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THE POTENTIAL OF THE NORTHERN SWAN COASTAL PLAIN FOR PINUS PINASTER AIT PLANTATIONS

by
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ABSTRACT

The potential for plantation establishment of *Pinus pinaster* Ait. on the Swan Coastal Plain north of Perth, the capital of Western Australia, was assessed on an ecological basis. The selection of this approach was necessitated by the lack of climatic data and soil and topographical maps.

The assessment was based on 67 pilot plots, 8 to 18 years old. Five-year height intercept, defined as the height growth of dominants over the period of maximum increment, usually from 3 to 8 years of age, was used as a measure of pine growth potential. Height intercept was related to the native vegetation in the surround of the pilot plots by means of principal component analysis.

The main determinants of vegetational patterns and pine growth potential were found to be the degree of leaching undergone by the soil and the moistness of the site. The extremes were represented by (a) strongly leached droughty sites, on which the site index, in form of five year height intercept, ranged from 7 to 13 ft., and by (b) weakly leached moist sites with site index ranging from 15 to 20 ft. The potential of the various site-vegetation types was also expressed in terms of top height, predominant height, basal area and merchantable volume at age 15. For each site—vegetation type, a set of shrub indicator species was defined.

Additional work was carried out to define sites on which satisfactory growth rates were combined with susceptibility to death by summer drought. A relationship was established between the drought probability, the density and complexity of the native woodland and the drought susceptibility of pine stands. Neutron probe studies under pine plantation and native woodland on two site types indicated that drought deaths were the result of progressive exhaustion of water reserves under the denser, taller pine stands, which were established with the aid of cultivation and phosphate and zinc fertilizer application. An experiment has been established to determine the stocking of the pine stands at which water reserves can be replenished annually during the wet winter season.

At the other extreme, the susceptibility to winter flooding on sites with a high ground water table was also studied. Reliable plant indicators of soil moisture regimes were discovered and a method ameliorating this site type by delay in planting is recommended.

In order to assess the practicability of the approach, the assessment method was applied to over 8,000 acres, representing 6.5 per cent. of the total unplanted area. It was found that site mapping on the ecological basis, using a combination of field mapping and photo-interpretation, could be carried out at the rate of more than 300 acres per day by a two-man team. The results were applied on a proportional basis to the entire unplanted area, and an overall assessment was made on the basis of distance to market, growth and susceptibility to drought or flooding.

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INTRODUCTION

The lack of indigenous softwoods has made it necessary for the Forest Department of Western Australia to engage actively in the establishment of softwood plantations. Extensive trials have narrowed the choice to the following two alternatives:—

(a) *Pinus pinaster,* of Portuguese origin, on infertile sands of the Swan Coastal Plain.

(b) *Pinus radiata* on the more fertile and moister soils of the inland valleys.

In the case of the former, intensive management is required to overcome the handicaps of the site. In order to reduce the competition of the native vegetation and raise the inherent low level of fertility of the soils, treatment requires complete clearing and cultivation prior to planting, application of superphosphate and zinc oxide and cultivation after planting.

The early plantations of *Pinus pinaster* were established mainly within 25 miles of the capital—Perth, in the 32 to 35 in. rainfall zone. The main concentration is at Gnangara, at the SE corner of State Forest No. 65, which comprises 150,000 acres extending NW from Gnangara in a narrow belt roughly parallel to the coast (Figure 1). So far about 14,000 acres have been planted. More recently, smaller areas of plantation have been established at Yanchep, 35 to 40 miles from Perth. As the bulk of suitable land at Gnangara is already planted, future development will need to take place between Gnangara and Yanchep, and beyond Yanchep. Such a development involves extrapolation beyond the known suitable localities, into an area characterised by relatively rapid changes of vegetation, and suspected, but as yet poorly documented, deterioration of climatic factors. It is suspected that there is a decrease in the annual rainfall and the length of growing season and an increase in the evapo-transpiration. The reason for the inadequacy of climatic records lies in the extreme infertility of soils, which until recently has been a barrier to economic development and close settlement of the area, in spite of its proximity to the capital. For this reason, a thorough appraisal of the potential for plantation establishment was considered necessary.

REVIEW OF PAST WORK

At the commencement of the current programme, much was already known about the area. Work carried out earlier, both by the Forest Department, other government agencies and the University of W.A., was utilized in the present study. This is briefly reviewed to show the reason for the adoption of the particular methods used in this study.

Climate.

Complete climatic data are only available for Perth. The nearest long term climatic station on the coast is at Geraldton over 200 miles to the north. Moderately long term rainfall records (34 years) have also been kept at Cowalla station, near the NE boundary of the State Forest. More recently rainfall and temperature data have been also kept by the Forest Department at Wanneroo and Gnangara, at the SW and SE corner of the area, and by

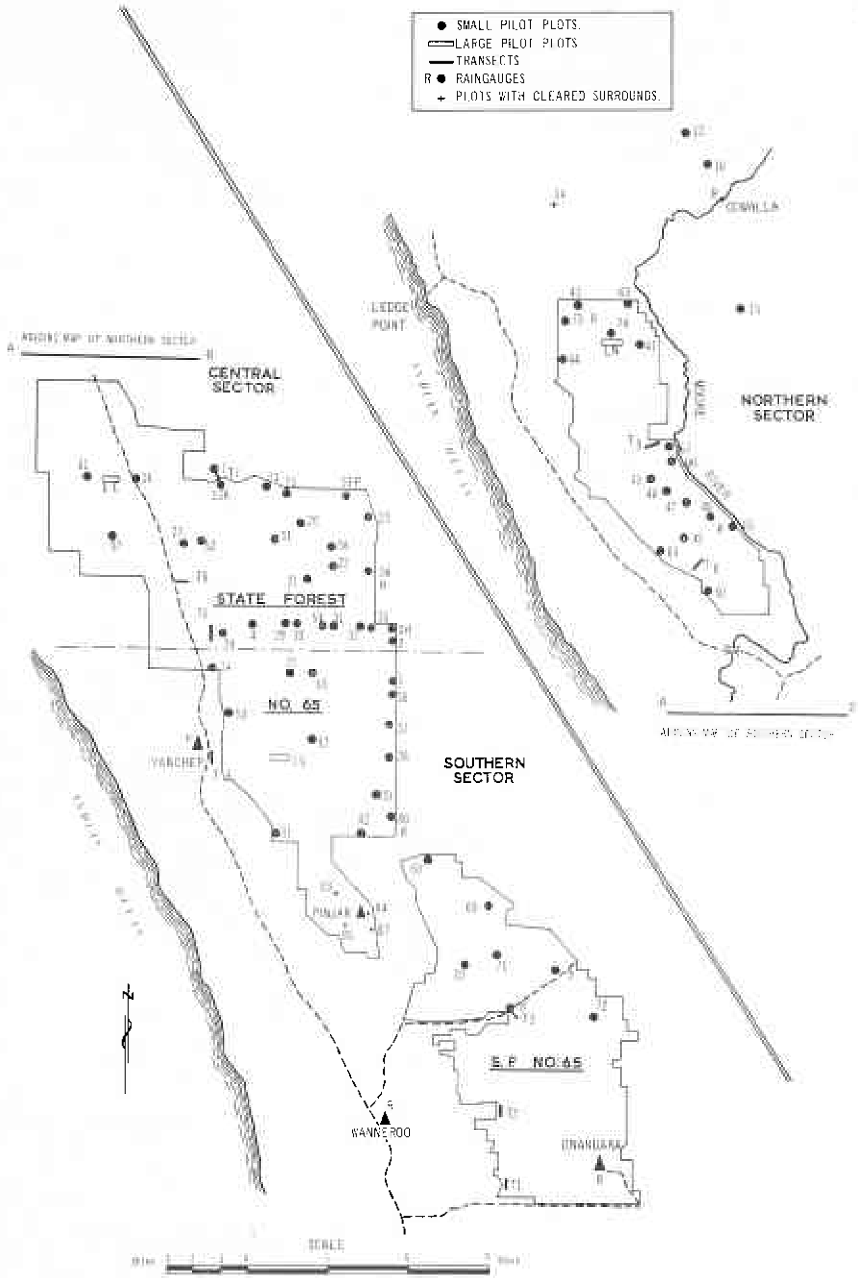

Figure 1.
Map of Wanneroo Division showing extent of State Forest No. 65, and location of settlements, pilot plots, transects and raingauges.

the National Parks Board at Yanchep, on the mid-western boundary. In addition, annual rainfall figures have been collected for the past eight years from seven field raingauges scattered through the forest. Further rainfall recordings are available from several settlements such as Muchea, Pearce and Gingin east of the area at the foot of the Darling Scarp. The chief deficiency of the climatic data is the lack of any proper evaporation data outside Perth, and the lack of long term rainfall recordings within the area itself.

Nevertheless, attempts have been made by Gentilli (1947, 1951) and the Bureau of Meteorology (Anon 1966) to describe the climate of the area and to evaluate it in terms of growth potential.

The Bureau of Meteorology (Anon 1966) places the area within the 25 to 30 in. mean annual rainfall belt. Using the formula $P = 0.54E^{0.7}$, it sets the commencement of the growing season at the 21st to 22nd April at the southern extremity, and the length of the growing season for Perth at 6.3 months. Considering the northerly trend, it estimates a reduction to 5.7 months at Yanchep. The probability of drought is calculated to be consistently higher for Yanchep than for Perth, the probability of a seven month drought being 41 years out of 100 at Yanchep, but only 16 out of 100 for Perth. For an 8 months drought the values are 14 and 1 respectively.

Gentilli (1947), dealing with the bioclimatic controls in Western Australia, considers Thornthwaite's moisture index for the coastal plain to be 0 to 35, as compared with over 35 for the jarrah forest and over 60 for the karri forest. He is of the opinion that an increase of 6.35 in. in mean annual rainfall would change the vegetation of the coastal plain from woodland to forest. He also states that an increase of 4.58 in. has been observed over the past 68 years. In another article (Gentilli 1951) he considers a forest climate to be one in which there are 9 months with a precipitation/potential evaporation ratio of more than 0.3, and 5 months with a ratio of more than 20. On this basis, the area in question is outside the forest climate.

Prescott and Lane-Poole (1947) considered that the optimum homoclime for the Atlantic races of *Pinus pinaster* occurred in the cooler, more humid region around Collie, Donnybrook and Bridgetown, some 110 to 150 miles to the south.

Landscape and Soils.

The geomorphology of the area, first dealt with by Woolnough (1920), was revised by McArthur and Bettenay (1960) in their discussion of the development of soils of the Swan Coastal Plain. State Forest No. 65 is situated within this unit. Proceeding from the coast eastward the first geomorphic element is the Quindalup Dune System, a narrow belt of unconsolidated calcareous sand dunes generally arranged parallel to the coast (Figure 2). This overlies the travertine surface of the Spearwood System, an older system of dunes consisting of a core of aeolinite with a hard capping of secondary calcite overlain by yellow and brown sand of varying depth. The junction of the two elements occurs outside the State Forest. The Spearwood System extends for up to 5 miles east of the Quindalup Dune System and reaches up to 250 ft. in altitude. Within the system is a line of deep depressions with steep sides extending for 20 miles from Yanchep southward. These are considered to be karst features formed by the collapse of underground caverns. In general the sand covering over the calcite capping increases in depth from west to east, indicating removal of material from the west by the prevailing westerly winds and its redeposition in the east. North of this a corresponding dune system, as yet unnamed, extends between the coastal dunes and the Moore River. The entire northern section of the State Forest is situated within this system, which is tentatively included within the Spearwood Dune System.

Along the eastern boundary of the Spearwood Dune System extends a second line of depressions, consisting of Yeal Swamp and Lakes Pinjar, Coogee, Mariginup, Jandabup and Gnangara. East of these depressions is the Bassendean Dune System, consisting of low hills of siliceous sand interspaced with low lying, poorly drained areas. This dune system, up to 10 miles wide, extends eastwards to the Pinjarra Plain, at the foot of the Darling Scarp. However, the junction of these two elements is entirely outside the State Forest.

McArthur and Bettenay consider the Bassendean, Spearwood and Quindalup dune systems to be three successive stages of aeolian depositions, whose ages they set tentatively at over 100,000, over 6,000 and 0 to 6,000 years respectively. The parent material is essentially the same in each case, that is, highly calcareous beach sand. The differences in the soils developed from them are thus attributable to the degree of leaching undergone by them. The following sequence of development is envisaged.

(1) *Deposition of calcareous beach sand (aeolinite) containing 50 to 70 per cent. of calcium carbonate.* The unconsolidated sand, strongly alkaline in reaction and showing little or no profile differentiation, is classed as the Quindalup Soil Association.

(2) *The removal of calcium carbonate from the surface and its redeposition as secondary calcite capping over the aeolinite.* This is followed by a gradual removal of iron from the residual sand above. The soils thus developed are podzolised sands, yellow to brownish yellow in colour, weakly acid or neutral, with a surface layer which is lighter in colour and lower in iron content. They belong to the Karrakatta and Cottesloe Associations, representing the deep and shallow phases of the Spearwood Dune System. The difference between the two associations is thought to be brought about by a slightly longer period of leaching in the former, and through the transfer of surface sand by prevailing westerly winds from the Cottesloe Association, occurring chiefly in the west, to the Karrakatta Association, occurring chiefly in the east. The pedological changes are accompanied by geomorphological changes, such as the formation of steep sided depressions, by the collapse of underground caves, and by change from more or less continuous travertine capping to isolated travertine pinnacles.

(3) *Further loss of iron and the development of an organic B horizon.* Progressive leaching leads to the formation of podzols of

the Bassendean Association. The loss of iron and the accumulation of organic matter is not only a function of time, but also of topography, proceeding most rapidly in low lying, poorly drained areas. The leaching is also considered to proceed more rapidly in the moister, cooler area south of Perth. On the basis of this, the following soil series are distinguished:—

(a) The Jandakot iron-humus podzols, occurring chiefly in the western section of the Bassendean Dune Systems, or on higher parts of the landscape. These are characterized by the presence of both iron and organic matter in the deposition horizon and are moderately acid.

(b) The Gavin and Muchea humus podzols, occurring chiefly in the eastern section and lower parts of the landscape, are characterized by a pale grey subsoil, a predominance of organic matter in the deposition horizon and moderate acidity.

(c) the Joel ground water podzols occurring chiefly in the depressions, are characterized by the complete removal of iron, a heavy incorporation of organic matter in the surface, and the formation of a very pronounced organic hard pan. These are strongly acid.

Concurrent with transition in soil features is a progression towards a milder topography characterized by low dunes and shallow depressions, and the complete disappearance of travertine.

In addition to the above associations, the Herdsman Association of black organic sands, peaty loams and true peats, occurs in the depressions between and within the Spearwood and Bassendean Dune Systems (Figure 2.)

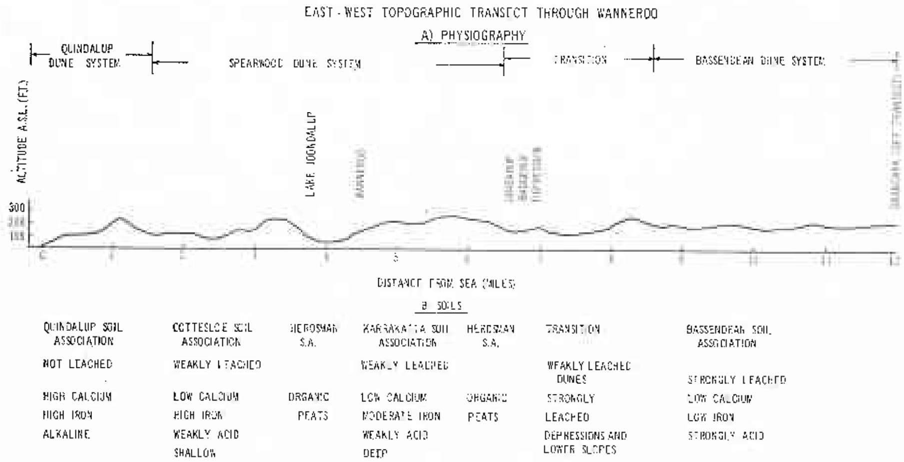

Figure 2.
Topographic and edaphic patterns along an east-west line passing through the Wanneroo township.

Vegetation

The classification of the vegetation of the metropolitan section of the section of the Swan Coastal Plain was attempted by Speck (1952). This approach was largely qualitative and descriptive, and aimed to classify the vegetational components according to the Braun-Blanquet system and its modification by Beadle and Costin (1952). Speck recognised two formations, forest and scrub. In the former, he recognised only one sub-formation, the dry sclerophyl forest, which he further subdivided into sclerophyllous savannah forest dominated by tuart (Eucalyptus gomphocephala) and scrub forest, dominated by jarrah (*Eucalyptus marginata*). The scrub formation was divided into tall and low sub formations, each of which was in turn subdivided into dry and moist phases. The difficulty experienced in assigning the various vegetational components into clear cut categories is reflected in the appearance of broad ecotones, such as that between the jarrah and tuart forests, and by use of topographical transects to present detailed descriptions of vegetational types. Within the transects, both formations occur within a short distance of each other, merging in such a way as to suggest a topographic continuum rather than distinct categories.

Plantation Establishment and Site.

It is not intended to review earlier work on plantation establishment as this has already been adequately done by Stoate (1939, 1950), Perry (1940) and Hopkins (1960). It is only intended to review publications which have a direct bearing on site classification.

An early attempt to classify soils of the Swan Coastal Plain with respect to their suitability for *Pinus pinaster* was that of Bednall (1940) who recognised three main soil groups within the Myalup plantation some 60 miles south of Perth. These were:—

(a) a low sandhill group, with considerable variation in colour and degree of podzolization;

(b) a flat group, characterized by humus incorporation in the surface and an organic hard pan; and

(c) a limestone hill group, with yellow and brown sands over travertine capping. These were subdivided into deep and shallow phases.

Bednall also recognised that a certain type of vegetation was associated with each soil group. On the basis of information given by him, group (a) corresponds to the Gavin and Jandakot Soil Series, with perhaps the more leached variants of the Karrakatta Association, group (b) to the Joel Series and group (c) to the Karrakatta and Cottesloe association. No adequate chemical criteria were found. Even the highest phosphorus values were below the minimum considered necessary for successful pine establishment. He ranked the three groups as above, with increasing potential from (a) to (c).

