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SITE-VEGETATION MAPPING IN THE NORTHERN JARRAH FOREST (DARLING RANGE)

2. LOCATION AND MAPPING OF SITE-VEGETATION TYPES

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101689—(1)

CONTENTS

101889—(2)

CONTENTS—*continued.* Page

TABLES

FIGURES

PLATES

101889—(3)

SUMMARY

Spatial relationships between various land parameters in the northern jarrah region were studied in four test areas spanning the main east-west environmental gradient in the region. Each test area was a catchment of a minor stream, ranging in size from 1 823 to 2 789 ha. They were surveyed on a grid pattern. At each grid point, records were made of topographic parameters, rock outcrops, topsoil, timber stand parameters and composition of the vegetation. On this basis, a number of maps were produced, and these were combined by means of a computer program (MIADS) to determine the joint occurrences of the various parameters. The ratio of observed occurrence to occurrence expected if the parameters were totally unrelated was used as a measure of the strength of the relationship. In general, strong relationships were found between the various parameters. This indicates that the region is a strongly integrated continuum with a high degree of predictability, so that both ordination of the vegetation and geomorphological classification of the landscape can be used for land-use planning on an ecological basis.

SITE-VEGETATION MAPPING IN THE NORTHERN JARRAH FOREST (DARLING RANGE)

2. LOCATION AND MAPPING OF SITE-VEGETATION TYPES

SECTION I

INTRODUCTION

The investigations described in Bulletin 86 (Havel, 1975) were primarily concerned with the detection and definition of biologically meaningful site-vegetation types. These were related to each other by means of a multi-dimensional framework based on principal component analysis. Each site type was viewed as a segment of the multi-dimensional continuum, or alternatively as a cluster of plots or a nodum. Each site-vegetation type was described in terms of forest stand characteristics, understorey indicator species and site characteristics.

It should be realised that each site-vegetation type was, up to this stage, merely an abstraction, derived from an analysis of a large number of geographically distant plots. In view of this, little or nothing could be inferred at this stage about the occurrence of the site-vegetation types within the landscape of the Darling Range. Initially, there was no proof that they existed in real space as distinct from the mathematically derived component space.

1. TEST OF FEASIBILITY OF SITE-VEGETATION MAPPING

In order to put the site-vegetation types to practical use in planning the land use of the region, it was necessary to bridge the gap between these abstract types and the land surface of the whole region by surveying selected test areas. The test surveys, covering manageable samples of the land surface, could then be used to provide the answers to the questions of:

(1) whether the site-vegetation types exist in real space,

(2) whether the predicted site-vegetation relationships are valid within real space,

(3) whether the types could be mapped sufficiently rapidly, preferably with a high ratio of photo-interpretation to ground surveys, or alternatively,

(4) whether the occurrence of types could be inferred from features readily observed on air-photos, especially geomorphology.

The first point would be positively answered if the occurrence of the individual types within the landscape could be found sufficiently aggregated to make it possible to map them as discrete areas of adequate size.

The second point could only be answered if both site characteristics and vegetative indicators were recorded, and these were subsequently mapped separately. Given sufficient co-variance between the two, it could then be assumed that site-vegetation types provided an adequate basis for routine mapping.

The answer to the third question could only be found by using the ground survey as ground truth, against which the reliability of photo-interpretation could be tested. This would be accomplished by comparing maps based predominantly on ground surveys with those prepared by photo-interpretation alone.

A positive answer to the fourth question would be provided by the repeated occurrence of each type on a characteristic portion of the landscape. In a way, this has already been partially anticipated, for example by referring Type T to upper slopes and ridges in the high-rainfall zone and Type L to lower slopes and valley floors in the low-rainfall zone. However, these observations, based on a small number of sample plots and some preliminary reconnaissance, require more thorough confirmation before they can be accepted as a conceptual basis for large-scale surveys.

The test area approach is not new (Thomas, 1969), and has been locally applied by Havel (1968) on the coastal plain.

2. LAND CLASSIFICATION TECHNIQUES

The need for a test survey is also indicated by a review of the relevant literature on large-scale land classification. Mabbutt (1968) distinguishes three main approaches—genetic, land system and parametric.

Genetic approach

The genetic approach attempts to arrive at distinctive land units by subdivisions based on supposedly causal environmental factors. As such it is logical and hierarchical. It was also hoped that it would be universally applicable. This hope has been shown to have rather shaky foundations because the environmental factors do not operate in the same mode, or at the same level, throughout their whole range. Equally serious is the fact that first subdivisions are very general, and this vagueness is, of necessity, transferred to lower levels of subdivisions. The genetic approach lacks precision for more detailed surveys. Its main usefulness is in providing world-wide comparison of more detailed local or regional surveys. This is essentially all that it could be used for in this project. Even if the biological significance of the various causal environmental factors was fully understood, its detailed application would be hampered by lack of maps and data.

Parametric approach

The parametric approach resembles the genetic approach in that the units are arrived at by a process of subdivision on the basis of environmental attributes, but substitutes detailed observation and measurement for logical derivation and specification. It is still in the experimental stage. Its feasibility is dependent on the availability of complex equipment such as sensors and computers for the collection and analysis of data. The main example of the parametric approach is the work of Speight and his associates (Speight, 1968, 1969; Scott and Speight, 1971; Scott and Austin, 1971).

Quite apart from the question of feasibility and reliability already discussed, the chief objection to the use of parametric and genetic approaches in the current study is that they are totally incompatible with the ecological work already completed. They are both intended to carry out the process of classification using basic environmental parameters, whereas the classification has already been accomplished by the use of vegetation as the integrator and indicator of environmental conditions.

Land system approach

No such objection can be made to the land system approach pioneered by Unstead (1933) and brought to its maximum development by the C.S.I.R.O. Division of Land Research (Christian, 1958). It is essentially empirical, as the land units or land systems are identified through their appearance on air photos. Large areas can be covered rapidly.

It is a synthetic rather than a divisive process, in that the smallest observed units are progressively combined into areas of higher order, and no single characteristic of the unit area is considered in isolation. As the accent is on the whole land complex, the concept of ecosystem or biogeocoenosis in ecology is approached, but at a larger scale. For this reason, the method is eminently suited to extend the completed ecological work to a regional scale. It is well suited for reconnaissance investigations and as a basis for initial multiple-use planning.

The chief criticism of the land system approach is its reliance on subjective recognition of landscape components and looseness of definitions. The assumption that a given land system consists of recurrent patterns of topography, soil and vegetation may not be valid, particularly as the recognition and delineation of the system is generally based on topographic patterns seen on small-scale air photos. It is, however, true that there are usually only a few independent variables, and that one of them is generally both constant and dominant over a broad area. There is thus a bond between the variables which in some cases can be attributed to common genetic origin. In fact, understanding of the landscape development (geomorphology) assists in mapping, especially where the visible pattern is not particularly clear.

Another common criticism concerns the reproducibility of land system recognition and delineation, which, as has already been pointed out, is subjective. In addition, the process involves considerable generalization and abstraction, as the individual recurrences of a land system or land unit are rarely if ever identical. The acceptance of variability within certain limits is essential, as the only alternative is the creation of a greater number of narrowly defined units. Narrowing the definition generally creates difficulty in recognising recurrences, and results in loss of the main advantages of the land system approach—speed and low cost. Mabbutt (1968) quotes only one case where actual tests of reproducibility were carried out. In this case, the chemical features of soils within land system components were found to be much more variable than physical features. He suggests that reproducibility could be improved by better sensing techniques, which would mean that some features could be seen rather than inferred, and by closer survey. Ultimately this would result in the situation where it would be just as effective and cheap to survey individual significant attributes, and the justification for the integrated land system approach would be lost.

Relationships between landscape features

Gibbons *et al.* (1968) point out that one of the major steps in the land system approach, namely the recognition of areas of high co-variance, is one function in which replacement of humans by computers is least likely to occur, because it involves judgement, intuition and purposive information seeking.

They also examine the land system approach from the viewpoint of desirable criteria, such as predictiveness, reliability and relevancy, and point out that use-relevant features may not always be correlated with visible features. By contrast, Lacate (1965) emphasises that form and structure of the terrain serve as an integrating framework for soils and vegetation. Ignatyev (1968) supports the claim that the land system approach is less laborious than separate mapping of individual attributes and their subsequent combination into a multi-purpose map.

Robertson *et al.* (1968) consider the land system approach as appropriate to the first stage of land-use planning only. Thomas (1969) sees this method as the best means of generalization and small-scale mapping. He considers the knowledge of landform genesis essential to the correct prediction of its occurrence, and recommends that the fundamental principles must be first worked out through the survey of sample areas. Geomorphology is seen by him as the most suitable basis for land surveys because it is least modified by human activity, and because landform patterns can be readily seen on small-scale photos. The use of geomorphology as the basis for soil and land-use mapping is also advocated by Bridges (1967).

Beckett (1968) points out the necessity for ground checks where delineation of land systems is based primarily on photo-interpretation. The unwarranted assumption on correlation between mappable and use-relevant features is also criticized by Benn and Grabau (1968). Both Benn and Grabau and Duffy (1965) look on mapping and classification as the subdivision of a physiographic continuum into classes.

Ruxton (1968) considers that the land system approach is likely to be most successful where parent rock, climate and relief are uniform. Under these conditions, the system is approaching the steady state, and good prediction is possible.

Conditions governing the feasibility of the land system approach

All the above experiences with the land system approach can be summarised as follows.

(1) The land system approach is suited for the early stages of land-use planning, but may lack precision for detailed surveys.

(2) The viewing of the landscape as an integrated whole, comprising climate, topography, soils and vegetation, which can be recognised on air photos, provides a means of rapid mapping over large areas.

(3) The assumption that there is integration between the various components should not be taken for granted but should be subjected to test.

(4) Best results are obtained where the development of the landscape is understood, that is if the survey is based on geomorphology.

(5) Best results may be expected in older landscapes approaching equilibrium.

3. GEOMORPHOLOGICAL STUDIES OF THE NORTHERN JARRAH REGION

The northern jarrah region (Darling Range) was considered as part of the Darling Peneplain by Woolnough (1918) and Jutson (1934). It was therefore dealt with only in the context of the western margin of the Plateau. It was studied more specifically by Clarke and Williams (1926). The more recent geomorphological studies of Playford (1954) and Churchward (1970) were based primarily on areas to the north and east of the present survey. The survey area itself was briefly described by Bettenay (1968), and an attempt was made in 1968 by Clifton (unpublished records, Forests Department of Western Australia) to extend the ideas of Mulcahy (1961) from the York-Quairading area in the north-east to the survey area itself. However, concurrent with this work, geomorphological studies were in progress in the north-eastern sector (Mulcahy *et al.*, 1972) and immediately south of the survey area (Finkl, 1971 a and b). Their published work provides an adequate geomorphological basis for extension of the detailed ecological work to the survey area as a whole.

There is a general agreement that the region is a part of the western margin of the Great Plateau of Western Australia, and that in common with the rest of the Plateau, it has been subjected to peneplanization, laterization and uplift. Furthermore, because of its proximity to the Darling Scarp and its higher rainfall, the area has been dissected to a much higher degree than the rest of the Plateau. Most workers have noted the apparent inversion of the usual sequence of the valley forms; the headwaters of most streams are in broad, open, mature valleys, which become progressively steeper and more juvenile downstream. Differences between the various interpretations lie chiefly in the chronological sequence of events, in particular whether there was one or more uplift, and whether the uplift or uplifts preceded, were concurrent with or followed the laterization. This may seem a highly theoretical point in relation to the avowedly applied land-use study. It is considered here because of its far-reaching implications. If laterization took place on a low-lying peneplain prior to the uplift, as postulated by Woolnough (1918), then primary laterites should be restricted to a relatively narrow altitudinal range. This in turn means that any soils occurring below this level would be developed from fresh country rock, and would be unaffected by laterization except perhaps for downward wash of lateritic material from the Plateau above. Soil and site mapping would be relatively simple in this context.

If, on the other hand, the uplift preceded laterization, or if there were several minor uplifts some of which preceded or were contemporaneous with the laterization, then primary laterites may be expected virtually anywhere within the landscape, and the site mapping would be correspondingly more difficult.

Jutson

Jutson (1934) postulated that the broad, mature north-south trending valleys (Meckering level), which are set only 60 m below the main Plateau, are associated with the first uplift. The second, major uplift increased the erosive power of the westward-flowing shorter streams and enabled them to head-off and capture the older north-south streams. He also considered the granitic monadnocks, such as Mt. Dale and Mt. Cooke, to be remnants of an earlier cycle of erosion. According to Jutson, there would be five main surfaces:

(1) the residual monadnocks,

(2) the former peneplain, now a plateau,

(3) the older shallow north-south drainage system,

(4) the younger, east-west, deeply incised drainage system,

(5) the Scarp, resulting from several movements.

Playford (1954) postulated that laterization occurred after uplift and dissection. He based this on the observation of laterite occurrences from 60 to 300 m altitude in the Geraldton District.

Mulcahy

Mulcahy *et al.* (1972) claim that laterite pallid zones up to 30 m in depth occur under all landscape elements, with the exception of the most deeply and sharply incised valleys and some monadnock summits and slopes. Within the north-eastern sector of the survey area they recognize the following units.

(1) Laterite-mantled uplands, a remnant of the Great Plateau, found in the form of ridge tops and summits. The ironstone gravels and boulders occurring there were often found to be composed of recemented fragments, and therefore were of a detrital nature. The shallow depressions within the upland are mostly filled with pisolitic ironstone gravels or yellow-brown sands. The entire unit is underlain by a deep pallid zone.

(2) The Goonaping Valley unit represents flat-foored valleys of the divides, which predate the uplift. The soils are frequently lateritic podzols (grey sands over ferruginous gravels and pallid clays) or deep podzolized sands. The valleys are set 30-60 m into the upland, and are deeply weathered underneath.

(3) The Beraking Surface consists of somewhat narrower but still flat-floored valleys, downstream from 2. The soils in this unit are chiefly sands over dense, domed clays, presumably of solonetzic origin, usually poorly drained.

(4) The Nockine Surface consists of long gentle 5-10° slopes, between 3 and 1. The soils here are chiefly colluvial sands and ironstone gravels over deep pallid zones. At the upper limit of the Surface, near its junction with the lateritic uplands, there may be a small scarp with exposure of pallid zone clays or underlying rock.

(5) Dissected lateritic slopes are a complex of valley spurs capped with lateritic ironstone gravel and moderate slopes on which pallid zone clays and outcrops of fresh rock are inter-mixed. The soils are chiefly yellow podzolics. The type occurs below 1 and 2 and above 3, and is in some ways analogous to 4. The dissected slopes reflect greater erosional activity, and generally occur where there is a greater altitudinal gap between the lateritic upland and the Beraking Surface.

(6) The Darkin Surface consists of moderately steep (up to 20°) valley slopes downstream and below 1, 3, 4 and 5. The common soils are reddish and yellowish loamy colluvials derived from a mixture of lateritic ironstone, pallid-zone clays and fresh rock. Outcrops of fresh rock are moderately common.

(7) The Helena Surface consists of steep (up to 30°) rocky slopes of narrow, deeply incised valleys near the Scarp, and the Scarp itself. It occurs below 1 and downstream from 6. There is virtually a complete absence of any deep weathering either in the form of ironstone gravels or pallid clays. The soils are podzolic over fresh rock at shallow depth.

(8) High-level granite residuals above the lateritic uplands are usually flanked by colluvial deposits of sand and gravel. No details of these are given.

In interpreting their findings, Mulcahy *et al.* (1972) rely primarily on the depth of weathering under valleys in postulating that laterization has proceeded concurrently with a number of uplifts. The Goonaping Valley unit is viewed as the equivalent of Great Plateau valleys eastwards of the line of drainage rejuvenation, and thus dates prior to any uplift. The Beraking and Darkin Valley forms, with progressively steeper slopes, are consequently viewed as successive stages of rejuvenation due to two uplifts. The still steeper Helena Valley form is considered to be possibly due to increased efficiency in downcutting and removal of weathered material and therefore not necessarily associated with a third uplift. Changes in river gradient, nick-points between two adjacent valley types and hanging valleys of the Goonaping Type are also used as additional proof of the above hypothesis.

Finkl

The very detailed and voluminous thesis of Finkl (1971b) is much more difficult to review. This can be partly attributed to the very large number of newly named surficial materials and soil types which are used in building up the hypothesis. Secondly, the area studied in detail by Finkl is one of considerable geological as well as geomorphological complexity. Nevertheless, there can be no doubt about the value of the work, particularly in view of the very large amount of soil profile description and chemical and physical analyses carried out in the course of the investigations.

The findings of Finkl are, at least in essence, comparable with those of Mulcahy *et al.* (1972). Finkl describes a Westralian drainage system for the Great Plateau as a whole, remnants of which occur within the area. On the basis of associated features such as lakes, upland swamps and lunettes, it would seem to correspond at least to some degree to the Goonaping Valley unit of Mulcahy *et al.* Further similarity can be seen in Finkl's comment on the paler, sandier weathering profiles developed on these materials as compared with those on crystalline rocks nearby. The Westralian drainage system has been dissected by the newer Darling drainage system near the Darling Scarp, though further inland there is often a coincidence between the two (palimpsest). Within the Darling system Finkl recognizes three main valley forms.

The first of these, the Darling Valley form, is described as being broad and shallow, 150 m wide and 25 m deep on average, with the valley floor about 50 m wide and side slopes of 5-8°. It is possible to relate it to the Beraking Valley of Mulcahy *et al.* The second valley form of Finkl, named Balingup, is described as 300 m wide and 50-150 m deep, with 15-20° slopes and valley floors 80 m wide. It tends to occur below the Darling Valley form. The Balingup Valley form of Finkl is probably sufficiently broadly defined to include both the Darling Valley form and the dissected lateritic slopes. The Bridgetown Valley form, the third described by Finkl, is very much wider (1 600-2 000 m) and deeper (250-300 m). Its slopes are steep, ranging from 15 to 40°. Its valley floor is also much wider and terraced. It is restricted to the main river valley and the lower reaches of its main tributaries.

In view of the much smaller size of the Helena Valley, as compared with the Blackwood, the correspondence between these two valley forms of Mulcahy *et al.* and Finkl respectively is only partial.

On the basis of his investigation, Finkl hypothesizes a three-stage uplift resulting in the development of the Darling, Balingup and Bridgetown Valley forms. The deep laterite weathering occurred when the landscape was already moderately dissected with slopes up to 10°. This undulating, laterized landscape was further dissected by the erosional processes which are still operating at present, but the major landscape features have remained practically unchanged.

On the basis of this hypothesis, Finkl then attempted to predict the distribution of various soil types within the landscape, and concluded that the prediction was likely to be more successful on the stable Darling Plateau than on the dissected landscape. On the Plateau, the usual sequence of soil characteristics from the ridges to the valleys is an increase in the depth of the gravel materials over the deep weathering zone, and increasing fineness of materials towards the centre of the valley.

On the dissected surfaces, there is less gravel, but the overall situation is extremely complex, complicated not only by differences in parent materials but also by stump features and infilled valleys. These features indicate great instability, and hence poor predictability. On the steeper slopes, the deep-weathering zones (mottled and pallid zones) are less likely to occur.

Significance of geomorphological studies

The similarity of the conclusions reached by Finkl and Mulcahy *et al.* is encouraging, particularly as they are derived from the two extremes of the survey area. It indicates that there is a recurrent pattern of topography and soil throughout the whole region.

The second conclusion that can be reached from the above studies is that there is a need for a simple classification of the soils of the region. The thirty-seven soil types of Finkl, added to those already enumerated by Northcote *et al.* (1967) and Smith (1952), create a powerful argument for some standardization of nomenclature, particularly for the rather unique lateritic soils. To a lesser degree, this is also true of geomorphological nomenclature, in that virtually every new study creates a new set of names of purely local significance, despite obvious similarities.

SECTION II

FIELD WORK

1. SELECTION OF TEST AREAS

The selection of test areas aimed at a full coverage of environmental and vegetational variation. In addition, it was intended that the results should be applicable to multiple land-use planning.

The Kelmscott Division was chosen in preference to the other four administrative divisions within the survey area because:

(a) it is intermediate between the drier Mundaring Division to the north and the moister southern divisions;

(b) it has the maximum east-west span of climate, vegetation and soils;

(c) it is experiencing the most acute land-use conflict;

(d) it has well-established patterns of occurrence of the jarrah dieback disease caused by *Phytophthora cinnamomi* Rands;

(e) it was sufficiently close to headquarters to avoid camping or transfer of staff.

Within the Division, the Canning River catchment was chosen for study in preference to the Serpentine River chiefly for convenience of access, compatible with adequate coverage of environmental variation (see Fig. 1).

The individual test areas largely, though not precisely, coincide with the catchments of three tributaries of the Canning River, located from immediately above the dam to the headwaters. In addition, a catchment of one of the tributaries of the Dale River, immediately east of the Canning River headwaters, was also surveyed because it differs markedly in topography. For future reference they will be referred to as Ashendon, Cooke, Leona and Flint respectively, on the basis of the administrative subdivisions (forest blocks) in which they occur.

Subsequently, a large area of virgin forest (30.1 km^2) was surveyed in the southern half of the region, in the Harvey Division. The survey was somewhat less detailed, but in all other respects comparable to northern test areas. It will be referred to as Surface Area. In addition, one large and several smaller experimental catchments, and several experimental planting areas, were surveyed by the same method.

2. SELECTION OF MAPPING SCALE

Initially, the scale of 1 inch = 10 chains (1:7920), normally used for detailed Departmental soil surveys, was contemplated. Subsequently, this was altered to 1 inch = 20 chains (1:15 840). At this scale, there was still adequate space for entering field data on to base maps, even at the sampling intensity of 20 x 5 chains (400 x 100 metres). A further reduction to 1 inch = 40 chains (1:31 680) was also investigated. At this scale, the information was too congested for satisfactory plotting but the completed 1:15 840 maps lent themselves to further reduction.

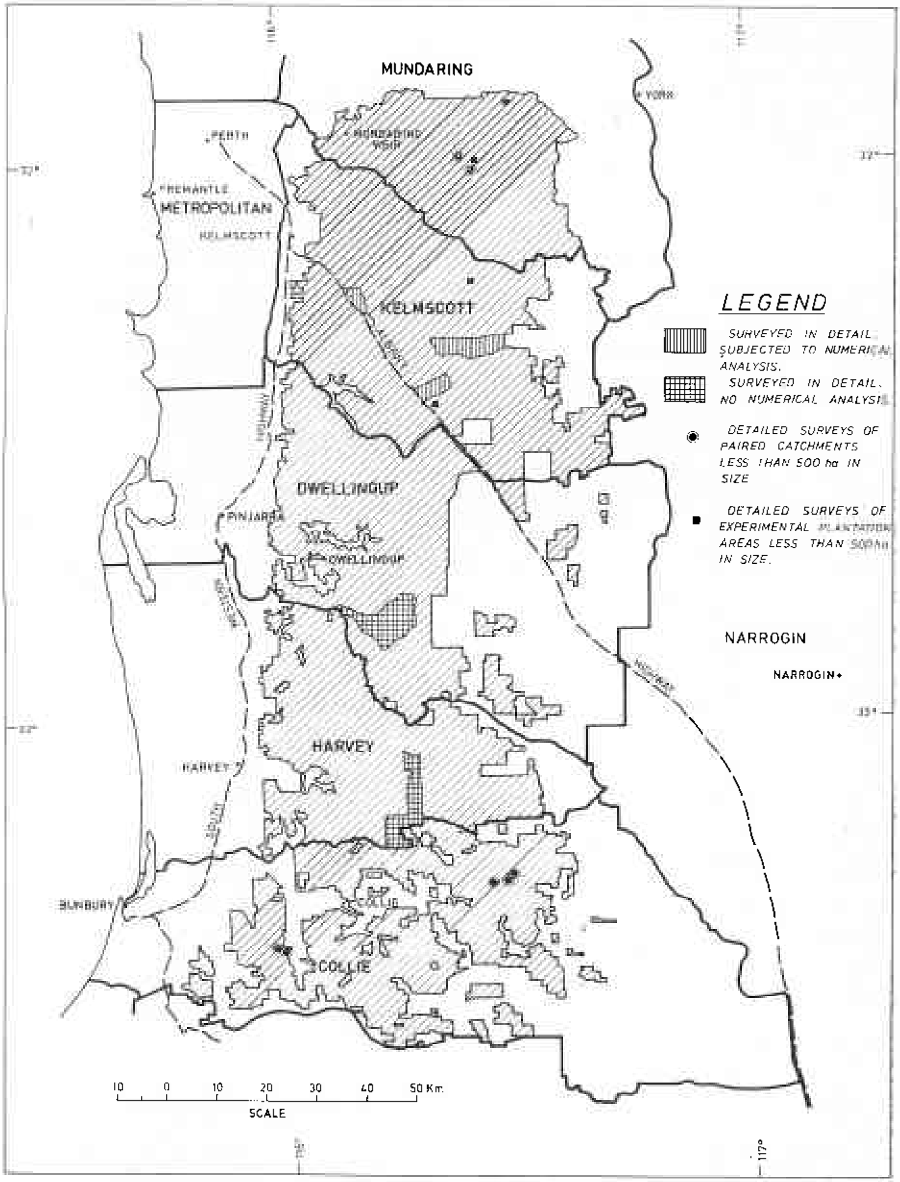


Figure I
Map of the northern jarrah region showing the location and extent of the test areas which were surveyed in detail.

The scale chosen is well within the range commonly used in land-use planning, being somewhat below the scale used for agriculture, but above that used for broad-scale regional planning (Bie and Beckett, 1970). It compares well with the scales used for vegetation mapping in Europe (Küchler, 1967) and the U.S.S.R. (Ignatyev, 1968), and does not conflict with Beckett's (1968) specification that maps should be properly adjusted to the frequency of boundaries to be mapped. Subsequent experience has shown that a larger scale would have created unnecessarily large areas of the more extensive upland features, whereas at a smaller scale, mapping of the rapidly changing valley features would have been difficult.

3. SELECTION OF MAPPING GRID

The initial selection of a 20 x 5 chain (400 x 100 metres) sampling grid proved ideal for the more accessible, heavily roaded Ashendon Test Area. For the more distant and less adequately roaded Leona and Flint Test Areas, it was necessary to increase the spacing to 20 x 10 chains (400 x 200 metres), and even to 40 x 10 chains (800 x 200 metres) when a planned prescribed burning operation imposed a deadline for completion of the survey. Fortunately there was some compensation, since the size of mappable units also tended to increase due to milder dissection of the landscape.

4. METHOD OF SURVEY

Reconnaissance

In two of the surveys (Ashendon and Cooke), considerable preliminary reconnaissance was carried out to obtain an appreciation of the range of site and vegetation types likely to be encountered. On the basis of this reconnaissance, an appropriate booking sheet was prepared which incorporated indicator species of greatest relevance to the area; for example, the high-rainfall species in the case of Ashendon and species of shallow, rocky sites in the case of Cooke.

For Leona and Flint, where a deadline set by a planned prescribed burn existed, only a brief reconnaissance was possible, and a general species list applicable to the entire region had to be used. As a result, some species which locally would have been of considerable use in the subdivision of the major types were not recorded. However, as the prescribed burn was delayed by unseasonal rains, it was subsequently possible to carry out a total enumeration of all species on several survey lines, and at least partially amend the deficiency. The booking sheets for environmental features and some quantitative non-specific features of the tree stratum were common to all test areas (see Fig. 2).

Establishment of the survey framework

Where ever suitable roads existed on the perimeter of the test areas, these were used as base-lines. Elsewhere, base-lines were cut on a bearing using a Wild compass theodolite. Ultimately all strip lines were tied by the compass theodolite survey to known survey points.

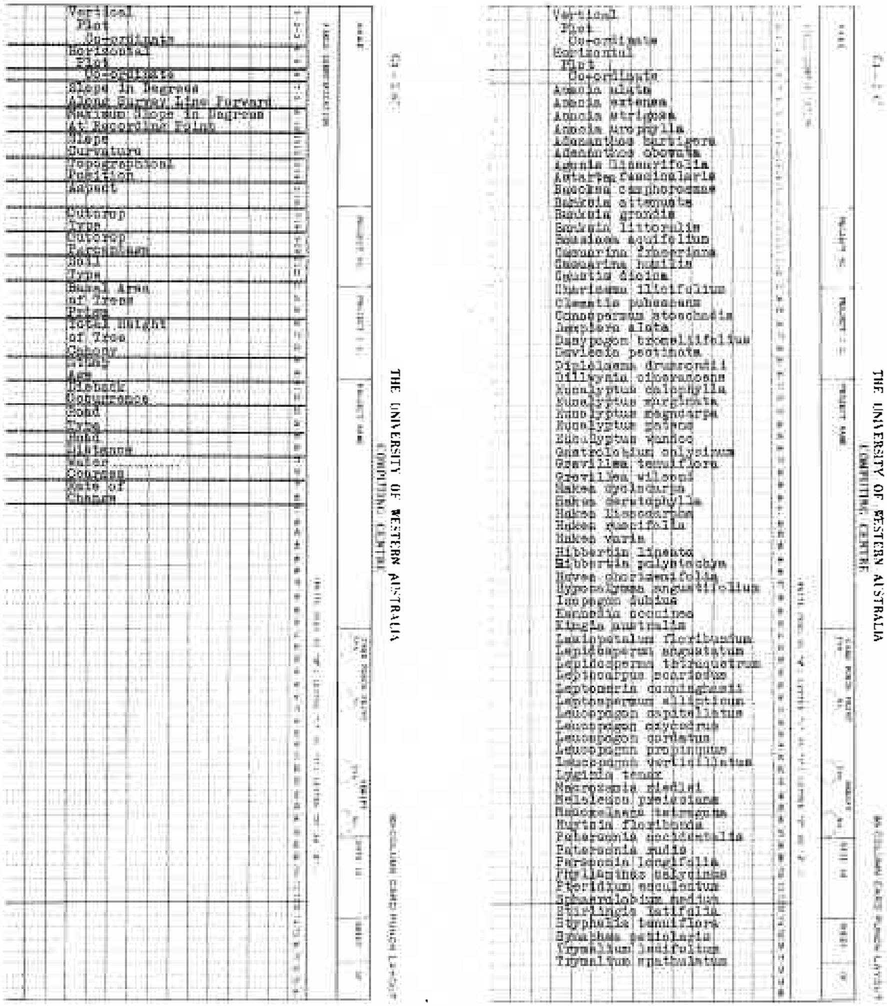


Figure 2
Example of booking sheets for vegetation and environmental features.

Actual survey

The survey team consisted of two men, one of whom set out the line using a Suunto hand compass, and recorded environmental features and tree stratum. The other assisted with distance measurements using a 5 chain (100 metre) steel band, and recorded the occurrence of plant indicators. The data were recorded on booking sheets designed for use with computers. The details of the vegetation booking sheet have already been discussed.

Environmental data recorded were as follows:

(1) Slope in degrees along the survey line.
(2) Maximum slope.
(3) Slope curvature.

(4) Topographical position.
(5) Aspect.
(6) Rock outcrop type.
(7) Percentage of area covered by rock outcrop.
(8) Texture of the surface soil horizon.
(9) Basal area of all trees (determined by prism).
(10) Height of the main canopy.
(11) Age of stumps (as a rough indication of logging history).
(12) Occurrence of dieback.
(13) Type and proximity of roads.
(14) Type and proximity of water courses.

Non-quantitative data were coded or ranked.

Because of the change-over from the Imperial to Metric System of measurement between completion of the survey and publication of the results, some of the categories now may appear to be odd, for example contour intervals and basal area classes.

Mapping

Each environmental attribute (e.g. slope, rock, outcrop, soil type) was mapped separately. Separate maps were also prepared for the attributes of the tree stratum (basal area, occurrence of dieback). Combination maps showing distribution of the various tree species were also prepared. The plant indicator data were first processed to allocate individual observations to types, and the types were then mapped. In each case, the plotted field observation was regarded as basic. Topographic maps and aerial photos were used in drawing boundaries, but this source of information was subordinate to that derived from field observations; that is, it could be used to supplement but not to override it.

Analysis of maps

In evaluating the degree of co-variance or coincidence between the various mapped attributes, two computer programs were used. The first of these was developed by Amidon (1964, 1966). The function of the program is to combine two coded maps, and to produce a combination map and a set of tables giving actual area and proportion of total area falling into each combined category. There are two versions of the program; one strictly numeric, capable of handling 98 combination categories, the other alphanumeric, capable of handling 2 304 combination categories. The latter appeared to be beyond the capacity of local computers at the time and for this reason it was the earlier, numeric program that was adopted for local use by H. Campbell. The program —MIADS (Map Information and Display System)—is flexible as to the scale of map handled. The minimum area dealt with is one sixth (4 mm) by one fifth (5 mm) of an inch, sufficient to enter a two figure number. This represents 1.33 acre (0.54 ha) at a scale of 1:15 840.

H. Campbell also developed the program CONTAB, which carries out analysis of multi-dimensional contingency tables after the method of Fienberg (1970). This program is essentially a follow-up of the program MIADS, using its tabular output. An example may help to explain its mode of operation.

