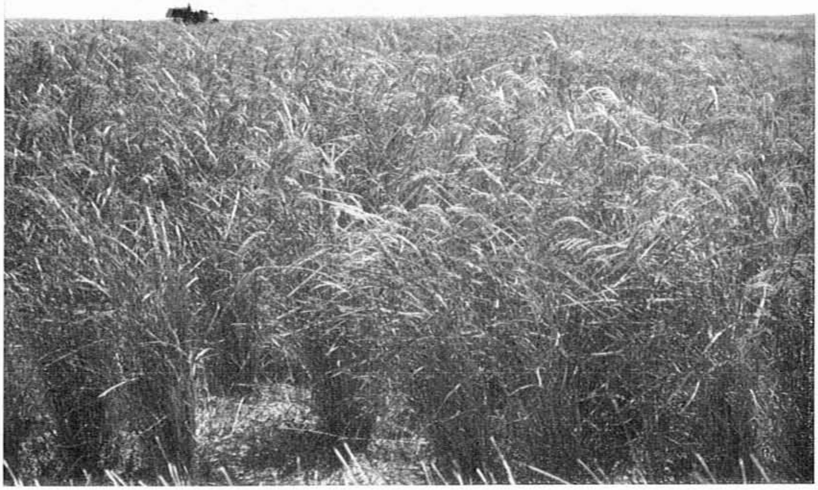

Fig. 2.—Dry-land agriculture is not recommended because of the unreliability and shortness of the agricultural growing season. Large rivers, excellent dam sites, and extensive areas of cracking clay soils associated with the flood-plains of the larger rivers and plains associated with limestone country offer the possibility of a range of irrigated crops including cotton, oil seeds, and rice, if the problems associated with commandability and flooding can be overcome.