Similar broad soil and vegetation groupings were outlined by Hopkins (1960) who recognised four site types at Gnangara.

(i) Poor banksia scrub (*Banksia attenuata*, *B. menziesii* and *B. ilicifolia*) on deep sands with a deposition horizon more than 10 ft. from the surface.

(ii) Jarrah—marri forest (*Eucalyptus marginata* and *E. calophylla*) on flats with a deposition horizon within 7 ft. of the surface.

(iii) Tuart (*Eucalyptus gomphocephala*) forest on yellow sand over limestone.

(iv) Paperbark (*Melaleuca preissiana*) on swampy areas.

He considered (ii) to be the best site, and (i) the poorest site. Types (iii) and (iv) were considered to be intermediate, with a tendency to summer drought and winter flooding respectively.

In a more recent report (Hopkins, unpublished) of the Bassendean sand dune system Hopkins concluded that the most important positive factor with respect to pine growth is the presence of a deposition horizon within a short distance of the surface. Sites with this characteristic carry a stand of eucalypts whose height and stocking can be used as an index of site potential. He stressed that water is a key factor, which determines the presence and growth of natural vegetation, and through it, the soil profile development.

On the basis of this, Hopkins concluded that the northern limit of pine planting on the coastal plain will be determined by the reliability of rainfall and the presence of suitable edaphic-topographic associations to concentrate and conserve water. He considers that Gnangara and Yanchep closely approach such limits for the Bassendean soil association.

Two minor but significant observations made by Hopkins are that changes in soil type may modify the influence of topography, and that topography is not a reliable indicator of subsoil features such as depth to a deposition horizon, or of pine growth potential.

Recently Demounem (1965) dealt with the relation between the soils, the floristic composition of the vegetation and growth of *Pinus pinaster* in Landes, France. Although another race of *Pinus pinaster* and a different set of native species is involved, there is a certain parallelism between the situation in Landes and that on the Swan Coastal Plain.

APPROACH TO THE PROBLEM

Availability of Test Areas

It has been stressed earlier that the northerly advance in plantation establishment amounts to an extrapolation beyond the areas of proven suitability. In anticipation of this possibility, the Forest Department has established 77 small pilot plots distributed throughout the State Forest No. 65, and adjoining Crown Land. The bulk of these was established in the years 1955 to 1957. In view of the inaccessibility of the area at the time, the plots were largely located along N-S and E-W access tracks. With one or two exceptions they were not established in or adjacent to swamps, or within eucalypt forest, as the larger trees found in such situations could not be adequately cleared with the equipment available.

The actual area planted at each trial plot is only 3 x 3 chains (0.9 acre). This is surrounded by a ploughed firebreak one chain wide, outside of which is found virtually undisturbed vegetation. Several of the plots located near limestone outcrops were planted partly with *P. pinaster* and partly with *Pinus brutia*. The remainder of the plots were planted entirely with *Pinus pinaster*. All subsequent treatments, such as the initial application of superphosphate and cultivation to reduce shrub competition were uniform for all plots. Usually only half of each plot received zinc sulphate spray, half being retained as a control. Pruning and thinning were carried out when the pines were considered to be sufficiently advanced, so that the better plots were treated much earlier than the poorer plots of the same age.

One of the plots, A5, situated approximately two miles north of Yanchep, was much larger, comprising 100 acres, divided between *Pinus pinaster* and *Pinus brutia* in the ratio 5 : 3, viz. 62.5 and 37.5 acres respectively. It will be subsequently referred to as the "Hundred Acre Block". The location of these plots is shown in Figure 1.

The only extensive areas of plantations over the age of 15 years, the age at which site classification was normally carried out in the past, are those at Gnangara in the south-eastern corner of the State Forest No. 65. They are restricted almost entirely to the Bassendean Dune System. The only stands of adequate age on the Spearwood Dune System are those at Somerville, 24 miles farther south.

The older stands in the south could be used in the assessment of pine planting potential in the north only by geographical extrapolation. Similarly, the small pilot plots in the north could only be used by carrying out an equally marked extrapolation with respect to age. The crux of the problem was thus how to combine the two sources of information, each of which was of limited use on its own.

Choice of Methods for Site Assessment

Two main approaches were available for the prediction of site potential:

(a) directly from environmental data, using an equation derived by multiple correlation regression (Coile and Schumacher 1953; Doolittle 1957; Jackson 1961; Steinbrenner 1963; Wilde 1964; Kormanik 1966); or

(b) through the native vegetation, which is used as an integrator and indicator of environmental conditions (Cajander 1926; Pogrebnjak 1955; Ure 1952; Pluth and Arnemann 1963; Lemieux 1963).

A review of literature revealed a significant trend in the past usage of these methods. Method (a) has been employed most effectively in central and western Europe and eastern United States. Method (b) proved successful in north-eastern Europe and Canada. It is suggested that this is a result of the combination of two main factors, the availability of environmental data and the complexity and state of preservation of the native vegetation.

Areas using method (a) are those in which the favourable climatic and edaphic conditions have resulted in a complex vegetational pattern (Hodgkins 1960). Usually this is strongly confounded by human interference, so that it may no longer reflect the environments factors. In such cases, detailed information on environmental factors is generally available, and offers the easiest way to an assessment of site potential. By contrast, in areas using method (b), more extreme environmental conditions result in a simpler vegetational pattern and lower population density, so that the effect of human interference is less severe and the vegetation remains a reliable indicator of the interaction of environmental factors and hence of site potential.

Applying these observations to the area in question, the following is found:

(1) there is no detailed topographical map, and soil mapping has so far been carried out only on a very broad scale of soil associations, virtually ignoring the important effect of topography within the soil associations. Soil sampling of the local deep sands must be carried out to a depth of several feet to reveal significant differences, and is thus rather cumbersome.;

(2) the only available data on climate are short term, restricted both in the number of factors measured and in the number of recording stations. In view of the extreme infertility of the soils, the vegetational patterns could be expected to be relatively simple and free of human interference.

The case thus appeared to be overwhelmingly in favour of the direct approach through the native vegetation. Before this was finally adopted, preliminary tests were carried out both with undisturbed native vegetation and with residual vegetation under young pine plantation. These showed that the vegetational patterns were clear cut and reflected both the environmental factors and the potential pine growth.

Choice of Methods for the Study of Vegetation.

The acceptance of the "vegetational" approach necessitated a decision on the best method of defining and describing vegetation. It would seem that in most of the reported site classifications based on natural vegetation the number of species involved was either small, or that some form of prior selection was employed to reduce the number of species to a level where the analysis of the pattern could be handled by simple methods resembling those of the Braun-Blanquet school (Cajander 1926; Illvessalo 1929; Ure 1950, Hodgkin 1960). In the areas under study the vegetation comprises 16 tree species and 180 smaller perennial species, chiefly dicotyledonous shrubs but including several monocotyledons and one cycad. Fortunately the past decade has seen vigorous development of quantitative methods in plant ecology, some of which are programmed for use in electronic computers. There was thus an opportunity to handle the full range of species initially, so that the best indicators could be determined by the analysis without the danger of prior subjective elimination.

It is desirable to discuss some of the methods which were considered to be of use in the solution of the problem. They fall into four main categories:—

(a) direct ordination of vegetation along environmental gradients (Pogrebnjak 1955; Whittaker 1956; Waring and Major 1964);

(b) ordination of stands through similarity indices (Curtis and McIntosh 1950; Bray and Curtis 1957);

(c) factor or principal component analysis (Goodall 1954; Dagnelie 1960);

(d) normal and inverse association analysis (Goodall 1953; Williams and Lambert 1959; 1960; 1961 a and b).

Method (a) has been used by Pogrebnjak (1955) in site classification of Russian forests, and by Whittaker (1958) in the U.S.A. The gradients used by them were moisture, fertility of the soil and altitude, established by subjective assessment of site conditions; in particular, topographical position and texture of the soil. The method assumes at the outset that certain environmental factors are the determinants of plant distribution and can therefore be used in the development of a co-ordinate system. The chief difficulty in using the method on the Swan Coastal Plain is that the moisture regime, though obviously important, could not be readily defined. The method was, however, used in the study of extreme habitats.

The remaining three methods make no prior assumption about environmental factors. Instead, the pattern of vegetation is used to indicate what these factors may be. In Curtis's (1951) method (b), data from a set of stands are arranged in the order of importance of the most prominent component species. The importance value is calculated as the sum of relative frequency, relative density and relative dominance of each species in each stand. In Curtis's case, the stand arrangement corresponded to a continuum from the driest, poorest sites to the richest and moistest sites. On this basis each species was assigned a climax adaptation number from 1 to 10, according to the portion of the continuum in which it occurred most commonly. The sum of the products of the importance value and the climax adaptation number for all species, the so-called continuum index, was used to rearrange the stands in a synthetic uni-dimensional continuum. All subsequent work can then be related to this continuum.

A simplified version of the method was used in preliminary studies investigating the suitability of the local vegetation for site studies. The limitation of this method is that it cannot handle a more complex vegetational pattern (Buell et al. 1966). A more complex method was used by Bray and Curtis (1957) to establish two-or-three-dimensional systems of synthetic co-ordinates which were later related to environmental factors. In this the method became an approximation to factor analysis (Dagnelie 1960). However, as it requires a considerable degree of subjective judgment and does not lend itself to computer programming, it does not warrant further consideration.

The factor analysis (c) is a mathematical analysis of multivariate systems, developed for use in psychological research, and first utilized for vegetational studies by Goodall (1953). It uses the inter-relationship between species to detect the underlying factors which determine the vegetational pattern. These factors are only mathematical abstractions which may or may not be identifiable with actual environmental factors. The loadings of the various species on the individual factors can be used to establish a multi-dimensional co-ordinate system in which the species with greatest affinities are placed closest to each other. Furthermore, by summing up the loadings of the component species of each stand another co-ordinate system can be built up in which the stands with the greatest floristic similarity are placed close to each other. If environmental data are known for each stand, these can be also plotted within the same co-ordinate framework, making it possible to identify the factors and to assess the capacity of the vegetation to reflect environmental conditions. The sum of squares of loadings on the various factors for each species can be taken as the measure of its value as an indicator.

As the factor analysis has been programmed for use in electronic computers the computational load, otherwise too great, ceases to be an obstacle to its use. Apart from the choice of species to be used in the analysis there is little scope for subjective judgment. Factor analysis is the main method employed in the present study. Its chief limitation was found to be in the restriction on the number of species which could be handled at any one time. This was found to be approximately one half of the number of plots. For this reason method (d), the association analysis, was also tried.

Association analysis, pioneered by Goodall (1953) but used more extensively by Williams and Lambert (1959; 1960; 1961), is an analysis of vegetation in terms of the association between species. It differs from factor analysis in that it uses qualitative data of presence and absence instead of the quantitative data such as frequency or percentage cover. It differs from the three preceding methods in that it results in the classification and delineation of groups of species or stands instead of ordination. The result of normal association analysis is a grouping of plots of stands defined by presence or absence of several key species. The inverse association analysis results in a grouping of species based on their presence or absence in several key plots. The former can thus be used to classify stands, the latter to define groups of indicator species. As both procedures are programmed for computer use, the difficulty of a heavy computational load can be overcome.

Williams and Lambert (1961 b) have combined the normal and inverse analysis into nodal analysis which defines groups of stands characterised by a set indicator species, called noda. This step is not programmed for computer use.

Choice of Methods for the Assessment of Pine Plots.

It has been stressed earlier that the only source of information on the growth of *Pinus pinaster* in the area under study were small pilot plots of less than one acre, mostly less than ten years old. In some of these, *Pinus brutia* was also planted, reducing the area under *Pinus pinaster*. The uniform area per plot which could be sampled was further reduced by differential application of zinc sulphate to the two halves of the plot. Ultimately it was found that after allowing for adequate surround to exclude the abnormal outside (break) trees, a sample area of 0.1 acres (2 x ½ chain) was the most that could be used in assessment of pine growth. Actually, usually two such areas were measured, one in the portion which was treated with zinc sulphate, the other in the control, but 0.1 acre remained the lowest common denominator for all plots.

Severe restrictions also existed in the choice of parameters that could be measured. As some of the plots had been thinned but others had not, volume, basal area and mean diameter, all of which are known to be strongly affected by stocking, could not be used. Some form of height growth measurement was thus the only avenue left. As the plots differed in age, mean height could not be used without some form of extrapolation to a standard age of 15, 30 or even 50. Consideration was therefore given to a parameter developed by Wakeley (1954) for the assesment of growing potential in young plantations. This parameter, described as the five-year height-intercept, consists of the total lengths of the five internodes above breast-height, assumed to represent the straight steep portion of the height growth curve. In plantation trees it corresponds to the period of growth in which the initial establishment difficulties were no longer important but the effect of mutual competition was as yet either absent or mild. In later studies (Wakeley and Marero 1958, Day et al 1960) it was shown that the height intercept accounts for a high proportion of variation in height growth between older stands.

Wilde (1964) questions whether the five-year height intercept retains the same relationship to subsequent height growth on all sites; that is, whether an early site potential and later site potential are the same. He submits that on poor infertile sites the ratio falls off, whereas on fertile, but weed infested sites, or on sites with a depleted surface layer but a fertile and moist subsoil, it rises. A similar objection is raised by Zahner (1962) with respect to height curves.

Curtis (1964) contends that the standard approach through site index curves is open to many objections, especially in the assumption that site quality is independent of age, and that there is a constant proportional relationship between the growth curves for all site and stand conditions. He suggests that height curves can only be accurately derived from repeated measurements of permanent plots. Failing that, he considers stem analysis to be a better means of deriving height curves than one measurement of a set of plots covering the full range of age-classes. Mader (1963) points out the possibility of the lack of correlation between height and other parameters of growth, especially volume, and maintains that the relationship should be studied before discarding volume as an index of site potential.

The approach ultimately selected was the use of the five-year height intercept tested against subsequent height growth by stem analysis in stands of up to 33 years of age, and against other parameters of pine growth, such as top height, predominant height, basal areas and volume for a group of 150 plots situated in a 15 year old plantation. It was considered that if the five-year height intercept passed these tests satisfactorily, it would be a suitable and reliable tool for valid comparison of the young pilot plots.

EXPERIMENTAL WORK

Test of the Five-Year Height Intercept as a Mensurational Tool.

As the validity of all work in northern areas covered only by young pilot plots hinged on the ability of the five-year height intercept to reflect not only the past, but also the future pine growth, it was essential to commence the investigation by testing this parameter in the older southern plantation.

The tests fall into two main categories:

(1) A test of its ability to predict height growth beyond the age at which it can first be measured, that is 8 to 10 years.

(2) A test of its correlation with other parameters of pine growth, such as predominant height, basal areas and volume.

Both tests were carried out in co-operation with the management research section, which at the time was engaged on the collection of data for a *Pinus pinaster* volume table and in testing the validity of the former methods of site quality assessment in 15 year old stands. The volume table work involved the felling of randomly located plots 1/40 acre in extent, in all stands of *Pinus pinaster* over 15 years of age, both on the Bassendean Dune System at Gnangara and the Spearwood Dune System at Somerville. The writer accompanied the management research crew and recorded the complete nodal growth of the three tallest trees per plot, with comments on the nature of each whorl. In addition four to five stem sections were cut out at intervals along the bole. A ring-count of all stem sections was carried out in the laboratory to establish the number of years required to reach a particular height and this, together with the field data, was used to reconstruct the height growth of the sample trees since the year of planting.

Although *Pinus pinaster* may form more than one whorl per year, it is relatively easy to establish which whorl represents the end of the annual height growth (Figure 3). The height growth of *Pinus pinaster* commences in early spring and continues until the moisture becomes limiting. Vigorously growing pines may form a partial whorl of one or two strong upright branches at a narrow angle with the bole early in the season, or a later complete whorl of thin branches situated just below the terminal whorl of four to seven strongly developed branches (Figure 3). The tendency to form additional whorls appears to have a genetical basis, but finds expression only on the better sites. On poor, dry sites virtually all trees are uninodal, reflecting the shortness of the growing season.

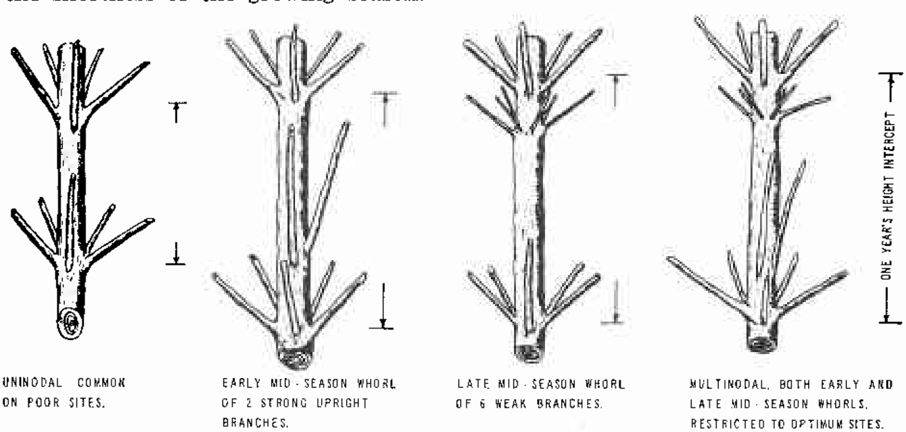

Figure 3.
Branch whorl types in *Pinus pinaster* (Ait.) illustrating the method used in determining annual height growth. (T—terminal. ME—early mid season, ML—Late mid season whorl).

The reconstruction of the height growth was accomplished by plotting the height to each terminal whorl against the age at which it was formed. The data for the three tallest trees on the plot were averaged, and the 5 year height intercept was measured as the combined length of five longest consecutive internodes at or above breast height. The five year height intercept and the full sequence of mean heights of the three tallest trees at the various ages for each plot was used in the derivation of the equation

$$\log_{10} H = 1.5043 + 0.02229S - 3.5066 \frac{1}{A} - 0.08458 \frac{1}{A} S$$

where H = predominant height at age A for site index S in the form of the 5-year height intercept.