31-MILE ROAD AREA—CONTOUR MAP

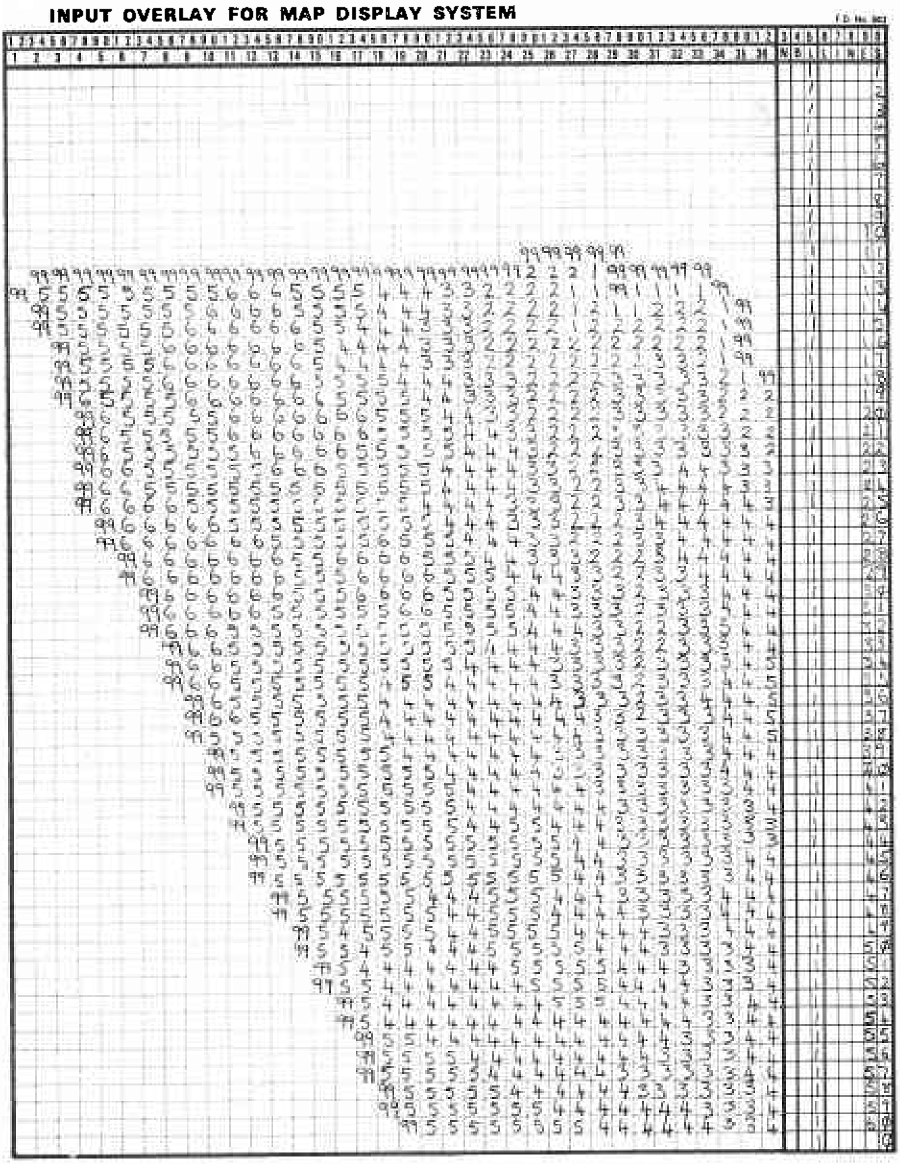
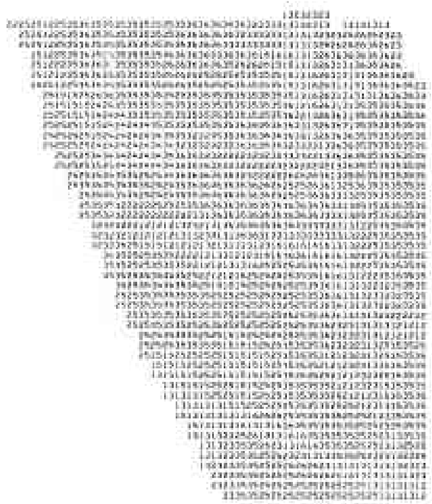


Figure 3
Example of input form for map display system.

The area falling into a combined category is determined partly by the areas of the individual categories contributing to it and partly by their mutual interrelationship. The basic possibilities are as follows.

Let us assume that the total area under consideration (T) consists of two slope categories, A (gentle) and B (steep), and two soil types, K (sandy) and L (stony). If there were perfect correspondence between the two attributes, all of soil type K (sandy) would occur on gentle slopes (A) and all of soil type L (stony) would occur on steep slopes (B). There would be no combination AL or BK. If, on the other hand, there were no relationship between soil types and slopes, one would expect proportionally the same occurrence of soil types K and L on both gentle (A) and steep (B) slopes. This can be set up as a contingency table, and tested for goodness of fit.

An example of the input form is given in Figure 3, and Figures 4 and 5 show examples of outputs by the programs MIADS and CONTAB respectively.



PAGE 1

PROGRAM MIADS(RUN ON 73/11/21)

TOTAL AREA = 1698.67
CELL TOTAL = 1274
SCALE = 15840.0
1 CELL = 1.33333 HECTARES

OUTPUT CODE	CELL COUNT	CODE AREA	PERCENT COVER	*	OUTPUT CODE	CELL COUNT	CODE AREA	PERCENT COVER	*	OUTPUT CODE	CELL COUNT	CODE AREA	PERCENT COVER
12	35	46.67	2.75	*	13	116	154.67	9.11	*	14	1	1.33	.08
15	58	77.33	4.55	*	16	33	44.00	2.59	*	21	15	20.00	1.18
22	32	42.67	2.51	*	23	63	84.00	4.95	*	24	19	25.33	1.49
25	220	293.33	17.27	*	26	50	66.67	3.92	*	31	26	34.67	2.04
32	39	52.00	3.06	*	33	32	42.67	2.51	*	34	12	16.00	.94
35	369	492.00	28.96	*	36	154	205.33	12.09	*				

Figure 4
Example of output from map display system.

31 MILE ROAD AREA SLOPE X CONTOUR COMBINATION

LIST OF DEPENDANCIES

MODEL NO. 1

OBSERVED	CELL COUNTS EXPECTED	CELL IDENTITY
16.00	11.41	1, 1,
0.00	2.52	2, 1,
12.00	15.32	3, 1,
7.00	5.75	4, 1,
176.00	118.63	1, 2,
0.00	26.19	2, 2,
108.00	159.36	3, 2,
80.00	59.81	4, 2,
201.00	212.82	1, 3,
5.00	46.99	2, 3,
228.00	285.89	3, 3,
219.00	107.29	4, 3,
373.00	427.27	1, 4,
53.00	94.34	2, 4,
613.00	573.97	3, 4,
272.00	215.41	4, 4,
692.00	630.97	1, 5,
221.00	139.32	2, 5,
856.00	847.60	3, 5,
167.00	318.10	4, 5,
109.00	165.89	1, 6,
67.00	36.63	2, 6,
288.00	222.85	3, 6,
45.00	83.63	4, 6,

31 MILE ROAD AREA SLOPE X CONTOUR COMBINATION

COMPONENT DUE TO	CHISQU. STATISTIC	D/F
MODEL 1	532.76	15

Figure 5

Example of output from program CONTAB.

The application of the survey and analysis method to the individual test areas will now be discussed.

SECTION III

DESCRIPTION OF INDIVIDUAL TEST AREAS AND OF INTERRELATIONSHIPS FOUND WITHIN THEM

1. ASHENDON TEST AREA

Location

This area covers the entire catchment of a small tributary of the Canning River, the so-called Thirty-One Mile Creek, which joins it from the west in the upper reaches of the Canning Dam, and a portion of the catchment of a neighbouring creek, which has no official name. The total area involved is 1 946 ha. It is bounded in the east by the Canning River and Ashendon Road and in the west by the Albany Highway. The northern and southern boundaries are merely survey lines. The highest point within the survey area is a ridge which reaches an altitude of 360 m; the lowest is at the confluence of the creek and the river at 198 m.

Topography, geomorphology and climate

The topography is that of an undulating dissected plateau (Fig. 6). The two creeks have the typical Darling Range sequence of profiles, from broad and shallow in the headwaters to moderately deeply incised near their confluence with the Canning River. The river itself is also moderately deeply incised into the plateau, with slopes of up to 16° within the survey area and up to 30° on the opposite bank. The fall of the main creek is approximately 19 m/km, with minor levelling above, and steepening below, the junction of the main creek with its major tributaries. The valley of the river and the lower portion of the tributary valleys fall into the Darkin Valley form (Mulcahy *et al.*, 1972); the remainder of the valleys fall into the Beraking Valley form. The rest of the area is occupied by the laterite-mantled uplands with possible remnants of Goonaping Surface within it.

The exact rainfall of the area is not known. A short distance downstream at the dam wall the average annual rainfall is 1 290 mm, and rainfall ranging from 1 200 to 1 350 mm is thus assumed for the test area. Because of the detailed nature of the survey carried out in the Ashendon Test Area, it can be used as a basis for examining the validity of the assumption that there is integration and intercorrelation between the various landscape components.

The relationship between height above sea level and steepness of slope was one of the many studied.

Effect of altitude

The total altitudinal range was subdivided into six strata, each stratum representing 100 ft (30 m) (Fig. 7). Stratum 1 referred to altitudes of 600-700 ft (183-213 m), Stratum 6 to altitudes above 1 100 ft (335 m). For steepness of slopes, four strata were established (Fig. 8):

(1) depressions less than 4°,

(2) upland plateaus less than 4°,

(3) slopes 5-8°,

(4) slopes over 8°.

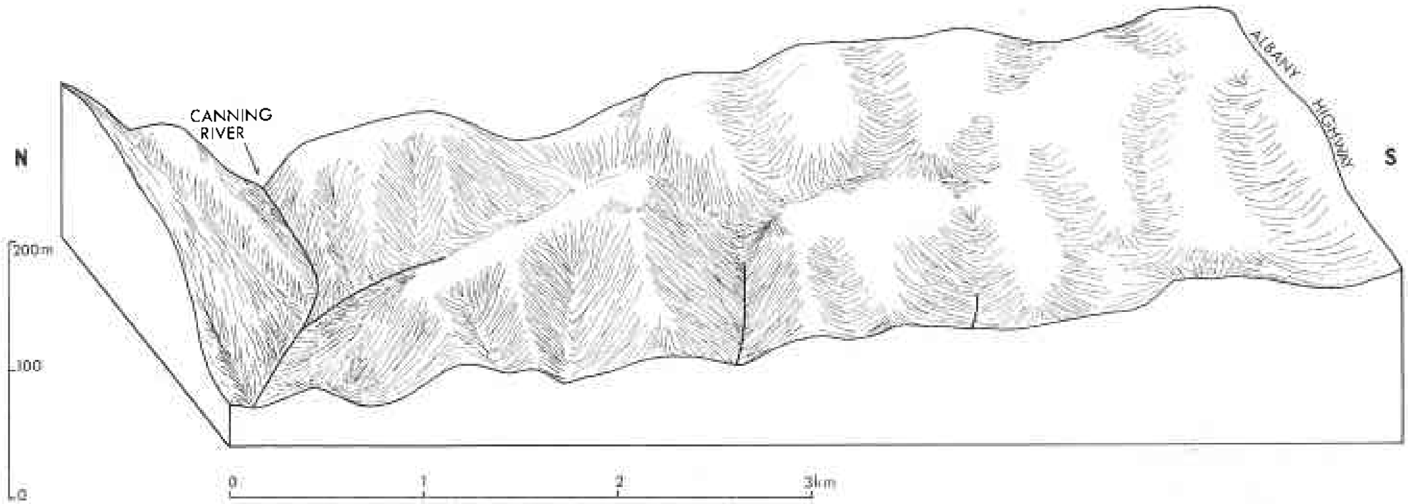


Figure 6

Three-dimensional topographic model of the Ashendon Test Area. (Central portion, east of the Thirty-One Mile Creek).

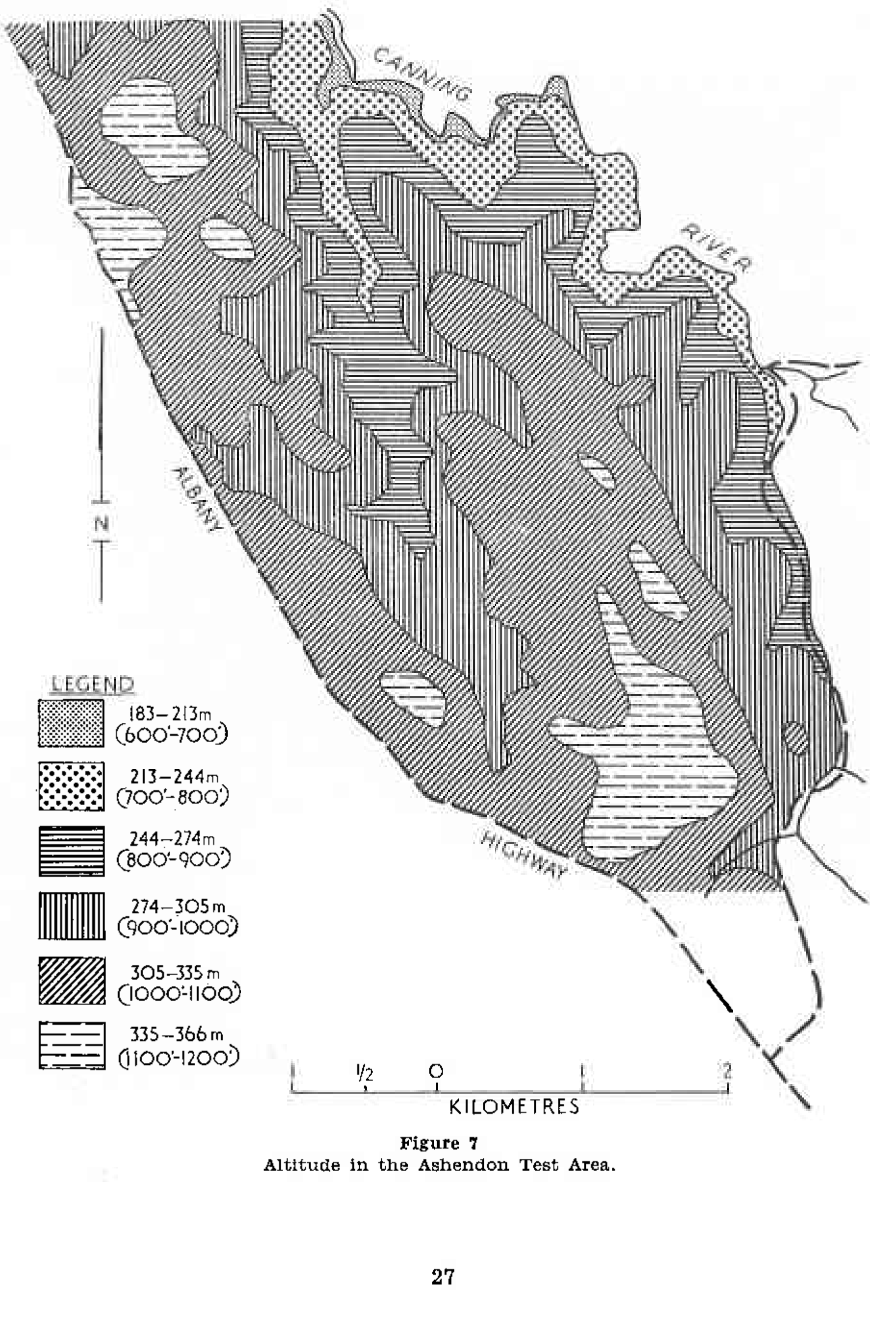


Figure 7
Altitude in the Ashendon Test Area.

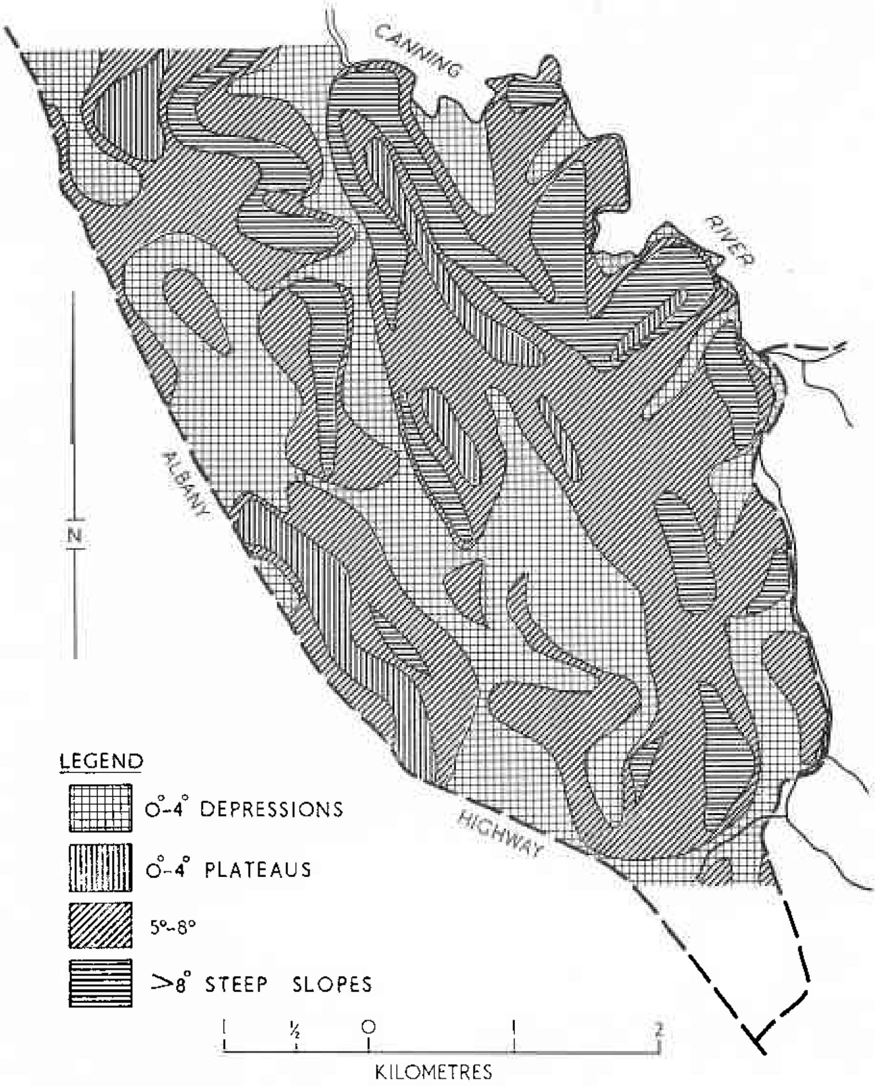


Figure 8
Slope in the Ashendon Test Area.

The two were combined, and areas falling within the various combinations were subjected to a test of independence. The contingency table (Table 1) shows the ratios of observed joint occurrences to joint occurrences expected if there were no relationship between the two elements.

TABLE 1

Relationships between altitude and slope, Ashendon Test Area.
(Ratio of observed to expected joint occurrences)

Slope Strata	Altitudinal Strata (m)					
	<213	213–244	244–274	274–305	305–335	>335
0–4° Depressions	1·4	1·4	0·9	0·9	1·0	0·7
0–4° Plateaus	0	0	0·1	0·6	1·5	1·8
5–8° Gentle slopes	0·8	0·7	0·8	1·0	1·0	1·3
8°+ Steep slopes	1·1	1·3	2·0	1·2	0·5	0·5

The departures from independence are statistically very highly significant. Some of the individual departures from expected values are axiomatic, such as the above-expected occurrence of plateaus above 305 m, and of depressions below 244 m. Others are less obvious, such as the twice-than-expected occurrence of steep slopes between 244 and 274 m, indicating that this altitude coincides with the upper limit of the newer dissection (Darkin Surface). The equally marked (half of expected) departure for steep slopes above 305 m reflects the mildly undulating nature of the main plateau. The as-high-as expected occurrence of depressions between 305 and 335 m suggests that these are probably remnants of the Goonaping Surface, even though there is not much sand now remaining in them. This idea is further strengthened by the fact that these depressions often appear at variance with the main drainage system as to direction and slope. The relationship between them appears to be either dissection or overlapping (palimpsest).

On the whole, there are a number of marked departures from expected occurrences, and these can be explained readily by Mulcahy *et al.'s* interpretation of the geomorphology of the area. The landscape elements are thus not independent of each other. On the other hand, there are no grounds for accepting that there is a full inter-correlation between them.

The above process can also be used to consider other relationships. In considering altitudinal zones and the nature of rock outcrops (Fig. 9), the major departures from expected values, assuming independence, are as follows:

(1) More granite outcrop than expected below 305 m, less granite than expected above 305 m.

(2) More basic rock (epidiorite) outcrop than expected between 213 and 274 m and above 335 m, less than expected between 274 and 335 m.

(3) Markedly less lateritic ironstone outcrops than expected below 244 m, markedly more than expected above 305 m.

(4) Markedly less outcrop-free surface than expected above 305 m, more than expected below this level.

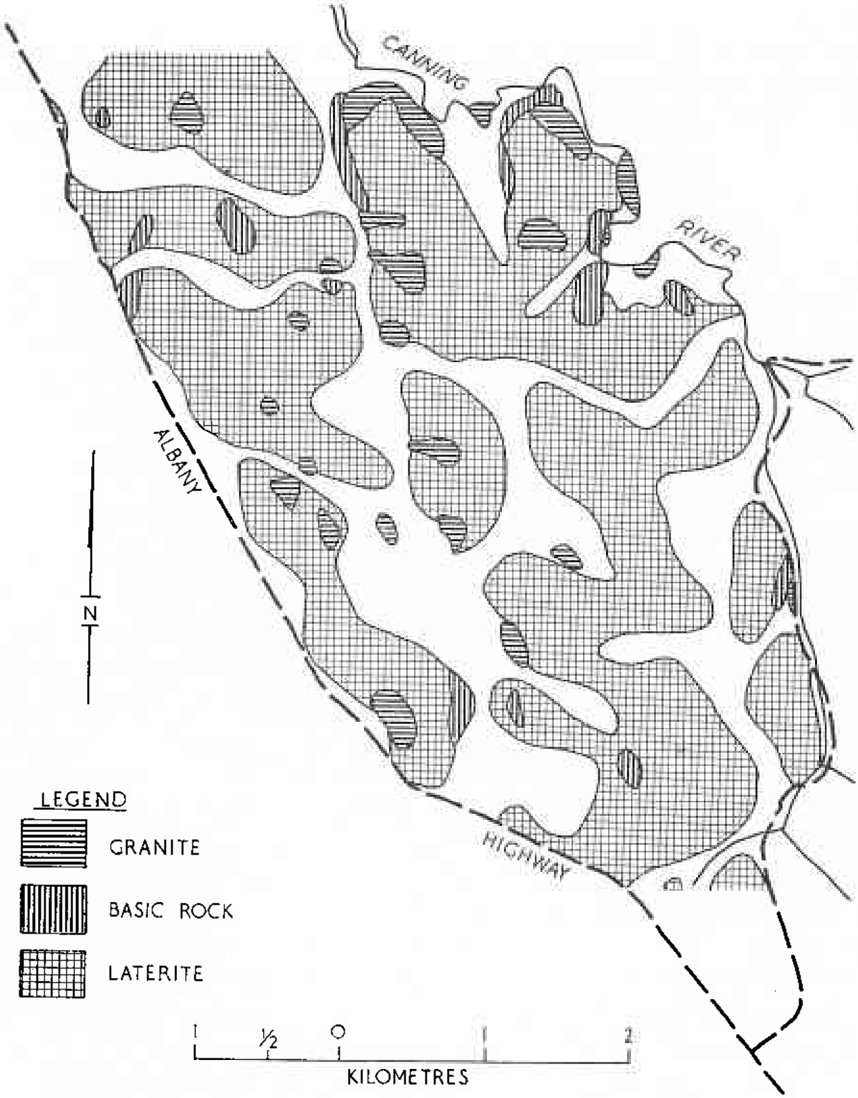


Figure 9
Occurrence of rock outcrops in the Ashendon Test Area.

This can be readily interpreted in terms of Mulcahy *et al.'s* geomorphological postulate, in that the most recent dissection, leading to the uncovering of fresh rock, occurred largely below the level of the main plateau at 305 m. The only exceptions are epidioritic floaters on the highest part of the landscape. Similarly, deposition, burying the laterite ironstone, or its removal by dissection, has chiefly occurred below 305 m altitude. However, outcrops of lateritic ironstone are found as low as 213 m, and its observed occurrence between 244 and 305 m is close to the expected occurrence. This agrees with Mulcahy *et al.'s* postulate that laterization took place in a partially dissected landscape.

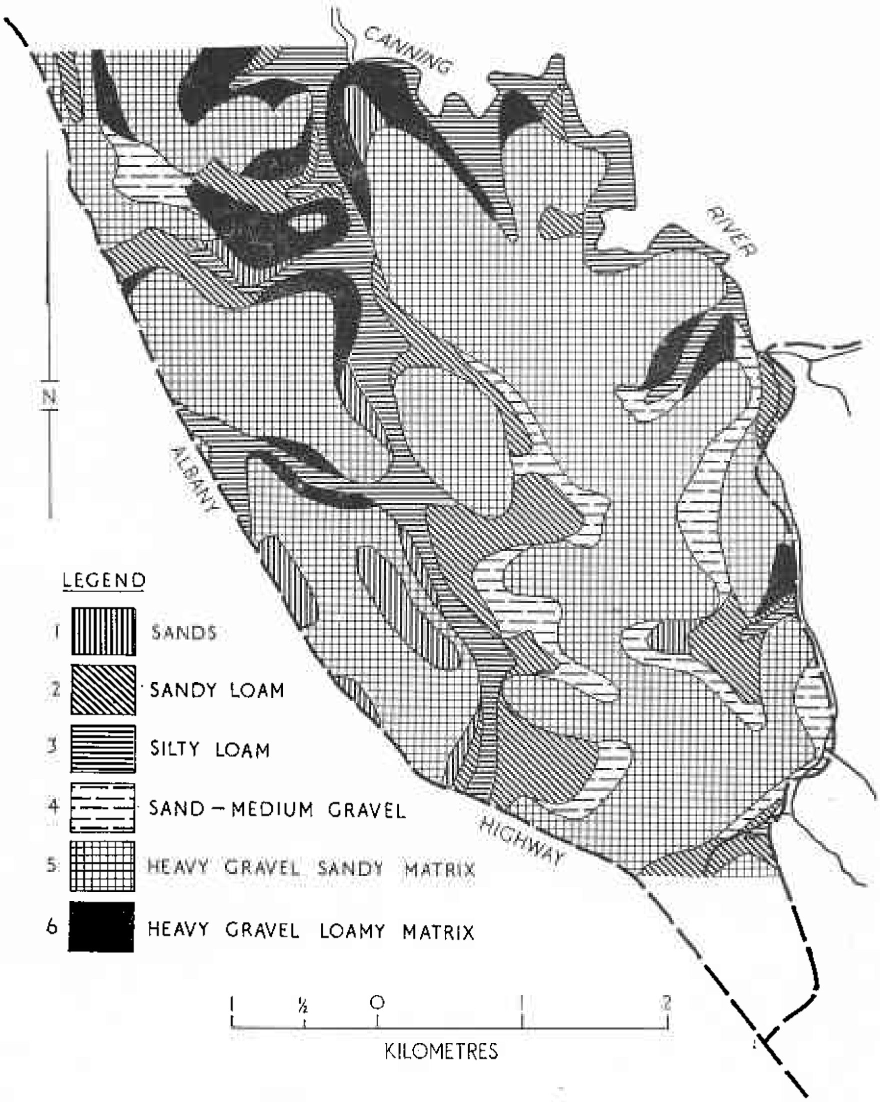


Figure 10
Distribution of soil texture types within the Ashendon Test Area.

The relationship between altitudinal zones and surface soil texture (Fig. 10) can be briefly summarized as follows. Sands occur below the expected occurrence between 203 and 244 m and again above 335 m. They occur above the expected occurrence between 305 and 335 m. Sandy loam occurs below the expected level of occurrence everywhere except between 244 and 335 m. Loams occur above the expected occurrence below 274 m, and below the expected occurrence above 305 m. The observed occurrence between 305 and 335 m is only one-fifth of the expected occurrence. No loam is found above

335 m. Sandy gravels are markedly below the expected occurrence below 274 m, and above the expected occurrence between 274 and 335 m. Heavy ironstone gravels with sandy matrix are below the expected occurrence below 274 m, and above the expected occurrence above 305 m. Heavy ironstone gravels with loamy matrix occur markedly above the expected occurrence between 213 and 274 m, and below the expected occurrence above 305 m.

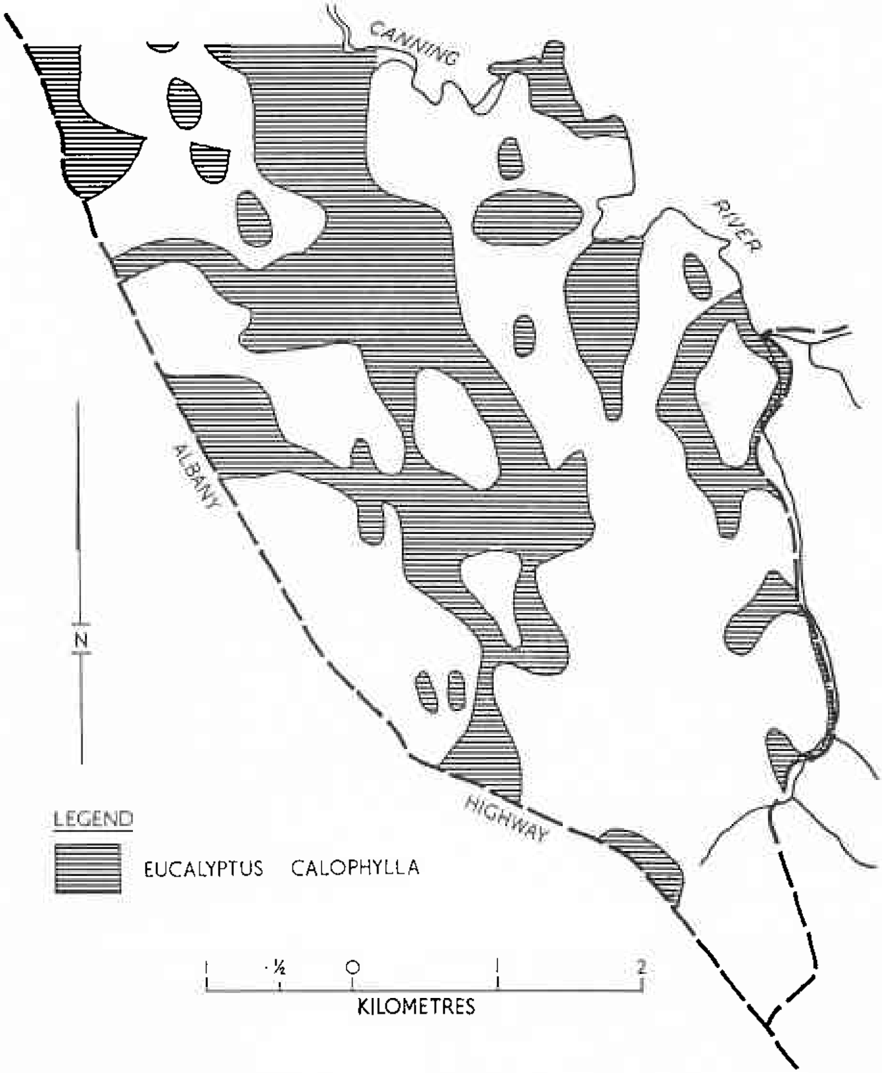


Figure 11
Occurrence of tree species in the Ashendon Test Area.
(a) Area in which *Eucalyptus calophylla* forms a significant component.