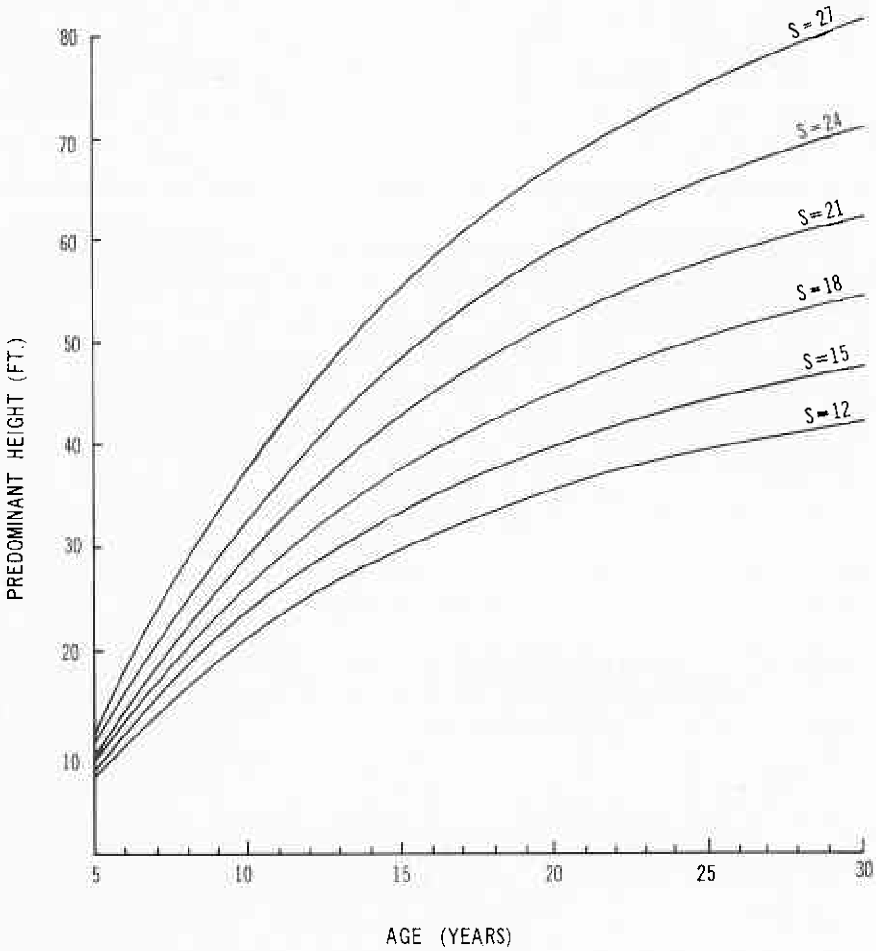

Figure 4.

Regression of predominant height on age and five-year height intercept for *Pinus pinaster* grown on Swan Coastal Plain near Perth. (H—predominant height in feet, S—five-year height intercept in feet, A—age in years.)

The above equation, one of several tested, gave the best fit for the data on which it was based. Height curves derived from the equation are shown in Figure 4. The relationship between predominant height (average height of the 100 tallest trees per acre), height intercept and age is shown in Table 1.

TABLE 1.

Relationship between Five-year Height Intercept, Age and Predominant Height in *Pinus Pinaster* Stands.

5-year height intercept	Predominant Height (ft) at age of					
	10 years	15 years	20 years	25 years	30 years	35 years
12	21	30	35	39	42	43
15	24	34	40	44	47	49
18	27	38	45	50	54	57
21	30	43	51	57	62	65
24	33	48	59	66	71	74
27	37	55	67	75	81	85

Although the relationship between height intercept and predominant height alters slightly with age, in that the height growth levels off more rapidly if the height intercept is low than if it is high (Figure 4), the ratio of the poorest to the best remains relatively constant, falling only from 0.54 at age 10 to 0.50 at age 35. Whatever difference there is between the various height intercept classes is already fully expressed at the age of 10. No significant difference was detected between the pattern of height growth of plots belonging to the two dune systems. Height intercept can thus be acceped as a suitable means of predicting the height growth of *Pinus pinaster* up to the age of 35 years.

In the second test, 150 temporary, variable radius plots were located in 120 acres of 15 year old pines in the North Kendall section of Gnangara plantation. Location was by random stratified sampling based on site mapping by the old subjective method which it was proposed to test.

The following parameters were determined for each plot:—

(a) Top height, that is height of 30 tallest trees per acre.

(b) Predominant height, that is height of 100 tallest trees per acre.

(c) Basal area of trees 4 in. D.B.H.O.B. and over.

(d) Basal area of all trees irrespective of size.

(e) Merchantable volume to 4 in. overbark.

It was found that the subjective classification, carried by ocular estimates with occasional instrument checks of height and basal area, delineated site classes which differed broadly in all of the above parameters but lacked consistency and precision.

Whilst the data was being analysed, the same area was remapped, using a 2 x 2 chain grid. At each point of the grid, the height intercept of the three tallest trees within a 0.1 acre circular plot was measured, and the ground vegetation described. The area was then remapped on the basis of the five year height intercept and ground vegetation types (Figure 5). The latter shall be discussed later. In the former, three strata were recognised:

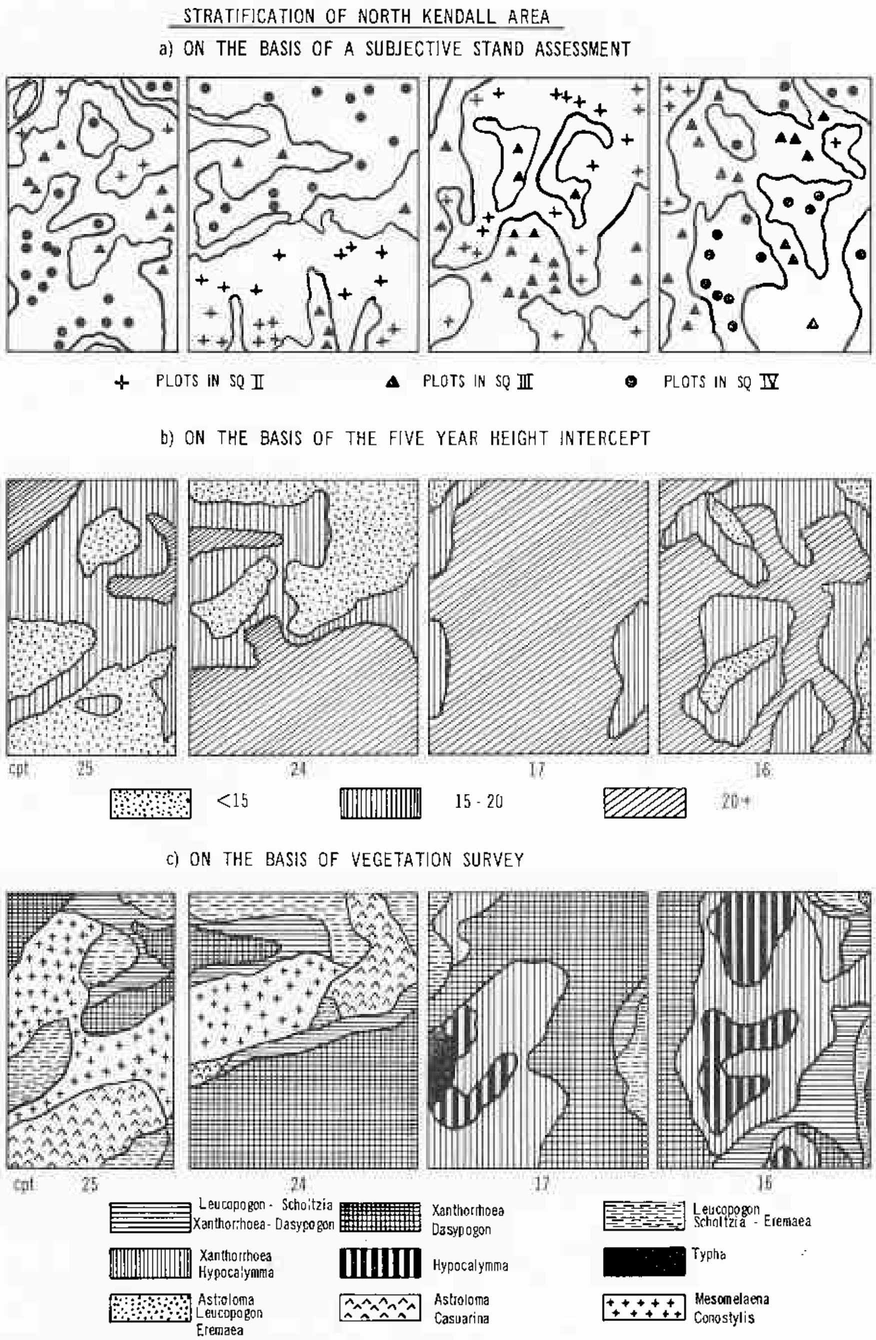

Figure 5.

Map of adjoining compartments 16, 17, 24 and 25, North Kendall sector of Gnangara plantation, showing stratification on the basis of subjective estimate, measurement of five-year height intercept and delineation of residual vegetation types.

(1) height intercept less than 15 ft., containing 30 samples.
(2) height intercept between 15-20 ft., containing 42 samples,
(3) height intercept over 20 ft. containing 78 samples.

The stratum means and confidence limits for all the parameters are given in Table 2.

TABLE 2.

Relationship Between Height Intercept and other Parameters of 15 Year Old *Pinus Pinaster* Stands.

Parameter		Height Intercept		
Description	Statistics	15 feet	15–20 feet	20 feet
Top height (ft.)	mean conf. lim. p = 0.05 conf. lim. p = 0.01	33.18 ± 1.41 ± 1·90	38.45 ± 1.03 ± 1.38	45.69 ± 0.79 ± 1.03
Predominant height (ft.)	mean conf. lim. p = 0.05 conf. lim. p = 0.01	31.45 ± 1.49 ± 2.01	36.76 ± 1.29 ± 1.73	43.89 ± 0.82 ± 1·08
Basal area O.B. of trees over 4 in. DBHOB (sq. ft/acre)	mean conf. lim. p = 0.05 conf. lim. p = 0.01	48.33 ± 9.65 ±13.00	89.39 ± 8.77 ±11.73	108.97 ± 6.78 ±11.68
Basal area all trees	mean conf. lim. p = 0.05 conf. lim. p = 0.01	50.00 ± 7.61 ±10.25	94.15 ± 8.40 ±11.25	108.97 ± 6.78 ±11.68
Merchantable volume (cubic ft. to 4 in. D.O.B.)	mean conf. lim. p = 0·05 conf. lim. p = 0.01	348.73 ±70·55 ±95.08	802.85 ±134·80 ±180.36	1,521.68 ±356·33 ±472.42

The data show clearly that the five-year intercept is a satisfactory index of other parameters of tree growth.

Test of Vegetation as an Indicator of Site Potential.

The test was carried out in the only two areas along the margin of older plantations where both pine plantation and relatively undisturbed native woodland occurred side by side in a topographical gradient. One of the areas, extending from a seasonal swamp to the upper slope of a dune, was situated within the Bassendean Dune System at West Gironde west of Gnangara. The other was situated within the Spearwood Dune System at the Hundred Acre Block north of Yanchep, and extended from a shallow depression to an elevated limestone outcrop. The method adopted was essentially the Whittaker (1956) environmental gradient study, modified so as to give synthetic data similar to those used in Curtis's (1951) study of continua. In each case, two lines of 33 ft. x 33 ft. (10 m. x 10 m.) plots were located along the slope to sample the maximum topographical variation. Within each plot the basal area of each species was determined by diameter measurements. The height of the tallest tree, irrespective of species, was also measured. In addition, the presence and absence of all perennial shrub species was determined on a centrally located 13 ft. x 13 ft. (4 m. x 4 m.) sub plot.

The two lines of small 33 ft. x 33 ft. tree plots gave excessive variation in basal area individually and were therefore merged into one line of 66 ft.

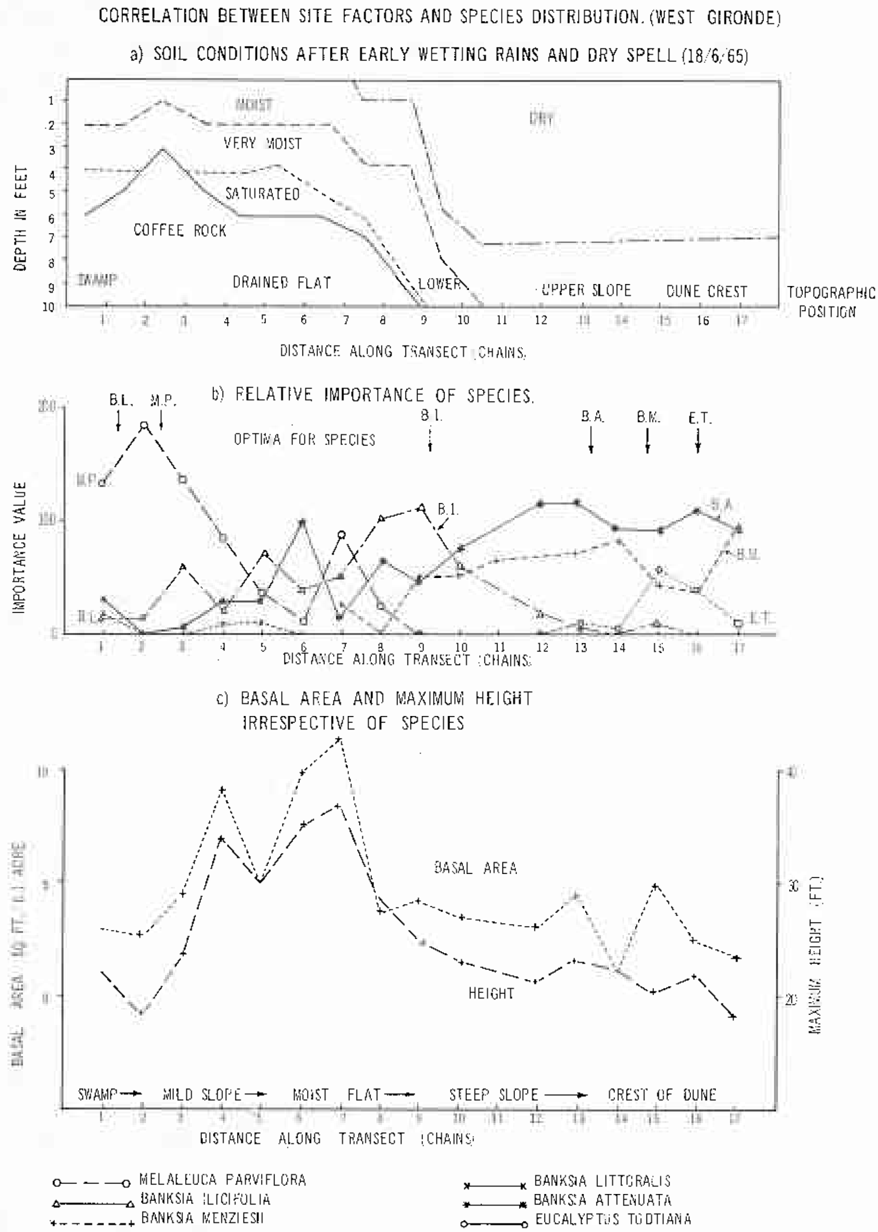

Figure 6.

Summary of findings of a preliminary test of the ability of native vegetation to reflect soil conditions, using both specific and no-specific features of the tree stratum.

x 66 ft. (0.1 acre) plots. Within each plot, the percentage of the total basal area contributed by each species was designated as its relative basal area, and the percentage of the total number of stems contributed by it as its relative density. No attempt was made to assess the relative dominance, as done by Curtis (1951), and the importance value of each species was defined as the sum of its relative density and its relative basal area, both of which could be determined objectively. The data from the Bassendean Dune System are used

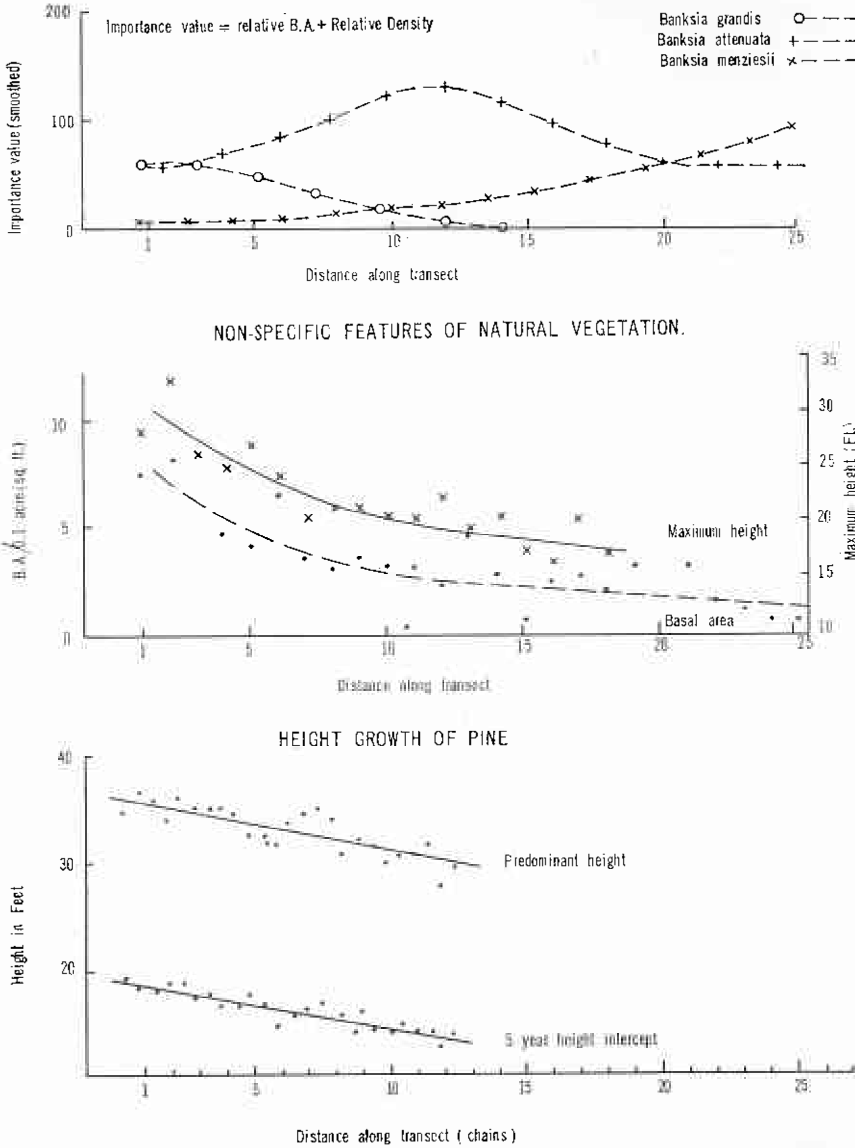

Figure 7.
Summary of findings of a preliminary test of the ability of native vegetation to indicate potential for pine growth, carried out along the boundary of a 13 year old plantation at Yanchep.

in Fig. 6 to show the relationship between native vegetation and environmental conditions. The data from the Spearwood Dune System are used in Fig. 7. to illustrate the relationship between native vegetation and the height growth of *Pinus pinaster*.

The transects were also used to develop a rating for the various tree species with respect to their moisture requirements and tolerances, after the pattern of Curtis's (1951) climax adaptation numbers. They ranged from 0.5 for drought tolerant *Banksia menziesii* to 4.5 for *Melaleuca rhaphiophylla* which is capable of surviving several years of root inundation. The ratings, together with importance value for each species, were used to determine the vegetational moisture index of the segments of the transect.

The approach proved of limited use in the main analysis of the pilot plots, partly because of the small range of native tree species found in the surrounding areas, partly because factor analysis was better suited to the multi-dimensional nature of the problem which obviously involves other factors besides moisture. It was, however, useful in testing the hypothesis that native vegetation is an indicator of environmental conditions and of the potential for pine growth. The answer to this was positive and definite.

MEASUREMENT OF PILOT PLOTS

Sampling of Pines Within the Plots.

The selection of the sample plots within the pilot plots has been dealt with earlier. The standard unit was a 0.1 acre, 2 chains x 0.5 chain plot, located in the centre of the pilot plot so as to avoid edge effects. In a few of the older plots, in which differential superphosphate treatments were applied, this had to be modified to 1 chain x 1 chain plots. Additional 0.1 acre plots were located in the no-zinc controls in those pilot plots where this was feasible. These were not used in the final analysis. The basic unit was thus a plot 0.1 acre in extent, cleared and cultivated prior to planting, treated with 2 ozs. of superphosphate per tree immediately after planting, recultivated at least once in the early stages of establishment, sprayed with a 2.5 per cent. solution of zinc sulphate at the age of three years and again fertilized with four cwt. of superphosphate per acre at the age of five to seven years. The treatments were somewhat delayed in the case of the older plots. Within each plot, the 10 tallest trees were located and their height and five-year intercept were measured.

Sampling of Surrounding Vegetation.

The surrounding vegetation was sampled by four 0.1 acre, 2 chains x 0.5 chain plots, located in the undisturbed woodland 0.5 chain in from the edge of the ploughed fire break. The location was purely systematic, the mid point of each vegetational plot being opposite the mid-point of the corresponding side of the pine plot. Within each plot, the basal area overbark of each species was determined from diameter measurement if DBHOB exceeded six inches, or by a stem count and multiplication by a standard factor if DBHOB was below six inches. In addition, the height of the tallest tree, irrespective of species, was also measured. Within each plot, two 13 ft. x 13 ft. sub-plots were located systematically for the determination of the presence of understorey shrub species. The size of the sub-plot was an approximation to 4 m. x 4 m. quadrats, commonly used in ecological studies for shrub sampling (Oosting 1948). The size of the tree plots was based on preliminary trials which indicated that the 10 m. x 10 m. (0.5 x 0.5 chain) plot, commonly used for sampling of the forest canopy, was too small for the scattered, broad-crowned *Eucalyptus* species.

Soil Sampling.

In the centre of each vegetation plot soil samples were taken by a Veihmeyer tube at the 0-3 ft and 3-6 ft levels. The soils were analysed by the soils section of the Forests Department. Each sample was analysed for percentage of iron and soil reaction, (considered to be indicative of the degree of leaching), and for loss on ignition (indicative of organic matter accumulation).

Assessment of Topography.

Topography was assessed qualitatively by a nine-point scale ranging from 1 for permanent swamps to 9 for exposed high ridges.

ANALYSIS OF DATA FROM PILOT PLOTS

The vegetational data from the surrounds of the pilot plots were used as the basis of ordination in the case of factor analysis, and as the basis of classification in the case of association analysis. The pine growth and soil data were then fitted within the resulting framework or classes.

Factor Analysis.

The method used, though known in ecological literature as factor analysis, is really principal component analysis (Dagnelie, 1960). It differs in some respects from the factor analysis in the strict mathematical sense, but the results are usually comparable. It was chosen because a computer programme developed by Mr. B. Horan of the W.A. University Computing Centre was already available locally. Before the computation proper could commence, minor programmes were used to calculate tree basal area from the basic data, and to sum up and tabulate the data from the four vegetation plots belonging to each pilot plot. The input data proper thus were, in the case of trees, basal area in square ft. per 0.4 acre, and in the case of shrubs, frequency out of eight 13 ft. x 13 ft. quadrats. As the surrounds of some of the pilot plots were lost in clearing, and other plots now situated in private property were lost altogether, only 67 pilot plots were available for vegetational analysis.

Earlier trials by Dr. Goodall of the CSIRO Division of Mathematical Statistics showed that the Horan programme could only be used if the number of plots was double that of the number of species. Thus the number of shrub species had to be reduced to 30 species of high to moderate occurrence.

The first output of the programme, the loading of the various species on the factors, shown in Figure 8, indicated quite clearly that the degree of leaching undergone by the soils was the main determinant of the species distribution.

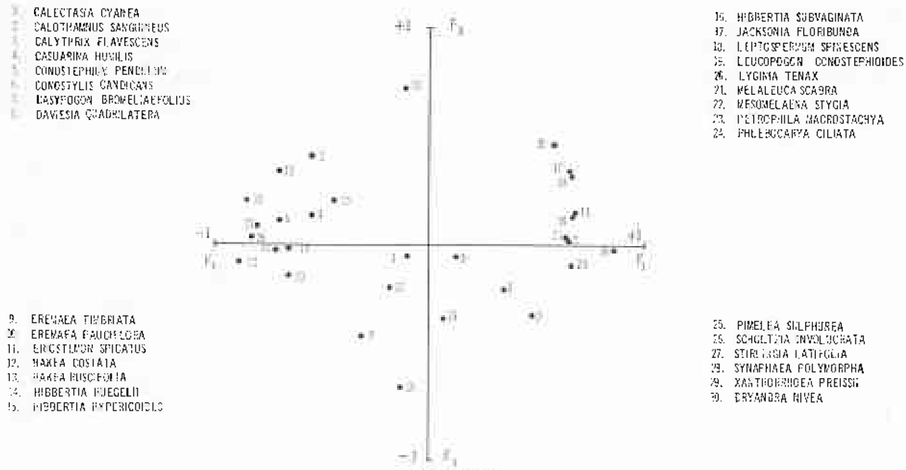

Figure 8.
First stage of output from factor analysis programme, that is, the loadings of the 30 species used in the analysis on the first and third factors.

The species known to be common on the highly leached light grey sands all had high positive loadings, whereas species characteristic of the lightly leached yellow sands had high negative values.

The second and subsequent factors could not be identified until the positions of the various plots were plotted within the factor space, on the basis of their factor scores.

It was found that the plots with high positive and high negative scores on the first factor invariably had negative or low positive scores on the second factor. Plots with low scores on the first factor had high positive scores on the second factor. When the percentage of iron in the soil relevant to each plot was plotted on the factor framework (Figure 9), the latter group was found to

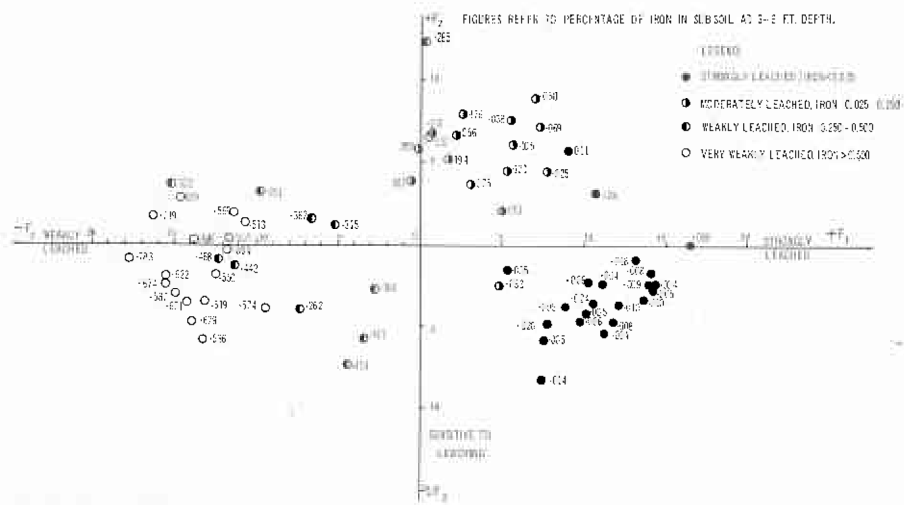

Figure 9.
Second stage of the factor analysis, that is, the plot factor scores on the first and second factor. The figures for each plot represent the mean percentage of iron in the subsoil.

be characterized by intermediate values, whereas the former groups had either very high or very low values. It was thus reasoned that the second factor represented insensitiveness to soil leaching, or tolerance to both very strongly and very weakly leached soils. It was therefore of limited use, being an inverted form of first factor.

Attention was then shifted to the third factor. A valuable lead was provided by the fact that the species with the highest positive loading on the third factor was *Eremaea pauciflora,* common on the inferior, droughty sites within the Bassendean Dune System at Gnangara, whereas the species with the highest negative loading on the same factor was *Xanthorrhoea preissii,* long recognised as the indicator of the optimum moist sites. Reference was then made to the topographical transects, for which soil moisture data were available. The graphical summary of the data clearly confirmed that *Eremaea pauciflora* and *Xanthorrhoea preissii* represent droughty and moist sites respectively.

The loadings on the third factor for other major species associated with droughty sites, e.g. *Calothamnus sanguineus, Hakea costata, Jacksonia floribunda* and *Leucopogon conostephioides* were positive, whereas those for species characteristic of moist sites, e.g. *Dasypogon bromeliaefolius* and *Eremaea fimbriata,* were negative. Thus the third factor could be identified with moisture availability. As the moisture regime is usually a function of topography, the subjective assessment of the topographical position of the pilot plots within the factor score framework showed plots situated in depressions (swales) to have mostly negative scores and plots situated on upper slopes of dunes to have positive scores. The classification of intermediate sites, such as flat-slope transition and lower slope, proved a failure. This agrees with earlier observations that topography is not a good indicator of soil moisture regime or site potential, except in extreme cases.

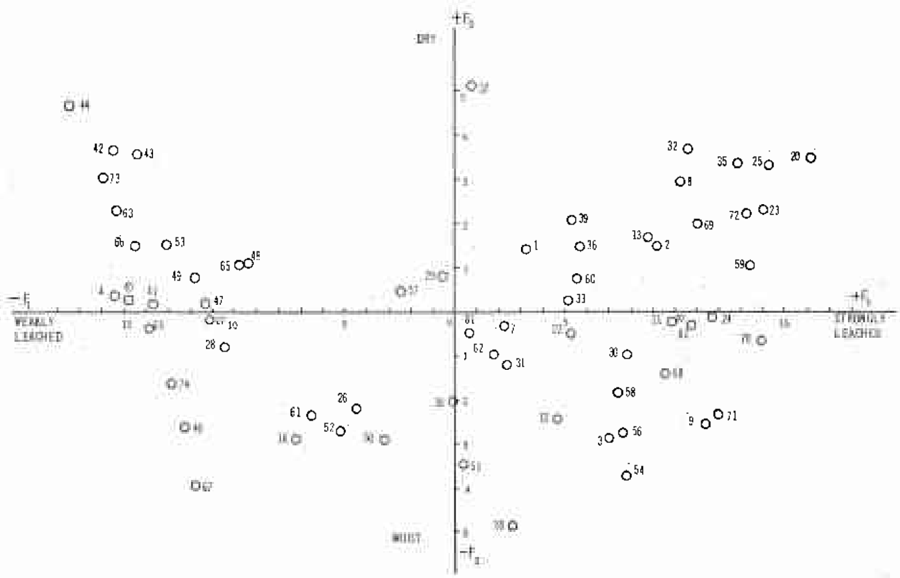

Figure 10.
Distribution of the pilot plots within the factor space, on the basis of the plot factor scores. The numbers refer to plot numbers as used in this study.

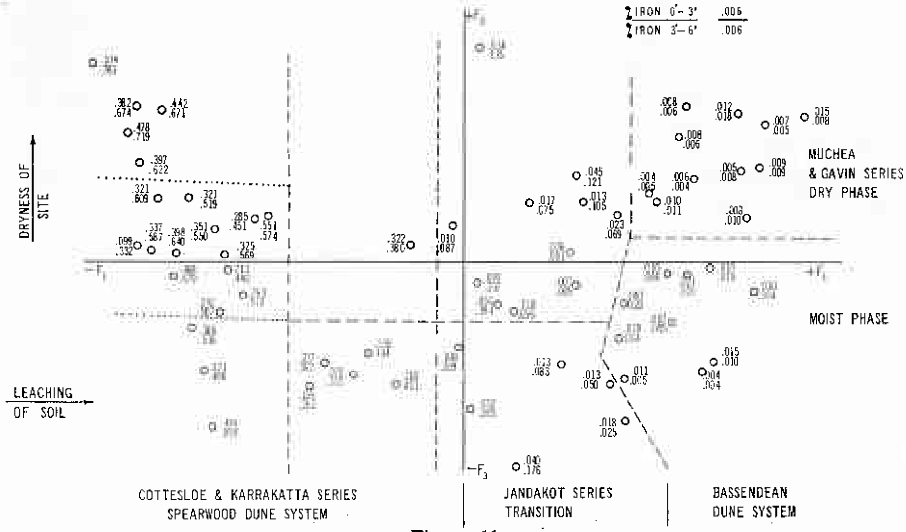

Figure 11.
Relationship between plot factor scores on first and third factors to the percentage of iron in the soil and to soil classification.

At this stage, a two-dimensional system of co-ordinates, based on the first and third factors, corresponding to soil leaching and soil moisture regime respectively, was thus available (Figure 10). Within this system, all other data could be meaningfully fitted. The first data so fitted were those for soil characteristics. The most clearcut of these was percentage of iron, which gave a perfect continuum from the strongly leached sands with values as low as 0.004 per cent to virtually unleached sands with values as high as 0.783 (Figure 11). For subsequent work, this continuum was arbitrarily divided into segments which correspond to moist and dry phases of the Bassendean Dune System, the Spearwood Dune System and the transition between them. The plotting of the soil reaction values gave a similar continuum but with a much smaller range and less consistency.

Though the ability of the vegetation to reflect soil features is important, the ultimate test of the values of this approach is whether or not the vegetation could both integrate environmental conditions and indicate potential for pine growth. When the site index values were plotted within the framework, all but seven of the plots appeared to fit a definite pattern (Figure 12). Checks were therefore carried out to see if there was some definite reason for the discrepancy. It was suspected that the causes of discrepancy would be either incorrect classification of the plot or failure of the pine trees to utilize the full potential of the site. To test the former possibility, the soil and vegetation data were inspected. It was found that some of the aberrant plots, namely 29 and 86, were situated astride a sharp transition between two soil types in such a way that the pilot plot itself was in one type only, but the surround covered both types. In addition, plot 86 was situated in a depression with three sides of its surround on slopes. Topographical position was no doubt the cause of the misclassification of plot 82, situated on a low rise but with one of its sides extending into a swampy depression, and of plot 35, situated in a small depression with all of its sides on slopes. Plot 7, situated in an unusual sandy swamp was not properly dealt with at all, as its surround contained only two out of the 30 species used in the analysis. It was merely placed in the analysis near the origin of the co-ordinates. The chief feature of plots 34 and 65 was the extreme slowness of initial growth, shown in the very short basal internodes. A complete height growth recapitulation was therefore carried out. It revealed that the pines in the two plots did not enter the stage of maximum height growth until the age of six or seven, instead of two or three. As they were given their supposedly second application of superphosphate at age five, it is suspected that the magnitude of their response is due to the fact that the initial application was either not carried out at all, or else was inadequate.

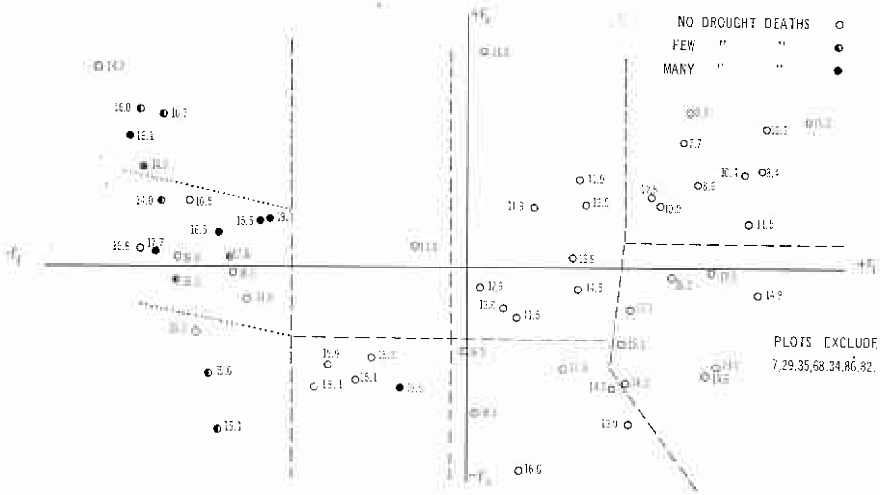

Figure 12.
Relationship between plot factor scores on the first (leaching) and third (moisture) factors and the potential for pine growth in terms of five year height intercept and drought death incidence.