Once more, it is possible to account for the departures from the occurrence expected if altitude and soils were independent by Mulcahy *et al.'s* postulate. The soils associated with the laterite-mantled upland, in particular the residual heavy gravels with sandy matrix, occur above the expected occurrence where the lateritic landscape has as yet not been greatly dissected, that is above 305 m. The colluvial sandy gravels follow a similar pattern, except for the highest altitudinal zone. The depositional sands and sandy loams occur below and within the laterite-mantled upland, but do not ascend into the highest altitudinal zone, or descend deep into the steeply dissected landscape where they would be removed by erosion. The heavy gravels with loamy matrix,

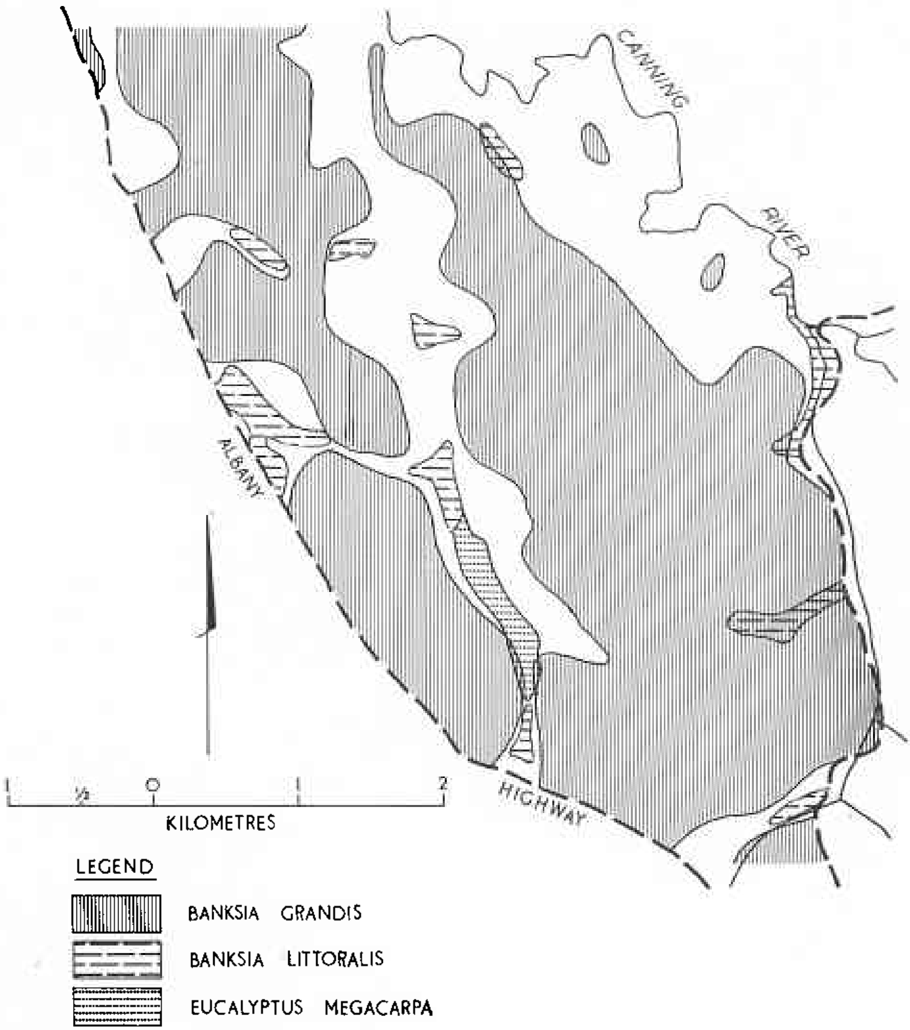


Figure 11

Occurrence of tree species in the Ashendon Test Area.

(b) *Banksia grandis, Banksia littoralis* and *Eucalyptus megacarpa,* at all levels of occurrence.

resulting from spilling of the lateritic mantle on to the erosional landscape, occur chiefly below the level of the laterite-mantled uplands (305 m). The loams are largely confined to the dissected landscape below 274 m.

The landscape elements so far discussed are essentially physical in nature, but the altitudinal zonation is also reflected in the distribution of tree species (Fig. 11). In the Ashendon area, jarrah is the overwhelming dominant over most of the landscape. It is absent only from the wettest and most fertile soils. For this reason, its distribution has not been mapped. Yarri (*Eucalyptus patens*) and marri (*Eucalyptus calophylla*) reach their optimum development

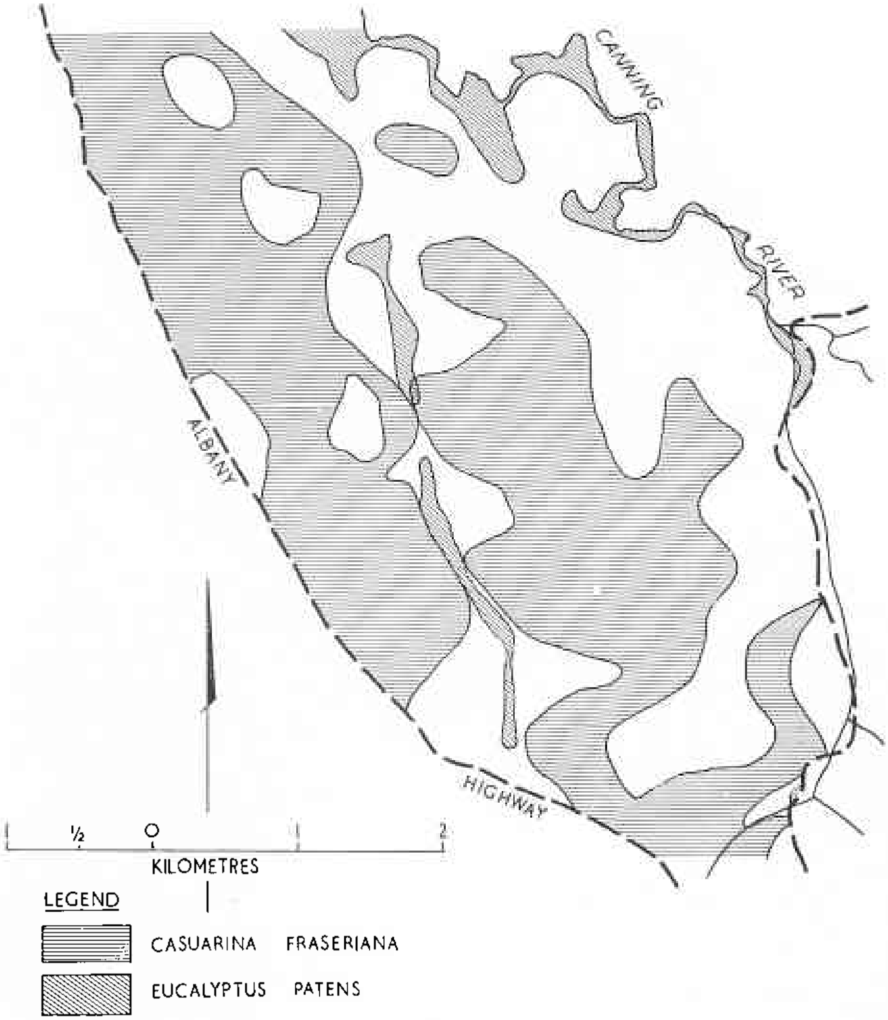


Figure 11

Occurrence of tree species in the Ashendon Test Area.
(c) *Casuarina fraseriana* and *Eucalyptus patens*, at all levels of occurrence.

below the level of the laterite-mantled upland, that is below 305 m. Bullich (*Eucalyptus megacarpa*) and swamp banksia (*Banksia littoralis*) occur mainly, though not exclusively, between 244 and 305 m, that is below the laterite-mantled upland but above the deepest dissection, in the broad upland valleys. Bull banksia (*Banksia grandis*) and sheoak (*Casuarina fraseriana*) reach their optimum development on the uplands above 305 m. Sheoak in particular is almost totally absent from the dissected landscape.

The association between dieback occurrence and lower altitudes, and high basal area of the stand and higher altitudes, is less pronounced.

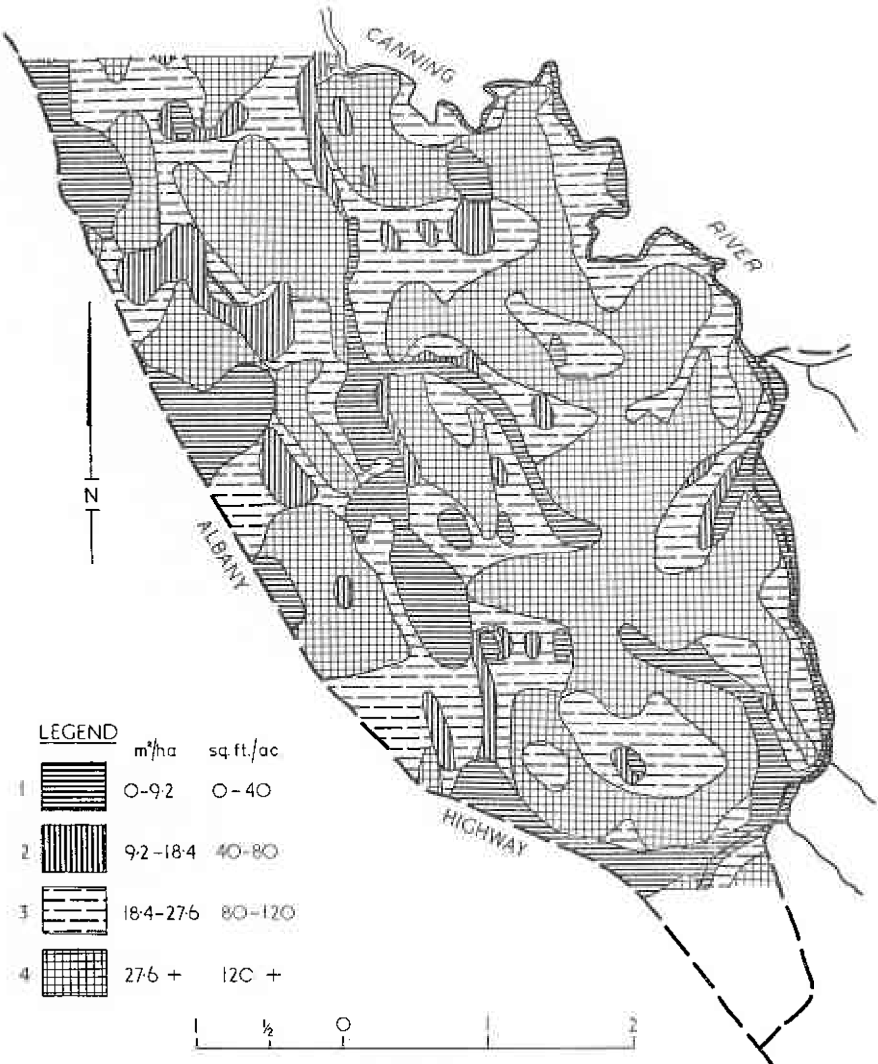


Figure 12

Patterns of stand density (in terms of basal area) in the Ashendon Test Area.

Effect of slope

Inasmuch as slope is apparently related to altitude, it would be expected that most if not all of the elements related to altitude would also bear some relationship to slope. This is in fact the case. For instance, granitic outcrops occur at almost twice and epidiorite at almost three times the expected occurrence on the steep (8°+) slopes. Outcrop-free surfaces occur at almost twice the expected occurrence in near-level depressions, but only at one fifth

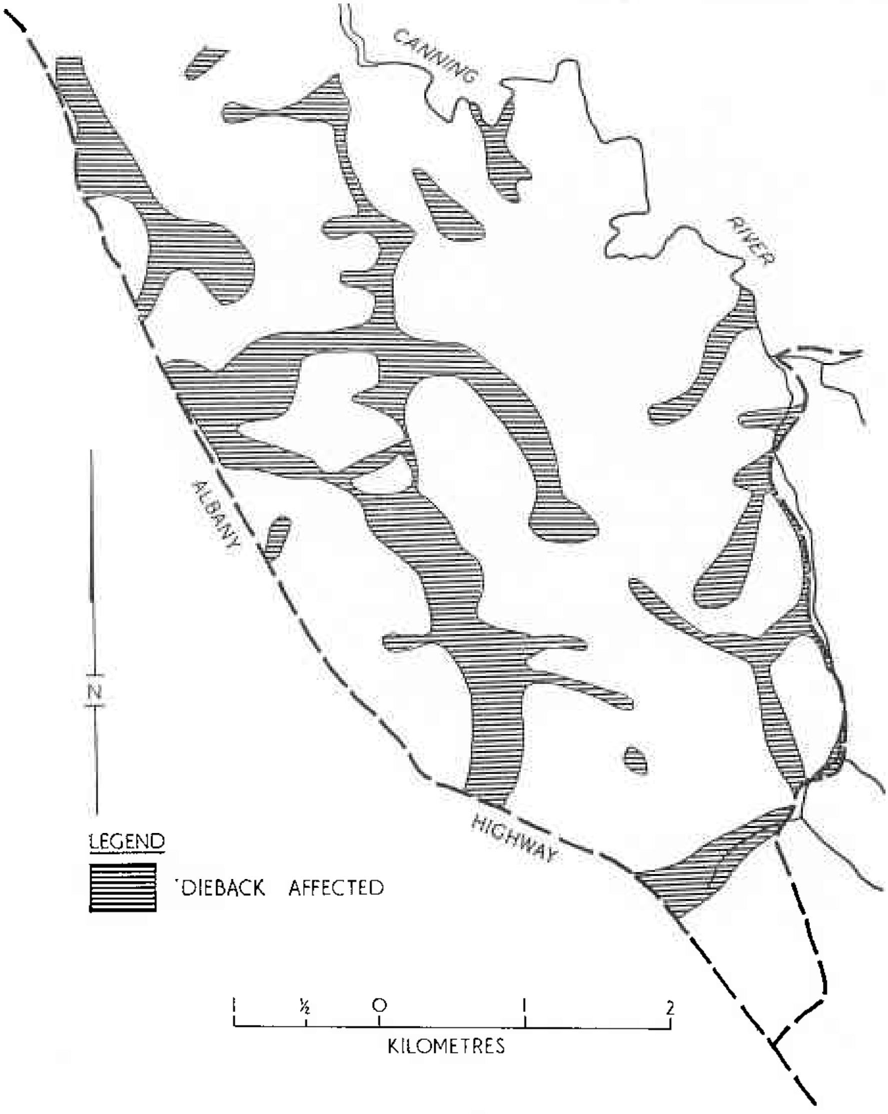


Figure 13
Occurrence of dieback disease caused by *Phytophthora cinnamomi* in the Ashendon Test Area.

of the expected occurrence on plateaus, and half the expected occurrence on steep slopes. Lateritic ironstone outcrops occur at half the expected occurrence in depressions, but are not entirely absent.

Sands occur at less than half the expected occurrence on steep (8°+) slopes. Sandy loams occur at almost twice the expected occurrence in near-level depressions, but are totally absent from plateaus and below the expected occurrence on both gentle and steep slopes. Loams occur at more than twice the expected occurrence in depressions, but at only one tenth of it on plateaus, one half on gentle slopes and one third on steep slopes. Heavy gravels with sandy matrix occur at almost twice the expected occurrence on plateaus, but at only little more than half in depressions. Heavy gravels with loamy matrix occur at half the expected occurrence in depressions, but at nearly three times the expected occurrence on slopes.

Severely understocked stands (basal area of less than 40 sq. ft/acre or 9.2 m^2/ha) occur (Fig. 12) at more than three times the expected occurrence in depressions, but only at one fifteenth the expected occurrence on plateaus, and one seventh on steep slopes. Heavily stocked stands (basal area of more than 120 sq. ft/acre or 27.5 m^2/ha) occur at half the expected occurrence in depressions, but above the expected occurrence on plateaus and slopes.

The occurrence of jarrah dieback disease (Fig. 13), a root rot caused by *Phytophthora cinnamomi*, is twice the expected occurrence in depressions, but only one tenth on plateaus, one half on steep slopes and two thirds on mild slopes. Whereas almost half of the total area of depressions is already dieback affected, only one twentieth of the plateaus, one sixth of mild slopes and one tenth of steep slopes have so far been attacked by the disease. The upland depressions, suspected to be remnants of the Goonaping Surface, have been almost totally affected.

Even human activity is not independent of the landscape pattern. The major sealed highway in the area passes through the plateaus at twice the expected occurrence, but avoids steep slopes altogether. One of the main arterial roads, the Ashendon Road, is entirely restricted to depressions and mild slopes. This is also true of a secondary road bisecting the survey area. Minor, graded roads and ungraded access tracks are not strongly tied to any particular slope category, although they traverse only one third of the expected steep slopes. Faint snigging (logging) tracks traverse all slope categories at approximately the expected occurrence.

Effect of rock outcrops and soils

Soil types are related to rock outcrops. A marked excess of granitic and epidioritic rock outcrops above their expected occurrence is associated with gravelly soils with loamy matrix. Sands, sandy loams and loams have outcrop-free surfaces well above the expected occurrence. By contrast, on gravelly soils the outcrop-free surface occurs at less than half of the expected occurrence.

There is also a strong relationship between soils and certain features of the forest stand. Severely understocked stands (basal area less than 9.2 m^2/ha) occur at approximately twice the expected occurrence on sands, sandy loams and loams; at approximately the expected occurrence on gravelly sands; at two-thirds on gravels with sandy matrix and at one quarter of the expected occurrence on gravels with loamy matrix. Much of this is unquestionably due to dieback disease.

Dieback-affected stands occur at twice the expected occurrence on sandy loams and loams; at two-thirds on gravels with sandy matrix and at one half on gravels with loamy matrix.

Marri forms a significant (more than one third) portion of the forest stands on moist sands, sandy loams and loams, but is of only minor importance on the heavy lateritic gravels. Yarri is almost exclusively confined to loams, and its edaphic range is virtually the exact opposite of that of sheoak, which is mainly confined to sands, sandy gravels and heavy gravels with sandy matrix.

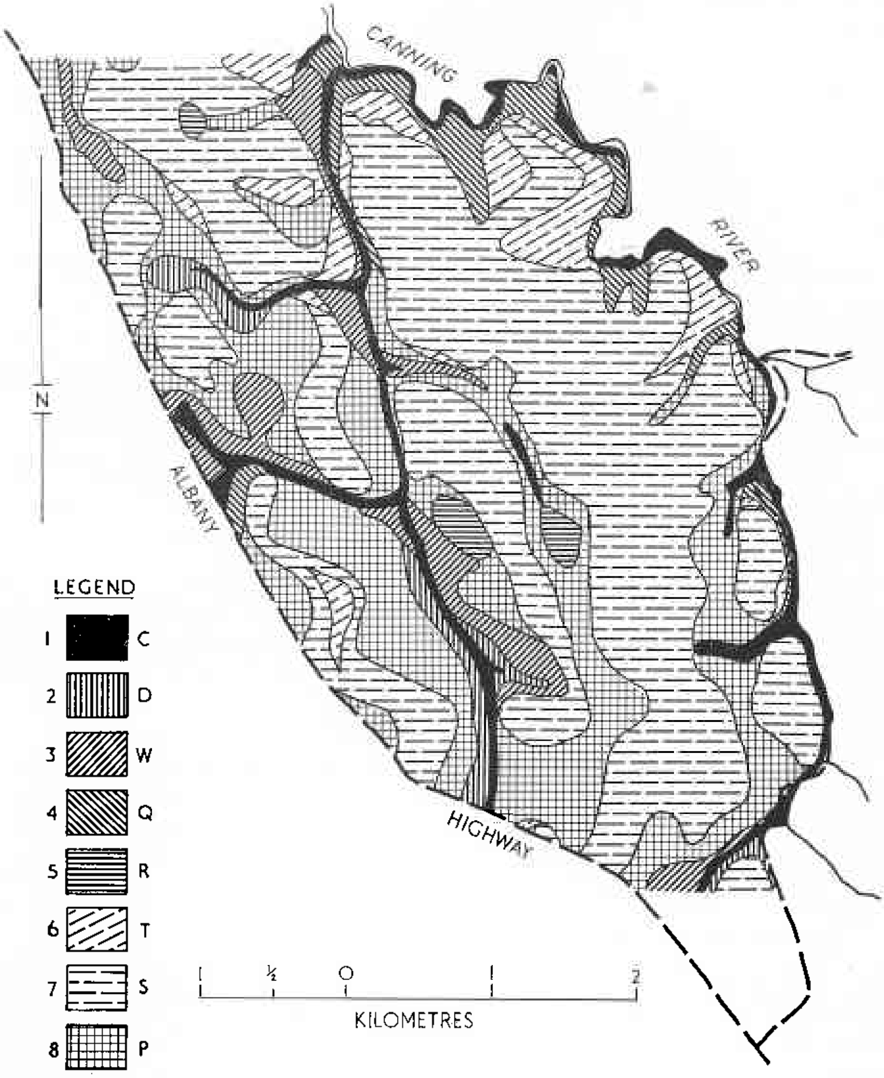


Figure 14
Distribution of site-vegetation types within the Ashendon Test Area.

Much the same relationship exists between swamp banksia of the wet sandy loams and loams and bull banksia of the gravelly upland soils. Bullich is largely confined to moist loams, though it may extend on to moist loamy gravels.

Because of the strong relationships of dieback to slope, and roads to slopes, a strong relationship of dieback to roads could be expected, particularly for the main forestry roads that largely follow depressions and valleys. This is in fact the case. The actual occurrence of dieback is at three times that expected for the arterial and secondary roads, and at twice that expected for minor graded roads and ungraded tracks. The association between major highways and faint snigging tracks (neither of which are closely tied to depressions) and dieback is very weak. On this basis, it would be impossible to separate the effect of roads as a means of spreading the disease from the effect of depressions as providing optimum conditions for development of the disease.

Site-vegetation types and their relationships to other landscape elements

So far, site-vegetation types (Fig. 14) have not been mentioned, chiefly because it would be meaningless to refer to them briefly by their letter code, yet any other description would be too cumbersome for repeated comments. Instead, the types will now be described, firstly by their indicator species and secondly by their relationships to landscape elements and forest stand characteristics. Vegetation will be seen as the integrator and indicator of environmental condition. The relationships of site-vegetation types to environmental and stand parameters are given in Tables 2 and 3.

TABLE 2

Relationships between site-vegetation types and environmental parameters, Ashendon Test Area.

(Ratio of observed to expected joint occurrence.)

Environmental Parameters	Site-Vegetation Type							
	C	D	W	Q	R	T	S	P
Altitudinal Zones (m)—								
<213	**2·8**	0	0	**16·5**	0	4·4	0	0
213–244	2·7	0	**1·3**	7·8	0	**4·7**	0·3	0·2
244–274	2·1	0	1·1	1·3	0	2·2	1·0	0·4
274–305	1·3	**1·8**	1·0	0·3	1·3	0·7	0·9	1·2
305–335	0·3	1·2	1·2	0·1	**1·6**	0·3	1·0	**1·3**
>335	0	0	0	0	0	0·2	**1·6**	0·6
Maximum Slope—								
0–4° depressions	**2·4**	**2·7**	**2·4**	**1·5**	1·4	0·5	0·5	**1·3**
0–4° plateaus	0	0	0·1	0	0	0·9	**1·7**	0·4
5–8° mild slopes	0·4	0·3	0·5	0·7	0·4	0·8	1·2	1·1
>8° steep slopes	0·3	0	0·1	1·3	**2·3**	**2·6**	1·2	0·5
Soil Texture (Topsoil only)—								
Sand	0·4	2·5	0	0	0	0·2	0·7	**2·2**
Sandy loam	1·7	**3·7**	**2·1**	0·2	**5·4**	0·6	0·4	1·7
Silty loam	**4·5**	2·8	2·0	**6·0**	0·6	1·8	0·3	0·4
Gravelly sand	0·5	0·5	1·4	0·1	0	0·3	0·9	1·5
Sandy gravel	0·3	0·2	0·6	0·2	2·9	0·7	**1·3**	0·9
Loamy gravel	1·1	0	0·7	2·0	1·7	**3·4**	0·9	0·5

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TABLE 3
Relationships between site-vegetation types and timber stand parameters, Ashendon Test Area (Ratio of observed to expected joint occurrences).

Timber Stand Parameters	Site-Vegetation Type							
	C	D	W	Q	R	T	S	P
Stand Basal Area (m^2/ha)—								
<9·2	**2·9**	2·7	**3·1**	**1·5**	**2·4**	0·4	0·4	1·2
9·2–18·4	2·8	**4·1**	1·1	0·4	0	0·1	0·7	**1·4**
18·4–27·6	0·6	0·9	0·9	**1·5**	1·3	1·2	1·1	0·9
>27·6	0·3	0	0·3	0·6	0·4	**1·3**	**1·3**	0·9
Dieback Occurrence—								
Dieback symptoms present	2·7	**3·8**	2·6	1·1	**1·3**	0·5	0·4	**1·3**
Dieback symptoms absent	0·5	0·1	0·5	0·9	0·9	**1·2**	**1·2**	0·9

The dominant type of the Ashendon Test Area is Type S (Plate 1), whose chief indicators are *Banksia grandis, Persoonia longifolia* and some *Casuarina fraseriana* in the second storey and *Adenanthos barbigera, Hovea chorizemifolia, Lasiopetalum floribundum, Macrozamia riedlei, Phyllanthus calycinus, Leucopogon capitellatus, Leucopogon propinquus, Acacia preissiana, Styphelia tenuiflora and Patersonia rudis* in the shrub stratum. It covers most of the laterite-mantled uplands above 274 m, characterized by gentle slopes and near-level plateaus, heavy outcrops of lateritic ironstone and gravelly soils with sandy matrix. The stands have a moderately dense upper storey consisting overwhelmingly of jarrah with a light (one-third) admixture of marri. The average height of the upper canopy is 30 m, and the basal area stocking is largely above 18 m^2/ha. It is, as yet, only weakly affected by dieback (less than half of expected occurrence).

The second most common type is Type P, which differs from S chiefly in the relative absence of *Macrozamia riedlei, Phyllanthus calycinus, Leucopogon capitellatus* and *Leucopogon propinquus,* in the frequent occurrence of *Lepidosperma angustatum* and *Grevillea wilsonii,* and in the greater development of *Casuarina fraseriana* in the second storey. It flanks Type S on the downslope, occupying mostly the gentle lower slopes within the uplands, mantled by colluvium of sandy gravels and gravelly sands. It occurs principally between 274 and 335 m above sea level. The stands are comparable with Type S in height, but the stocking tends to be markedly more variable, the observed values being near the expected occurrence for all basal area classes. There is a considerably higher incidence of dieback (1.5 times the expected occurrence), which at least partially accounts for the variable stocking.

Type S, and to a lesser extent Type P, occupy the bulk of the laterite-mantled uplands.

The remaining types are much more restricted in occurrence, and tend to occupy relatively narrowly defined environmental niches.

Type T resembles Type S in many respects. It shares with it *Macrozamia riedlei, Acacia preissiana, Leucopogon capitellatus, Leucopogon propinquus, Lasiopetalum floribundum* and *Phyllanthus calycinus,* but *Adenanthos barbigera, Styphelia tenuiflora* and *Patersonia rudis* tend to be replaced by *Leucopogon* *verticillatus, Pteridium esculentum, Clematis pubescens, Acacia urophylla* and *Bossiaea aquifolium*. Marri tends to play a larger part in the main canopy, and is occasionally joined by yarri. *Casuarina fraseriana* is largely absent from the second storey.

The stands are as tall as, or slightly taller than, Type S (33 m), but the basal area and diameter are similar. Dieback occurs at less than half of the expected occurrence. The Type occurs at the upper limit of the Darkin Surface, between 213 and 274 m, near its rather abrupt boundary with the laterite-mantled upland, which sometimes approaches the nature of a breakaway. The slopes are generally (2.5 times the expected occurrence) steep, over 8°. There is an abundance of lateritic ironstone outcrops in the form of large boulders, and occasional epidioritic outcrop in the form of smaller floaters. The soils are chiefly loamy gravels (four times the expected occurrence), the proportion of gravel decreasing downslope.

Type Q occurs downslope from T, almost entirely within the Darkin Surface below 244 m above sea level. It differs from T in the total absence of *Adenanthos barbigera* and *Styphelia tenuiflora*, and in the occurrence of *Hypocalymma angustifolium, Trymalium spathulatum, Acacia extensa* and *Hibbertia lineata*. *Chorizema ilicifolium* and yarri, which occur occasionally in T, are much more strongly developed in Q. The latter tends to dominate the tree stratum, though marri and jarrah also contribute. The tree stratum is comparable in both height and basal area to T. The Type occurs chiefly on moderate lower slopes on loamy soils (six times the expected value). Although dieback occurs at the expected occurrence, its impact on the overstorey is not heavy.

Still further downslope, on the banks of the river and its main tributaries, is a narrow fringing belt of Type C (Plate 2). Its chief indicators are yarri in the overstorey and a dense, tall shrub stratum of *Agonis linearifolia* and *Grevillea diversifolia*. Less consistently there is bullich in the tree stratum and *Trymalium spathulatum* in the dense, tall shrub storey. The short scrub and perennial herb stratum contains *Hypocalymma angustifolium, Mesomelaena tetragona, Lepidosperma angustatum, Astartea fascicularis* and *Leptocarpus scariosus*. The Type occurs primarily at the lower limit of the Darkin Surface, below 215 m, but extends somewhat upstream into the Beraking Surface as a narrow band up to 305 m. It is here that bullich is chiefly found. The soils are mostly loamy alluvials. The tree stratum tends to be lower than in Q, presumably because of some drainage impedance. It is also usually less well stocked, below 18 m^2/ha. Because the species most suspectible to dieback (jarrah and bull banksia) are not common in this Type, the disease, if present, has not had a great impact.

Types T and Q occupy the bulk of the strongly dissected Darkin Surface. Type C occupies a surface which is not provided for by Mulcahy *et al.* (1972), but is described as the Micklanup Surface by Finkl (1971b).

At the upper margin of the Beraking Surface, Type C is flanked by Type D, the indicators of which are *Leptocarpus scariosus, Leptospermum ellipticum, Mesomelaena tetragona, Synaphea petiolaris, Lepidosperma angustatum, Kingia australis, Dampiera alata, Baeckea camphorosmae, Hypocalymma angustifolium* and *Accacia extensa*. The overstorey, originally an admixture of jarrah, marri, yarri and bullich, has been severely decimated by dieback (four times the expected occurrence), virtually throughout the whole test area (Plate 3).

Jarrah has ceased to be a major component. This has led to a depression in the stocking, and even the height, of the stand, which is now generally very open ($<18.4\,m^2/ha$). The Type occurs on valley floors and lower slopes, mainly between 274 and 335 m above sea level, and is chiefly associated with moist to wet sandy loams and loams (three times the expected occurrence), which are frequently underlain by impervious clay or secondary laterite.

Type W resembles D in many respects. In fact, in view of their proximity, similarity and generally restricted occurrence, Types C, D and W could be considered minor components of a valley complex. Type W differs from D in the greater occurrence of yarri, *Hypocalymma angustifolium* and *Hakea lissocarpha* and lesser occurrence of *Leptocarpus scariosus* and *Leptospermum ellipticum*, suggesting somewhat drier and more fertile soils. Like D, it occurs chiefly on mild lower slopes and valley floors. Also like D it has been largely decimated by dieback (2.5 times the expected occurrence), and the tree stratum is now very open, generally below $9.2\,m^2/ha$. There is an indication of a recent build up in the proportion of marri. Types C, D and a portion of W thus constitute the vegetation types of the Beraking Surface.

Only a few restricted occurrences of Type R were observed in the Ashendon Test Area, although it appears to be quite common in the surrounding landscape, in particular on the eastern slopes of the main river valley. Its chief indicators are *Trymalium ledifolium*, *Phyllanthus calycinus*, *Macrozamia riedlei*, *Leucopogon capitellatus*, *Leucopogon propinquus* and *Hakea lissocarpha*. Other species found in it are those of very broad edaphic tolerances, such as *Hibbertia hypericoides*, *Hibbertia montana* and *Dryandra nivea*. Species of Types P and S, such as *Lepidosperma angustatum* and *Adenanthos barbigera*, also often extend into it.

Type R generally forms a fringing transition zone between the almost bare granitic outcrops and the laterite-mantled slopes. Marri is a prominent asscciate of jarrah in the overstorey. Because it is a transition type in a rather steep environmental gradient, it varies markedly in height and density of the tree stratum. The soils are an admixture of lateritic ironstone, gravels, kaolinitic clays of the pallid zone and sandy loams which are the products of granite weathering. It occurs chiefly between 274 and 335 m above sea level.

Types W, R and parts of Type P comprise the vegetation of the Nockine Surface.

The picture that emerges from the above examination of the Ashendon Test Area is one of a highly integrated landscape, whose components are strongly correlated. The correlation is reflected in the relatively small number of site-vegetation types described. Most of the possible combinations of environmental factors do not occur at all, thus leading to a considerable simplification in the overall view of the landscape.

The environmental patterns can generally be explained in terms of the geomorphological surfaces of Mulcahy *et al.* (1972) and Finkl (1971b).

2. COOKE TEST AREA

Location

The second test area, Cooke, covers 2 234 ha. It is dominated in virtually every respect by the large monadnock of Mt. Cooke, which rises more than 200 m above the general level of the Darling Plateau (Fig. 15).

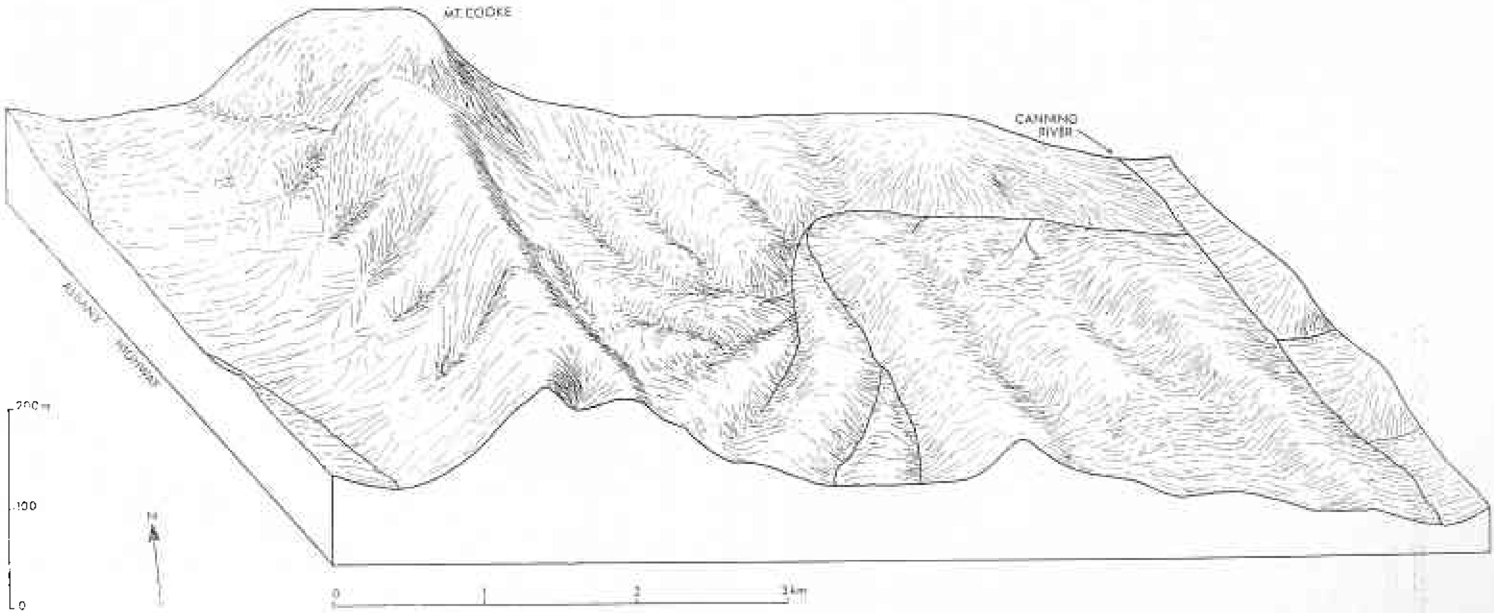

Figure 15
Three-dimensional topographic model of the Cooke Test Area.