All seven aberrant plots are omitted from Figure 12, which illustrates the pattern of five-year height intercept within the co-ordinate framework. It can be summarized rather simply: The poorest sites, with a height intercept of 7-12 are those with high positive F_1 and F_3 values characterized by droughtiness and a high degree of leaching; that is the Gavin and Muchea soil series. Roberts (1966) demonstrated that this soil type is unfavourable to plants. Next to these, with a height intercept of 11-14, are droughty, but somewhat less leached sites corresponding to the dry phase of the Jandakot soil series. The moist counterpart of the poorest group, with high positive F_1 but negative F_3 corresponding to the moist phase of Muchea and Gavin soil series, is next with a height intercept of 13 to 17. The moist phase of the Jandakot series with a high negative F_3 and low positive F_1, and the dry phase of the Cottesloe and Karrakatta soil series with high negative F_1 and positive F_3, showed a similar potential. The intermediate and moist phases of the Karrakatta and Cottesloe series, with negative F_1 and low positive to high negative F_3 proved more variable, the height intercept ranging from 14 to 19.

On the whole, then, moistness of the site was more important to height growth on the highly leached sands of the Bassendean Dune System, where the height intercept was markedly lower on the dry sites, than on the lightly leached sands of the Spearwood Dune System. Similarly the degree of leaching was markedly more significant on the dry than on the moist sites.

It needs to be stressed that because the heavier timbered areas were avoided in the initial location of plots ,the optimum sites corresponding to a height intercept of over 20 were not sampled. However, in the northern areas these represent only a very small proportion of the total, being virtually restricted to the margin of the Yeal Swamp complex.

Apart from the potential for height growth, the capacity to maintain high stocking throughout the usual severe summer drought also needs to be considered. Plotting the summer drought death incidence within the co-ordinate framework (Figure 12) revealed that it is entirely restricted to the Spearwood Dune System, and is particularly prevalent in its intermediate and dry phases, that is, in plots with positive or low negative F_3 factor scores. The plots affected were all located in the northern section.

Use of Plant Indicators to Identify Sites.

Two avenues are opened in this respect: The listing of native species for each of the plot groups, to determine the species which characterize them or alternatively, plotting of the species occurrence within the co-ordinate framework to determine the co-incidence between the various species and plot groups. The former approach can be illustrated by reference to the poorest sites, with high positive F_1 and positive F_3, considering the 30 species used in the factor analysis.

This group is clearly defined by high frequencies of *Calythrix flavescens, Eremaea pauciflora, Hibbertia subvaginata, Jacksonia floribunda, Leucopogon conostephiodes, Lyginia tenax, Melaleuca scabra* and *Scholtzia involucrata,* and virtually complete absence of *Calectasia cyanea, Calothamnus sanguineus, Conostylis candicans, Eremaea fimbriata, Hakea costata, Leptospermum spinescens, Mesomelaena stygia, Petrophila macrostachya, Synaphea polymorpha* and *Dryandra nivea.*

By contrast the group of plots characterised by high negative F_1 and high positive F_3 typical of dry, virtually unleached sites, is equally clearly defined by high frequencies of *Calothamnus sanguineus, Conostylis candicans, Eremaea pauciflora, Hakea costata, Hibbertia huegelii* and *H. hypericoides, Leptospermum spinescens, Mesomelaena stygia, Petrophila macrostachya* and *Synaphaea polymorpha,* and virtually complete absence of *Dasypogon bromeliaefolius, Hibbertia subvaginata, Jacksonia floribunda, Leucopogon conostephioides, Lyginia tenax, Melaleuca scabra, Phlebocarya ciliata* and *Scholtzia involucrata.*

The second approach can be illustrated by reference to Figures 13, 14 and 15.

All weakly leached sites within the Spearwood Dune System, that is those with negative F_1 scores, are defined by a high frequency of *Mesomelaena stygia* and the complete absence of *Hibbertia subvaginata;* the reverse is true of the strongly leaches sites of the Bassendean Dune System with high positive F_1 values. Only in the transition zone of the Jandakot series do the two species occur concurrently (Figure 13).

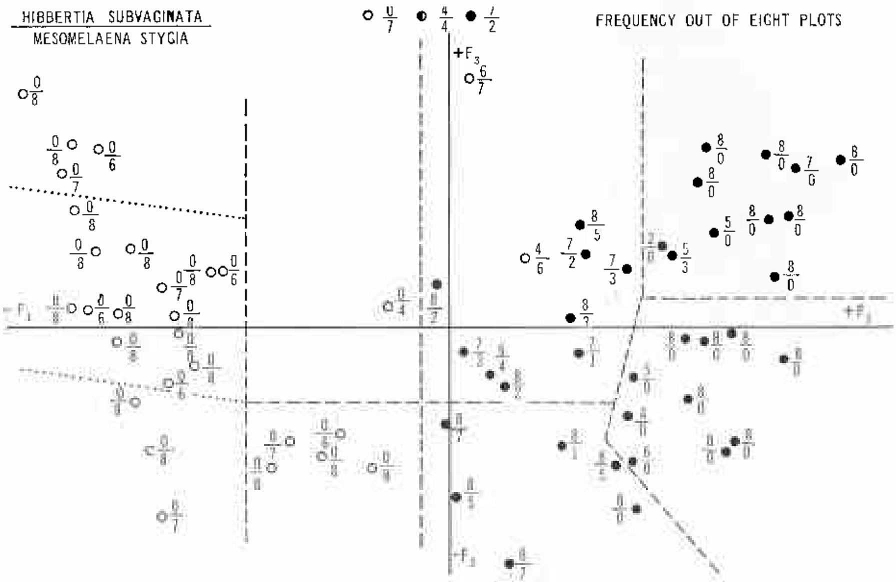

Figure 13.
Distribution of two shrub indicator species within the factor space. The species are those with the highest positive and highest negative loadings on the first factor, that is, with the highest sensitivity to the leaching of soil. The figures refer to mean frequency out of a set of eight 13 ft. x 13 ft. sub-plots.

Similarly the moist phases of all soil series, characterised by negative F_3 scores, are typified by high frequencies of *Xanthorrhoea preissii* and low frequencies of *Eremaea pauciflora;* the reverse is true of droughty sites characterized by positive F_3 scores (Figure 14).

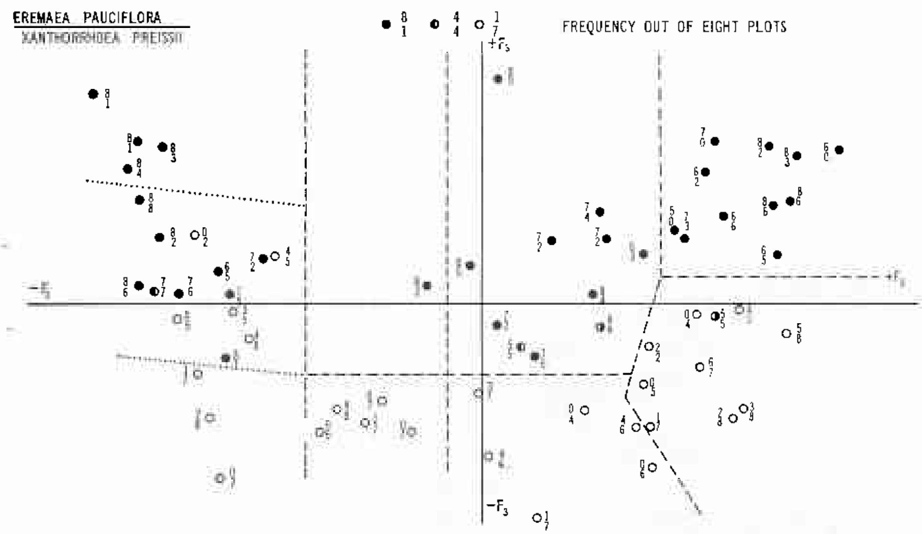

Figure 14.
Distribution of two shrub indicator species within the factor space. The species are those with the highest positive and highest negative loadings on the third factor, that is, with the highest sensitivity to soil moisture availability. The figures refer to mean frequency out of a set of eight 13 ft. x 13 ft. sub-plots.

In addition there are some less common species, some of which were not used in the factor analysis but can be utilized here, which are strongly responsive both to leaching and moisture, and therefore give a more precise indication of site conditions (Figure 15). Thus *Astroloma xerophyllum* is restricted to moderately to strongly leached, dry sites, whereas *Dasypogon bromeliaefolius* reached high frequencies only on moist, moderately to strongly leached sites. *Hakea costata* is typical of dry, weakly leached sites. The ultimate result of both approaches is the definition of a site type by the occurrence of a number of native shrub species, in a more precise and rapid way than would be possible even after deep soil sampling.

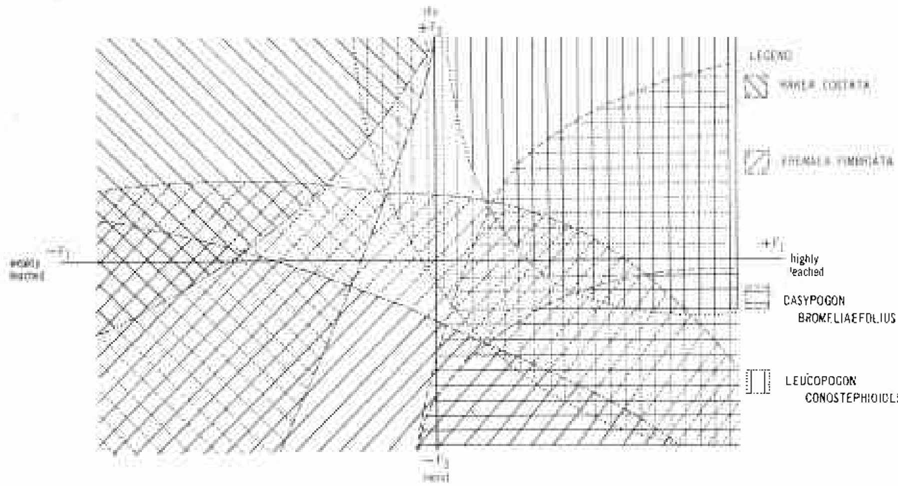

Figure 15.

Distribution of four shrub indicator species within the factor space. The species have widely divergent loadings on the first and third factors, that is, they reach their optimum development under markedly different combinations of soil moisture and soil leaching. Solid hatchuring indicates maximum occurrence and dotted hatchuring sporadic occurrence.

Association Analysis.

The work so far described refers entirely to factor (principal component) analysis. The results of the association analysis were disappointing, and add little to the findings of the first method. In as far as the classification of sites with respect to degree of leaching is concerned, the second method gave comparable results. It failed to classify the sites adequately with respect to moisture regime. The reason for this lies in the nature of data treatment. Because the normal association analysis utilizes only the presence or absence of a species, it performs well with respect to degree of leaching, which gives rise to clear cut patterns; it fails with respect to degree of moisture, which leads to gradual transitions. The inverse form of association analysis likewise proved of limited value in that it adequately classified only the moderately common species. All very common species, such as *Xanthorrhoea preissii, Eremaea pauciflora, Mesomelaena stygia* and *Hibbertia subvaginata* were placed in one group, all rare species in another group. The reason is relatively easy to detect: all common species occur on too many and all rare species on too few plots to lend themselves to classification by purely qualitative criteria.

RELATIONSHIP BETWEEN NATURAL VEGETATION TYPES AND PINES IN LARGE ESTABLISHED PLANTATIONS.

The work so far described was characterized by a strong emphasis on natural vegetation and relatively poor coverage of the various aspects of pine growth. This lack of balance was unavoidable, because the proportion of the northern area planted with pines was so small, and the pines so young, that the only parameter of pine growth measureable was the five year height intercept. As the height intercept has been shown to be correlated with other parameters, such as height, basal area and volume, it can be used to relate these parameters to natural vegetation indirectly. There is, however, an alternative which is a virtual reverse of the situation described above.

A certain proportion of the native understorey species survive the clearing and cultivation involved in the establishment of plantations. They form a scattered understorey in the pines, and could presumably be used in site classification of large areas of plantations. The possible objections to this approach are that the residual understorey within the plantations represents a biased selective sample, composed of species with greater shade tolerance, or that it is merely a temporary seral stage. Despite these possible limitations, this approach has been successfully used by Ure (1950) in New Zealand and Gadnon and McArthur (1959) in Canada. A preliminary reconnaissance of the Gnangara plantations indicated that apart from *Adenanthos sericea* (woolly bush) few if any of the native shrub species could be looked upon as colonizers, and that the bulk of the residual shrubs were survivors from the original vegetation, rather than individuals which have grown up since the establishment. Furthermore the topographical sequence of residual species from swamp to crest of dune was broadly the same as in the undisturbed native woodland.

The work involved in the measurement of height, basal area and volume of a sufficiently large number of sample plots would have been prohibitive, were it not that such a set was already available. The set referred to is that of 150 variable radius plots established by the Management Research Section, already utilized in the testing of five-year height intercept.

Concurrently with the testing of the height intercept, and using the same 2 chain x 2 chain grid, the entire 120 acre section of the plantation in which the plots were situated was stratified on the basis of residual vegetation (Figure 5). Five basic vegetational types were recognised:

(a) *Hypocalymma angustifolium.*

(b) *Xanthorrhoea preissii—Dasypogon bromeliaefolius.*

(c) *Leucopogon conostephioides — Scholtzia involucrata — Eremaea pauciflora.*

(d) *Astroloma xerophyllum—Acacia sphacelata—Casuarina humilis.*

(e) *Mesomelaena stygia—Hibbertia hypericoides—Conostylis candicans.*

The first three groupings formed a continuum, which proved very difficult to map as discrete areas. For this reason, two transitional types were added, namely:

Hypocalymma angustifolium—Xanthorrhoea preissii

and

Xanthorrhoea preissii—Leucopogon conostephiodes.

In addition two other vegetational types, occurring on very small areas only, were also observed. One of these, composed *Typha spp.* and sedges, obviously represented the wet and the other, composed of *Eremaea pauciflora* and *Astroloma xerophyllum,* the dry end of the continuum on the Bassendean Dune System. The last two groupings d) and e) represented the transitional edaphic types between the Bassendean Dune System in the east and the Spearwood Dune System to the west. They generally occupied the higher topographical positions. With the exception of two very small areas in the extreme east, the vegetational types typical of the Bassendean Dune System were in fact restricted to lower slopes and depressions. This is in direct contrast to the small pilot plots on the Bassendean Dune System, which occurred chiefly on slopes. The two studies thus complement, rather than parallel, each other in that they deal with opposite ends of the continuum.

Relevant data are included as Table 3. One plot falling into the wet end of the continuum within the Bassendean Dune System, and two plots falling into the *Xanthorrhoea-Leucopogon* transition have been omitted because a reliable estimate of the mean and confidence limits is not possible for such a small sample. The height intercept, which was sampled systematically along with the vegetation, is presented only as a class average, without any estimate of error term.

It will be seen that the *Xanthorrhoea-Dasypogon-Adenanthos obovata* type, is markedly superior to any other type. Judging from residual stumps it carried an overstorey of large eucalypts (*E. marginata* and *E. calophylla*). There is a fall off in all parameters toward both ends of the moisture continuum. However, the *Astroloma xerophyllum-Leucopogon strictus-Boronia purdieana-Eremaea pauciflora type,* characteristic of the dry end of the continuum is so poorly represented here that no plots actually fall within it. An ocular estimate of a small example of this type indicated a height intercept of approximately 10 ft. and little or no merchantable volume at the age of 15 years.

In the edaphic transition zone in the elevated western portion of the area, the *Mesomelaena stygia-Conostylis candicans-Hibbertia hypericoides* type of the yellow sands is superior to the *Astroloma xerophyllum-Acacia sphacelata-Casuarina humilis* type of the pale yellow sands.

It will be seen that each of two lower height intercept strata (less than 15 ft. and 15-20 ft.) is composed of more than one vegetational type. These in turn are determined by the combination of soil leaching and moisture. There is a high degree of correspondence between the over 20 ft. stratum and the *Xanthorrhoea-Dasypogon-Adenanthos obovata* type, which represents the optimum growth conditions within the State Forest No. 65.

The proportion of trees of poor form, that is trees whose utilization would involve discarding section of the stem due to bend, fork or buttsweep, is markedly higher for some vegetation types than others. As a broad generalization it can be said that the higher the moisture availability, the poorer the form. The extremes are represented by the swampy *Hypocalymna angustifolium* type with 23.8 per cent. and by the dry *Astroloma xerophyllum-Acacia sphacelata* type, with 0.0 per cent. of trees of poor form.

LIMITATIONS TO PLANTATION ESTABLISHMENT

The work so far described dealt primarily with the rate of growth of *Pinus pinaster* on various site types. It is important to realize that growth of *Pinus pinaster,* particularly height growth, is strongly seasonal, and thus

TABLE 3.

Relationship Between Ground Vegetation Types and Growth of *Pinus Pinaster* in Established Plantations.