Topography, geomorphology and climate

The altitudinal range extends from 274 m above sea level in the valley of the Canning River in the east to 583 m above sea level at the summit of Mt. Cooke. An unnamed tributary of the Canning which drains the western slopes of the monadnock leaves the survey area at 305 m above sea level and joins the river approximately 16 km downstream. It is a rather sluggish stream, flowing in a broad, open swampy valley. The minor creeks which cascade down the western slopes of the monadnock lose their identity on the lower slopes and floor of this valley. By contrast, most of the creeks draining the eastern slopes of the monadnock retain their identity until they join a tributary of the Canning which enters the area from the south and flows generally northwards in a broad, open valley parallel to the river. It joins the river via a deeper east-west valley following a sharp right-angled turn. This suggests a capture of the S-N stream by the W-E stream, which, by virtue of its shorter route to the Canning River, possessed a greater erosive capacity.

The geomorphology of the area, particularly of the western portion, does not lend itself to description in the terminology of either Finkl (1971b) or Mulcahy *et al.* (1972). The former did not encounter any monadnocks in his survey area. The latter encountered Mt. Dale along the western perimeter of their area, but beyond describing it as a high-level granitic residual flanked by gravelly and sandy deposits did not discuss it any further. Yet monadnocks (Mt. Dale, Eagle Hill, Mt. Randall, Mt. Cuthbert, Mt. Vincent, Mt. Cooke and Mt. Solus) dominate the landscape of the Kelmscott Division and the Canning and Serpentine catchments.

The geomorphic surfaces that can be recognised on and around the monadnocks are as follows:

(a) The mildly sloping summit areas, bearing evidence of past laterization.

(b) The steeply sloping 8-40° crests and upper flanks, with thin freshly-formed soils and excessively drained, extensive rock outcrops.

(c) Undulating lower flanks dissected by moderately deeply incised creeks, with moderate 5-16° slopes and strong evidence of laterization in the form of ironstone outcrops and gravels, adequately but not excessively drained.

(d) Piedmont with mild 0-4° slopes, covered by deep deposits of sands, sandy gravels and sandy loams, frequently inadequately drained.

Category (a) could for practical purposes, possibly be included in laterite-mantled uplands, in that it does not differ from them markedly except in altitude, and is not sufficiently extensive to warrant a separate category. It is absent from some of the monadnocks and occurs as only small disjunct areas on others.

Category (b) bears a certain resemblance to the Helena Surface of Mulcahy *et al.* However, it belongs to a much earlier cycle of erosion, and occurs above not below the extensive laterite-mantled uplands. The name Cooke Surface is proposed (with reluctance) for this category.

Category (c) can probably be retained within Mulcahy *et al.'s* laterite-mantled upland even though the presence of extensive fresh rock outcrops above it, and of steeply incised creeks within it, sets it somewhat apart.

Category (d), whilst bearing a certain superficial resemblance to Mulcahy *et al.'s* Goonaping Surface, differs from it in the relatively recent nature of many of the deposits, and by its overall greater wetness; the name Randall Surface is proposed for this category.

The geomorphic surfaces outside the monadnock zone of influence, that is in the east and north-east, fit readily into Mulcahy *et al.'s* categories. The valley floor of the main eastern tributary, and especially the valley of the Canning River itself, belong to the Beraking Surface, and the weakly developed valley slopes to the Nockine Surface. The rest of the area is the normal laterite-mantled upland. Small enclaves of the Goonaping Surface extend into the test area from the south-east. There is possibly a small remnant of a monadnock, worn down to the level of the laterite-mantled uplands, in the south-eastern portion of the area.

The rainfall of the area is not precisely known, the isohyetal map being obviously an interpolation between known levels in the west (Jarrahdale, Serpentine) and the east (Brookton, Wandering). There is no recording station within the area itself. It is, however, reasonable to assume that the average annual rainfall ranges between 750 mm in the east and 1250 mm in the west, and it is probable that this range could be further reduced to 900 mm and 1100 mm respectively. It is also likely that Mt. Cooke, which forms a massive barrier at right angles to the prevailing rain-bearing winds, induces marked local variations within the area itself.

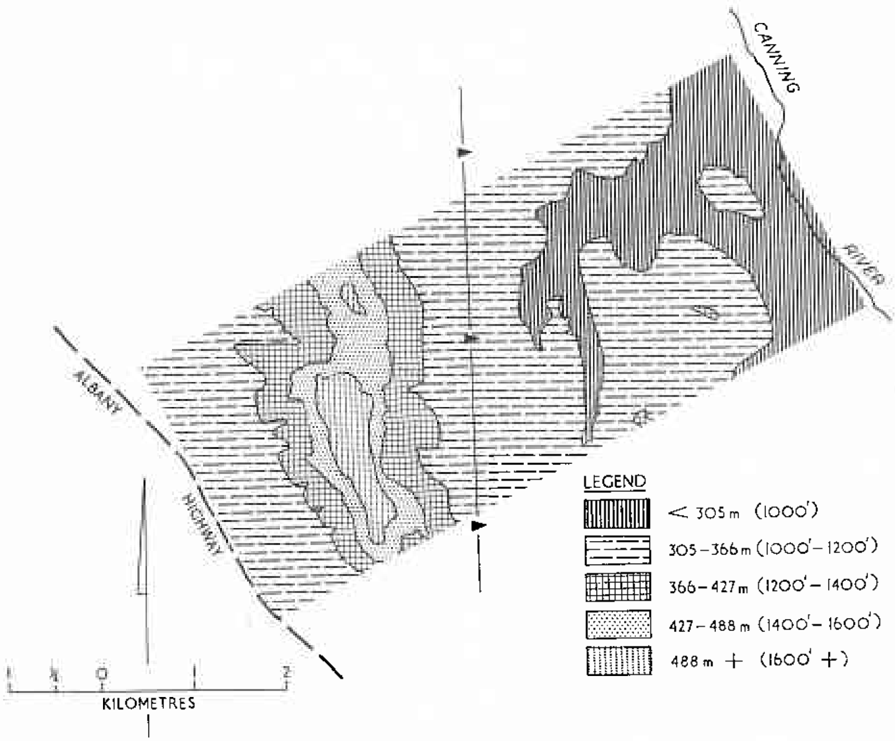

Figure 16
Altitude in the Cooke Test Area

The integration and correlation of landscape elements will be discussed somewhat more briefly than for the Ashendon Area.

Effect of altitude

In view of the greater altitudinal range, the altitudinal stratification had to be altered, the five categories being (Fig. 16):

(a) below 305 m above sea level,

(b) 305-366 m,

(c) 367-427 m,

(d) 428-488 m,

(e) above 488 m.

Steep slopes in excess of 16° are chiefly found at the higher altitudes, above 366 m, whereas gentle slopes of less than 4° are largely absent above this altitude (Fig. 17).

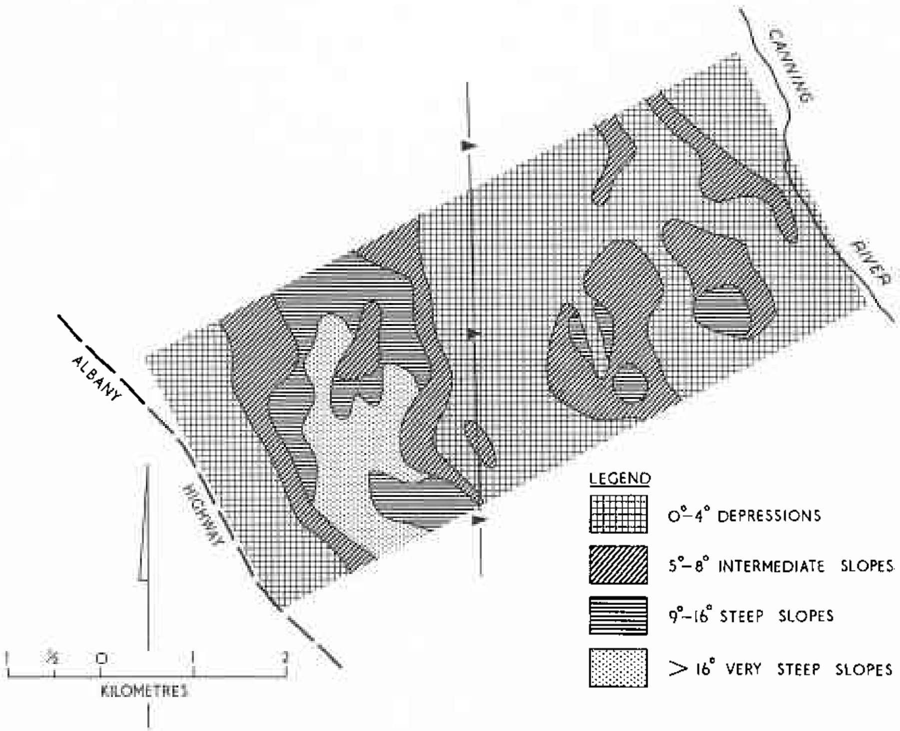

Figure 17
Slope in the Cooke Test Area.

Similarly, granitic and epidioritic outcrops (Fig. 18) reach maximum development above 427 m, which is also the upper level of occurrence of outcrop-free surfaces. The lateritic outcrops occur chiefly between 306 and 427 m.

Sands and silty loams (Fig. 19) are largely restricted to below 367 m. By contrast, sandy loams derived from granite occur chiefly above 366 m. Heavy gravels with sandy matrix reach maximum development between 306 and 407 m, but extend into the highest zone above 489 m. This is the highest known occurrence of lateritic gravels in the region apart from Mt. Saddleback, a forest outlier in the agricultural belt east of Dwellingup.

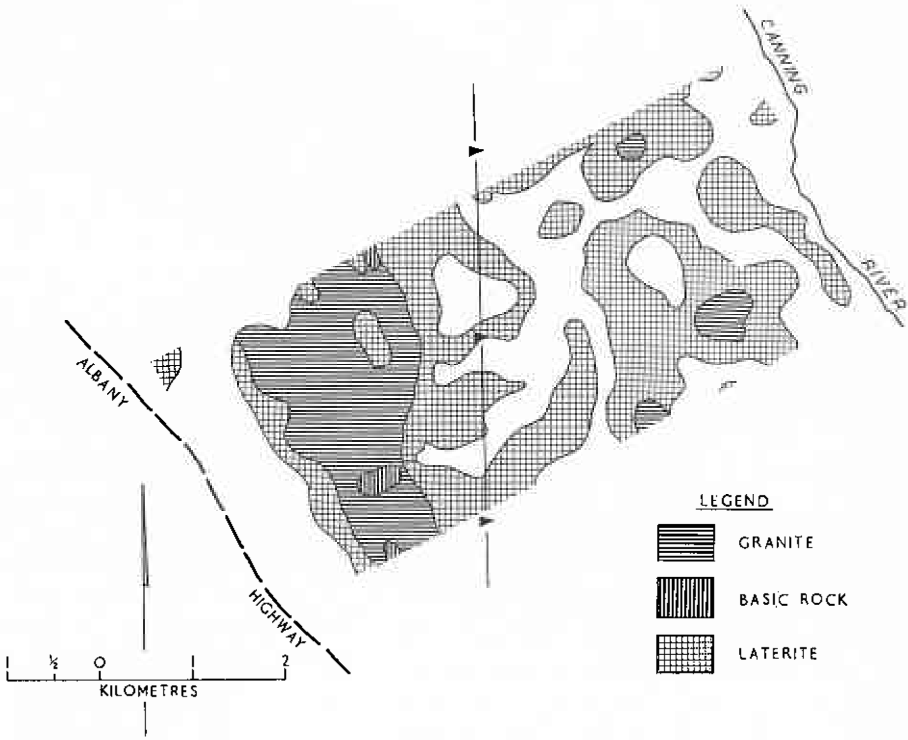

Figure 18
Occurrence of rock outcrops in the Cooke Test Area.

There is also a strong altitudinal zonation of vegetation, which appears to reflect altitudinal zonation of soils rather than direct climatic influence. Jarrah dominates the landscapes, with the exception of the eastern valleys below 274 m and the monadnock slopes above 427 m. In the former it is replaced by wandoo *(Eucalyptus wandoo)* (Fig. 20), on the latter by Darling Range ghost gum *(Eucalyptus laeliae)*. Marri reaches its maximum development below 366 m and above 427 m. Bull banksia and sheoak reach their maximum development in the jarrah zone between 306 and 427 m. Swamp banksia (*Banksia littoralis*) is largely restricted to broad open valleys between 306 and

366 m. Yarri has a discontinuous appearance in valleys below 367 m, but recurs as isolated trees around granitic outcrops near the crest of the monadnock, above 427 m.

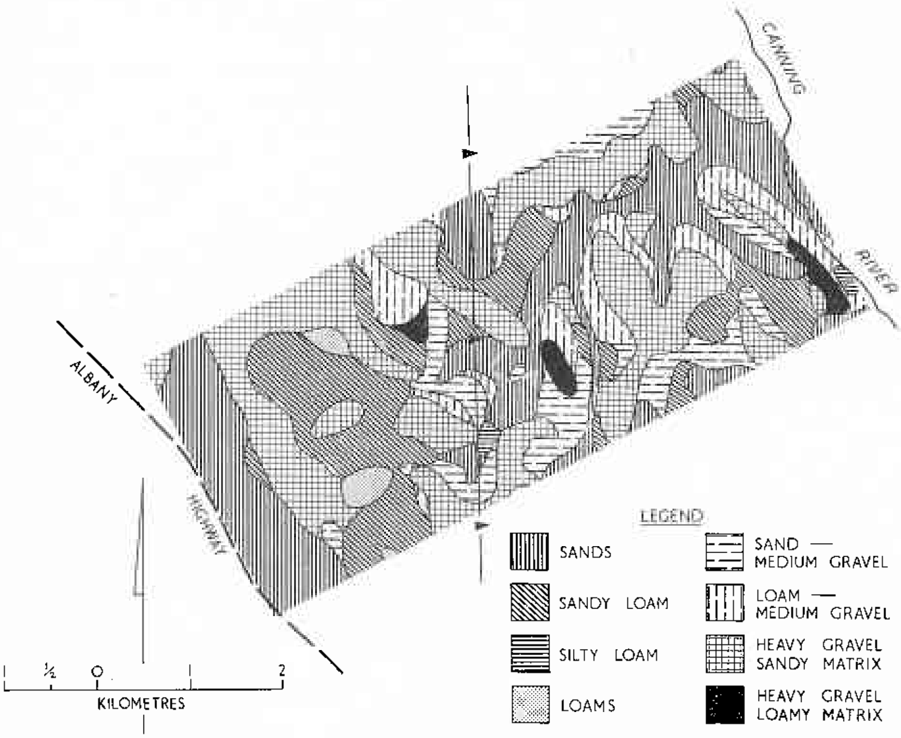

Figure 19
Distribution of soil texture types within the Cooke Test Area.

The occurrence of dieback (Fig. 21) is largely confined to below 367 m. There are, however, very considerable areas below this altitude as yet not affected by the disease. This, together with the lower percentage (15.5 per cent) of affected area compared with Ashendon, suggests that the disease has not as yet covered all the ecologically predisposed areas.

Effect of slope

There is also a strong relationship between slope and other landscape elements. Outcrops of lateritic ironstone exceed the expected occurrence on medium slopes of less than 9°, fall slightly below it on steep slopes of 9-16° and plummet to less than one quarter on very steep slopes above 16°. By contrast, granitic and epidioritic outcrops exceed the expected occurrence on steep and very steep slopes above 8°, but fail to reach it on gentle slopes below 9°. Outcrop-free surfaces exceed the expected occurrence on gentle slopes (less than 5°), and are virtually absent on slopes over 8°.

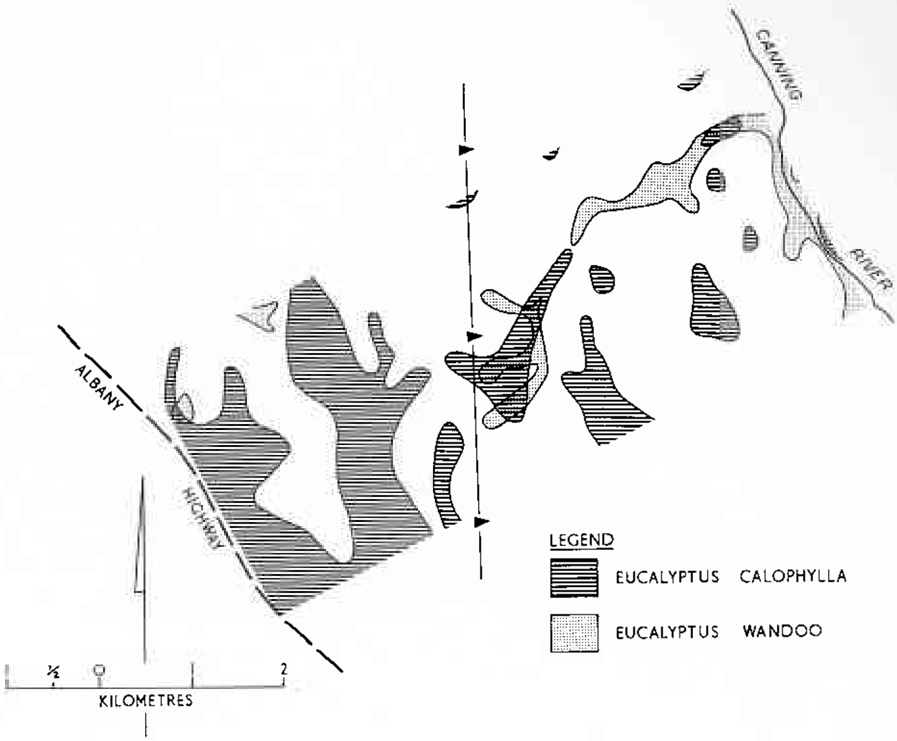

Figure 20
Occurrence of tree species in the Cooke Test Area.
(a) *Eucalyptus calophylla* as a significant component of the overstorey. *Eucalyptus wandoo* at all levels of occurrence.

Sands and silty loams are overwhelmingly associated with near-level surfaces, both in the relative and absolute sense. Sandy loams occur in all slope categories, but exceed the expected occurrence only on steep and very steep slopes over 8°. Gravelly sands are largely absent from slopes in excess of 8°, and exceed the expected occurrence on moderate slopes of 5° to 8°. Loams reach their maximum development on slopes in excess of 8°, and are virtually absent on slopes of less than 9°. By contrast, gravelly loams are mainly associated with slopes between 5° and 16°, although they do also occur on gentle slopes of less than 5°. Heavy gravels with loamy matrix are associated chiefly with slopes of less than 9°, and occur at twice the expected occurrence between 5° and 8°. Heavy gravels with sandy matrix exceed the expected occurrence between 5° and 16°.

There is a fairly strong relationship between slope and stand density (Fig. 22). Very heavily stocked stands with a basal area over 36.8 m^2/ha, which are relatively rare, occur at twice the expected occurrence on steep 9-16° slopes and at or near the expected occurrence on moderate 5-8° slopes. Strongly understocked stands with less than 9.2 m^2/ha basal area are chiefly associated with very steep slopes over 16° and steep slopes of 9-16°. Stands with intermediate stocking do not depart markedly from the expected occurrence in any of the slope categories. The apparent anomaly of the 9°-16° slope category,

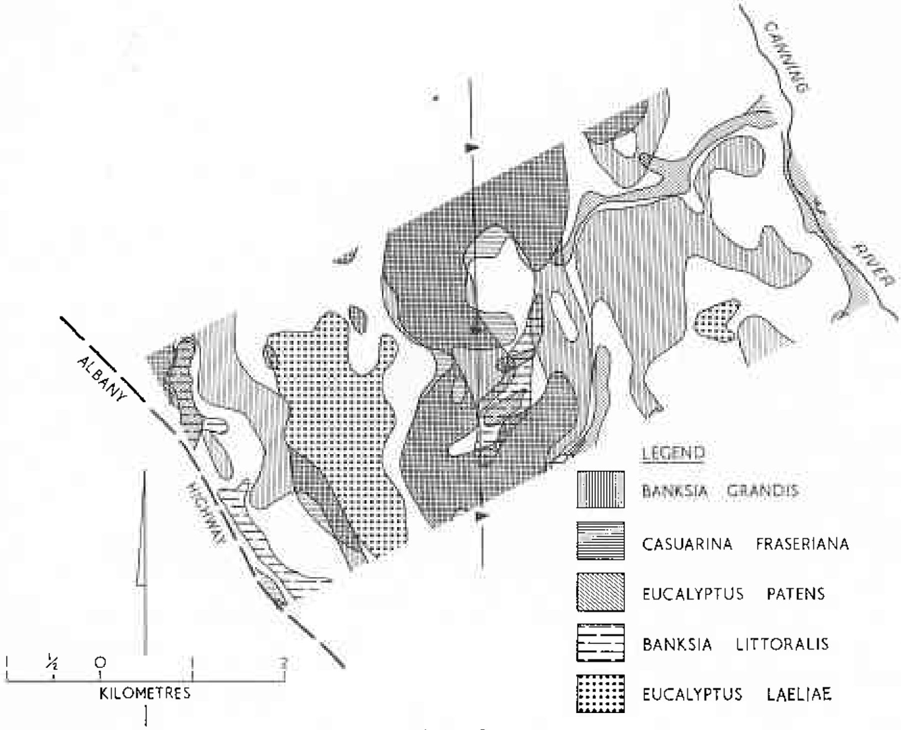

Figure 20

Occurrence of tree species in the Cooke Test Area.
(b) *Banksia grandis, Casuarina fraseriana, Eucalyptus patens, Banksia littoralis* and *Eucalyptus laeliae,* at all levels of occurrence.

which exceeds the expected occurrence for both the very heavily stocked and the strongly understocked stands, is probably due to the fact that logging has left this category largely untouched. Where the stand is virgin jarrah on deeper soils, it is heavily stocked. On shallow podzolic soils over granite, jarrah is replaced by open stands of the Darling Range ghost gum *(Eucalyptus laeliae)*. The very steep slopes in excess of 16° with very shallow soils are almost exclusively occupied by the latter species or are completely treeless, hence the uniformly low density. Areas cleared for establishment of plantations were treated as a separate basal area category, which was largely confined to gentle slopes of less than 5°.

The observed dieback occurrence is greatly below the expected occurrence (one fifteenth) for all slopes above 4°. It is twice the expected occurrence on gentle slopes of less than 5°. It occupies 36 per cent of the total area within this category. This also represents 98 per cent of the total occurrence of dieback in the test area. The impact of dieback is not strongly reflected in basal area values because much of the dieback-affected area has already been, or is in the process of being, reforested with exotic pines, and has been treated as a separate category.

The influence of slope is also very obvious in the location of roads. The Albany Highway, which forms the western boundary of the test area, is here entirely confined to gentle slopes of less than 5°. The major arterial roads,

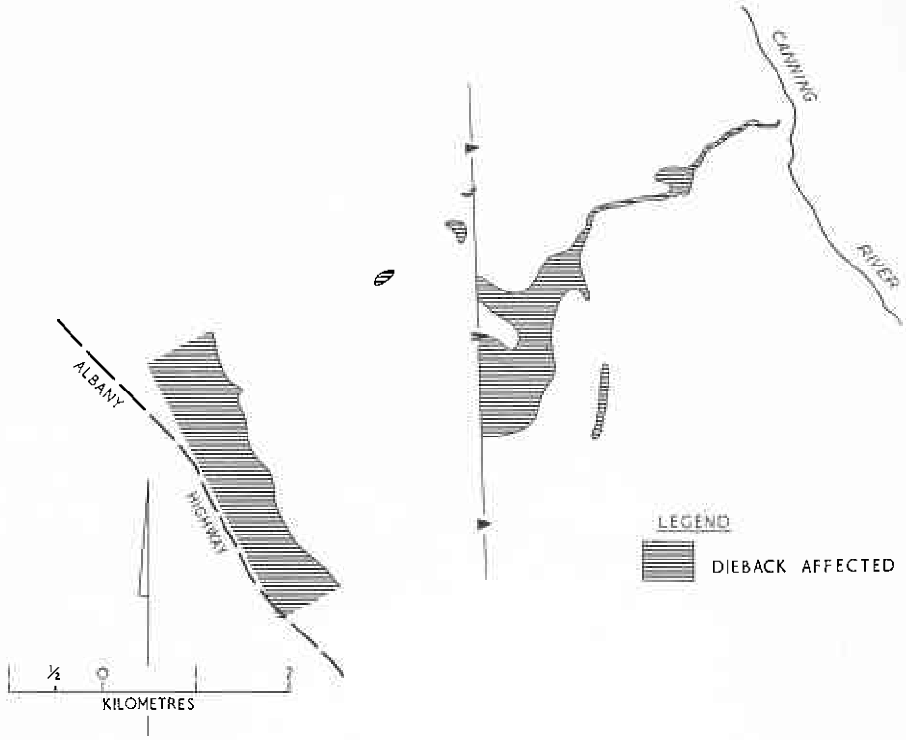

Figure 21
Occurrence of dieback disease caused by *Phytophthora cinnamomi* in the Cooke Test Area.

the construction of which involves considerable earth movement, traverse moderate (5-8°) slopes at approximately the expected occurrence, and gentle slopes of less than 5° at well above the expected occurrence. They avoid steep and very steep (over 8°) slopes entirely. Minor, ungraded roads enter slightly on to the steep and very steep slopes, but at well below expected occurrences. They reach the expected occurrence on moderate slopes and exceed it on gentle slopes. Faint snigging tracks occur at or near the expected occurrence everywhere except on the very steep slopes.

Effect of rock outcrops and soils

Strong relationships are also indicated between soil types and rock outcrops. Lateritic outcrops occur at well below the expected occurrence everywhere except on gravelly sands and heavy gravels. Granitic outcrops occur at three times the expected occurrence on sandy loams. Elsewhere they are either totally absent or occur markedly below expected occurrences. The only exception is heavy gravels with loamy matrix, where the granite occurs only slightly below the expected occurrence. The relatively restricted outcropping of epidiorite is almost entirely confined to sandy loams and loams. Outcrop-free surfaces occur at twice the expected occurrence on sands and silty loams, but at less than expected occurrences on all other soil types.

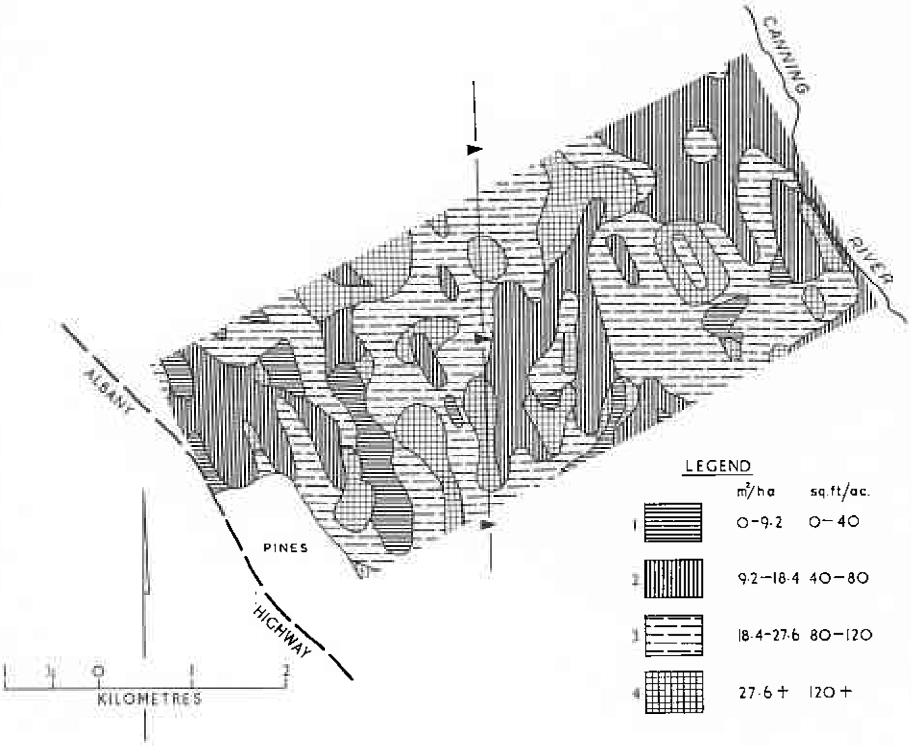

Figure 22
Patterns of stand density (in terms of basal area) in the Cooke Test Area.

Very heavily stocked stands with basal area over 36.8 m^2/ha exceed the expected occurrences only on loams, gravelly loams, gravelly sands and heavy gravels with loamy matrix. They approach the expected occurrences on heavy gravels with sandy matrix, but fall below them on sands, sandy loams and silty loams. Areas cleared for plantations because the original hardwood stands were decimated by dieback occur overwhelmingly on sands. Poorly stocked stands with basal area less than 9.2 m^2/ha occur at above the expected occurrences on sandy loams and loams, presumably because of the prevalent shallow depth associated with these soil types.

The seeming anomaly of loams, which support both very heavily and very poorly stocked stands, lies in the dichotomy between fertility and depth. Loams of adequate depth support the best forest stands; however, very frequently loams are too shallow and the stands are correspondingly lightly stocked. Poorly stocked stands with basal areas of 9.2-18.4 m^2/ha occur at well above the expected occurrence on sands, partly because sands are often associated with a seasonally high ground-water table, partly because of the past decimation by dieback. Heavily stocked stands (basal area of 27.6-36.8 m^2/ha) occur most extensively, and above the expected occurrence, on heavy gravels with sandy matrix.

The specific composition of the stands is likewise strongly related to soil types. Jarrah (*Eucalyptus marginata*) remains the dominant species on all soil types except shallow sandy loams, loams, wet sands and silty loams. Marri (*Eucalyptus calophylla*) is a significant component on moist sands and sandy loams. Yarri (*Eucalyptus patens*) is primarily associated with moist to wet sands and loams. The Darling Range ghost gum (*Eucalyptus laeliae*) is largely confined to shallow, sandy loams and loams. Bull banksia and sheoak are chiefly associated with heavy gravels and gravelly sands, but the latter species is largely absent from the drier eastern portion of the test area. Paperbark (*Melaleuca preissiana*) and swamp banksia (*Banksia littoralis*) are largely confined to seasonally wet sands.

Dieback occurs at three times the expected occurrence on sands and silty loams, which, because of their colluvial or alluvial origin, tend to be associated with seasonally high ground-water tables that predispose the trees to the disease. The observed occurrence of dieback in the remaining soil types is one quarter or less of the expected occurrence.

Roads of all categories traverse sands at or above the expected occurrence. Only primary arterial roads occur above the expected occurrence on sandy loams. All other road types traverse this soil type well below the expected occurrence. The only road traversing the relatively small area of silty loams is a minor ungraded road. The road types traversing gravelly sands at or above the expected occurrence are secondary arterial roads, ungraded minor roads and snigging tracks. Heavy gravels with sandy matrix are traversed at approximately the expected occurrence by primary and secondary arterial roads, minor ungraded roads and snigging tracks. Roads of all types are totally absent from heavy gravels with loamy matrix and loams. Gravelly loams are traversed by primary arterial roads at above, and by secondary arterial roads and minor upgraded roads at below, the expected occurrence. The association appears to be an indirect one through slopes, rather than direct through soil texture. The same complication also applies to dieback.

The relationship between road type and dieback cannot be divorced from the relationship of both roads and dieback to basic elements of the landscape, such as slope and soil. The main highway is totally located within the dieback-affected area. As it has no doubt been the source of original infection and occurs largely in sands, this is not surprising. The primary arterial roads are associated with dieback only at one-fifth of the expected occurrence. This is partially due to the fact that they are not aligned with depressions; however, they may have been sufficiently well constructed to minimize the spread of the disease. The secondary arterial roads and minor ungraded roads are associated with dieback at approximately the expected occurrence. Perusal of the dieback distribution map (Fig. 21) suggests that there have been three main stages of the disease dispersal:

(a) The original introduction by the Albany Highway, which lead to decimation of the western half of the western valley (pre World War II).

(b) Subsequent lateral extension by logging across the valley, which decimated the eastern half of the valley (post World War II).

(c) More recent introduction from Albany Highway by construction of the Muja-Perth powerline, and its subsequent spread downstream and downslope, which led to decimation of the eastern piedmont zone.

TABLE 4

Relationships between site-vegetation types and environmental parameters, Cooke Test Area.
(Ratio of observed to expected joint occurrences).

Environmental Parameters	Site-Vegetation Type													
	AY	B	C	E	G	H	J	M	P	R	S	T	W	Z
Altitudinal Zones (m)														
<305	0·9	0	**4·3**	0	0·1	**1·6**	0	**3·5**	0·6	0	0	0	**2·9**	**2·8**
306–366	**1·4**	**1·8**	0	**1·8**	0·1	1·1	**1·8**	0·4	**1·4**	0	0·1	0·9	0·6	0·6
367–427	0	0	0	0	2·6	0	0	0	0·9	2·9	4·2	**4·0**	0	0·2
428–488	0	0	0	0	4·9	0	0	0	0	**8·8**	3·8	0·7	0	0
>488	0	0	0	0	**8·0**	0	0	0	0	0·4	**4·9**	0	0	0
Maximum Slope—														
<5°	**1·7**	**1·8**	**1·8**	**1·6**	0	**1·3**	**1·6**	**1·6**	1·1	0	0	0	**1·5**	1·0
5°–8°	0·2	0	0	0·4	0·4	1·0	0·4	0·6	**1·3**	1·4	1·1	2·2	0·7	**1·4**
9°–16°	0	0	0	0	2·5	0·1	0	0	0·6	**3·8**	**4·2**	**3·3**	0	0·9
>16°	0	0	0	0	**7·1**	0	0	0	0·3	2·4	2·5	0·9	0	0
Soil Texture (Topsoil only)														
Sand	3·2	**3·5**	**3·1**	**3·3**	0	**1·4**	**3·0**	2·1	0·5	0	0	0	**2·8**	0·5
Sandy loam	0	0	0	0	3·8	1·1	0·5	0·4	0·4	1·9	**2·9**	1·0	0·7	0·5
Silty loam	**9·4**	0	0	0	0	0·3	0	**6·1**	0	0	0	0	0	0·6
Gravelly sand	0·3	0	0	0	0	1·2	0	0·1	**2·0**	0	0·1	0	1·1	0·6
Sandy gravel	0	0·1	0·3	0·3	0·4	0·6	0·3	0·5	1·4	1·6	1·0	2·4	0	1·5
Loamy gravel	1·0	0	0	0	0	0·6	0	1·2	1·2	0·4	0·5	0	0	**3·5**
Loam	0	0	0	0	**9·1**	0	0	0	0	**1·8**	0	**2·9**	0	0
Gravelly loam	0·4	0	0·7	0	0	0·8	0	1·6	1·3	1·4	1·5	0	0	2·1

TABLE 5

Relationships between site-vegetation types and timber stand parameters, Cooke Test Area.
(Ratio of observed to expected joint occurrences).

Timber Stand Parameters	Site-Vegetation Type													
	AY	B	C	E	G	H	J	M	P	R	S	T	W	Z
Stand Basal Area (m²/ha)–														
<9·2	1·6	0·7	0	0	**5·8**	0·3	0	2·0	0·3	0·2	1·4	0·7	**5·1**	0·3
9·2–18·4	1·7	1·7	**2·5**	0	0·5	1·1	0	**2·2**	0·7	0·6	0·2	0·7	1·6	**2·0**
18·4–27·6	0·3	0	0·4	0	0·8	1·1	0	0·5	1·4	**1·2**	1·0	**1·5**	0	0·7
27·6–36·8	0·3	0	0·5	0	0·6	0·9	0·3	0·8	1·2	**2·3**	2·2	0·8	1·1	0·7
>36·8	0·1	0	0	0	0·8	0·5	0	0	**1·7**	0	**3·6**	1·2	0	0·1
Converted to pine plantation following dieback	**3·5**	**7·0**	0	**16·9**	0	**1·4**	**16·0**	0	0	0	0	0	0	0
Dieback Occurrence—														
Dieback symptoms present	**5·2**	**6·5**	**3·7**	**3·9**	0	**1·3**	**2·7**	1·0	0·2	0	0·2	0	**1·8**	0
Dieback symptoms absent	0·2	0	0·5	0·5	**1·2**	0·9	0·7	1·0	**1·1**	**1·2**	**1·2**	**1·2**	0·9	1·2

So far, the monadnock and the eastern uplands have been left largely unaffected.

The dieback situation has been discussed here in greater detail because the patterns are still developing, and the mode of dispersion is still traceable. By contrast, in Ashendon dieback has affected all susceptible areas, and the history of its introduction is no longer traceable. In Leona and Flint there are as yet no occurrences of dieback.

Site-vegetation types and their relationships to other landscape elements

The relationships of site-vegetation types to environmental and stand parameters are summarized in Tables 4 and 5.

The dominant site-vegetation type of the Cooke Test Area (Fig. 23) is Type P, already described for the Ashendon Area. On the western slopes of the monadnock it is restricted to a narrow zone of heavy lateritic gravels with sandy matrix, but it is very widespread east of the monadnock, where it occupies the bulk of the laterite-mantled uplands. It occurs here chiefly on gentle to moderate slopes up to 8°, on soils ranging from sands through sandy loams and gravelly sands to heavy ironstone gravels with sandy matrix, all of which are either the original lateritic mantle or colluvials derived from it. Jarrah is the dominant species of the tree stratum, marri being only a minor associate. The understorey of sheoak and bull banksia is well developed. The bulk of Type P stands have basal areas between 18.4 and 36.8 m^2/ha, though densities above and below this figure do occur. The stands falling below this average are chiefly those affected by dieback. The height of the tree canopy ranges from 22 to 39 m, with an average of approximately 27 m.

The second most widespread and extensive site-vegetation type in the area is Type H, which shares with P such indicators as *Daviesia pectinata, Hakea ruscifolia, Lepidosperma angustatum, Mesomelaena tetragona, Styphelia tenuiflora, Patersonia rudis* and *Acacia strigosa*. It differs from it in the much poorer development of second storey species, in particular *Casuarina fraseriana*, and in the relative absence of *Adenanthos barbigera* and *Grevillea wilsonii*, which tend to be replaced by *Stirlingia latifolia, Sphaerolobium medium, Hakea cyclocarpa* and *Isopogon dubius*. The dominant tree species is jarrah, although on the topographically low sites marri is often an important associate. The changes in indicator species suggest a shift towards the dry end of the continuum, due to either the lower rainfall or the sandier texture of the topsoil, or a combination of both. This is also reflected in the lower density and height of the tree stratum. In the western occurrences of Type H (or more precisely the transitional Type JH, which is largely below and adjacent to P, and on sandier soils) the incidence of dieback tends to be high. In the eastern occurrences, where H tends to replace P on the gently sloping uplands with sandy gravels, dieback incidence is very low.

The third major type within the Cooke Test Area is Type G, which is really a localized but important variant of Type R, already described. It largely coincides with the steep Cooke Surface characterised by frequent granite and epidiorite rock outcrops and fresh, loamy, shallow soils. It is more correctly a complex of types ranging from lichen-covered rocks, through *Borya nitida* herbfields on thin soil veneers, through largely treeless thickets of *Grevillea bipinnatifida, Hakea elliptica, Hakea undulata, Hakea trifurcata,*

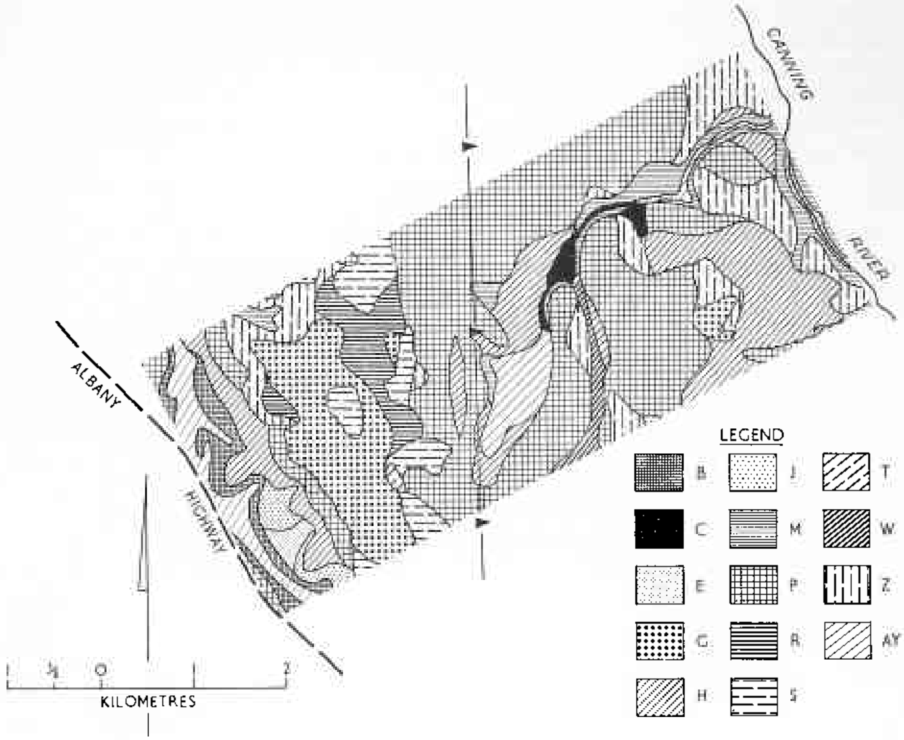

Figure 23

Distribution of site-vegetation types within the Cooke Test Area.

Hakea lissocarpha and several *Acacia* and *Melaleuca* species, to an open low woodland of Darling Range ghost gum with an admixture of marri and jarrah on the somewhat deeper soils (Plate 4). The small size of the individual components, and their intricate intermixture, make it impossible to map them separately, despite great structural diversity.

Type R has been retained as a separate type from G, and is characterised by a lack of extensive rock outcrops, by the absence of Darling Range ghost gum and by better development of the jarrah-marri tree stratum. It adjoins G downslope, on milder slopes and deeper soils.

Type S, which is so prominent in the Ashendon Area, is here restricted to gravelly loams and gravels on the southern and eastern flanks of the monadnocks and a small level area on its crest. It coincides with some of the densest and tallest stands within the test area. Its absence from analogous positions on the northern and western flanks would seem to suggest that these positions, exposed to the afternoon sun, are too hot and too dry for it.

The occurrence of Type T is even more restricted. It could only be mapped as one small area in a sheltered head of a creek on the south-eastern flank of the monadnock, though its chief indicators—*Leucopogon verticillatus, Pteridium esculentum* and *Clematis pubescens*—occur sporadically along the interface of the Cooke Surface and the laterite-mantled upland. This can be attributed to localised improvement in moisture and nutrient availability where the runoff from the rocky slope seeps into the deep laterite soils. *Podocarpus drouyniana*, a shrubby gymnosperm which reaches its optimum development in the cool moist region 300 km to the south, occurs as a relict outlier along the same interface.

Gravelly soils on the moderately steep northern and western flanks of the monadnocks, from which Type S is absent, are occupied by Type Z. This type, which can be regarded as the dry-climate equivalent of S, shares with it such indicators as *Macrozamia riedlei, Phyllanthus calycinus, Leucopogon capitellatus* and *Leucopogon propinquus*, but differs from it in poor development or complete absence of the understorey species such as bull banksia and sheoak, and replacement of *Adenanthos barbigera* and *Leucopogon verticillatus* by *Styphelia tenuiflora, Acacia preissiana, Patersonia rudis* and *Petrophile striata*.

Type Z also occurs on the gently sloping upland surfaces in the eastern portion of the area, where it is chiefly associated with gravelly loams and heavy gravels with loamy matrix. In both height and density of the tree stratum it falls below S, having an average codominant height of only 25 m and basal area of less than 18.4 m^2/ha. It is as yet relatively free from dieback.

Types P, H, S, T and Z between them occupy the laterite-mantled uplands. Type R is a transition between them and Type G, which occupies the Cooke Surface. Types P and H also extend on to the upper levels of the Randall Surface of the piedmont zone. Type Z also extends on to the upper levels of the Nockine Surface of the eastern valleys.

The wettest, low-lying portion of the Randall Surface is occupied by Type A, whose chief indicators are the trees *Melaleuca preissiana* and *Banksia littoralis*, the shrubs *Hakea ceratophylla, Hakea varia, Leptospermum ellipticum, Astartea fascicularis* and *Synaphea petiolaris* and the perennial sedges and rushes *Leptocarpus scariosus, Mesomelaena tetragona* and *Lepidosperma angustatum*. The type generally occurs on seasonally wet, leached grey soils over clay or organic-iron hardpan and on flat, poorly drained floors of valleys. Where the valleys steepen slightly and the sandy surface horizon over clay becomes shallower, wandoo tends to enter into the tree stratum, and several shrubby *Melaleuca* species enter into the shrub stratum. This represents a swing towards Type Y, and should perhaps be mapped as a separate type, Type AY. For the sake of simplicity, A and AY have been mapped together, as neither is very extensive.

The tree stratum is generally low (average height 13 m) and open (basal area of less than 18.4 m^2/ha). The poor development of the tree stratum is largely attributable to poor internal drainage and seasonal waterlogging and flooding.

The shrub stratum is generally well developed, tall and dense. Although the type normally occurs within the dieback-affected zone, the effect of the disease is generally not pronounced, even though swamp banksia and the *Hakea* species are susceptible to the disease. It seems that the site is too wet for optimum development of the causative fungus. A serious problem observed within this type in the Cooke Area is the rise of the saline groundwater table to the surface following the destruction of vegetation upslope.

Type A is frequently flanked by Type B, which shares with it the indicators *Mesomelaena tetragona, Lepidosperma angustatum, Leptocarpus scariosus* and

Synaphea petiolaris. It differs from it in that marri largely replaces *Melaleuca preissiana* and *Banksia littoralis* and in that jarrah was formerly a significant component of the tree stratum. In addition, *Astartea fascicularis, Leptospermum ellipticum* and the *Hakea* species tend to be replaced by *Adenanthos obovata, Dasypogon bromeliaefolius, Petrophile linearis, Conospermum stoechadis, Patersonia occidentalis, Leucopogon cordatus, Lyginia tenax* and *Hibbertia polystachya*.

The tree stratum is taller and denser than that of Type A, but with a basal area still less than 18.4 m^2/ha. The codominant height averages 21 m. However, the impact of the dieback disease is becoming increasingly evident, and the bulk of this Type has already been affected (Plate 5). Type B occurs chiefly on the gentle lower slopes of the valleys, and is associated with moist deep, leached sands.

Two types with rather restricted occurrences are intermediate between Type B and Type H. The first of these, Type E, differs from B in the absence of *Dasypogon bromeliaefolius, Adenanthos obovata, Petrophile linearis, Leucopogon cordatus* and *Hibbertia polystachya* and in the stronger development of *Baeckea camphorosmae, Dampiera alata, Kingia australis* and *Hypocalymma angustifolium*. It occurs in a similar position to B, but on less-leached sands and earths which are seasonally moist to wet. Within the test area, it has been converted to pine plantations.

The second of these, Type J, differs from B chiefly in the stronger development of *Conospermum stoechadis, Hibbertia polystachya, Nuytsia floribunda, Isopogon dubius* and *Sphaerolobium medium, Patersonia rudis* and *Styphelia tenuiflora* and the absence of *Dasypogon bromeliaefolius* and *Adenanthos obovata*.

It is comparable to B in the height of the tree stratum, but tends to be more open. It occurs usually above B and below H on gentle slopes. It is associated with yellow sand over lateritic ironstone gravel in a sandy clay matrix. Within the test area, it has been largely converted to pine plantation.

Types A, B, E, J and to a lesser extent P and H occupy the Randall Surface at the foot of the monadnocks. All have been strongly affected by dieback.

Within the Beraking Surface of the eastern valleys there is a sequence of several site-vegetation types, reflecting minor variations in the slope of the valley floor. Type W, already described in the Ashendon Area, occupies the broad valley floor of the main eastern tributary of the Canning River where it enters the test area. Further down, the tributary becomes larger and less seasonal as it is joined by other creeks. This is reflected in the replacement of Type W by Type C, which differs from it chiefly in the occurrence of *Agonis linearifolia*, essentially a stream bank species occurring on moist, moderately fertile alluvium. Still further downstream, where the valley is more deeply incised below the laterite-mantled uplands, the valley floor becomes rather narrow, and it is difficult to map it as a separate type distinct from that of the slopes of the Nockine Surface. The slopes of the valley carry Type M, whose chief indicators are wandoo in the tree stratum and the shrubs *Hakea lissocarpha* and *Macrozamia riedlei*. Associated tree species are yarri and jarrah, usually at the opposite ends of the slope. Other associates are the shrubs *Gastrolobium calycinum, Hypocalymma angustifolium, Baeckea camphorosmae* and *Acacia pulchella* and the perennial herbs *Dampiera alata, Patersonia rudis, Loxocarya flexuosa* and *Ptilotus manglesii*. The soil is usually brown sandy loam or gravelly loam over red-brown clay loam.

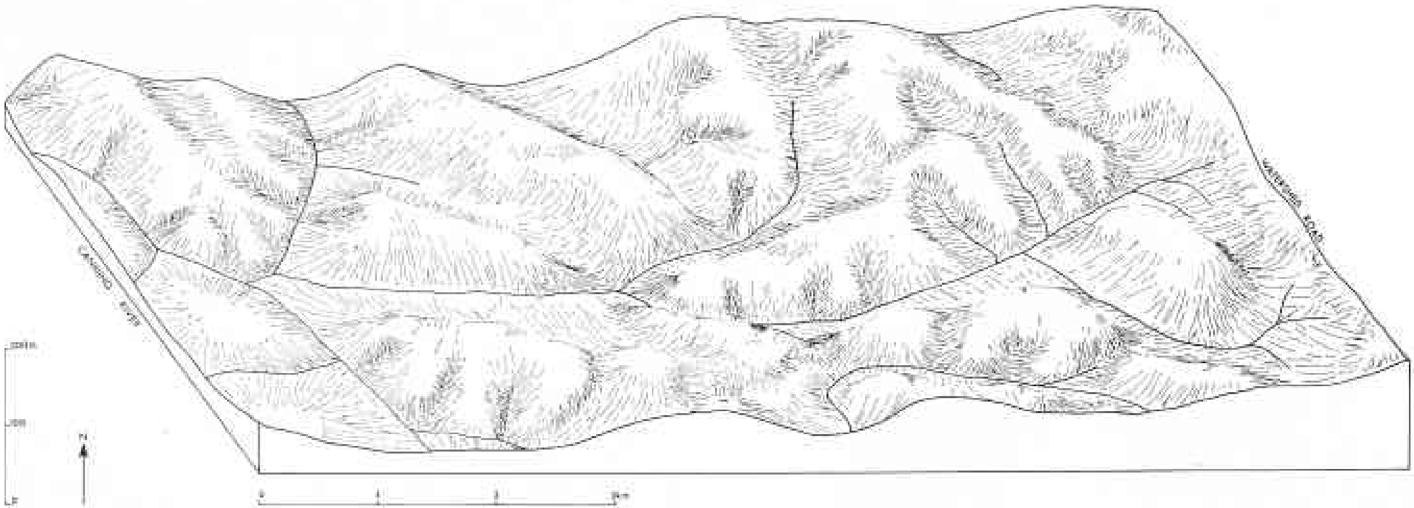

Figure 24
Three-dimensional topographic model of the Leona Test Area.

On the valley floor of the Canning River, Type M gives way to Type AY, already described for the western portion of the test area.

Within the Beraking type valleys of the eastern portion, the Beraking Surface of the valley floors is thus occupied by minor occurrences of Types C, W and A. The Nockine Surface is occupied by M on the predominantly loamy lower slopes and Z on the more gravelly upper slopes.

The same picture emerges from the examination of the Cooke Test Area as for the Ashendon Test Area, namely one of a highly integrated landscape composed of strongly correlated elements. This again makes it possible to account for the whole range of environmental variation by a relatively few site-vegetation types which bear definite relationship to the geomorphic surfaces.

The remaining two test areas, Leona and Flint, will not be dealt with in the same detail as Ashendon and Cooke because it is considered that the high degree of integration and correlation in the landscape of the Darling Range has been amply demonstrated in earlier sections.

3. LEONA TEST AREA

Location

The Leona test area covers 2 789 ha and extends from the eastern bank of the Canning River to the crest of the divide between the Canning and Dale Catchments. Dale River is a tributary of the Avon River, flowing in a

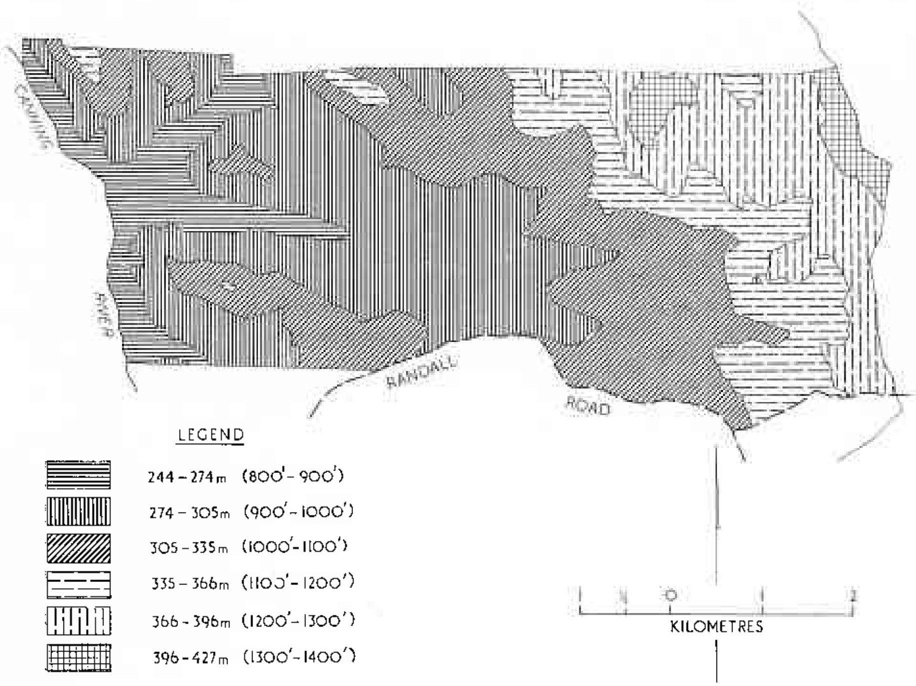

Figure 25
Altitude in the Leona Test Area.

generally easterly direction. The Leona Test Area is 3 km to the north-east of the eastern boundary of the Cooke Test Area, and approximately 15 km to the south-east of the Ashendon Test Area. It extends eastwards from the Canning River for approximately 8 km.

Topography, geomorphology and climate

The topography is on the whole rather gentle (Figs. 24, 25). In three-quarters of the area, the slopes are less than 5° (Fig. 26), either in the form of broad, open valleys or mildly undulating uplands. In addition to the major divide, there are several minor divides separating the smaller creeks draining the area. These have generally slightly steeper (5-8°) slopes. The only steep slopes (9-16°) found in the area are the flanks of these minor divides facing either the main tributaries or the river itself.

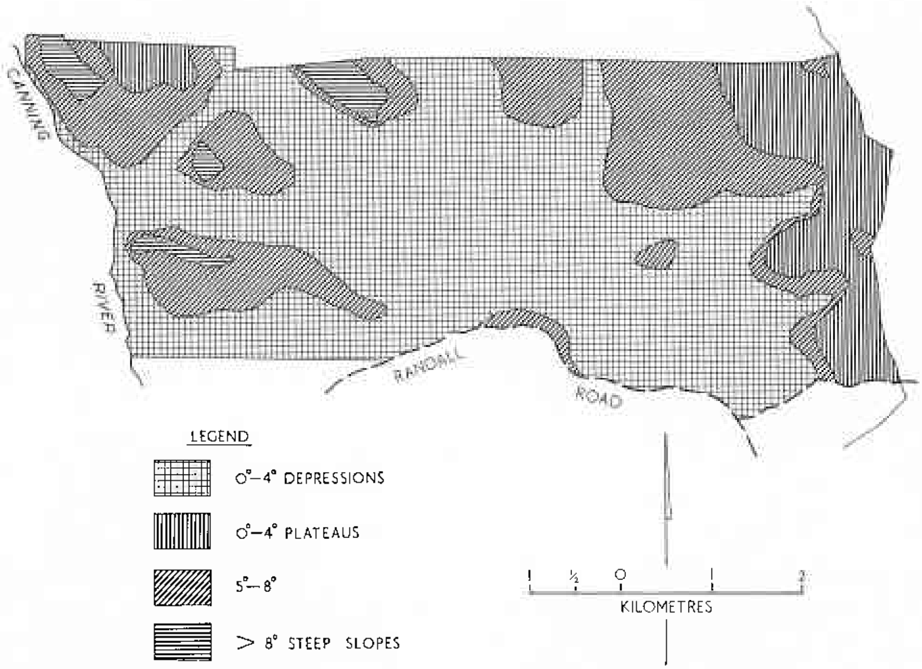

Figure 26
Slope in the Leona Test Area.

The area is geomorphologically rather simple. The divides belong to Mulcahy *et al.'s* (1972) laterite-mantled upland. They occur almost entirely above 305 m above sea level. Small enclaves of the Goonaping Surface are scattered among the uplands, but its main development is a few kilometres to the north. The valleys, which occur mainly below 305 m, are of the Beraking type, with slopes belonging to the Nockine Surface, and valley floors belonging to the Beraking Surface. Within the Leona Area, the proportion of outcrop-free surface is very high (Fig. 27). The outcrops of lateritic ironstone are almost entirely associated with the major divide on the eastern boundary and with some of the minor internal divides. The granitic and epidioritic outcrops have a very restricted occurrence, chiefly as small enclaves on the western margins of the divides, where the slopes are somewhat steeper and where active erosion by the smallest tributaries is proceeding.

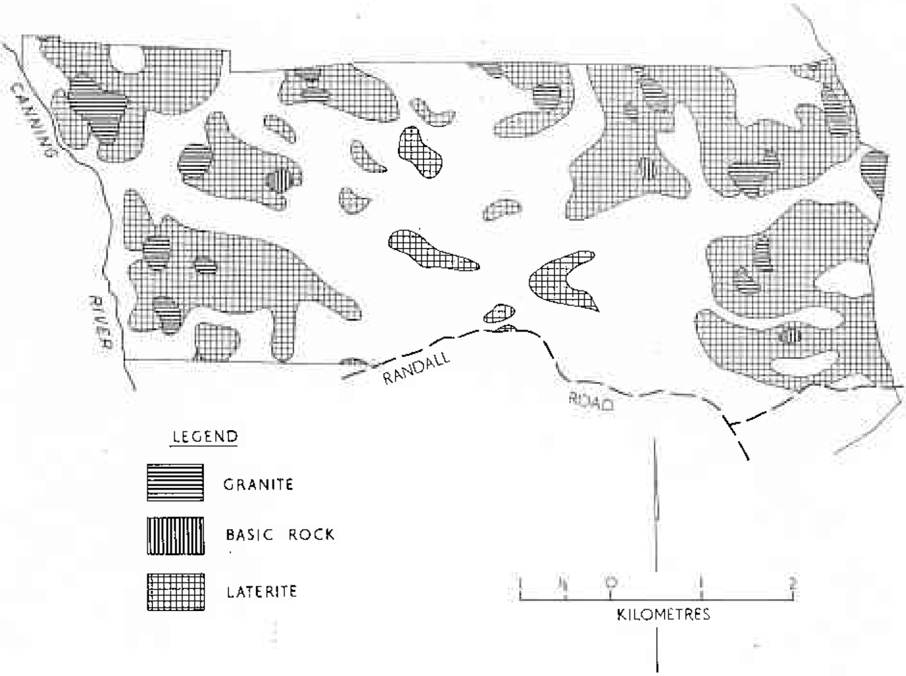

Figure 27
Occurrence of rock outcrops in the Leona Test Area.

The rainfall in this area is largely unknown, the isohyetal map being an interpolation between Jarrahdale and Canning Dam in the west, and Brookton and Beverley in the east. The broad range obtained by interpolation is from 1 000 mm in the west to 625 mm in the east. This could possibly be narrowed down to 875 mm to 750 mm. Within the area the altitudinal range is 152 m, from 259 m on the river to 411 m at the highest point of the divide. The main tributary begins as a distinct stream at approximately 366 m, so that its average fall is about 12 m/km or 1.2 per cent. The fall is greatest in the upper quarter and least in the middle two quarters of the stream course.

Soils

The main surface soil textures encountered are (Fig. 28):

(a) Sands, which occur mainly on the Goonaping Surface, the upper portions of the Beraking Surface, and the lower portions of the Nockine Surface.

(b) Sandy loams and silty loams which occupy the lower portions of the Beraking Surface.

(c) Gravelly sands, gravelly loams and heavy gravels with loamy matrix, which occupy the upper portions of the Nockine Surface and lower portion of the laterite-mantled uplands.

(d) Heavy gravels with sandy matrix which cover the bulk of the laterite-mantled uplands.

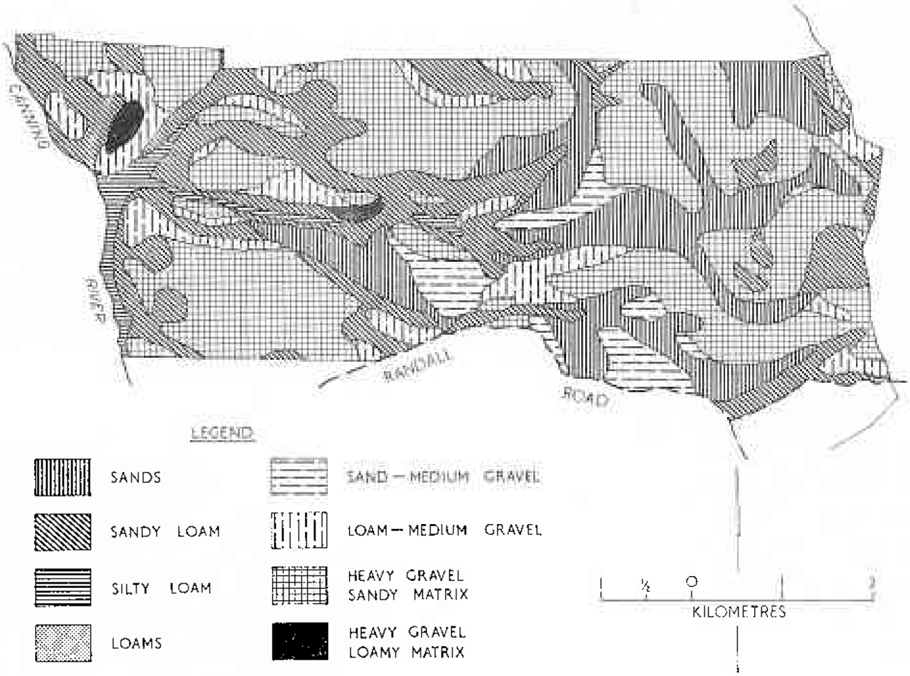

Figure 28
Distribution of soil texture types within the Leona Test Area.

Although deep soil pits were not dug during this extensive multiple-purpose survey, it is known from pilot plot assessment and detailed minor surveys that whereas the sands of the Goonaping Surface are relatively deep, those of the Beraking Surface tend to be shallower and overlie dense clays.

Forest stands

The vegetation of the area has as yet been little disturbed, because logging has been rather selective and light. The heaviest-stocked stands invariably occur on the laterite-mantled uplands, where the basal area ranges from 18.4 to just over 27.6 m^2/ha (Fig. 29). On the Nockine Surface, the basal area is mostly between 9.2 and 18.6 m^2/ha. On the Beraking Surface it is mostly below 9.2 m^2/ha. As a broad generalization, the density of the stands decreases with descent into the valleys, the cause being decreasing depth of solum above an impeding layer, which in this low-rainfall area is critical. Low stocking is also found on and around the granitic outcrops, where soils are also shallow.

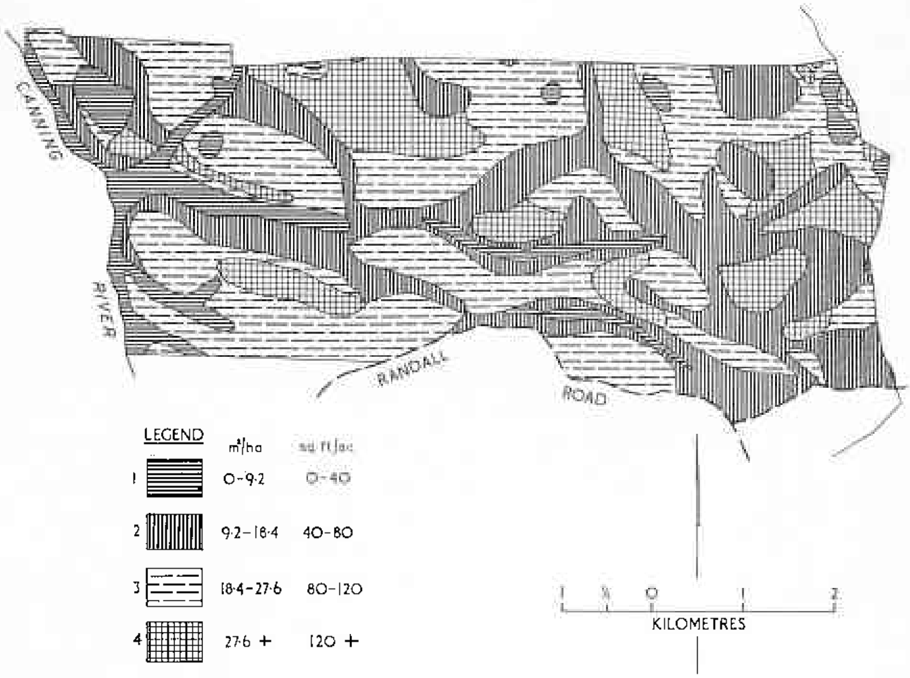

Figure 29

Patterns of stand density (in terms of basal area) in the Leona Test Area.