Parameter		Vegetational Type					
Description	Statistic	Hypocalymma-angustifolium	Hypocalymma-Xanthorrhoea	Xanthorrhoea-Dasypogon	Scholtzia-Leucopogon	Astroloma-Acacia-Casuarina	Mesomelaena-Conostylis-Hibbertia
Number of Plots		12	28	57	18	11	21
Five-year height intercept (mean)		18.1	20.4	22.0	13.9	13.2	15.8
Top Height (ft)	mean conf. lim. p = 0.05 p = 0.01	35.25 ± 2.97 ± 4.19	43.04 ± 1.54 ± 2.08	46.21 ± 1.06 ± 1.41	33.36 ± 2.15 ± 2.95	33.68 ± 1.34 ± 1.90	38.71 ± 0.83 ± 1.14
Predominant Height (ft)	mean conf. lim. p = 0.05 p = 0.01	33·29 ± 2.68 ± 3.79	40·91 ± 1.52 ± 2.05	44·58 ± 1.06 ± 1.41	31·52 ± 2.15 ± 2.95	32·05 ± 1.96 ± 2.79	37·04 ± 1.75 ± 2.39
Basal area of trees 4 in. DBHOB and over (sq. ft/acre)	mean conf. lim. p = 0.05 p = 0.01	57.5 ±10.34 ±14.59	99.64 ±12.95 ±17.48	111.32 ± 7.20 ± 9.58	56.11 ±19.15 ±26.31	50.90 ±25.11 ±35.71	86.19 ±13.30 ±18.15
Basal area (O.B.) of all trees (sq. ft/acre)	mean conf. lim. p = 0.05 p = 0.01	70.00 ±15.07 ±21.27	102.50 ±11.45 ±15.46	112.46 ± 7.14 ± 9.50	68.33 ±15.65 ±21.50	58.17 ± 9.26 ±13.18	88.57 ±13.98 ±19.06
* Merchantable volume (cu. ft/acre)	mean conf. lim. p = 0.05 p = 0.01	424.3 ±170.7 ±240.9	1,312.4 ±204.2 ±275.7	1,582.5 ±137.2 ±183.4	437.0 ±179.7 ±246.8	549.6 ±55.7 ±79.5	865.6 ±188.5 ±257.0
Proportion of trees of poor form		23.8	19.6	11.7	3.3	0.0	2.7

* Overbark volume to 4 inches D.O.B.

reflects only a segment of the environmental conditions. The period of maximum height growth is from August, when the winter dormancy periods ends, to November or December when soil moisture becomes limiting. Sites with the best height intercept growth are thus those which, due to higher content of colloidal matter in the form of iron or organic matter in the soil, or due to a high but not excessive ground water level, provide the optimum moisture and nutrient conditions during spring. Diameter growth follows a similar pattern, but some growth may occur in April and May, after moisture ceases to be a limiting factor and before winter dormancy sets in. There are thus two periods, from May to August, and from December to March, in which growth virtually ceases. Yet it is in these periods that extremes in moisture availability occur. It is thus probable that a consideration of growth rates alone is insufficient to assess the site potential.

This is in fact indicated in the work already described. The plots with high negative scores on factor 1, that is those on weakly leached soils with high iron content both in surface and sub-surface level, combine satisfactory growth rates with susceptibility to summer drought. Within the older plantations at Gnangara the *Hypocalymma angustifolium-Xanthorrhoea preissii* type of swamp-flat transition combines good height growth rate with a high proportion of deformed stems (Table 3). Observation in younger plantations suggest that this is due to an excessively high water table during winter months. In its more extreme form it causes death of seedlings and young trees.

To consider the two problems concurrently within the entire framework erected by the factor analysis may prove too difficult. It is in fact, unnecessary to do so, because the summer drought incidence in older stands is important only in the Spearwood Dune System, whereas the swampy sites are of importance only in the Bassendean Dune System. There are several reasons for this, all of which are basically derived from the geomorphological differences between the two systems.

In the Spearwood Dune System the pattern is one of moderately high dunes and relatively narrow, steep-sided lakes. The internal water movement is through the cavities in the under-lying calcareous deposits. With the exception of the lake shores there are thus virtually no sites on which tree roots reach down to an extensive, static water table. Once the winter and spring flow of water through the profile has ceased, the trees are dependent on the water held within the profile. Due to weak leaching, the colloidal content is moderately high and satisfactory growth is possible. By contrast the Bassendean Dune System consists of low dunes interspersed with shallow lakes and swampy depressions, which with few exceptions, are not connected by surface drainage line. The movement is thus through the soil down to the regional water table, and then in mass laterally through the coarse textured soil. The only sites satisfactory for pine growth are those in which the tree roots are in contact with a direct ground water table influence. It is on these sites that the heavier growth of native vegetation, in particular *Eucalyptus* species, has raised the level of organic colloids near the surface to a sufficient level. Away from the effect of ground water the colloidal content of soil, both of inorganic (iron) and organic (humus) origin is too low for satisfactory retention of moisture and nutrients. The growth rate of pines is correspondingly low.

In the transition zone the differential leaching of moist and dry sites has led to a predominance of strongly leached soils of the Bassendean Association in the depressions, and of weakly leached soils of Karrakatta Association on the dune slopes and crests. Swampy sites with weakly leached soils are thus a rare combination, and do not warrant further consideration.

In as much as the summer drought incidence and stem deformation by high water ground-water table occur at the opposite ends of the leaching continuum the two problems can be dealt with separately. The first problem can thus be simplified to a consideration of the adequacy of water reserves of the weakly leached sands of the Spearwood Dune System. The second problem can be reduced to a study of the maximum height of the ground-water table in the highly leached sands of the Bassendean Dune System.

Vegetational Transects.

The above simplification makes it possible to reintroduce the transect method of vegetation study.

This is particularly desirable as both of the problems involve the study of extremes. It has been stressed earlier that in the establishment of the pilot plots the more extreme site types, such as swamps and limestone outcrops, were avoided. Yet it is on these site types that the extreme forms of environmental limitation are best seen. By aligning the transects along the steepest environmental gradient in a area under study, the variation in the environmental conditions and in the structure and composition of the native vegetation can be studied side by side.

Two of the transects employed, the West Gironde and the Hundred Acre Block transects, are the extension of the preliminary trials. The others were established later to sample, as far as possible, the full range of environmental conditions within the State Forest No. 65. Their limitation lies in their subjective selection, and their small number. There are only nine of them and they are not by themselves representative, adequate samples of the whole area. They have, however, proved very valuable in the study of correlation between environment and native vegetation.

The transects consist of lines of 2 chain x 2 chain (40m x 40m) tree plots, each containing eight 13 ft. x 13 ft. (4m x 4m) sub plots for the study of ground vegetation. The basic dimensions are thus the same as in the case of the surrounds of the small pilot plots, but in one solid block. There is a soil sampling station corresponding to most of the plots, though in the case of the longer transects there is only one station to each two plots. This was necessitated by limitations in laboratory facilities for moisture determination. For each station, chemical data, and bi-monthly gravimetric moisture readings are available to the depth of 10 ft., or to a barrier to soil sampling such as limestone. Each transect covers the full topographical variation in the locality, from a swamp or depression to a dune crest. The length of the transect varies from 12 to 24 chains.

Delineation of Excessively Wet Sites.

Because all three transects, on which the problem of excessive wetness was studied, occur in the southern sector, their applicability to more northern areas may be questioned. The Bassendean Dune System is restricted within the State Forest No. 65 to the southern sector, and to a small NE section of the central sector, north of Yeal Swamp. The reconnaissance of the area and detailed study of the several pilot plots situated within it suggests that there is no major change in the composition of the vegetation. It will be recollected from earlier discussion that the vegetation on the Bassendean Dune System is basically determined by the height of the ground water table and, provided the rainfall is adequate for percolation of water down to the ground table, minor variations of climate are of limited importance. In the northern sector, the Bassendean Dune System or its counterpart occurs wholly outside the State Forest. It is therefore considered that the findings obtained in the southern sector are applicable to the central sector and are irrelevant with respect to the northern sector.

The bi-monthly moisture determination carried out along the transects made it possible to reconstruct the pattern of moisture fluctuations. To date, only gravimetric data are available, and it is difficult to assign them biological significance without knowing the field capacity and wilting point for the various horizons. On the other hand the fluctuations are so violent, and the differences between the various sites so extreme, that it is difficult to see how they could be unrelated to the equally marked variations in vegetation. It is proposed to carry out suction plate studies, but in the meantime, the following categories have been chosen on the basis of field observations:

less than 3 percent moisture (by weight)	—dry.
3-10 percent	—moist.
10-20 percent	—very moist.
more than 20 percent	—saturated, standing water.

A moisture content of over 20 percent was considered to indicate that the soil sample was obtained from below the ground water table. It is possible that this is also true of some of the samples with moisture content between 10 percent and 20 percent.

The moisture observations on two of the transects were carried out from September 1965 to September 1966. They were continued for a longer period on the third transect. As the 1965 winter rains were markedly above, and the 1966 markedly below the average, the ground water level at the conclusion of the observation was generally below the starting point. The year 1965 was the last of three years of above average rainfall, and the ground water table was correspondingly high throughout the region. Conclusions based on the September 1965 ground water level are thus likely to be conservative as far as danger of excessive wetness is concerned. This is confirmed by observations from the third transect, which were continued for a further period.

The main determinants of soil moisture conditions within the Bassendean Dune System appear to be the topography, the height of the regional water table and the presence of a deposition horizon. These are not independent of each other, but the relationship is not clear cut. Initially topography was no doubt the prime factor in the formation of a deposition horizon, but subsequent

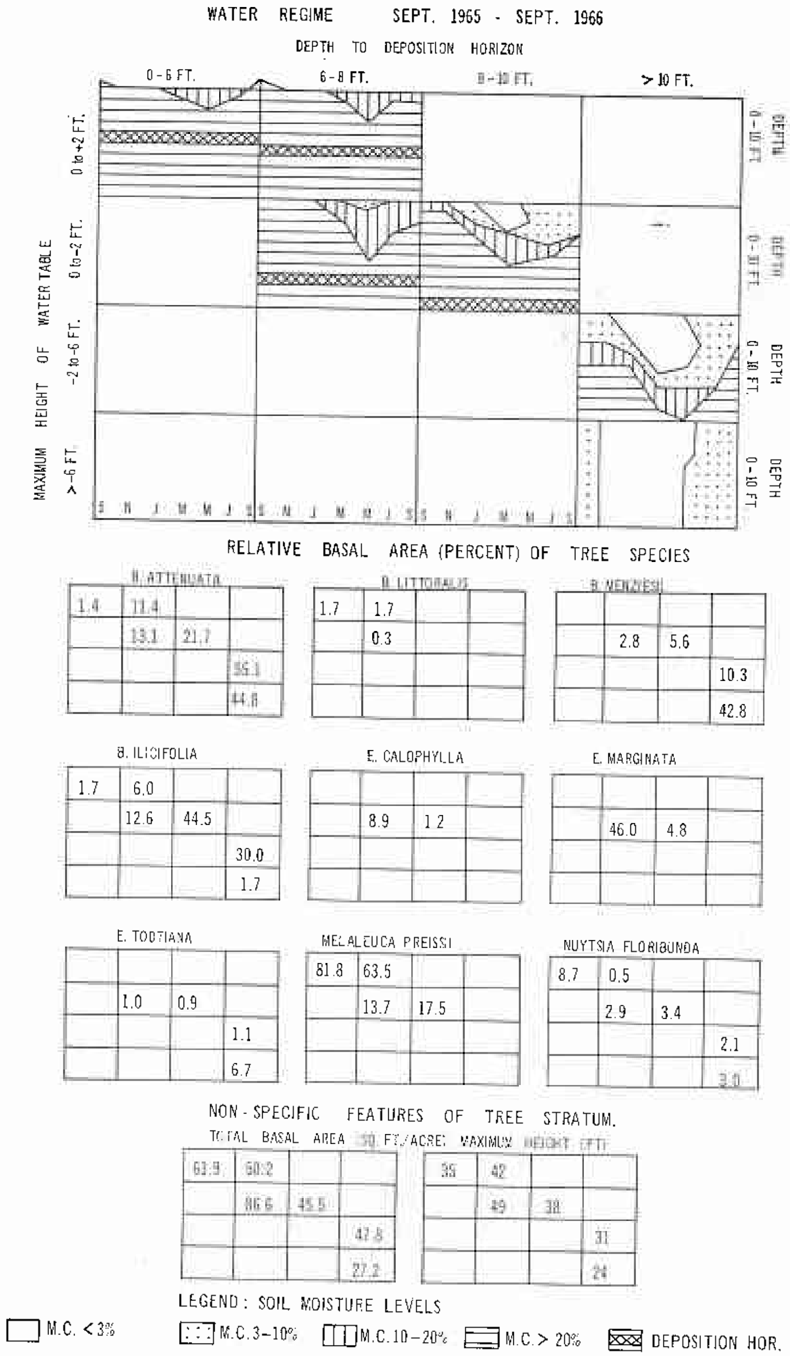

Figure 16.
Ordination of vegetation of the Bassendean Dune System on the basis of the maximum height of water table and the depth to a deposition horizon. The diagram deals only with the tree stratum. The corresponding distribution patterns for the shrub stratum are shown in Figure 17.

changes in topography have obscured the relationship. To overcome this problem, a two-way co-ordinate system, using depth to water table at the end of the 1965 winter, and the depth to deposition horizon, was employed, It will be seen in Figure 16 that not all of the possible combinations were found, in that an increased depth to water table was usually associated with increased depth to deposition horizon.

The analysis of tree data is presented in Figure 16. The individual species are represented by their relative basal area, calculated as the mean of all plots falling within this category. In addition, mean total basal area per acre, and the maximum height of canopy, are given for each category.

The tree species fall into four main categories:—

(a) Species tolerant of excessive wetness—*Melaleuca preissiana, Banksia littoralis.*

(b) Species of optimum moist sites, intolerant of extremes in moisture conditions—*Eucalyptus marginata, Eucalyptus calophylla, Banksia ilicifolia* and, infrequently, *Banksia grandis.*

(c) Species with wide tolerance, but with maximum development on dry sites—*Banksia attenuata, Banksia menziesii.*

(d) Species without clear cut site preference—*Eucalyptus todtiana, Nuytsia floribunda.*

A further species, *Eucalyptus rudis,* though not present within this set of transects, is common in many swampy areas, and can be assigned to category (a).

The analysis of shrub data is presented in Figure 17. The separate numbers refer to the mean frequency of each species within each category, for clusters of eight 13 ft. x 13 ft. sub-plots. The mean frequency of eight thus means that the species was found on each sub plot falling within the particular category. Four groups of shrub species, similar to the four groups of tree species, can be observed:—

(a) species tolerant of excessive wetness:
Patersonia xanthina, Hibbertia stellaris, Calothamnus lateralis, Leptospermum ellipticum, Astartea fascicularis, Pultenaea reticulata, Regelia ciliata, Euchilopsis lineraris, Hypocalymma angustifolium.

(b) species of optimum, moist sites:
Adenanthos obovata, Melaleuca seriata, Dasypogon bromeliaefolius, Xanthorrhoea preissii, Phlebocarya ciliata.

(c) species with maximum development on dry sites:
Beaufortia elegans, Conostephium minus, Hibbertia helianthemoides, Leucopogon conostephioides, Scholtzia involucrata, Oxylobium capitatum, Melaleuca scabra, Eremaea pauciflora, Jacksonia floribunda, Astroloma xerophyllum, Leucopogon strictus, Boronia purdieana.

(d) species without clear-cut site preference:
Hibbertia subvaginata, Lyginia tenax, Conostephium pendulum, Bossiaea eriocarpa, Calythrix flavescens.

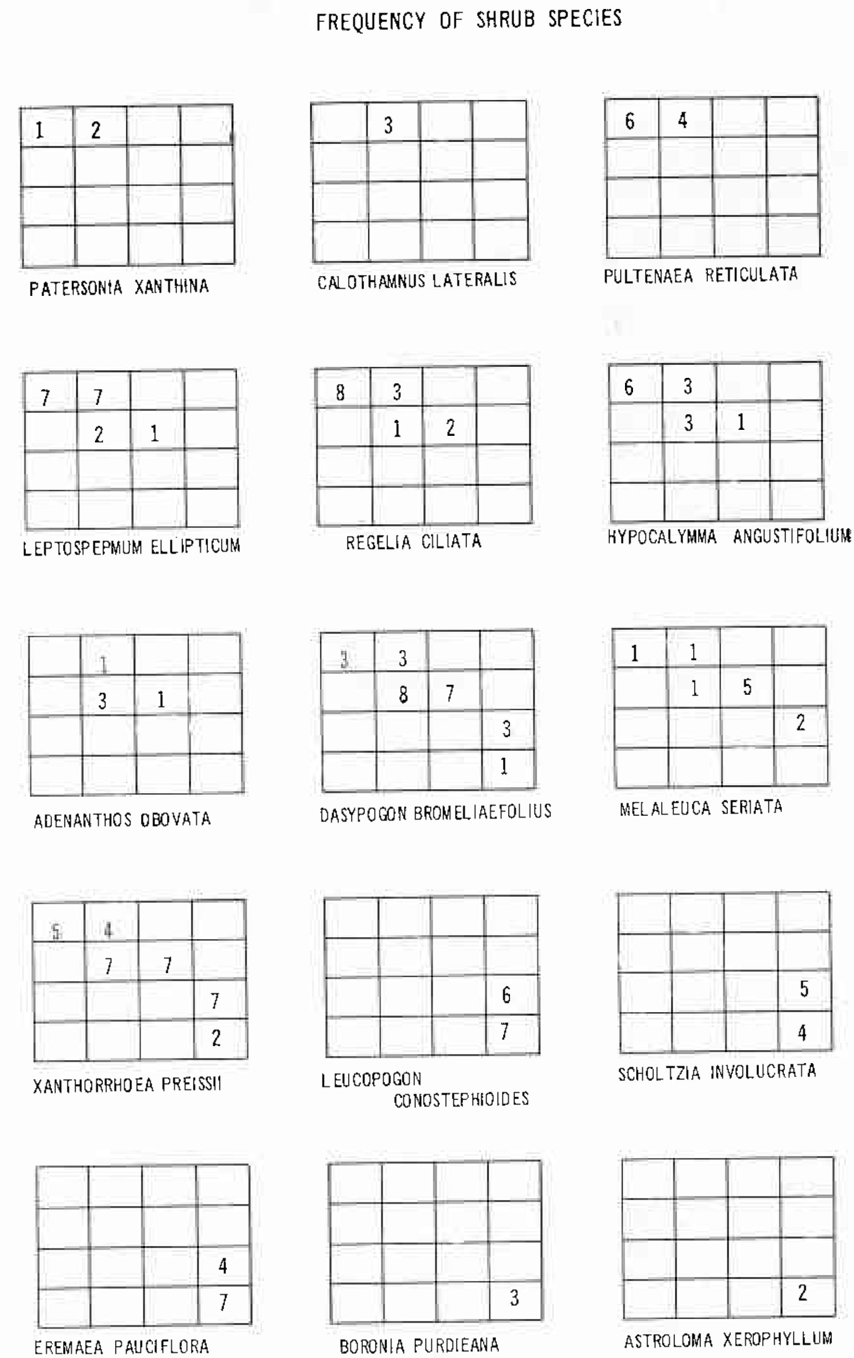

Figure 17.

Ordination of vegetation of the Bassendean Dune System on the basis of the maximum height of water table and the depth to a deposition horizon. The diagram refers to shrub species only. The figures show the frequency of occurrence in a set of eight 13 ft. x 13 ft. sub-plots.

It will be also seen that within each of the first three groups there are some species with extremely narrow environmental ranges, such as *Calothamnus lateralis* in group (a), *Adenanthos obovata* in group (b) and *Astroloma xerophyllum*, and *Boronia purdieana* in group (c). Where these species occur, they provide the means of rapid and accurate site classification.

The determination of the cut-off point with respect to excessive wetness cannot be done without first specifying the condition of the area at the time of planting. Clearing of large areas invariably leads to a rapid rise in the regional water table so that, at least temporarily, the problem of excessive wetness is aggravated. This can be best illustrated by reference to plot 87 (7) situated in a seasonal swamp adjacent to Lake Pinjar. Its initial growth was very good, though the form was poor. The surrounding area, topographically and ecologically equivalent, was cleared five years later as part of a large block of several hundred acres, and planted with *Pinus pinaster*. There have been many deaths due to flooding, and the rate of growth is inferior to that of the older pilot plot. Conversely, in the old plantations, there are areas which appear to have been swamps, as indicated by their topographical position and remnants of native vegetation. They are swamps no longer because the heavy water uptake by surrounding pine stands has lowered the water table markedly. In the past, attempts have been made to prevent the rise of water table on newly cleared areas by drainage. It would seem that the same effect could be obtained more cheaply and thoroughly by postponing the planting of marginal sites until the water usage on surrounding planted areas has returned to or passed that of the native vegetation.

Under the current management system of large compact plantation areas, planting is a doubtful proposition on all sites carrying an overstorey of *Melaleuca preissiana* and *Banksia littoralis* and an understory of *Regelia ciliata, Leptospermum ellipticum, Astartea fascicularis* and *Pultenaea reticulata*. Stands with satisfactory growth rates but poor form occur on sites where *Hypocalymma angustifolium* occurs in admixture with *Xanthorrhoea preissii* under *Melaleuca preissiana* overstorey. Sites with *Calothamnus lateralis, Astartea fascicularis* and *Leptospermum ellipticum* without overstorey and without admixture of *Xanthorrhoea* will probably prove too difficult to handle with mechanical equipment. They are definitely out of question for planting of *Pinus pinaster*.

Because *Melaleuca preissiana* occurs not only on a wet, but also on moist sites, its occurrence on aerial photographs cannot be used as a clear-cut indication of planting limits. The difference in total basal area and maximum height of the overstorey between moist and excessively wet sites is likewise insufficiently clear cut to be of use in photo-interpretation. It is therefore necessary to rely on shrub indicators and ground reconnaissance.

The transects discussed above can be also used to reinforce the findings of factor analysis on the planting limits at the dry end of the Bassendean Dune System. Some of the species of groups (b) and (c) have already been shown by factor analysis to be indicators of moist and dry conditions respectively. The remaining species can be used for the same purpose. There is thus a wealth of species which can serve as negative indicators of pine planting potential in that their presence indicates sites which are too dry and too leached for satisfactory planting establishment.

Several other species, in particular *Adenanthos obovata, Melaleuca seriata* and *Dasypogon bromeliaefolius* can be looked upon as positive indicators, whose presence is indicative of good pine planting potential. In the case of *Xanthorrhoea preissii* the abundance, rather than mere presence, must be considered.

Delineation of Sites Susceptible to Summer Drought Deaths.

Summer drought deaths are naturally not restricted to Western Australia. Drought deaths have been recorded even in the cooler and moister climate of New Zealand. Beckhuis and Will (1966) attribute these to the unbalance between large dense crowns developed under luxury moisture conditions, and the lack of available water during the subsequent drought period. Zahner (1956) stresses that summer water deficiencies of upland forest can be evaluated only when the water need is compared with the water supply. He looks on atmospheric potential for evapo-transpiration as a measure of the need, and on current rainfall together with stored water as the supply. In another article (Zahner 1954) he concluded that the soil moisture depletion by pine and hardwood stands within a climatic region is the same.

The water usage by native vegetation of the Swan Coastal plain has been studied by Grieve (1955). He reports that with the exception of *Eucalyptus marginata,* all the scherophylls tested by him showed decreasing rates of transpiration with increasing dry conditions. In the dry summer season the soil suction was found to rise above the osmotic value of the leaves. The plants remained under severe water stress until break-of-the-season rains. The stress was more severe in the case of shallow rooted shrubs such as *Bossiaea eriocarpa* and *Hibbertia hypericoides,* than in the case of trees such as *Banksia attenuata* and *Banksia menziesii.* The reason for this was the increase in moisture content of soil with depth, and a corresponding decrease in suction from 50 atm. at 1 ft. depth to 0 atm. at 11 ft. Grieve classified the sclerophylls of the Swan Coastal Plain into the following categories:—

(i) Deciduous plants failing to show appreciable stress throughout the summer—viz. *Phyllanthus calycinus.*

(ii) Evergreen plants physiologically active throughout the summer——viz. *Eucalyptus marginata.*

(iii) Evergreen plants restricting their physiological activity to the point of near dormancy—viz. *Hibbertia hypericoides* and *Bossiaea eriocarpa.*

(iv) Evergreen species capable of restricting water losses by stomatal closure or some internal factor before water source is completely exhausted—viz. *Banksia attenuata* and *B. menziesii, Eucalyptus calophylla.*

The three tree species in category (iv) differed slightly in their pattern of transpiration. *Banksia menziesii* had a high rate of water loss in spring but low in summer. *Banksia attenuata* had a low rate of water loss in spring and a relatively high one in summer *Eucalyptus calophylla* was found capable of reducing transpiration to very low levels on summer days. By contrast, the stomata of the *Eucalyptus marginata* of group (ii) were frequently wide open even in summer and the rate of water loss was correspondingly high. Grieve described it as a species prodigal of water use which maintains a water balance through its deep root system.

In the area under review, the marked seasonality of rainfall, and the coincidence of the dry season with the long hot summers results in a very simple soil moisture pattern. The almost complete exhaustion of soil moisture during the summer is followed by a recharge during late autumn, winter and early spring. The moisture reserves of the soils of the Karrakatta and Cottesloe Association, which lack a clearly defined deposition horizon, are dependent on the retention of water within the profile. Some minor ponding possibly occurs in the hollows of the underlying travertine capping, but is of little importance. Therefore the potential reserves are related to the water-holding capacity of the soils and to the depth of the soil above the travertine capping. The actual reserves are determined by the completeness of the recharge which is in turn dependent on the quantity and intensity of winter rainfall, and on the degree of exhaustion of the reserves in the preceding summer. Exhaustion in the preceding summer is determined by the duration and intensity of the drought. The vegetation of the site affects both the exhaustion of the reserves and their recharge. As a general principle, the heavier the vegetation, the more complete the exhaustion and the greater the interception of rainfall. The combined effect of these is the reduction of the reserves.

One can further postulate that in the undisturbed native vegetation a balance is reached between the soil moisture reserves and the vegetation above. There is however, the possibility that the vegetation is not limited by the moisture availability, but by the infertility of the soil (Specht 1966). In such a case application of the deficient nutrient may be expected to cause a disequilibrium. An even more severe case of disequilibrium is created when an exotic species, subsidised by the application of fertilizers and the removal of competition, replaces the native vegetation. Presumably summer drought deaths are in such a case a means of establishing a new equilibrium with the water reserves of the site. As long as the deaths are restricted to inferior trees regularly spaced through the stand they could be accepted as a form of non-commercial, free-of-cost thinning. However, as the deaths sometimes occur in clumps, it is necessary to determine the level of stocking to which the stands need to be reduced by thinning in order to avoid such a situation. As a further step, it is necessary to ascertain if this level of stocking is sufficiently high to justify the cost of plantation establishment.

The study thus needs to determine the relationship between the density of native vegetation and that of the established pine stands. This involves testing the assumption that native vegetation does in fact reach an equilibrium with the water resources of the site.

There are two sources of data available for this study. Five of the nine transects established to investigate the correlation between the native vegetation and environment, occur wholly within the Spearwood Dune System. A further transect occurs within the transition zone reaching into the Spearwood Dune System at its upper end. All but one of these transects terminate on or adjacent to a limestone outcrop, where the water reserves appear to be most limiting. In their distribution they cover virtually the whole N-S range within the State Forest No. 65. The normal gravimetric moisture determinations were carried out on all transects. In addition one of the transects provides a link with a neutron probe study. This study of the relative water usage under native vegetation and a young pine stand was carried out in co-operation with Dr. F Roberts of the C.S.I.R.O. Division of Plant Industry.

Data on native vegetation alone are available from three large pilot plots of 12 acres each, which were mapped prior to clearing. Inasmuch as the location and sampling was less subjective and the data lend themselves to factor analysis, they shall be dealt with first.

Large Pilot Plots.

The first step consisted of selecting three comparable localities having reasonable access and possessing similar topographic and edaphic features, but spaced widely along the N-S axis so as to sample the full range of climatic variation within State Forest No. 65. It was found that there was virtually no choice, the above specification being held by only very few localities. The sites ultimately selected had the following in common:—

(i) A distance of approximately 4 miles from the sea.

(ii) A westerly exposure.

(iii) A moderate slope spanning the range from depression to upper slope in 20 chains.

(iii) Moderate to weakly leached yellow sands of the Karrakatta and Cottesloe soil Associations.

They were located (a) between Pinjar and Yanchep near the SW boundary, (b) between Yanchep and Moore River, and (c) N.W. of Moore River near the N.W. boundary of the State Forest, respectively (Figure 1). In each case, a plot 20 chains x 6 chains (12 acres) was delineated, with the long axis across the contours. The vegetation was then sampled by restricted random stratified sampling, the strata being arranged along contours. The sampling unit was an elongated plot 2 chains x 0.5 chain long, orientated along the contours.

The basal area of all tree species within the plot and the height of the tallest tree, were determined. The shrub layer was sampled by a chain of eight one metre square quadrats, spaced systematically along the major axis of the tree plot. On each plot, the percentage cover of each species was assessed, and the average for the set of 8 plots was calculated. The basal area of the trees, and percentage cover of the shrubs, were used as basic data for factor analysis using the Horan computer programme already described. The set of 81 plots was used by Dr. Goodall of the C.S.I.R.O. Mathematical Statistic section as a test case for use of the Horan programme for phytosociological data. It was found that for proper functioning of the programme the full range of species had to be reduced to 40, that is to half of the number of plots.

Because the plots were established within the Spearwood Dune System, the the dominating effect of leaching found in the first factor analysis was absent. It was necessary to establish a full three-dimensional system of co-ordinates based on factor scores before the factors could be interpreted in terms of environmental conditions.

The first factor appeared to be related to the north-south climatic variation, but with some confounding effects. On-the-spot inspection revealed that the southern and central study areas included a shallow phase of the Cottesloe series, underlain by limestone at the up-slope end, but a similar shallow phase occurred beyond the boundary of the plot in the northern study area. Review of the species distribution revealed that this was the source of confounding of the first factor, which reflected both the climatic variation indicated by reduction in both size and complexity of the tree layer, and the presence of limestone, indicated by the specific composition of the shrub layer.

The second factor corresponded closely to the first factor of the previous factor analysis, that is, it reflected the degree of leaching of the soil, but this time its effect was far less pronounced. Within the central and northern plot it was related to topography, the soils of the depressions being more strongly leached than those of the slopes.

The third factor resembled the third factor of the previous analysis, the moistness or droughtiness of the site. As a rule the topographically lower sites had positive scores on the third factor. The proportion of the plots with positive scores was greater in the southern than in the central and northern study areas.

A summary of the site types and corresponding species groups, separated on the basis of score on the first three factors, is contained in Appendix I. A graphical summary of the relationship between major tree species and the first and third factors is contained in Figure 18.

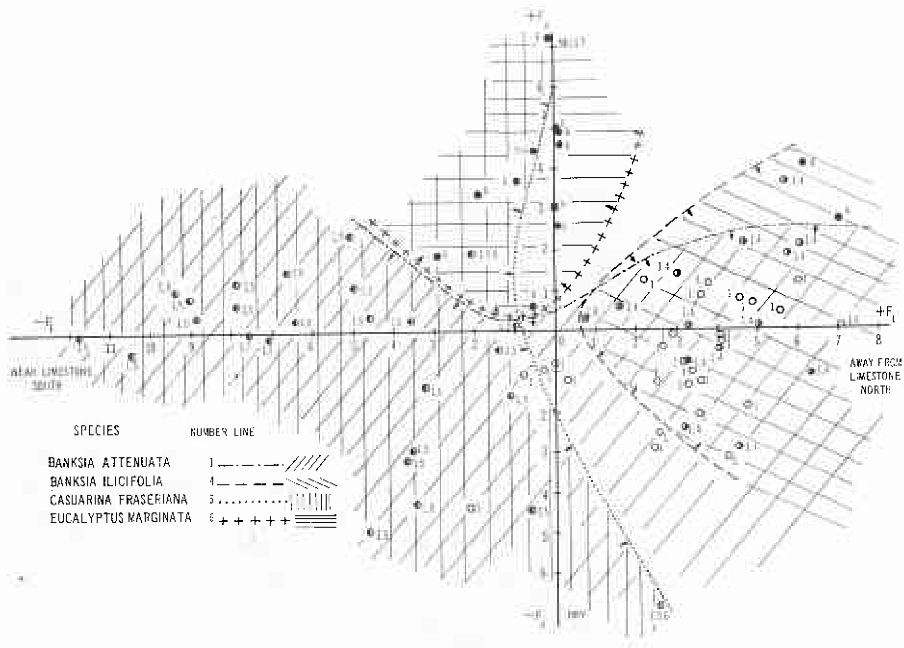

Figure 18.
Distribution of main tree species of the Spearwood Dune System within the factor space developed from factor analysis of data from large pilot plots.

The change in the tree stratum within the Spearwood Dune System, in particular its relationship to the N-S variation in climate, is of major interest in this study. The jarrah (*Eucalyptus marginata*) is restricted to the southern study area. It does, however, occur as small scattered stands on sheltered, moist sites in the central sector of the State Forest. It is entirely absent from the northern sector. The bull-banksia (*Banksia grandis*), and the sheoak (*Casuarina fraseriana*), the common associates of jarrah on heavier soils further south, are widespread in the southern and central sectors. In the northern sector the sheoak is absent and the bull-banksia is restricted to several small sheltered, moist areas, chiefly along the Moore River. Holly-leaved banksia (*Banksia ilicifolia*), a relatively rare associate of jarrah on the moister sites in the south, replaces jarrah on these sites in the central and northern sectors. *Banksia attenuata* and *Banksia menziesii* are present in all three sectors, but their importance increases from south to north. Although the sand-plain blackbutt (*Eucalyptus todtiana*) is only recorded within the southern study area it normally extends throughout the three sectors. The Chrismas tree (*Nuytsia floribunda*), a root parasite, is present but relatively unimportant in all three sectors.

On the whole then, the progress northwards is accompanied by the reduction in importance and the eventual disappearance of species characteristic of the moister, cooler region of the south and a corresponding increase in the species which reach their maximum development on the northern study area or slightly to the north of it. It is interesting to note that at the McLarty and Myalup plantations, 100 miles further south, *Banksia menziessii* and *Eucalyptus todtiana* are either extremely rare or absent on the Spearwood Dune System: even *Banksia grandis* and *Casuarina fraseriana* are largely displaced in the understorey by *Agonis flexuosa* and *Xylomelum occidentale*. By contrast at Cockleshell Gully, 125 miles further south, even *Banksia menziesii, Banksia attenuata* and *Eucalyptus todtiana* are reduced to clumps of shrubby treelets on the best sites within an otherwise treeless heath.

Apart from the changes in the specific composition of the tree stratum there are also marked changes in non-specific features, in particular basal area, which is the most readily obtainable measure of site occupancy. The change in average basal area from south to north is from 61.6 sq. ft. to 29.6 sq. ft. to 16.9 sq. ft. per acre, for the pilot plots as a whole. This is possibly an exaggerated picture, due to the replacement of the relatively dense *Eucalyptus marginata* stands on the southern lower slopes and depressions by the open, frost damaged *Banksia ilicifolia—B. attenuata* stands in the corresponding positions in the north. However, even on the mid slopes, which are free of frost damage and are particularly well matched with respect to soils, the average basal area falls from 45.9 sq. ft. to 27.6 sq. ft. per acre proceeding from south to north. Yet the distance between the southern and northern plots is only 33 miles or 24 minutes of latitude. The drop in mean annual rainfall between Perth to the south and Cowalla to the north of these plots, separated by a distance of 66 miles or 50 minutes of latitude, is from 35.05 in. to 28.75 in.; equivalent to 20 percent. The length of the growing season, calculated by the formula $P=0.54\ E^{0.7}$ (where P=effective rainfall and E=evaporation) is given by the Bureau of Meteorology (Anon 1966) as 6.3 months at Perth and 5.7 months at Cowalla. Even more pronounced is the increase in the probability of severe drought. The Bureau of Meteorology (Anon 1966) provides probabilities in terms of number of years out of a hundred, of seasonal drought of three to nine months duration. This is contained in Table 4.

TABLE 4.

Number of Years Out of 100 in which Drought Duration Exceeds Specified Periods.

Locality	Duration of drought in months						
	3	4	5	6	7	8	9
Perth	100	99	90	65	16	1	0
Yanchep	100	97	90	83	41	14	0
Cowalla	100	100	91	90	48	18	2

Data in Table 4 would indicate that the absence of the less drought tolerant species, and the lower basal area of the stand in the north are determined more by periodic drought deaths than by any consistent lowering of the growth potential.