The height of the stands appears to be less variable. For the bulk of the area, the heights range between 15 and 21 m. There are very few departures above this figure. The more frequent departures below it are mainly associated with the more extreme edaphic conditions, in particular seasonal water-logging.

Over most of the upland surface, jarrah is still the dominant tree species. Marri is much less prominent but still widespread. It is of importance only in some of the moister depressions and below the granitic outcrops. Neither marri nor jarrah are shown in Figure 30 which deals only with species of a more restricted occurrence. On some of the moist sandy sites jarrah is accompanied by Christmas tree (*Nuytsia floribunda*), which is semi-parasitic. Whereas in the west, on the minor steeper divides, jarrah has an understorey of bull banksia and to a lesser extent sheoak, on the main divide in the east these are restricted to isolated patches at the heads of valleys. The eastward progression thus results in a change from a two-storey forest to a single-storey forest.

Over the entire Beraking Surface, jarrah is largely displaced by wandoo, which forms much more open stands.

On the moister portions of the Beraking Surface, wandoo is accompanied by yarri. A tree species as yet not referred to is granite sheoak (*Casuarina huegeliana*), almost entirely confined within the test area to shallow, sandy loams adjacent to granitic outcrops.

TABLE 6

Relationships between site-vegetation types and environmental and stand parameters, combined Leona and Flint Test Areas. (Ratio of observed to expected joint occurrences).

Environmental and Stand Parameters	Site-Vegetation Type											
	Z	E	JH	Y	S	P	H	A	M	L	HM	J
Altitudinal Zones (m)—												
<274	0·2	0·8	0·3	**3·8**	**3·8**	0	0·8	**11·6**	0·6	0	**2·4**	0·5
274–305	**1·1**	**1·8**	1·0	2·4	2·3	0·9	0·4	1·0	1·1	**2·3**	1·1	0·4
305–335	**1·1**	1·1	0·6	0·2	0·3	1·6	0·7	0·3	**1·5**	**1·0**	0·9	**1·8**
335–366	1·0	0·6	0·7	0	0·1	0·5	1·7	0	0·9	0·1	0·8	1·3
366–396	1·0	0	**2·6**	0	0	0·6	2·0	0	0·1	0	0·8	0·7
>396	0·7	0	1·5	0	0	**1·8**	**2·4**	0	0	0	0·8	0
Maximum Slope—												
0–4° depressions	0·7	**2·0**	1·0	**1·9**	0·3	0·7	0·7	**2·2**	1·1	**2·0**	**1·2**	**1·3**
0–4° plateaus	0·5	0	**2·4**	0	0·3	1·2	2·0	0	0·3	0	0·6	1·1
5–8° mild slopes	1·5	0·1	0·4	0·3	2·0	1·0	0·9	0	**1·2**	0·2	1·0	0·6
9–16° medium slopes	**2·3**	1·0	0·1	0·4	**5·6**	**4·8**	0	0	0·9	0	0	0
Soil Texture (Topsoil only)—												
Sand	0·5	**4·6**	**1·7**	0·1	0	0	0·9	1·3	0·9	0	1·9	**3·0**
Sandy loam	0·6	0·6	1·1	1·9	0·8	0·7	0·8	1·5	1·4	1·2	1·0	0·9
Silty loam	0	0·6	0	**6·0**	0	0	0·1	**9·3**	1·2	**17·8**	0·5	0·1
Gravelly sand	0·4	0·5	0·1	0	0	0	**1·6**	0	0·3	0	**5·2**	0·6
Sandy gravel	**1·7**	0·2	0·8	0·1	1·1	**2·2**	1·3	0·1	0·6	0	0·4	0·5
Loamy gravel	0	0	0	3·0	**20·6**	0	1·0	0	0	0	0	0
Loam	0	0	0	5·3	0	0	0	0	**2·6**	6·3	0·3	0
Gravelly loam	1·0	0·1	1·1	0·6	2·7	0·2	1·1	0	1·2	0	1·0	0·7
Stand Basal Area (m^2/ha)—												
<9·2	0·7	0·3	0	**3·5**	0·9	0	0·5	**4·7**	**1·6**	**3·8**	**1·1**	0·2
9·2–18·4	0·5	**2·0**	1·2	0·9	0·6	0·5	0·8	0·2	1·4	0·7	1·0	**1·9**
18·4–27·6	1·2	0·9	1·2	0·1	**1·7**	1·4	1·3	0	0·6	0	1·0	0·9
>27·6	**1·9**	0·1	**1·5**	0	0·5	**2·3**	**1·4**	0	0·2	0	0·7	0·4
Dieback Occurrence	As yet none detected in the area.											

Site-vegetation types

The relationships of site-vegetation types of the Leona and Flint Test Areas to environmental and stand parameters are summarised in Table 6.

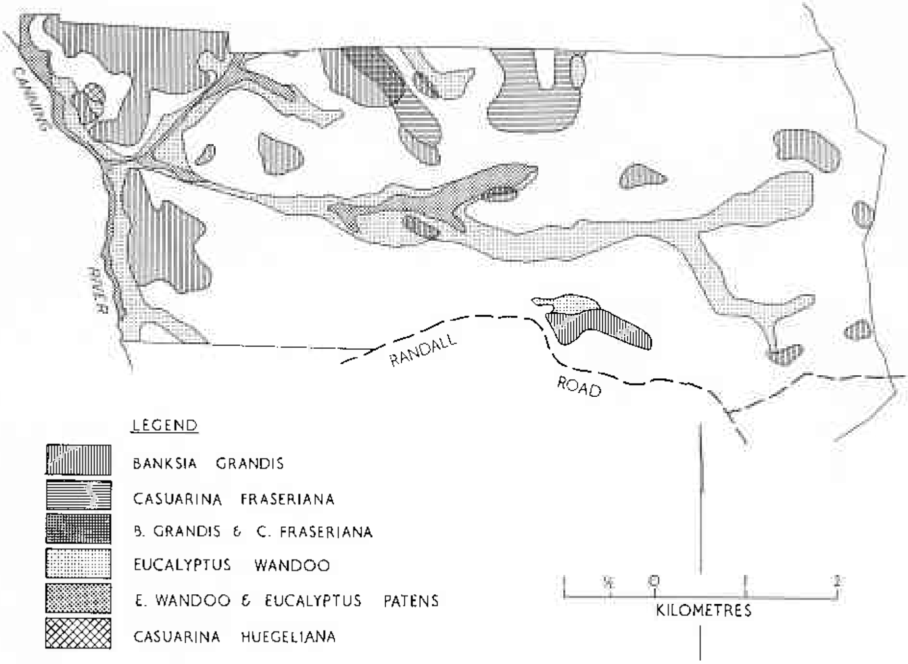

Figure 30
Occurrence of tree species in the Leona Test Area.

The dominant vegetation type of the Leona Test Area is Type H (Fig. 31 and Plate 6), which occupies virtually all of the eastern laterite-mantled uplands. Because it is so extensive and because here its main indicators, in particular *Isopogon dubius, Hakea cyclocarpa, Sphaerolobium medium* and *Daviesia pectinata,* appeared to be broadly indicative of lateritic soils in a low-rainfall zone, two edaphic variants were split off from it. One of these is essentially a transitional type, Type JH, identified by the occurence of *Mesomelaena tetragona* and *Synaphea petiolaris*. It is associated with more sandy, moister sites than the bulk of the Type H in this area. It corresponds closely with the westernmost occurrences of Type H in the Cooke Test Area. The other variant is also a transitional type, Type HM, identified by the occurrence of *Baeckea camphorosmae* and *Hypocalymma angustifolium.* It differs from M in the virtual absence of wandoo. It occurs generally between H and M, on slightly moister soils of higher fertility than H, but not quite as heavy as those on which M is found. The narrowly defined Type H, identified by the presence of *Petrophile striata* and by the low occurrence or absence of *Mesomelaena tetragona* and *Baeckea camphorosmae,* is almost entirely associated with heavy lateritic gravels with sandy matrix.

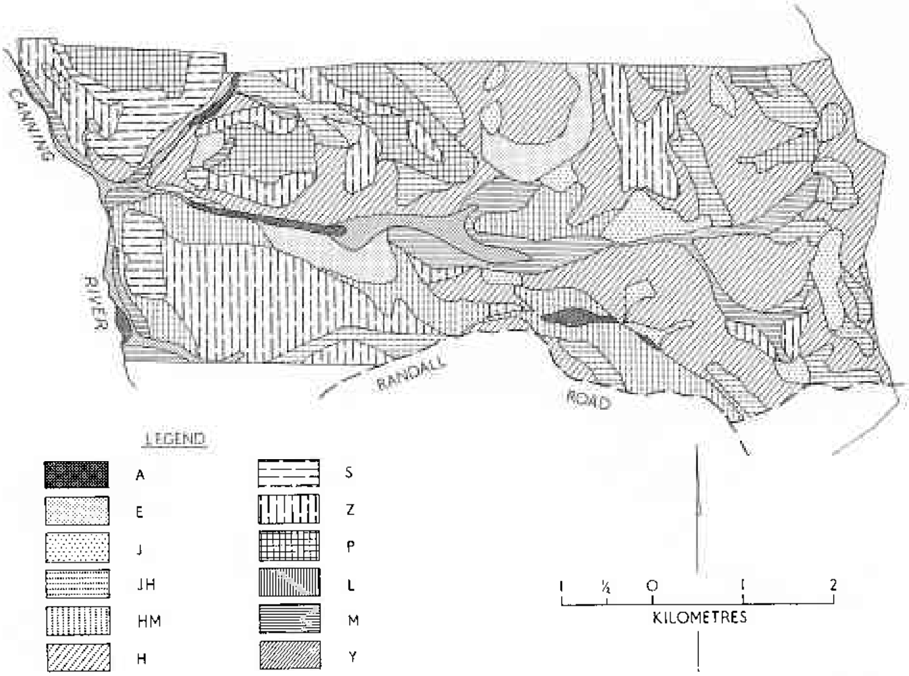

Figure 31
Distribution of site-vegetation types within the Leona Test Area.

Type P, which dominates the Cooke Test Area, is far less common here. It is almost entirely restricted to the northwestern sector, where it occupies the moderately sloping stable lateritic uplands with gravelly soils. Type S, which dominates the Ashendon Test Area, is here restricted to moderate upland slopes and somewhat heavier-textured soils, especially heavy gravels with loamy texture. It appears to be more common on southerly exposures, but is not confined to them. Type T is entirely absent.

Type Z is the second most extensive site-vegetation type in the Leona Area. It occurs almost exclusively on the laterite-mantled upland surface, mainly on heavy gravels but also on gravelly sandy loams, particularly in association with minor granitic outcrops.

Types H, P, S and Z are thus the main types of the laterite-mantled uplands. Of these, S and P are restricted to the moister western portion, whereas H and Z occur throughout and are more extensive.

The characteristic type of the Goonaping Surface is Type J, briefly referred to in the description of the Cooke Test Area (Plate 7). It will be discussed more fully here. Its chief indicators are *Conospermum stoechadis, Hibbertia polystachya, Nuytsia floribunda, Synaphea petiolaris, Mesomelaena tetragona, Lepidosperma angustatum, Leptocarpus scariosus, Patersonia rudis, Styphelia tenuiflora, Stirlingia latifolia, Isopogon dubius, Sphaerolobium medium, Baeckea camphorosmae and Dampiera alata.* The tree storey is dominated by jarrah, and is usually lightly stocked. An associate of jarrah, but never very prominent, is marri. Occasionally yarri and wandoo also intrude into it. On the higher surfaces along the eastern boundary of the State Forest, *Banksia attenuata*, *Banksia menziesii* and *Nuytsia floribunda* may largely replace jarrah. It occurs on near-level surfaces with pale sands over laterite gravel. The transitional type, Type JH, also common on the Goonaping Surface, has already been dealt with.

The Nockine surface is largely occupied by Type M and the transitional type, Type HM, described earlier. These are normally associated with colluvial materials, such as sands and sandy loams and gravels, over a kaolinitic clay subsoil. Two medium-sized occurrences of Type E, associated with moist sands on mild slopes, also fit into this surface. The tree stratum is relatively open, with basal area below 18.4 m^2/ha.

The Beraking Surface is occupied by Type Y and Type A (Plate 8). Of these, Type Y is better-drained, and occurs where the water course has sufficient fall and is well-enough defined to avoid ponding and flooding. Type A appears to be associated with ponding and waterlogging. The transitional Type AY has already been described for the Cooke Test Area.

Type Y is characterized by wandoo in the tree stratum, sometimes accompanied by yarri. The stratum is usually rather open, with basal area below 9.2 m^2/ha. The chief indicators in the low shrub and perennial herb stratum are *Hakea lissocarpha, Hypocalymma angustifolium, Baeckea camphorosmae, Hibbertia lineata, Dampiera alata, Gastrolobium calycinum, Mesomelaena tetragona* and *Lepidosperma angustatum*. The associated soils are loams or clayey sands over sandy clay, showing evidence of salt influence in the strong textural differentiation between topsoil and subsoil.

Human impact

The area is lightly roaded, and the roads are generally of poor quality, being seasonally impassable except to four-wheel-drive vehicles. This is partly due to the fact that they tend to follow drainage lines. The only exception is the Watershed Road, a secondary arterial road which follows the divide. Most of the roads are not surfaced.

So far no evidence has been found that dieback has been introduced into the area. However, the introduction may be obscured by the fact that most of the moist, seasonally waterlogged sites are occupied by species not susceptible to the disease, such as *Eucalyptus wandoo* and *Eucalyptus patens*. In view of the overall lower level of human impact, the likelihood of introducing the disease has been much less than in the Ashendon or Cooke Areas. In addition, the drier climate would mitigate against the spread of the disease.

4. FLINT TEST AREA

Location

The Flint Test Area covers 1823 ha. It adjoins the Leona Test Area in the west along the Canning-Dale divide, and extends eastwards for 6 km to the boundary between State Forest and the agricultural belt. It falls entirely within the headwaters of the west branch of the Dale River.

Topography, geomorphology and climate

The topography of the area is moderately steep (Figs. 32, 33). The western portion takes the form of a broad, undulating plateau. The eastern

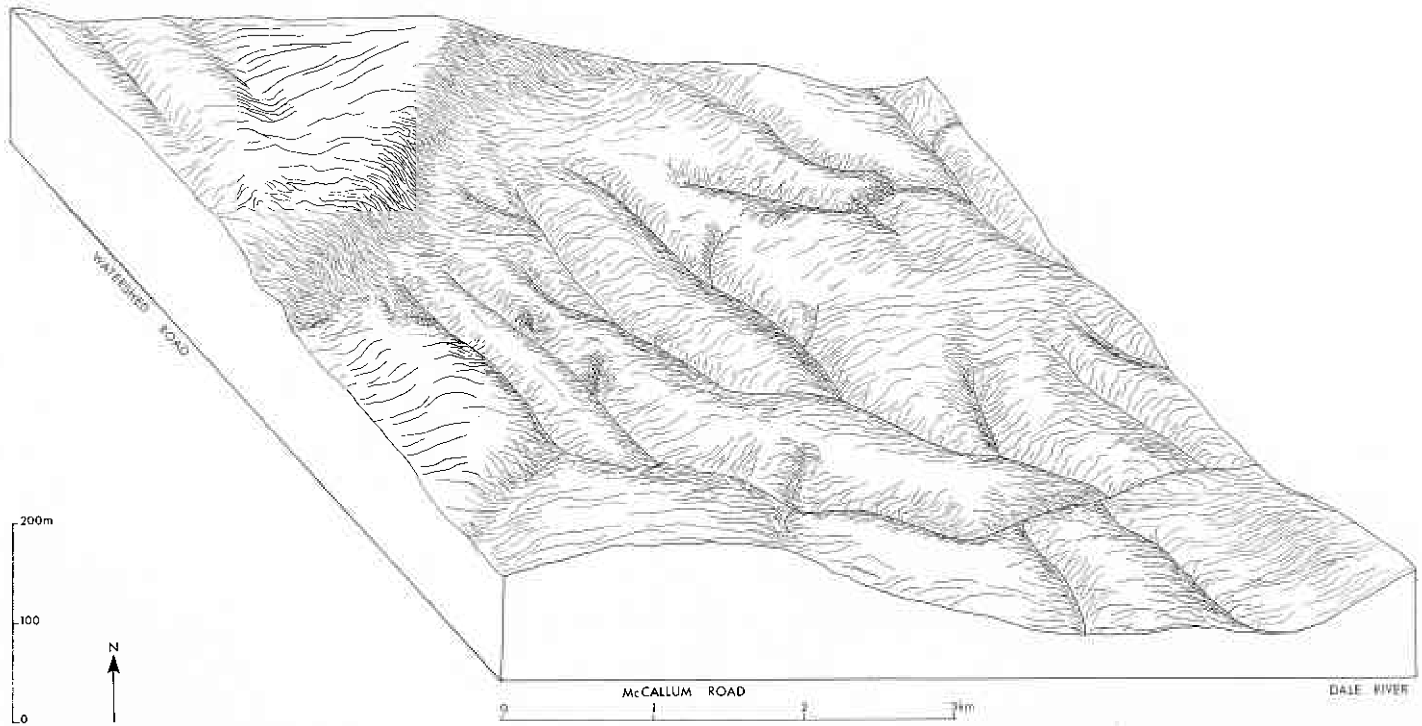

Figure 32
Three-dimensional topographic model of the Flint Test Area.

portion consists of several minor valleys which join together within, or immediately outside, the test area. In between is a zone of numerous small valleys, ridges and spurs with slopes ranging mostly between 5 and 8° (Fig. 34).

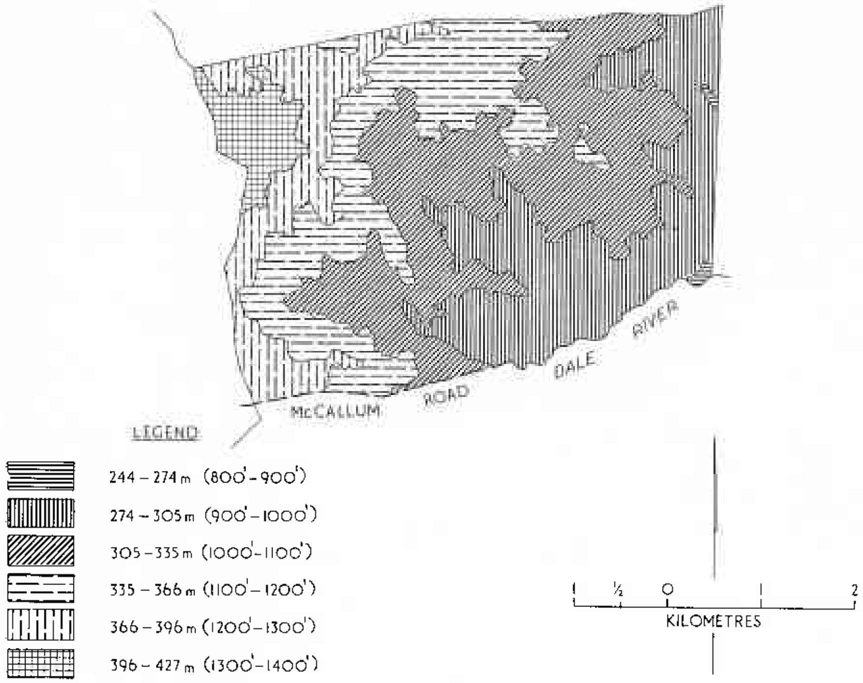

Figure 33
Altitude in the Flint Test Area.

The altitudinal range in the area is 138 m, from 274 m on the lowest point of one of the streams to 412 m on the highest point of the divide. The average fall of the headwater tributaries of the Dale River is 38 m/km, or 3.8 per cent. They are now actively eroding right up to the divide. The density of well-defined watercourses is high.

Geomorphologically the area fits largely into Mulcahy *et al.'s* (1972) category of dissected lateritic slopes, that is a zone of active erosion. The laterite-mantled uplands have escaped dissection only on the northern and western margin. The dissected lateritic slopes consist of valley spurs still capped with lateritic ironstone, below which are encountered exposures of the pallid zone of the lateritic profile and fresh rock, chiefly granite. Rudimentary escarpments (breakaways) occur at the interfaces of the dissected slopes and the uplands.

The area has very extensive outcrops of fresh granitic and epidioritic rocks, which occur chiefly along the slopes of the numerous valleys and at :he heads of the valleys (Fig. 35). By contrast, the outcrops of lateritic ronstone are minor, and are largely confined to the undissected uplands in he north and west of the area. Elsewhere they occur only along the ridges nd spurs.

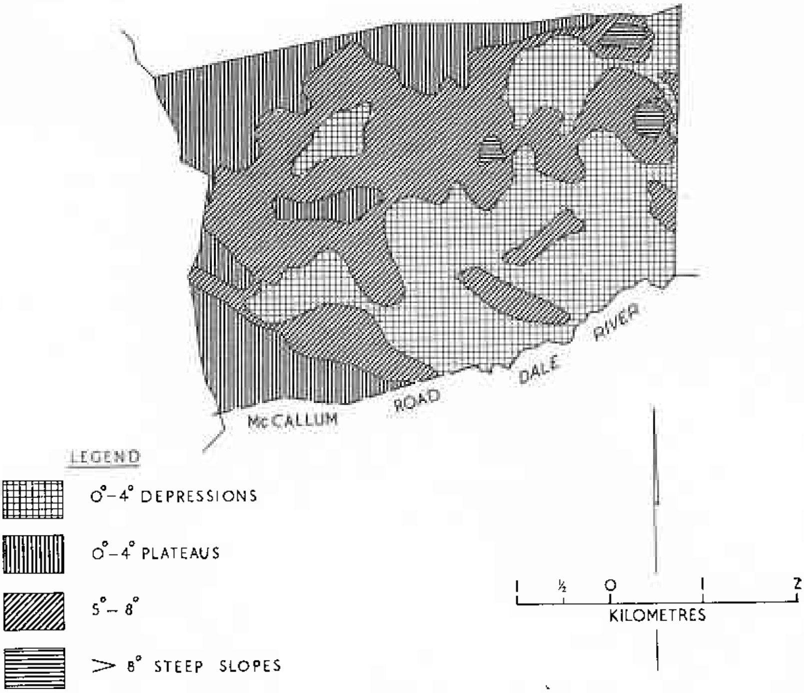

Figure 34
Slope in the Flint Test Area.

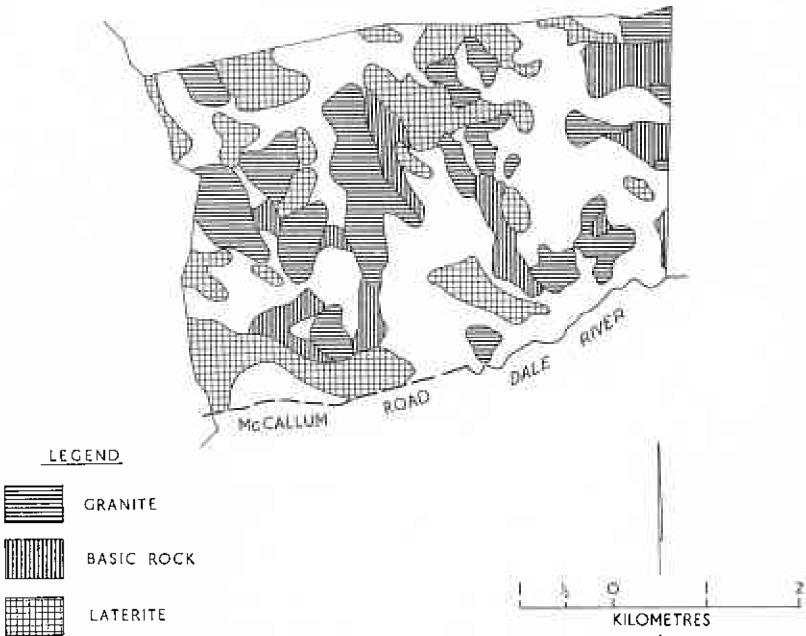

Figure 35
Occurrence of rock outcrops in the Flint Test Area.

The climate of the area is not known precisely. The isohyetal map obtained by interpolation between weather stations east and west of the Test Area indicates an annual rainfall range from approximately 625 mm in the east to 750 mm in the west.

Soils

The area contains a wide range of textures in the surface horizon of soils (Fig. 36). The remnants of the laterite-mantled uplands and the valley spurs have heavy gravels with sandy matrix. These are flanked below by sands on gentle slopes and by heavy gravel with loamy matrix on steeper slopes. The bulk of the dissected slopes is covered by sandy loam, with occasional occurrences of loam, mostly associated with epidioritic outcrops. Where the valleys broaden and flatten out there are small areas of silty loams. Heavy-textured subsoils occur over much of the dissected slopes.

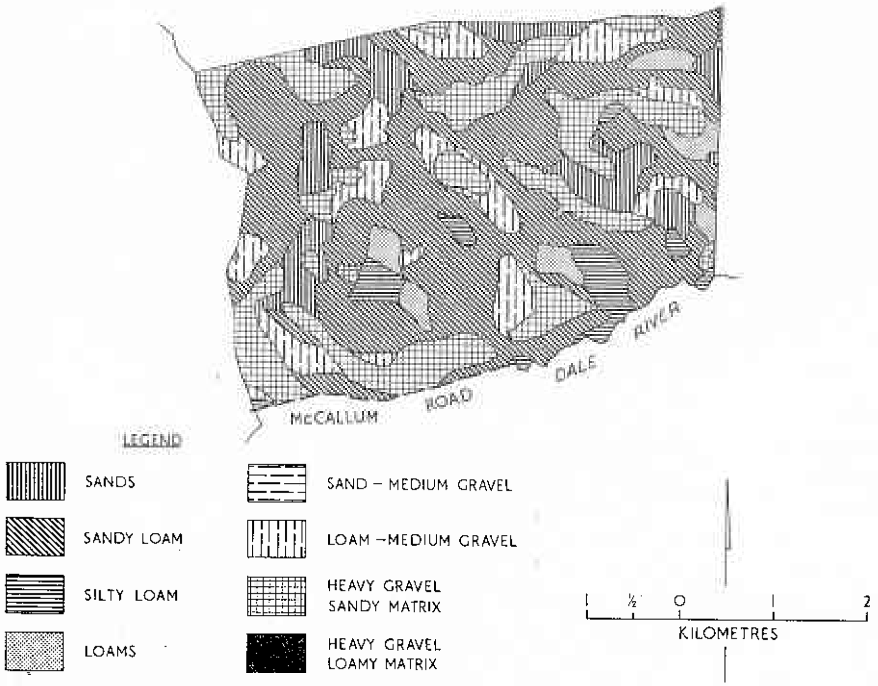

Figure 36
Distribution of soil texture types within the Flint Test Area.

Forest stands

The vegetation of the area has been disturbed only slightly by highly selective logging. Heavier-stocked stands with basal area exceeding 27.6 m^2/ha are restricted to the laterite-mantled uplands in the north-western portion (Fig. 37). The valley spurs and upper slopes carry forest with intermediate basal areas between 9.2 and 27.6 m^2/ha. Lower slopes and valleys within the dissected surface and granite outcrops and their immediate surrounds carry very open stands with a basal area of less than 9.2 m^2/ha. The density of the stands obviously reflects the depth of the solum above an impermeable horizon.

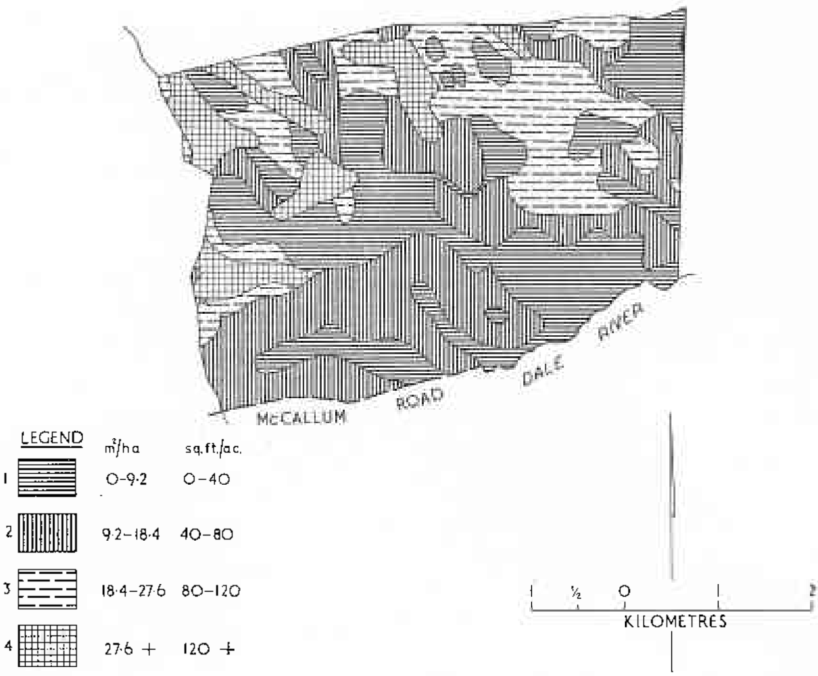

Figure 37
Patterns of stand density (in terms of basal area) in the Flint Test Area.

Apart from a depression of height on granitic outcrops and poorly drained soils, there is no consistent major variation. Over much of the dissected surface the height of the canopy ranges from 13 to 18 m. On parts of the laterite-mantled uplands it occasionally reaches 22 m, but mostly ranges between 15 and 21 m.

Jarrah retains its dominance only on the laterite-mantled uplands, where it occurs largely without any understorey species. Marri accompanies jarrah, but reaches importance only locally, in moister depressions. Once again, these two species have been omitted from the tree species map (Fig. 38), which deals only with species of a more restricted occurrence.

On the upper portion of the dissected slopes, jarrah and marri tend to share dominance with wandoo. On lower slopes, jarrah is largely phased out, and wandoo becomes dominant. Along the moist to wet valley floors, wandoo is accompanied by yarri and flooded gum. On the very shallow soils on and around rock outcrops, granite sheoak accompanies or completely displaces wandoo.

Site-vegetation types

The dominant type within the area is Type M, which occupies most of the dissected slopes (Fig. 39 and Plate 9). The tree stratum ranges from pure wandoo to various admixtures of wandoo, jarrah and marri. Some of the valley spurs and the transition zone between the uplands and the dissected

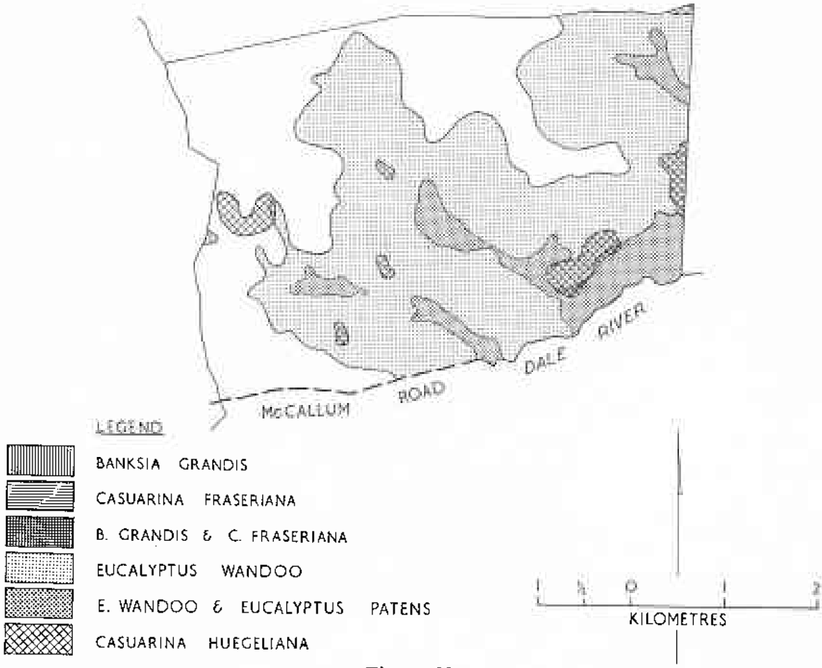

Figure 38
Occurrence of tree species in the Flint Test Area.

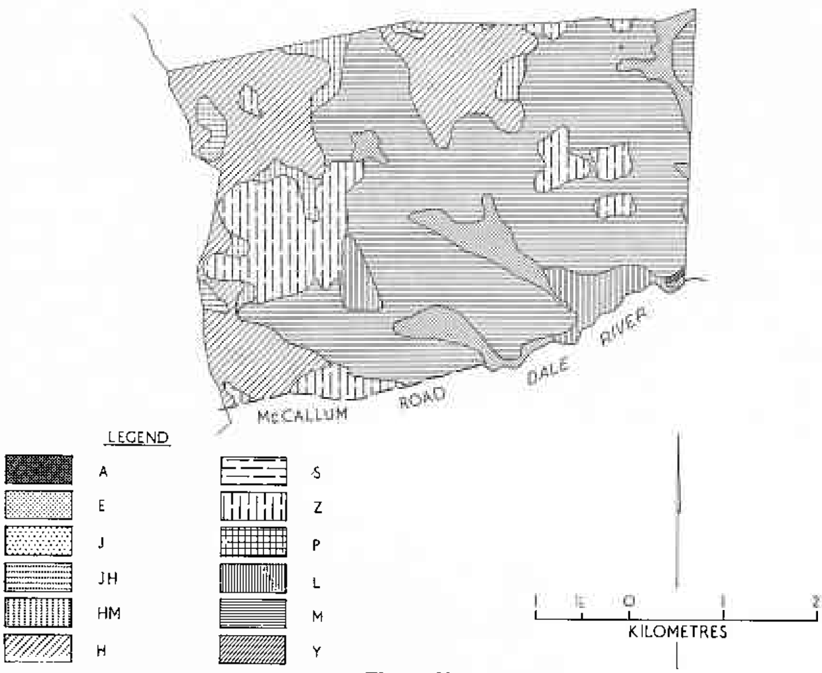

Figure 39
Distribution of site-vegetation types within the Flint Test Area.

slopes belong to Type Z, differing from M chiefly in the absence of wandoo. The transitional Type HM is also common along the upland-slope interface. The bulk of the laterite-mantled uplands is of Type H, except for some minor depressions in which the transitional Type JH is found. It is possible that these occurrences represent small remnants of the Goonaping Surface within the uplands.

Although the localized occurrences of granite sheoak have not been mapped as a separate type, they should perhaps be considered as the climatic variant of Type G, and as this is in turn closely related to R, it is the extreme variation of R (Plate 10).

The valleys chiefly belong to Type Y, but there are two localized occurrences of Type L, distinguished from Y chiefly by the presence of *Diplolaena microcephala* var. *drummondii* and a strong development of *Hibbertia lineata*. Type L is mainly associated with brown silty loams of high fertility, and tends to occur downslope from outcrops of epidiorite.

Human impact

Human impact in the area is very minor. The lightness and selectivity of past logging has already been referred to. With the exception of the Metro Road, which is a primary arterial all-weather road, the construction of all other roads has not involved any major earth moving. All roads tend to descend steeply from the laterite-mantled uplands on to the dissected slopes and then use the somewhat milder slopes of the valleys. This predisposes them to excessive wetness and a tendency to bog during the wet winter period, when all roads except Metro Road are impassable to ordinary-drive vehicles.

There is as yet no evidence of dieback in the area. Remoteness, lack of human activity and drier climate are presumably contributing factors.

Along the banks of one of the creeks, which enters the test area from adjacent cleared agricultural land, there is salt damage in the form of death of the vegetation and accelerated erosion of the bared, deflocculated soil. In midsummer the surface of the affected soil is covered by salt encrustation

SECTION IV

INTEGRATION OF THE REGION

1. ENVIRONMENTAL PATTERNS

The preceding descriptions of individual test areas have demonstrated the strong integration of landscape elements within the watersheds of three tributaries of the Canning River and a tributary of the Dale River. The test areas between them span a considerable climatic range, and illustrate a variety of geomorphic units. It is desirable at this stage to take the process one step further and consider the integration of the region as a whole. The discussion will be based primarily on the four test areas. In addition, areas surveyed in detail but not analysed will also be considered. Features known to occur outside but not within the survey areas will also be referred to on the basis of broad-scale reconnaissance.

The geomorphological studies of Mulcahy *et al.* (1972) and Finkl (1971) have shown that within the Darling Range there is on the whole a predictable sequence of valley forms eastward from the Darling Scarp. The test surveys here described have shown that within each valley form there is a predictable complex of slopes, rock outcrops, soil and vegetation types. This is further illustrated by a series of topographic, edaphic and vegetational transects (Figs. 40 to 47). Human activity is also fairly predictable within this setting. Although the effect of rainfall on vegetation has been briefly referred to, the climatic patterns have not been examined systematically, due to the lack of precise data.

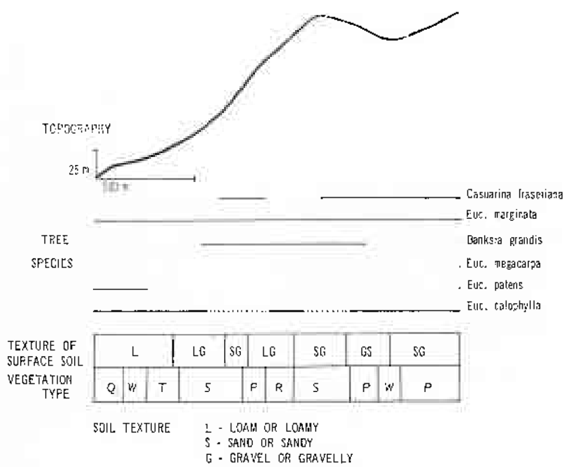

Figure 40

Topographic, edaphic and vegetational transect through the northern sector of the Ashendon Test Area. (Lateritic uplands and Darkin-type valley in high-rainfall zone).

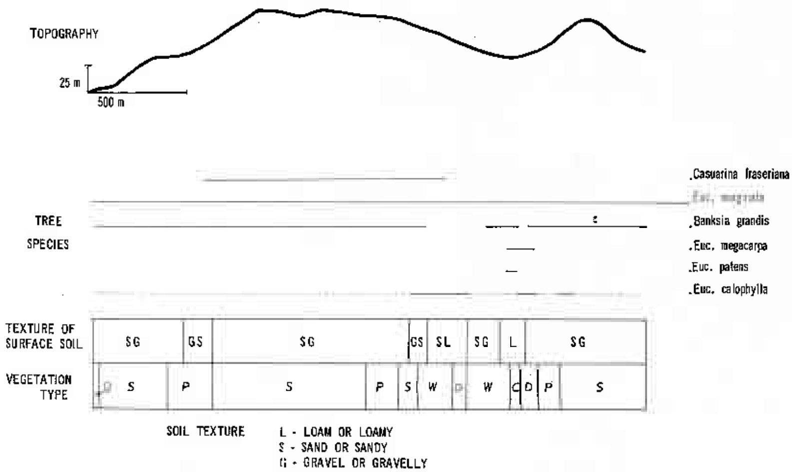

Figure 41

Topographic, edaphic and vegetational transect through the southern sector of the Ashendon Test Area. (Lateritic uplands and Beraking-type valley in high-rainfall zone).

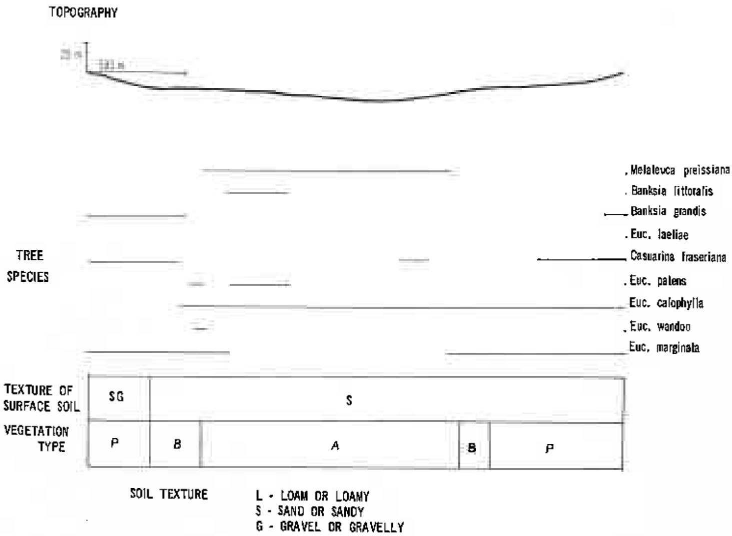

Figure 42

Topographic, edaphic and vegetational transect through the western sector of Cooke Test Area. (Piedmont in medium-rainfall zone).

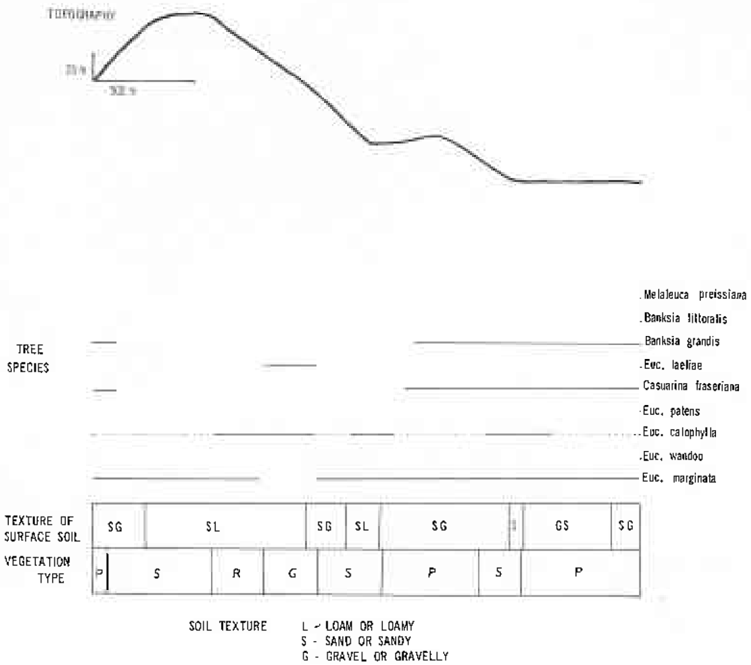

Figure 43

Topographic, edaphic and vegetational transect through the central sector of Cooke Test Area. (Monadnock and lateritic uplands in medium-rainfall zone).

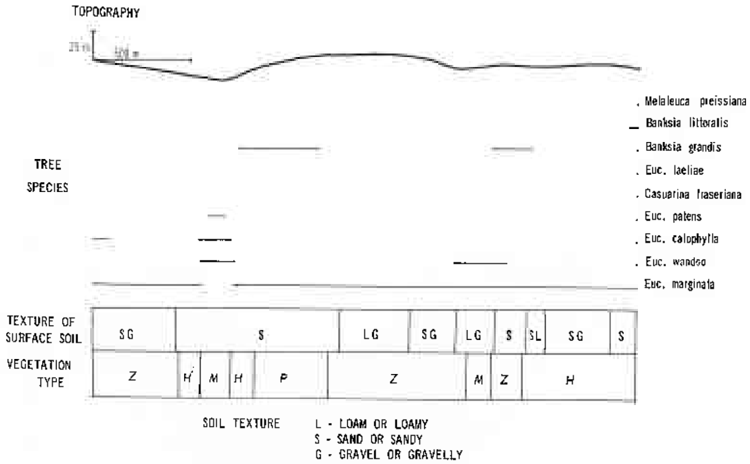

Figure 44

Topographic, edaphic and vegetational transect through the eastern sector of Cooke Test Area. (Lateritic uplands and Beraking-type valleys in medium-rainfall zone).

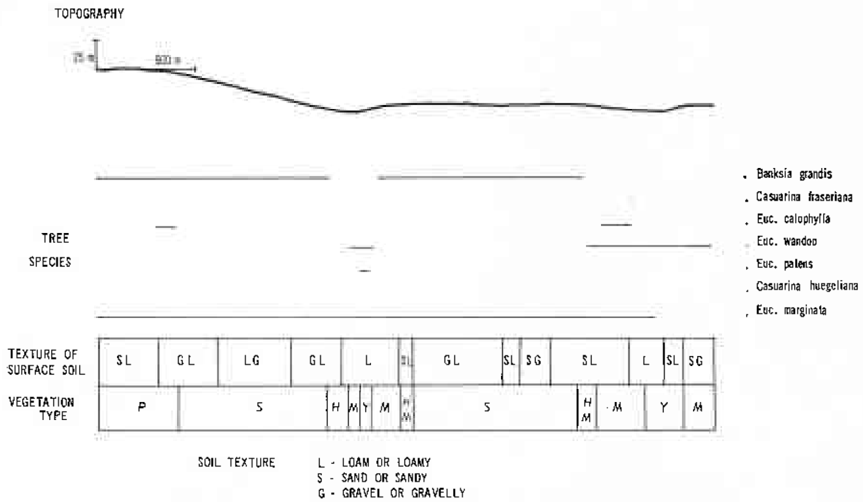

Figure 45

Topographic, edaphic and vegetational transect through the western sector of Leona Test Area. (Lateritic uplands and Beraking-type valley in moderately low rainfall).

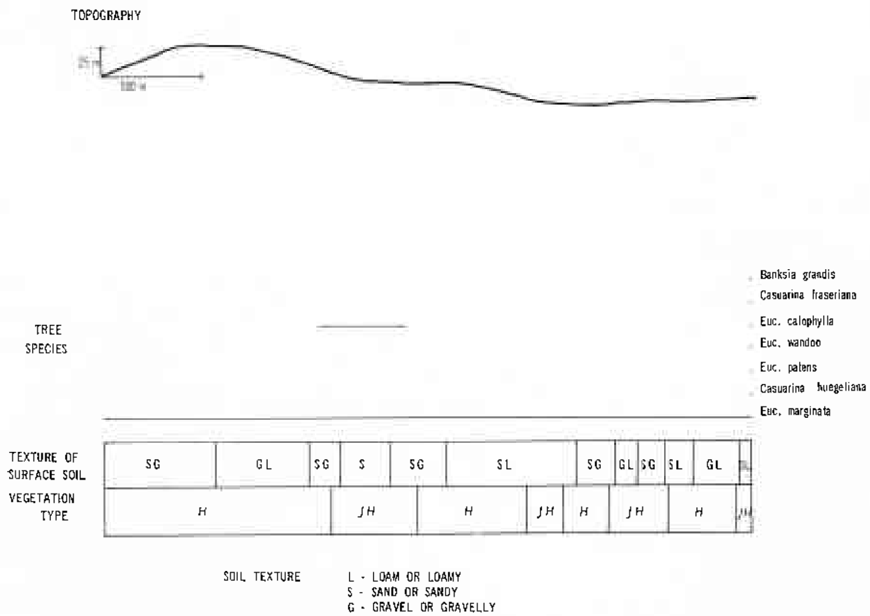

Figure 46

Topographic, edaphic and vegetational transect through the eastern sector of Leona Test Area. (Lateritic uplands with Goonaping-type depressions in low-rainfall zone).

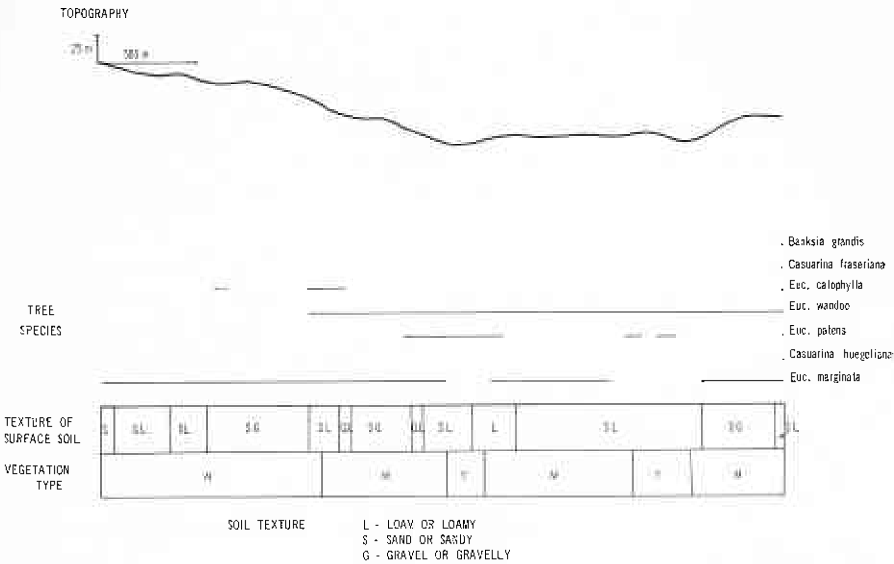

Figure 47
Topographic, edaphic and vegetational transect through the central sector of Flint Test Area. (Lateritic uplands and dissected slopes in low-rainfal zone).

The annual rainfall range of 880 mm (from 600 mm in the north-east to 1 480 mm in the west), combined with the strongly seasonal nature of the precipitation, can be expected to result in major changes in vegetation and land use potential. Thus in the Darling Range one encounters the unique situation in which a strong geomorphological trend, largely conditioned by distance from the escarpment, is overlain by an equally strong, parallel climatic trend also conditioned by the distance from the escarpment. This reinforces still further the integration already described on a local scale, and leads to further simplification of vegetational patterns. There are, however, several exceptions to this, and these provide valuable reference points by means of which the effect of the integration can be measured. Whilst it is true that the dissection of the landscape and the related steepness of land, erosion of the lateritic mantle and removal of the products of erosion decrease eastwards, this does not apply to the Cooke Surface of the monadnocks (Fig. 43), to the dissected slopes in the east (Fig. 47) and to the small residuals of the Goonaping Surface in the west.

In examining the climatic influences, consideration will be given to the relative distribution of both the site-vegetation types and the individual tree species on the four test areas.

2. VEGETATIONAL PATTERNS

No site-vegetation type is common to all four test areas. Certain of the vegetation types have shown a definite bias towards either the Ashendon (Figs. 14, 40) or the Flint (Figs. 39, 47) Test Areas, which represent climatic extremes. These types can thus be expected to be largely climate-conditioned, because both areas are moderately strongly dissected and therefore possess the comparable range of edaphic variation. Types which are mainly restricted to the Ashendon Area are T, Q, D and to a lesser extent also W and C.

T, W and C only occur as small enclaves in the Cooke Area (Fig. 23); Q and D are entirely restricted to the Ashendon Area. All are completely absent from the Leona (Fig. 31) and Flint Areas (Fig. 39). Without exception, all are associated with valley slopes and floors. By contrast, the types with wider distribution, that is Types P and S, are associated with the laterite-mantled uplands.

The types largely restricted to the Flint Area (Fig. 39) are Y and L, and to a lesser extent M. Type L is entirely confined to the Flint Area, though this may be somewhat misleading, as a comparable combination of edaphic and topographic factors does not occur on the neighbouring Leona Area (Fig. 31). Type Y extends in an unchanged form to Leona, but further west occurs only as the transitional Type AY. Both L and Y are associated with valley floors and lower slopes. Type M of the dissected slopes is the dominant type in Flint, and occurs on a progressively decreasing scale in Leona and eastern Cooke. It is totally absent in Ashendon.

Types H and Z and the transitional Types JH and AY are more widespread. The first two are associated with uplands, the third with minor upland depressions and the fourth with waterlogged, seasonally flooded valley floors. Types H and Z are quite extensive in the Leona Area, and are moderately common in the Cooke Area. The transitional Types JH and AY occupy narrow environmental niches in both Leona and Cooke.

The lessened climatic influence on uplands, characterized by deep laterite soils, agrees well with the observations of Lange (1960). The behaviour of jarrah on valley slopes with truncated profiles is also consistent with the above conclusions. In the high rainfall of the Ashendon Area (Figs. 14, 40, 41), jarrah descends on to the shallower loamy soils of the Darkin Surface. In the low rainfall of the Flint Area (Figs. 39, 47), jarrah is largely absent from the shallower, loamier soils of the dissected slopes, where it is replaced by wandoo. It is also replaced by wandoo on the very shallow loamy soils of the steep Helena Surface in the north-west (Mundaring), but less so in the cooler moister south-west (Collie). The most complete replacement of jarrah by wandoo occurs on the Beraking Surface, with its heavy clay subsoils at shallow depth (Figs. 31, 39).

Overall, the main effect of increasing climatic dryness is to accentuate the difference in the moisture-storing capacity of the shallow loamy soils of the erosional surfaces and the deep gravelly soils of the stable uplands. The most extreme cases appear to be the major qualitative change on the shallow sandy loams near granitic outcrops, occupied by a jarrah-marri mixture in Ashendon (Figs. 14, 40), by the Darling Range ghost gum (*Eucalyptus laeliae)* in Cooke (Figs. 23, 43) and by granite sheoak (*Casuarina huegeliana*) in Flint (Figs. 39, 47). The most gradual change occurs on the deep lateritic soils of the uplands, where it is quantitative rather than qualitative. Throughout the entire range from the 1 250 mm annual rainfall in Ashendon (Figs. 40, 41) to 625 mm in Flint (Fig. 47), jarrah remains the dominant tree species. The reduction in rainfall is reflected in reduction of height and density of the stand and in the progressive disappearance of the understorey of sheoak and bull banksia (Figs. 40, 41, 46). In the valleys, the change is intermediate, in that yarri grows on moist alluvium throughout the full range, but its chief associate is marri in the west and wandoo in the east. There is also a marked reduction in the height of the stand. There is a surprisingly pronounced change in the vegetation of swamps, suggesting that there is possibly an equally definite change in environmental conditions, such as greater seasonality and greater influence of salt in the east as compared with the west.

A brief summary of the relationships of site-vegetation types to geomorphology and climate is given in Appendix 1.

3. FACTORS UNDERLYING THE OCCURRENCES OF TREE SPECIES

Main tree species

The well-known nutritional paucity of lateritic gravels, especially their capacity to fix phosphate, could give rise to the idea that the dominance of jarrah on these soils is due to its better ability to cope with low levels of fertility. However, its disappearance from loamy soils of higher fertility is much more clearcut and definite in the dry north-east than in the moist south-west. This suggests that in the south-west it is a case of displacement by species of comparable size and tolerance, such as marri, yarri and ultimately karri (*Eucalyptus diversicolor*), with a greater capacity to use higher levels of nutrition; and in the north-east it is merely a case of replacement. It therefore seems probable that wandoo, which replaces jarrah in the north-east on moist loamy soils (Figs. 45, 47), merely occupies sites from which jarrah is excluded by inadequate soil moisture storage, as it is neither tall enough nor sufficiently shade-tolerant to displace it. The studies of Grieve (1955), Doley (1967) and Grieve and Helmuth (1968) provide ample eco-physiological backing for this theory. In the south-west, jarrah is not completely displaced by yarri and marri in the moist, fertile Type Q (Fig. 40), which apparently has adequate fertility and moisture for marri, yarri and jarrah. The ground vegetation of this type consists of several species with a southern centre of occurrence, and which also enter into the ground vegetation of the karri forests.

Minor tree species

So far, the discussion has centred largely on tree species which are moderately common and have a wide range of distribution. There are however. several minor species with a much more restricted range of occurrence, and which may, therefore, throw further light on the environmental influences in the Darling Range. They fall into four main categories.

The first of these contains species of a narrow edaphic range, widespread geographically but confined to special niches within any particular area. The foremost of these are species of waterlogged or seasonally flooded sites, such as flooded gum (*Eucalyptus rudis*), paperbarks (*Melaleuca preissiana*, *Melaleuca rhaphiophylla*) and swamp banksia (*Banksia littoralis*) (Fig. 42). They occur chiefly in Types C, D, W, A and AY. Their ability to cope with these extreme soil moisture conditions presumably frees them from the otherwise overwhelming influence of climate. Surprisingly, this is not true of their shrub and herb associates, which rarely extend over the full range. Yet another species influenced far more by edaphic than climatic factors is *Nuytsia floribunda*, which is found on leached sandy soil throughout the Darling Range. *Banksia attenuata* and *Banksia menziesii*, whilst having a similar bias towards deep, leached sands, have a much poorer capacity to co-exist with jarrah, and are thus restricted to the dry eastern zone where they partially or completely displace jarrah on Types J and F, generally occupying the Goonaping Surface. However, they do occur in a moister cooler climate on edaphically more extreme sites on the coastal plain, on the Blackwood Plateau and in the Collie Basin. *Banksia ilicifolia* is restricted to moist, leached, deep sands, chiefly in the Collie Basin, but also in some small outliers further north. *Banksia prionotes* is restricted to the extreme north-east of the region, to site-vegetation Type J.

The second group contains species with a marked bias towards the drier conditions of the east and north. Within this overall bias they are generally associated with a particular set of edaphic conditions. For instance, *Casuarina obesa*, which enters the survey area on the lowest part of the Goonaping Surface at the head of the Darkin River, occurs there on solodic soil of a type uncommon in the Darling Range. It is an extreme form of Type Y. *Acacia acuminata*, which also enters the survey area only in the Darkin Valley, is confined to moderately fertile but shallow loams on the valley floor in Type L. *Eucalyptus drummondii* and *Santalum acuminatum* appear to be restricted to heavy-textured kaolinitic clays, occurring on the surface in the vicinity of granitic outcrops in an extreme form of Type G. Similar sites are occupied by the mallee *Eucalyptus decurva*. The prevalence of *Casuarina huegeliana* on the sandy loams and loams on and around rock outcrops has already been referred to. *Eucalyptus accedens* is chiefly associated with deep lateritic soils and lateritic breakaways, where it sometimes accompanies and sometimes replaces jarrah in the dry north-east. The associated site-vegetation Types are H, M and Z. *Acacia microbotrya* occasionally forms a low, open understorey to wandoo in Type Y on sandy soils with clay subsoil. All the above species, including wandoo, largely occur east of the Mt. Cooke-Mt. Dale chain of monadnocks. The only exception to this is occasional occurrences of wandoo and *Casuarina huegeliana* on the thin soils of the Helena Surface. All species have their centre of distribution east of the survey area, in the agricultural region. With the single exception of *Eucalyptus accedens*, they are associated with soils that have some impedence to root penetration in the subsoil, such as impervious clay or massive rock. In low-rainfall zones, where *Eucalyptus accedens* replaces jarrah, the two species are of comparable size, and are at their western and eastern limits of distribution (i.e. at their optimum and minimum) respectively. *Eucalyptus decipiens* enters the survey area from the south-east, where it occurs sporadically on Types M and Y.

The third group contains species with an equally definite bias towards the cooler, moister conditions of the south-west. Of these, *Xylomelum occidentale* extends southwards from the Serpentine River, west of the chain of monadnocks. The leached, pale sandy nature of the soils and the low, level, poorly drained locations associated with its occurrence suggest that these are the westernmost remnants of the Goonaping Surface. Together with a relatively high rainfall, the site virtually duplicates the environmental conditions of the Blackwood Plateau, where the species has its centre of distribution. The associated site-vegetation Type is B.

Eucalyptus megacarpa and *Albizzia lophantha* occur with increasing frequency south and westward from Mundaring (Fig. 41). They are generally associated with loamy soils on the margins of swamps or near ill-defined headwaters of creeks, in Types C, D and W. *Banksia littoralis* var. *seminuda*, previously known erroneously as *Banksia verticillata*, extends northwards to the South Dandalup River on the banks of perennial streams in Types C and Q. The Western Australian peppermint (*Agonis flexuosa*) extends north and eastwards to the Helena Valley form on the Harvey River, and is associated with Type C on the banks of this river. The mountain marri (*Eucalyptus haematoxylon*) advances from its centre of occurrence in the Whicher Range northwards along the face of the Darling Scarp as far north as North Dandalup. Again the Mt. Dale-Mt. Cooke chain of monadnocks emerges as a major vegetation boundary. In addition to the two tree species already mentioned (*Xylomelum occidentale* and *Eucalyptus megacarpa*), two shrubs prominent in the south-west (*Podocarpus drouyniana, Adenanthos meissneri*) reach the limit of their distribution immediately south and west of this line. The remaining two tree species (*Banksia littoralis* var. *seminuda* and *Agonis flexuosa*) fail to reach the line. All four tree species are associated with water-gaining sites, which provide additional compensation for the drier, hotter climate at their north-eastern limit.

The main representative of a fourth group (trees characterized by limited range of occurrence and lack of clear-cut climatic bias), is *Eucalyptus laeliae*. It has its centre of distribution on the chain of monadnocks (Fig. 43), where it mainly occurs on the fresh soil on steep exposed slopes in Type G. However, there are also a few successful establishments of the species on the banks of creeks below the monadnock on moist loams in Type W. The second centre of occurrence is on the Darling Scarp, where it occurs on the thin shallow loams of the Helena Surface. There are a few extensions along the valleys of minor creeks draining the western margin of the Darling Range. These occur on moist, loamy soil within Type W. *Eucalyptus lane-poolei* is restricted to a narrow zone of moist loamy soils at the foot of the Scarp, between the Canning and Murray Rivers. There are only two known occurrences of the gymnosperm *Actinostrobus pyramidalis* in the northern part of the Darling Range. Its occurrence is possibly determined by edaphic factors. It is located on the Goonaping Surface within the Darkin and Harris River Valleys, on strongly leached wet sands underlain by clay, an extreme form of Type A. The species occurs fairly extensively on comparable sites on the coastal plain immediately west of the Scarp.

The function of rivers as migration routes for species responding to climatic changes has been suggested by Holland (1953). This theory is relevant both to species centred in the moist south-west and to those centred in the dry north-east. Mulcahy *et al.'s* (1972) postulate that the Darkin Valley represents the earlier course of the Avon River may account for the occurrence of *Casuarina obesa* and *Acacia acuminata* within the survey area only in that valley and in the present valley of the Avon.

The patterns of occurrence of the various tree species and vegetation types within the survey area do not support the individualistic view of species distribution put forward by Churchill (1961). Most of the 130 species studied by him can be combined into a relatively small number of groups on the basis of his own distribution maps. The resulting groups (Appendix 2) show a great deal of correlation with species groups derived by the analysis of vegetation reported earlier. Many of the groups reflect common edaphic, rather than climatic, requirements.

SECTION V

CONCLUSIONS

It is now appropriate to return to questions posed at the beginning of this Bulletin. It is possible to say that the site-vegetation types do exist in real space. Wide variations exist in the actual areas occupied by the various types. Types S, P and H, characteristic of the laterite-mantled uplands, are more extensive than the rest (Figs. 14, 23, 31, 39). The next most extensive group of types is M, Z and Y, occurring on dissected lateritic slopes and on the Beraking and Nockine Surfaces. Other types are locally important, such as Type Q on the Darkin Surface in the west, Type T on the laterites of the western high-rainfall zone, Type J on the Goonaping Surface and Types A, B and E on the Randall Surface. Types C and W are consistently associated with valley floors, but the total area occupied by them is not great. Types R, D and L have a very localized and restricted occurrence. Types F and U have not been encountered at all. This is due to inadequate coverage by the test areas, as F has been observed during broad-scale reconnaissance. It was found necessary to establish an additional type, Type G, to account for the vegetation and sites of the Cooke Surface. Several transitional types were also used to deal with locally important departures from existing types.

It is also possible to confirm that site-vegetation relationships are valid within real space. Types A, B, D, E and W are invariably found on water-gaining sites, and Types T, S, P and Z on uplands. Types S, P and H are consistently associated with porous, infertile lateritic gravels, whereas Types Q and L are restricted to fertile, heavier-textured loams and Types B, E and J to leached sands. Types H, L and Y have just as definite a bias towards eastern low-rainfall conditions (Figs. 31, 39) as Types Q, D and T have towards western, high-rainfall conditions (Fig. 14). Within the Types T, S, P and H, characterized by a high positive score on the fourth factor (indicative of phosphate-fixing lateritic gravels), the sequence for the second factor is the same (T-S-P-H) as the west-east sequence which the second factor reflects.

Finally, there is adequate evidence that the occurrences of site-vegetation types can be related to geomorphic surfaces visible on small-scale aerial photographs.

Thus the laterite-mantled uplands are mainly occupied by Types S and P in the high-rainfall western zone (Figs. 14, 43, 44) by P and H in the medium-rainfall central zones (Figs. 23, 43, 44) and by H in the dry eastern zone (Figs. 46, 47).

The Darkin Surface in the wet western zone (Figs. 14, 40) is occupied by T, Q and C arranged in a topographic sequence. The Nockine Surface in the same area is occupied by Types P, R and W, which could be separated on the basis of slope and topographic sequence. In the dry eastern zone (Figs. 45, 46, 47) the same surface is occupied by H, Z and M, again separable on the basis of topographical position and slope. The dissected lateritic slopes in the eastern zone (Fig. 47) are occupied by Z, M and Y in a predictable pattern. The Goonaping Surface in the east is largely occupied by Types J and JH (Fig. 46). The Cooke Surface (Fig. 43) is largely occupied by Type G, with smaller occurrences of R and Z. The Randall Surface (Fig. 42) has a predictable sequence of Types AY, B, E, J and H, reflecting varying moisture regimes determined by topographic position.

The implication of this is that geomorphic surfaces are an adequate basis for preliminary mapping of large areas for the purpose of land-use planning on an ecological basis. This can subsequently be refined by site-vegetation mapping.

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APPENDIX 1

Relationships between Geomorphological Surfaces, Rainfall and Site-Vegetation Types in the Northern Jarrah Region

Geomorphic Surface	Rainfall Zone	A	B	C	D	E	F	G	H	J	L	M	O	P	Q	R	S	T	U	W	Y	Z
		Site Vegetation-Type																				
Laterite Mantled Uplands	High												M	C			M	M				
	Medium								C				C	M			C	C				C
	Low								M					O								C
Goonaping	High	O	O																			
	Medium	C	M				M			C												
	Low	C	C				C			M												
Beraking	High			O	M									O						O		
	Medium	C			O																C	
	Low	M				O															M	
Nockine	High				O	O							O	O			O			O		
	Medium								C			C										C
	Low								C			M										M
Dissected Lateritic Slopes	High																					
	Medium							C			O	C										
	Low							C			M	C										O
Darkin	High			M	C								O		M	C		C	M	M		
	Medium			C	C						C				C	C	O	C	O	O		
	Low																					
Randall	Medium	C	C			M	O		O	O											O	
Cooke	Medium							M				O				O	O					O
Helena	High			C				C							O	M		O				
	Medium							C								C						

LEGEND: O—Occasional occurrence. C—Common occurrence. M—Maximum occurrence.

APPENDIX 2

Grouping of plant species in south-western Australia on the basis of their geographical distribution, as mapped by Churchill (1961).

(a) Species confined to cool, moist south-western coast (the karri region)—*Eucalyptus diversicolor, Casuarina decussata, Agonis juniperina, Chorilaena quercifolia.*

(b) Species confined to the karri region and the wet western edge of the Great Plateau between Collie and Mundaring—*Bossiaea aquifolium, Eucalyptus megacarpa, Banksia verticillata, Oxylobium lanceolatum.*

(c) Species confined to the karri region, the western edge of the Great Plateau, the lower west coast and adjacent Blackwood Plateau—*Trymalium spathulatum, Agonis linearifolia, Albizzia lophantha, Hakea amplexicaulis.*

(d) Species of the karri region and the Blackwood Plateau, with small outliers along the western edge of the Great Plateau—*Kingia australis, Agonis parviceps, Hakea lasiantha, Podocarpus drouyniana.*

(e) Species of the karri region, the Blackwood Plateau, the western edge of the Great Plateau and the coastal plain south of Perth—*Xylomelum occidentale, Adenanthos obovata, Pteridium esculentum.*

(f) Species of the southern and western jarrah forest, the Blackwood Plateau and the karri region—*Xanthorrhoea gracilis, Leucopogon verticillatus, Bossiaea linophylla.*

(g) Species occupying most of the area south-west of the line from Albany to Gingin, with a few small outliners to the east and north (particularly Mt. Leseur)—*Eucalyptus marginata, Eucalyptus calophylla, Eucalyptus patens, Casuarina fraseriana, Banksia grandis, Banksia littoralis.*

(h) Species occurring virtually throughout the south-west region from Kalbarri to Albany—*Macrozamia reidlei, Banksia attenuata, Xanthorrhoea preissii, Dryandra floribunda,* syn. *D. sessilis, Hakea prostrata, Eucalyptus rudis* (absent, south coast) *Acacia cyanophylla, Melaleuca rhaphiophylla, Melaleuca parviflora* syn. *M. preissiana, Nuytsia floribunda.*

It will be seen that up to this point the groups increasingly occupy larger proportions of the south-west region by advancing into the drier, hotter, continental north-east.

(i) Species occurring throughout the whole of the south-west region with the exception of the high-rainfall area of the karri and jarrah region and the Blackwood Plateau—*Casuarina glauca* syn. *C. obesa, Hakea trifurcata, Acacia microbotrya, Melaleuca uncinata.*

(j) Species differing from (i) only in that they extend west through the Avon Valley and south along the Darling Scarp for varying distances, but are absent from the coastal plain—*Eucalyptus wandoo, Borya nitida, Casuarina huegeliana, Santalum acuminatum, Acacia acuminata.*

(k) Species of the predominantly narrow coastal belt along the west and south coasts—*Agonis flexuosa, Eucalyptus gomphocephala, Dasypogon bromeliaefolius, Banksia ilicifolia.*

(l) Species of the norhtern coastal plain, with outliers east of south-east of the main forest region—*Stirlingia latifolia, Eucalyptus decipiens, Banksia menziesii, Adenanthos cygnorum, Conospermum triplinervium, Banksia prionotes.*

(m) Species of the inland, not entering jarrah region—*Eucalyptus salmonophloia, Eucalyptus salubris.*

(n) Species of the far inland (outside the wheatbelt)—*Callitris preissii, Codonocarpus cotinifolius, Brachychiton gregorii, Triodia basedowii, Acacia aneura, Acacia sibirica, Eucalyptus camaldulensis, Eucalyptus kingsmillii.*

(o) Species of the western wheatbelt and eastern margins of the forest—*Eucalyptus astringens, Eucalyptus accedens, Eucalyptus macrocarpa.*

(p) Species of the south-east wheatbelt and south-east coast—*Eucalyptus platypus, Eucalyptus occidentalis, Hakea corymbosa, Eucalyptus tetragona.*

APPENDIX 3

List of plant species referred to in Bulletins 86 and 87.

Acacia acuminata Benth.
Acacia aneura F. Muell ex Benth.
Acacia alata R. Br.
Acacia cyanophylla Lindl.
Acacia drummondii Lindl.
Acacia extensa Lindl.
Acacia microbotrya Benth.
Acacia nigricans R. Br.
Acacia pulchella R. Br.
Acacia sibirica S. Moore
Acacia strigosa Link.*
Acacia urophylla Benth.
Actinostrobus pyramidalis Miq.
Adenanthos barbigera Lindl.
Adenanthos cygnorum Diels.
Adenanthos meissneri Lehm.
Adenanthos obovata Labill.
Adiantum aethiopicum L.
Agonis flexuosa (Spreng.) Schau.
Agonis juniperina Schau.
Agonis linearifolia (DC.) Schau.
Agonis parviceps Schau.
Albizzia lophantha (Willd.) Benth.
Astartea fascicularis (Labill.) DC.
Astroloma ciliatum (Lindl.) Druce
Astroloma pallidum R. Br.
Baeckea camphorosmae Endl.
Banksia attenuata R. Br.
Banksia grandis Willd.
Banksia ilicifolia R. Br.
Banksia littoralis R. Br.
Banksia littoralis R. Br. var. *seminuda* A. S. George
Banksia menziesii R. Br.
Banksia prionotes Lindl.
Boronia spathulata Lindl.
Borya nitida Labill.
Bossiaea aquifolium Benth.
Bossiaea linophylla R. Br.
Bossiaea ornata (Lindl.) Benth.
Bossiaea pulchella Meissn.
Brachychiton gregorii F. Muell.
Callitris preissii Miq.
Calytrix flavescens A. Cunn.
Casuarina decussata Benth.
Casuarina fraseriana Miq.**
Casuarina huegeliana Miq.
Casuarina humilis Otto & Dietr.
Casuarina obesa Miq.
Caustis dioica R. Br.
Chorilaena quercifolia Endl.
Chorizema ilicifolium Labill.

Clematis pubescens Hueg.
Codonocarpus cotinifolius (Desf.) F. Muell.
Conospermum stoechadis Endl.
Conospermum triplinervium R. Br.
Conostylis aculeata R. Br.
Conostylis setigera R. Br.
Cyathochaete clandestina R. Br.
Dampiera alata Lindl.
Dampiera linearis R. Br.
Dasypogon bromeliaefolius R. Br.
Daviesia longifolia Benth.
Daviesia pectinata Lindl.
Daviesia polyphylla Benth. ex Lindl.
Daviesia preissii Meissn.
Daviesia rhombifolia Meissn.
Dillwynia cinerascens R. Br.
Diplolaena microcephala Bartl. var. *drummondii* Benth.
Dryandra bipinnatifida R.Br.
Dryandra nivea R.Br.
Dryandra sessilis (Knight) Domin
Eucalyptus accedens W. V. Fitzg.
Eucalyptus astringens Maiden
Eucalyptus camaldulensis Dehn.
Eucalyptus calophylla R.Br.
Eucalyptus decipiens Endl.
Eucalyptus decurva F. Muell.
Eucalyptus diversicolor F. Muell.
Eucalyptus drummondii Benth.
Eucalyptus haematoxylon Maiden
Eucalyptus kingsmillii Maiden and Blakely
Eucalyptus laeliae Podger and Chippendale
Eucalyptus lane-poolei Maiden
Eucalyptus longicornis F. Muell.
Eucalyptus loxophleba Benth.
Eucalyptus macrocarpa Hook.
Eucalyptus marginata Sm.
Eucalyptus megacarpa F. Muell.
Eucalyptus occidentalis Endl.
Eucalyptus patens Benth.
Eucalyptus platypus Hook.
Eucalyptus rudis Endl.
Eucalyptus salmonophloia F. Muell.
Eucalyptus salubris F. Muell.
Eucalyptus tetragona (R.Br.) F. Muell.
Eucalyptus wandoo Blakely
Gastrolobium calycinum Benth.
Gompholobium knightianum Lindl.
Gompholobium marginatum R.Br.
Gompholobium polymorphum R.Br.
Grevillea bipinnatifida R.Br.
Grevillea diversifolia Meissn.
Grevillea pulchella Meissn.
Grevillea synapheae R.Br.
Grevillea wilsonii A. Cunn.
Hakea amplexicaulis R.Br.
Hakea ceratophylla (Sm.) R.Br.
Hakea corymbosa R.Br.
Hakea cyclocarpa Lindl.
Hakea elliptica (Sm.) R.Br.
Hakea lasiantha R.Br.
Hakea lissocarpha R.Br.
Hakea marginata R.Br.
Hakea prostrata R.Br.
Hakea trifurcata (Sm.) R.Br.
Hakea undulata R.Br.
Hakea varia R.Br.
Helipterum cotula (Benth.) DC.
Helipterum manglesii (Lindl.) Benth.
Hemigenia pritzelii S. Moore
Hibbertia amplexicaulis Steud.
Hibbertia hypericoides (DC.) Benth.
Hibbertia huegelii (Endl.) F. Muell.
Hibbertia lasiopus Benth.
Hibbertia lineata Steud.
Hibbertia montana Steud.
Hibbertia polystachya Benth.
Hibbertia subvaginata (Steud.) F. Muell.
Hovea chorizemifolia (Sweet) DC.
Hovea trisperma Benth.
Hypocalymma angustifolium Endl.
Hypocalymma cordifolium (Lehm.) Schau.
Isopogon dubius (R.Br.) Druce
Isopogon sphaerocephalus Lindl.
Jacksonia stenbergiana Hueg.
Kennedia coccinea Vent.
Kennedia prostrata R.Br.
Kingia australis R.Br.
Kunzea micromera Schau.
Lasiopetalum floribundum Benth.***
Lechenaultia biloba Lindl.
Lepidosperma angustatum R.Br.
Lepidosperma scabrum Nees
Lepidosperma tenue Benth.
Lepidosperma tetraquetrum Nees
Leptocarpus scariosus R.Br.
Leptomeria cunninghamii Miq.

Leptospermum ellipticum Endl.
Leucopogon capitellatus DC.
Leucopogon cordatus Sond.
Leucopogon oxycedrus Sond.
Leucopogon propinquus R.Br.
Leucopogon verticillatus R.Br.
Lomandra caespitosa (Benth.) Ewart
Lomandra endlicherii (F. Muell.) Ewart
Lomandra purpurea (Endl.) Ewart
Lomandra sonderii (F. Muell.) Ewart
Loxocarya cinerea R.Br.
Loxocarya fasciculata (R.Br.) Benth.
Loxocarya flexuosa (R.Br.) Benth.
Lyginia tenax R.Br.
Lysinema ciliatum R.Br.
Macrozamia riedlei (Gaud.) C.A. Gardn.
Melaleuca preissiana Schau.
Melaleuca rhaphiophylla Schau.
Melaleuca scabra R.Br.
Melaleuca uncinata R.Br.
Mesomelaena tetragona (R.Br.) F. Muell.
Mesomelaena sp. nov.
Millotia tenuifolia Cass.
Mirbelia spinosa Benth.
Nuytsia floribunda (Labill.) R.Br.
Opercularia hispidula Endl.
Patersonia occidentalis R.Br.
Patersonia rudis Endl.
Petrophile linearis R.Br.
Petrophile macrostachya R.Br.
Petrophile seminuda Lindl.
Petrophile striata R.Br.
Persoonia elliptica R.Br.
Persoonia longifolia R.Br.
Persoonia saccata R.Br.
Phyllanthus calycinus Labill.
Pimelia suaveolens (Endl.) Meissn.
Pinus pinaster Ait.
Pinus radiata D.Don
Podocarpus drouyniana F. Muell.
Pteridium esculentum (Forst. F.) Nakai
Ptilotus manglesii (Lindl.) F. Muell.
Santalum acuminatum (R.Br.) Druce
Scaevola striata R.Br.
Sphaerolobium medium R.Br.
Stirlingia latifolia (R.Br.) Steud.
Synaphea petiolaris R.Br.
Styphelia tenuiflora Lindl.
Tetratheca viminea Lindl.
Tetrariopsis octandra (Nees) C.B. Clarke
Triodia basedowii E. Pritzel
Trymalium ledifolium Fenzl.
Trymalium spathulatum (Labill.) Ostf.
Waitzia acuminata Steetz.
Xanthorrhoea gracilis Endl.
Xanthorrhoea preissii Endl.
Xanthosia candida (Benth.) Steud. ex Bunge.
Xanthosia ciliata Hook.
Xylomelum occidentale R.Br.

* Since the completion of the field work, taxonomic revision has resulted in the subdivision of *Acacia strigosa* Link. into *Acacia preissiana* (Meissn.) B.R. Maslin and *Acacia lateriticola* B.R. Maslin. Where uncertainty exists as to which of the two new species is involved, the old name has been retained.

** The rectification of an old spelling error has resulted in the recent changing of *Casuarina fraseriana* to *Casuarina fraserana*. This announcement came too late for the amendment to be made in this Bulletin, and the incorrect spelling therefore remains.

*** As in the case of * (above) *Lasiopetalum floribundum* Benth. has been subdivided into *Lasiopetalum floribundum* Benth. and *Lasiopetalum glabrotum* S.Panst.

Plate 1
Ashendon Test Area, stable lateritic uplands. Selectively logged forest of Type S dominated by *Eucalyptus marginata*.

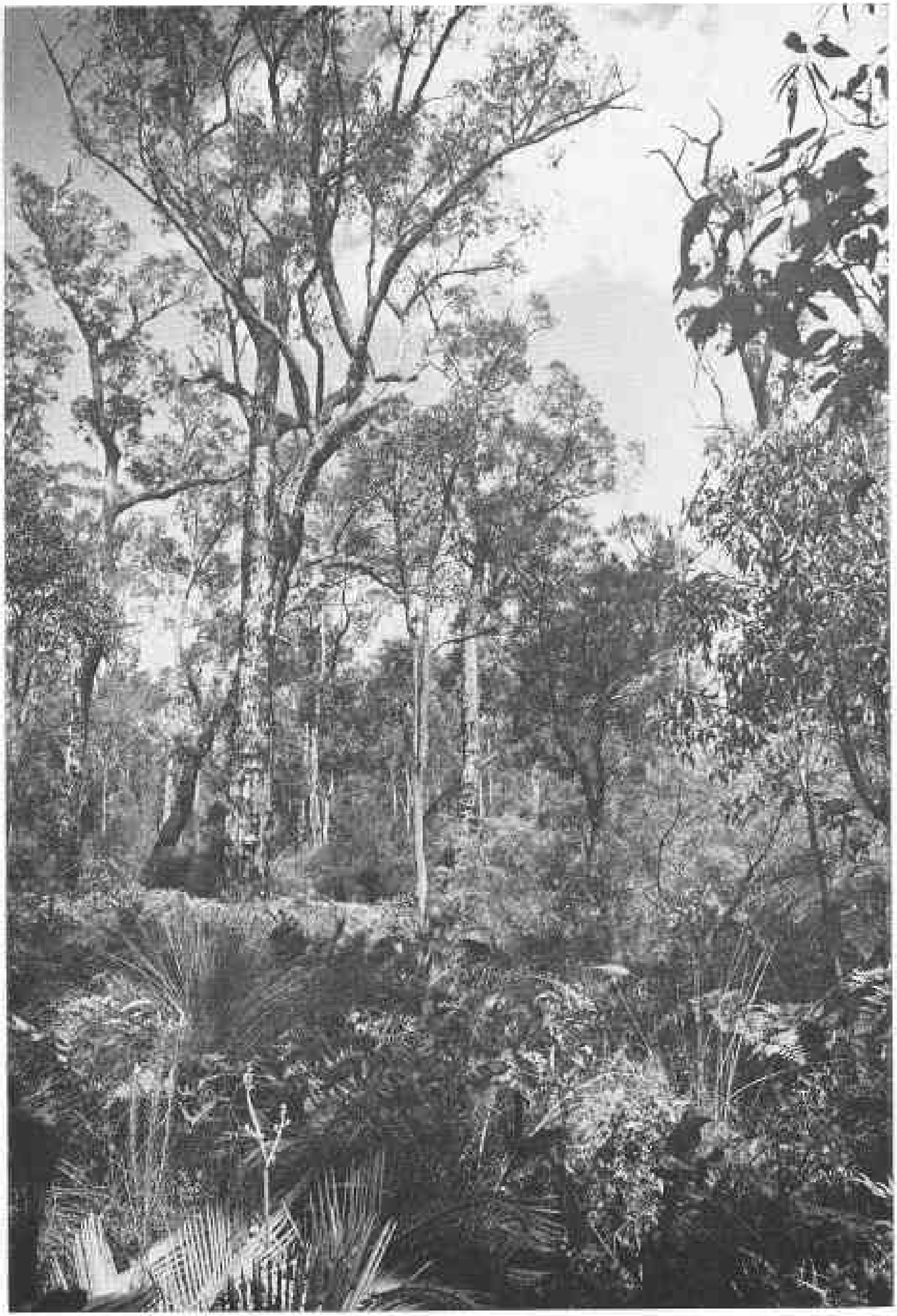

Plate 2
Ashendon Test Area, Darkin Valley type. Middle reaches of the Canning River, with stream vegetation of Type C dominated by *Eucalyptus patens*.

Plate 3
Ashendon Test Area, Beraking Valley type. Revegetation of dieback-ravaged forest of Type D by *Eucalyptus calophylla* and *Eucalyptus megacarpa.*

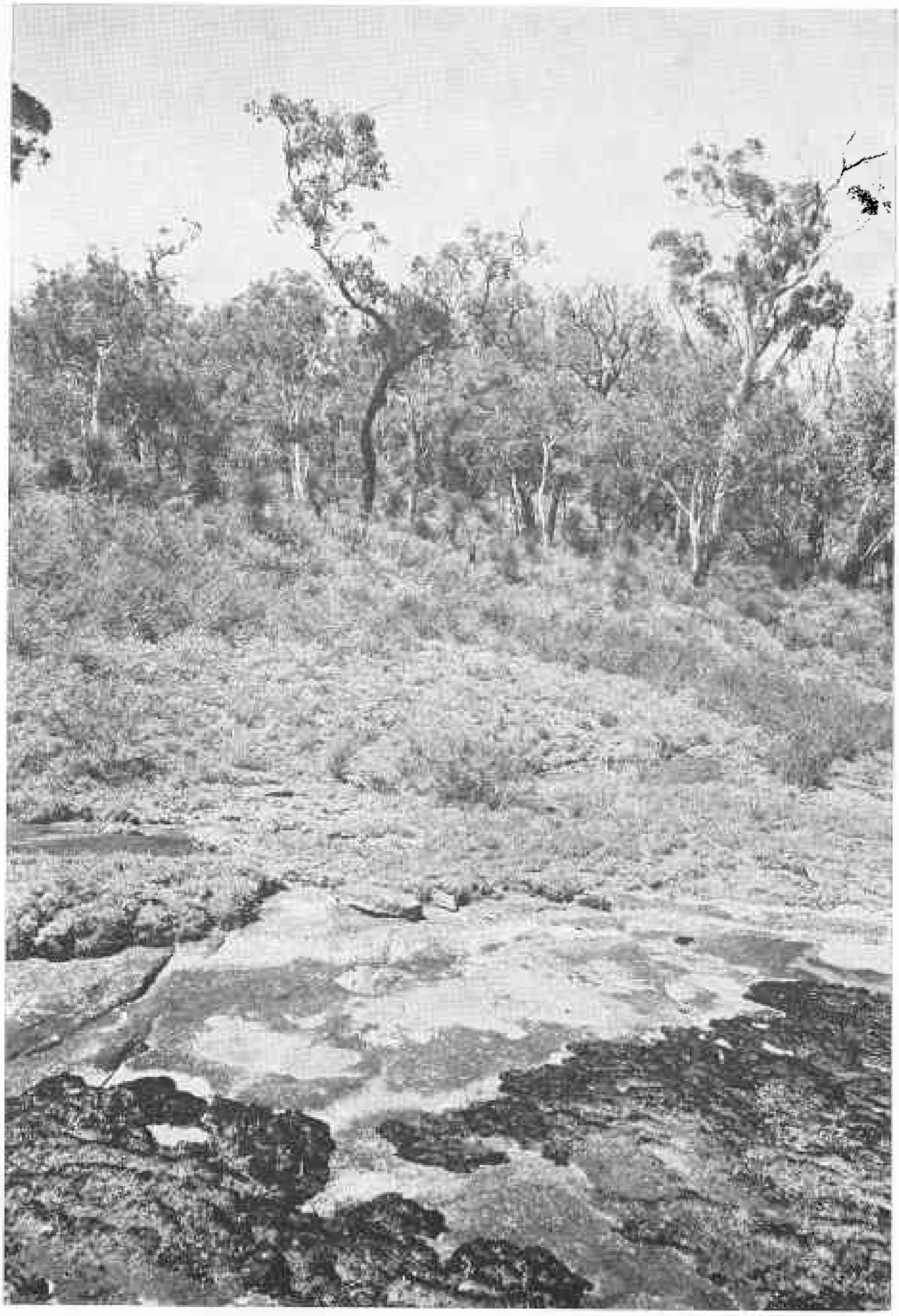

Plate 4
Cooke Test Area, Cooke Surface. Granitic outcrop surrounded by shrubberies and open woodland of *Eucalyptus laeliae* (Type G).

Plate 5

Cooke Test Area, Randall Surface. Dieback-affected forest of Type B dominated by *Eucalyptus marginata.*

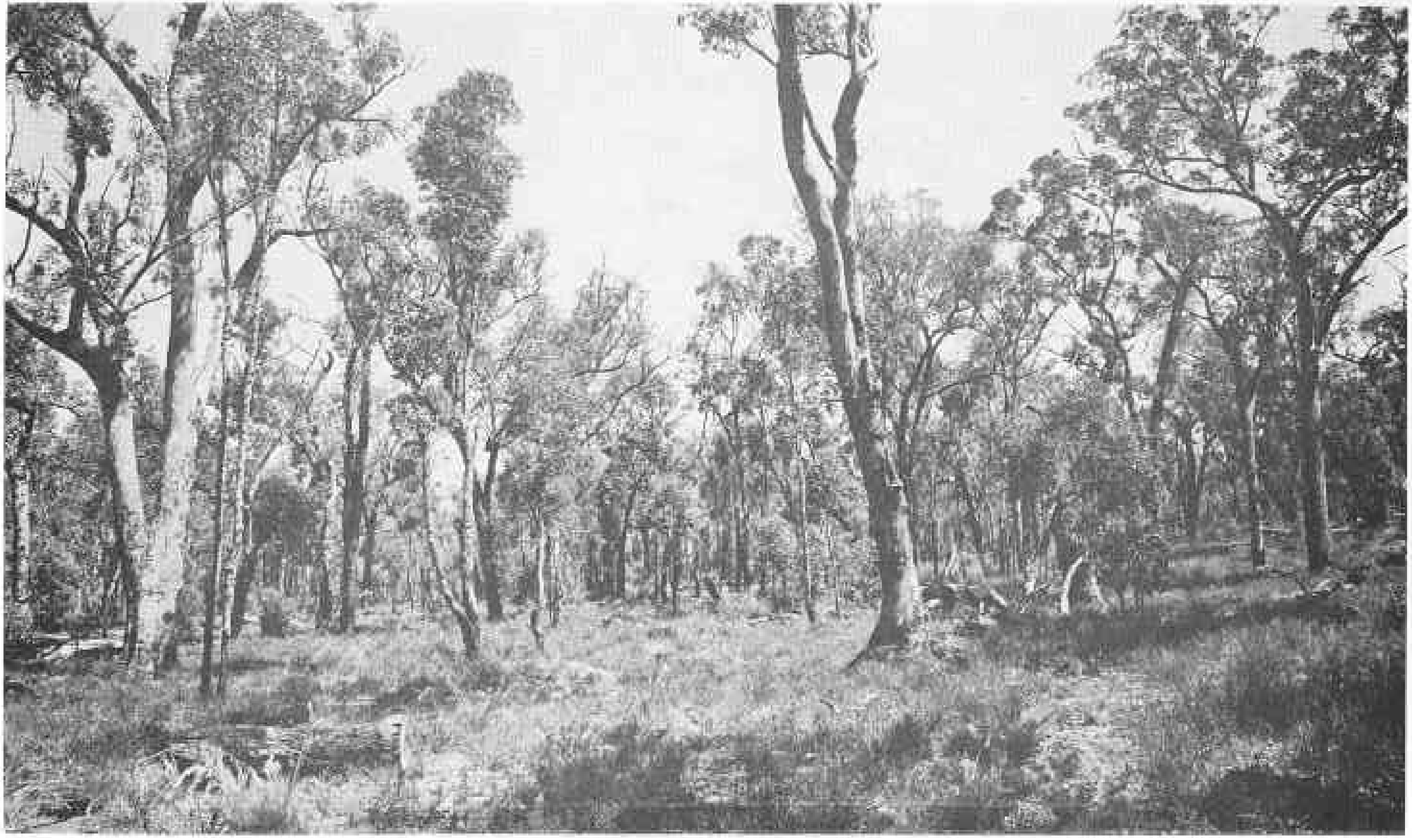

Plate 6

Leona Test Area, stable lateritic uplands. Selectively logged forest of Type H dominated by *Eucalyptus marginata*.

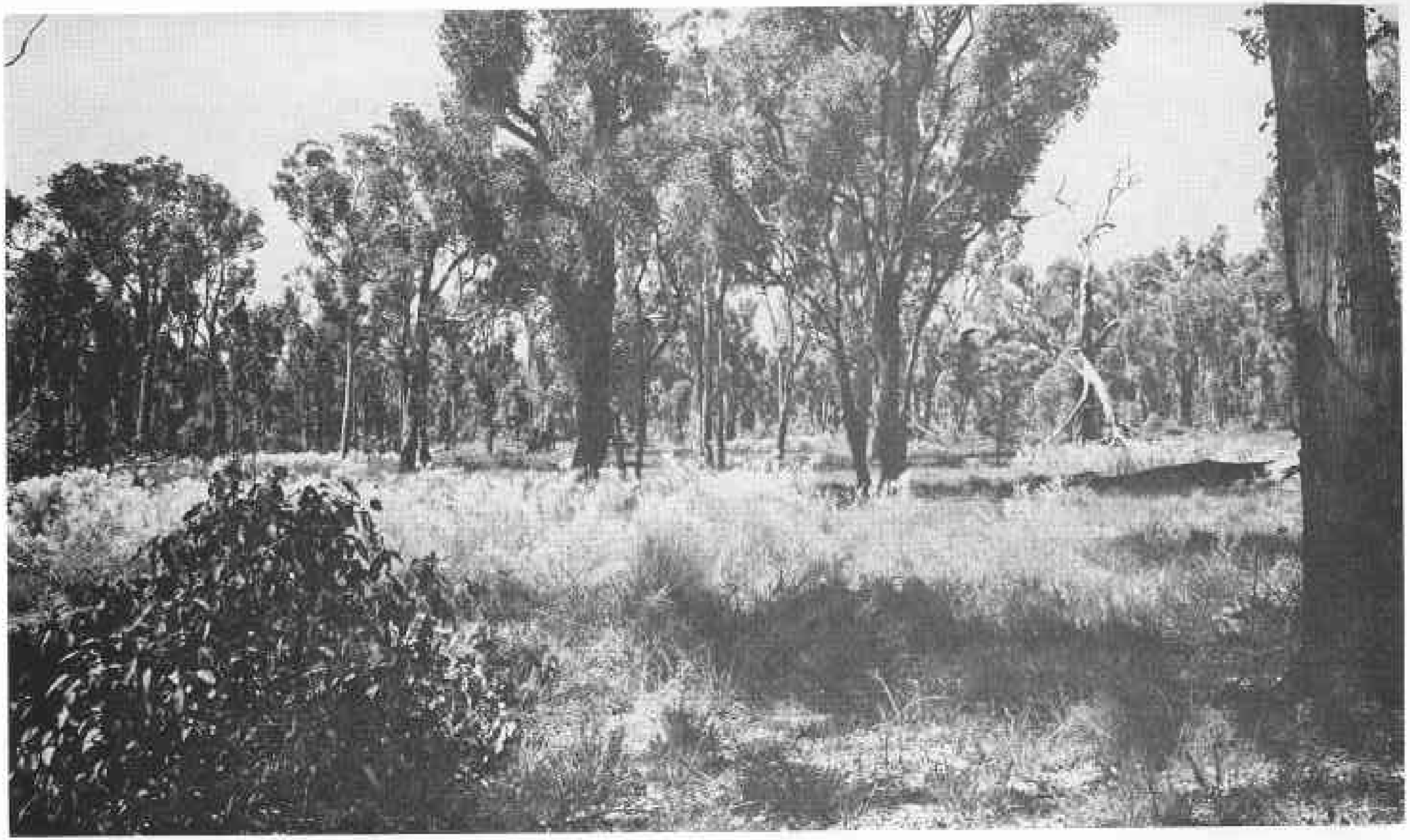

Plate 7
Leona Test Area, Goonaping Surface. Woodland of Type J dominated by *Eucalyptus marginata.*

Plate 8

Leona Test Area, Beraking Valley type. *Hakea-Melaleuca shrublands* (Type A) in the foreground, woodland of *Eucalyptus wandoo* (Type Y) in the background.

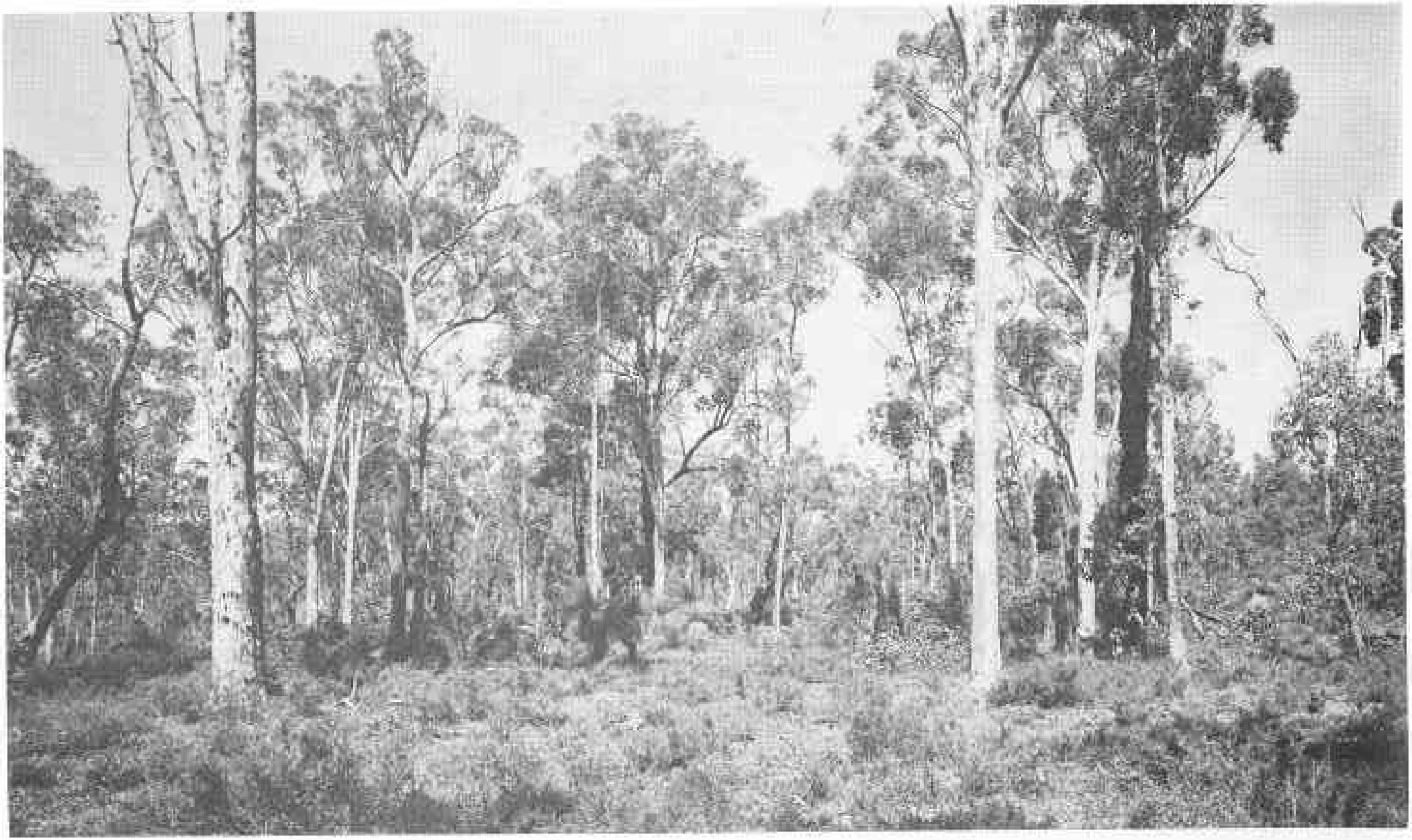

Plate 9

Flint Test Area, dissected lateritic slopes (deep phase). Woodland of Type M, dominated by *Eucalyptus wandoo* and *Eucalyptus marginata*.

Plate 10

Flint Test Area, dissected lateritic slopes (shallow phase). Granitic outcrop with fringing woodland of *Casuarina huegeliana* (Type G).

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