The regional limitation of water reserves is modified locally by topographic and edaphic factors. The effect of these was studied in five transects located within the Spearwood Dune System, which covered the full latitudinal range within State Forest No. 65. In addition to vegetative data, bi-monthly moisture determinations and chemical analyses were also available. The shrub data from the transects were combined into a two-way co-ordinate system on the basis of depth of soil over limestone and topographical position. The distribution of 19 species within the system is shown in Figure 19. They can be broadly divided into the following groups:—

(1) Species restricted to shallow soils and limestone outcrops e.g. *Acacia heteroclita, Trymalium ledifolium, Melaleuca huegelii, Grevillea thelemanniana* and *G. vestita*.

(2) Species of moderately shallow soils, extending somewhat into both deep and shallow soils e.g. *Calothamus quadrifidus, Leschenaultia linearioides, Jacksonia hakeoides, Conospermum triplinervium var. linearis, Melaleuca acerosa, Petrophila brevifolia* and *P. serruriae*.

(3) Common species occurring on both shallow and deep soils, e.g. *Stirlingia latifolia, Mesomelaena stygia, Xanthorrhoea preissii, Hibbertia hypericoides*.

(4) Species restricted to deep soils, e.g *Melaleuca scabra, Calothamnus sanguineus*.

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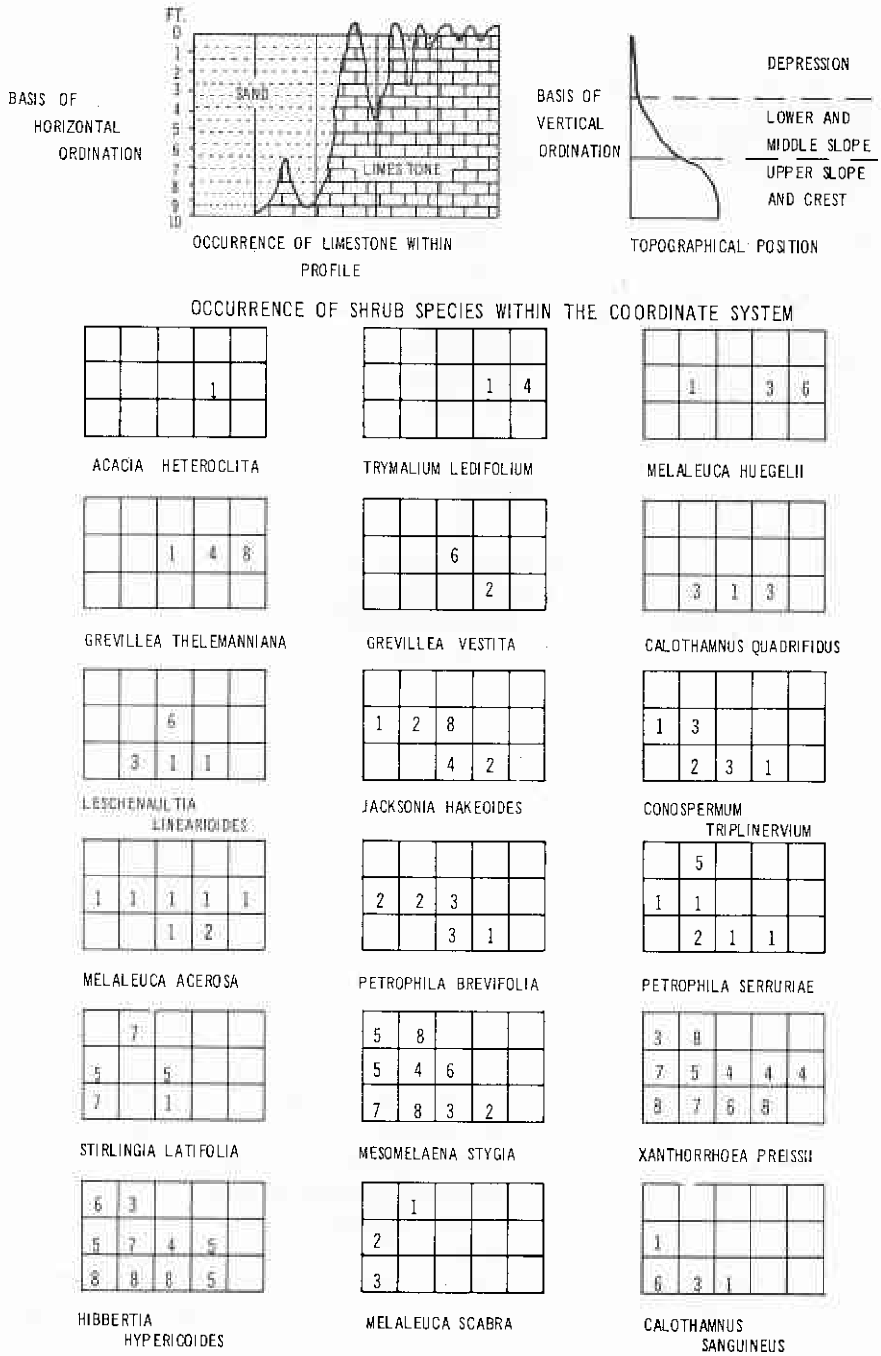


Figure 19.

Ordination of vegetation of the Spearwood Dune System on the basis of topographical position and occurrence of limestone within the soil profile. The figures refer to the frequency of occurrence of the main shrub species in a set of eight 13 ft. x 13 ft. sub-plots.

Species of group (2) are of greatest use in assessing depth of soil as they indicate the presence of limestone at depth. Limestone outcrops are normally plainly visible on sites ocupied by group (1). Species of group (4) are negative indicators as they are normally absent from soils underlain by limestone.

The two-way co-ordinate system is inadequate to describe the variation in the tree-layer since it does not take into account the very strong effect of the north-south climatic variation. The rapid change in total basal area, maximum height of the canopy and the relative basal area of individual species on approaching a limestone outcrop is shown in Figure 20. This figure summarises observations from Boongarra transect (T.6), which includes one of the northernmost stands of jarrah (*Eucalyptus marginata*) on the coastal sands. It is here restricted to sheltered lower slopes. Within the transect, the effects of soil depth and topography combine to produce an extremely steep environmental gradient, which is reflected in a sharper than usual delineation of vegetational types. At the transition between the types, there is evidence of drought deaths dating back to the 1959 drought. Dead trees of *Eucalyptus marginata* can be seen in the *Casuarina fraseriana* type, dead *Casuarinas* in the *Banksia attenuata* type and dead *Banksias* near the treeless crest of the dune where limestone outcrops at the surface.

Similar, but less striking patterns, exist in other transects. An attempt to illustrate these is made in Figure 21, which is a subjective summing-up of observations made in transects, large pilot plots and surrounds of small pilot plots. In Figure 21 the potential occurrence of the main tree species is related to the latitudinal position, topographical position and depth of soil. No attempt is made to depict the relative importance of the species under a given combination of environmental conditions. Thus all species included can, and occasionally do, appear under the optimum combination of a deep soil in a depression in the southern sector, where, however, they are normally dominated or completely displaced by *Eucalyptus marginata,* which is capable of forming the tallest and densest stands. It is on the sites from which *Eucalyptus marginata* is excluded by less favourable environmental conditions, that the other species develop more fully. On the more extreme sites the number of potential species is progressively diminished until only one or two species can occupy the site. This is the case for instance, with *Eucalyptus gomphocephala* on limestone outcrops in the south, or *Banksia attenuata* on moderately shallow soils on upper slopes in the north. Ultimately no tree species can exist, and the tree stratum disappears completely.

On the weakly leached sands of the Spearwood Dune System the reduction in height and basal area of the tree stratum and in the number of tree species is an indication of increasing susceptibility to drought. The decrease in tree species and average basal area proceeding northwards is paralleled by an increase in susceptibility of young pine stands to summer drought deaths.

In the northern sector, summer drought deaths following the dry 1966-67 season occurred in 14 out of 18 pilot plots situated within the Spearwood Dune System. Although severe needle cast occurred in most of the corresponding pilot plots in the central sector, no deaths were recorded. Some deaths did, however, occur in those portions of the Hundred Acre Block which

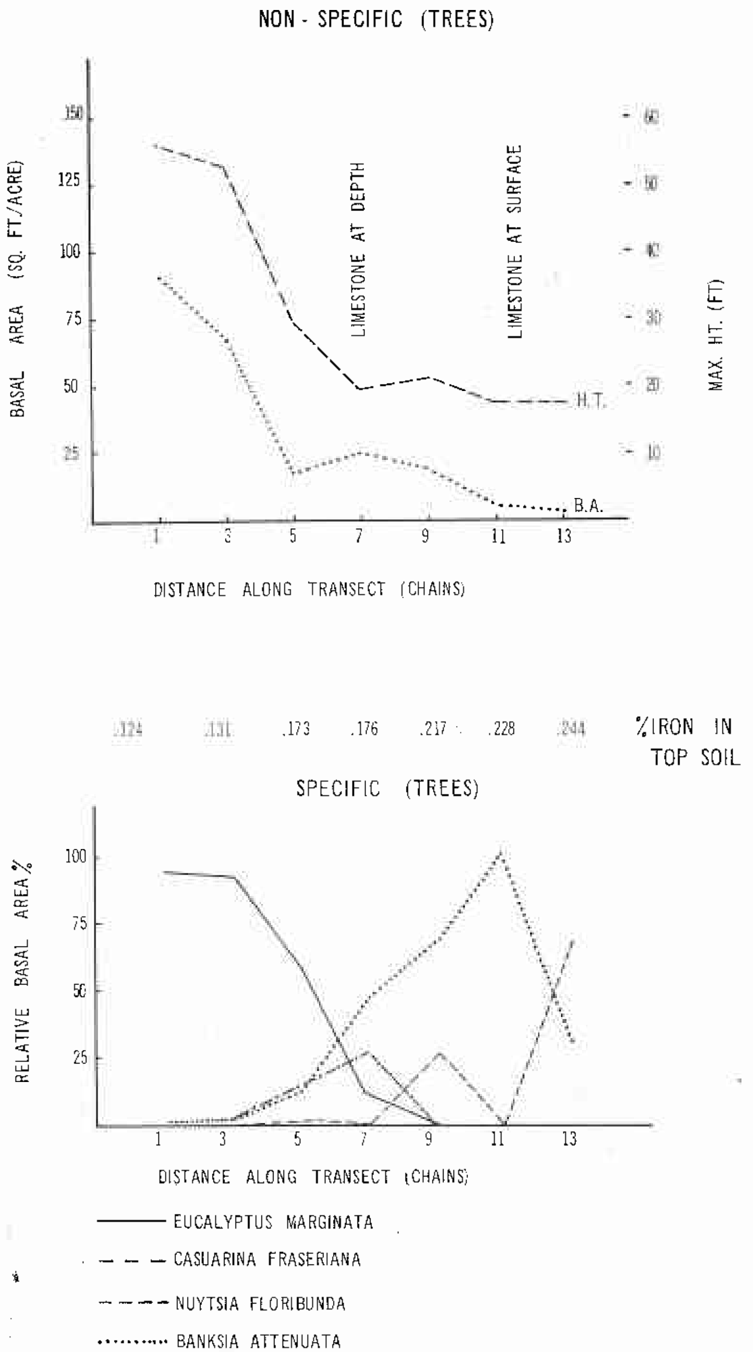


Figure 20.

Variation in the specific and non-specific features of the tree stratum in the Boongarra vegetational transect North of Yanchep.

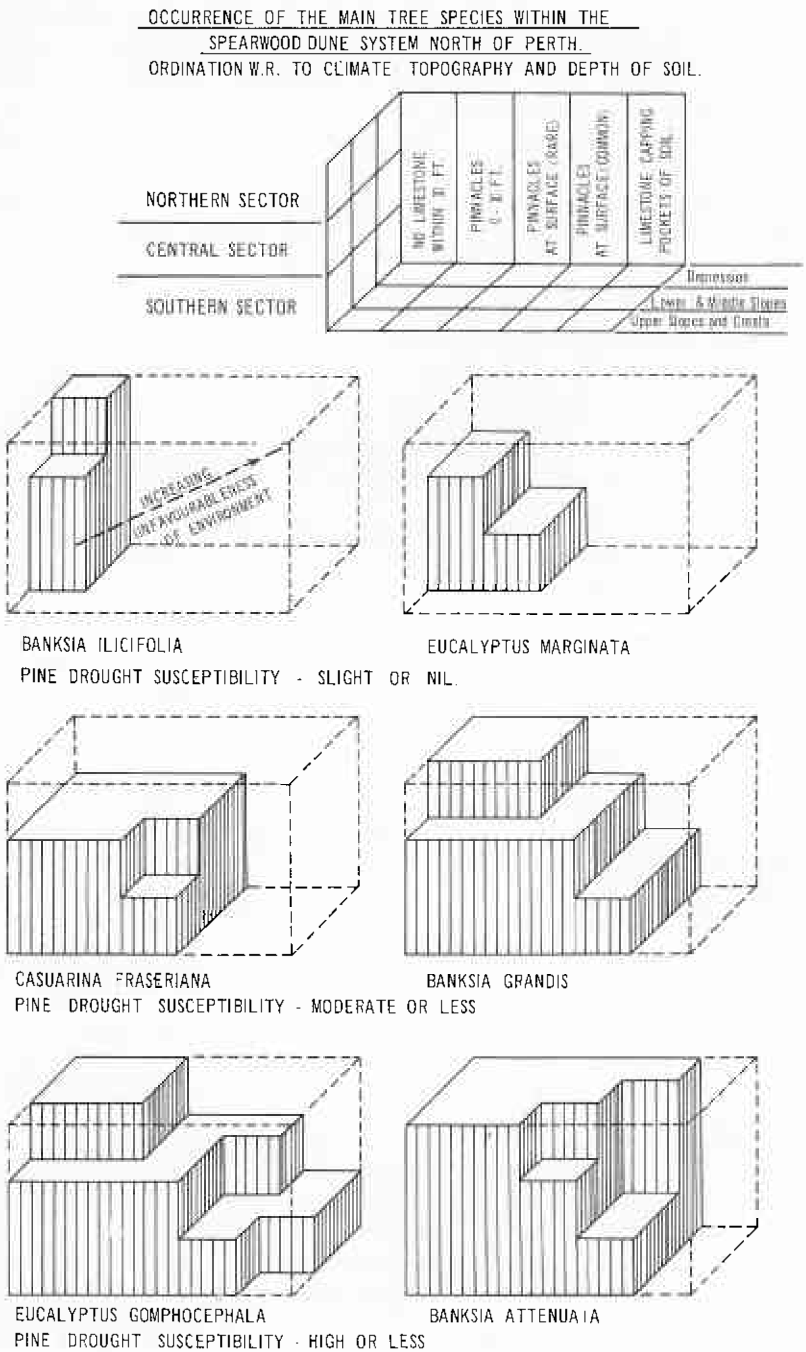


Figure 21.

Subjective ordination of main tree species of the Spearwood Dune System on the basis of climate, topography and depth of soil. The portion of the total space shown as solid represents the potential occurrence of the particular species.

have not been thinned since a light non-commercial thinning in 1962. As these are well documented as regards soil moisture patterns, they shall be discussed in greater detail later. Some deaths were also recorded in the southern sector. They were restricted to portions of the Pinjar plantation adjacent to limestone outcrops.

The age of the affected stands varied from 9 to 18 years. A recurrence of summer drought deaths was observed in an 18 year old plot previously affected. This plot is situated in private land north of the northern sector of State Forest No. 65. No drought deaths were observed in plots 13, 15, 16, which are situated in the transition zone between the Spearwood and Bassendean Dune System, though they are of the same age and occur equally far north as the above plot. Although *Banksia ilicifolia* is moderately common in the northern sector, it was not found in the surround of any of the plots affected by the summer drought deaths. It was found in surrounds of plots 41 and 74; which, though surrounded by drought affected plots, were free of drought damage. It was also present in plots 13, 15 and 16 mentioned earlier.

Mechanism of Summer Drought Deaths.

The environmental conditions leading to summer drought deaths have been studied in the Hundred Acre Block, situated centrally within the Spearwood Dune System. The initial purpose of the investigations was the study of pine growth on two site types, and its relationship to the native vegetation. As no marked difference in soil moisture between the two sites could be detected in the 1965 winter by gravimetric sampling to ten feet depth using the Veihmeyer tube, the assistance of the C.S.I.R.O. Division of Plant Industry was sought. A set of three neutron probe access tubes was sunk down to 23 feet on each site in October 1965. Within each set, one sampling station was located in a pine stand (then 13 years old), one in the adjacent ploughed firebreak and one in the relatively undisturbed native woodland on the other side of the ploughed firebreak.

The two sites differed markedly. The first site, subsequently referred to as site A, was characterised by weakly leached yellow to yellowish brown sand with little difference between surface and subsurface layers. Limestone was encountered at various depth from 7 ft. downwards when sinking the access tubes, and several attempts were necessary before the tubes could be sunk to the full depth of 23 ft. The pine stand on this site had a site index (five-year intercept) of 18, and reached a basal area of 100 sq. ft. per acre by the age of 15 years. The crowns were dense and the canopy closure was virtually complete, despite a light non-commercial thinning in 1962. The native vegetation consisted of a moderately dense woodland of *Banksia grandis, B. attenuata* and *B. menziesii, Eucalyptus todtiana, E. decipiens* and *Nuytsia floribunda* and was 30 feet high, with a basal area of 60 sq. ft./acre. *Xanthorrhoea preissii, Stirlingia latifolia* and *Petrophila serruriae* were prominent in the undergrowth.

The second site (B) was situated approximately six chains up along a mild 2° slope. It was characterised by a moderately leached pale grey surface soil overlying yellow sand of unknown depth. No limestone was encountered in the sinking of the access tubes. The pine stand had a site index of 15, and reached a basal area of only 70 sq. ft. per acre by the age of 15 years. The crowns were relatively thin and narrow and canopy closure was incomplete, resulting in a strong development of residual shrub species, in particular

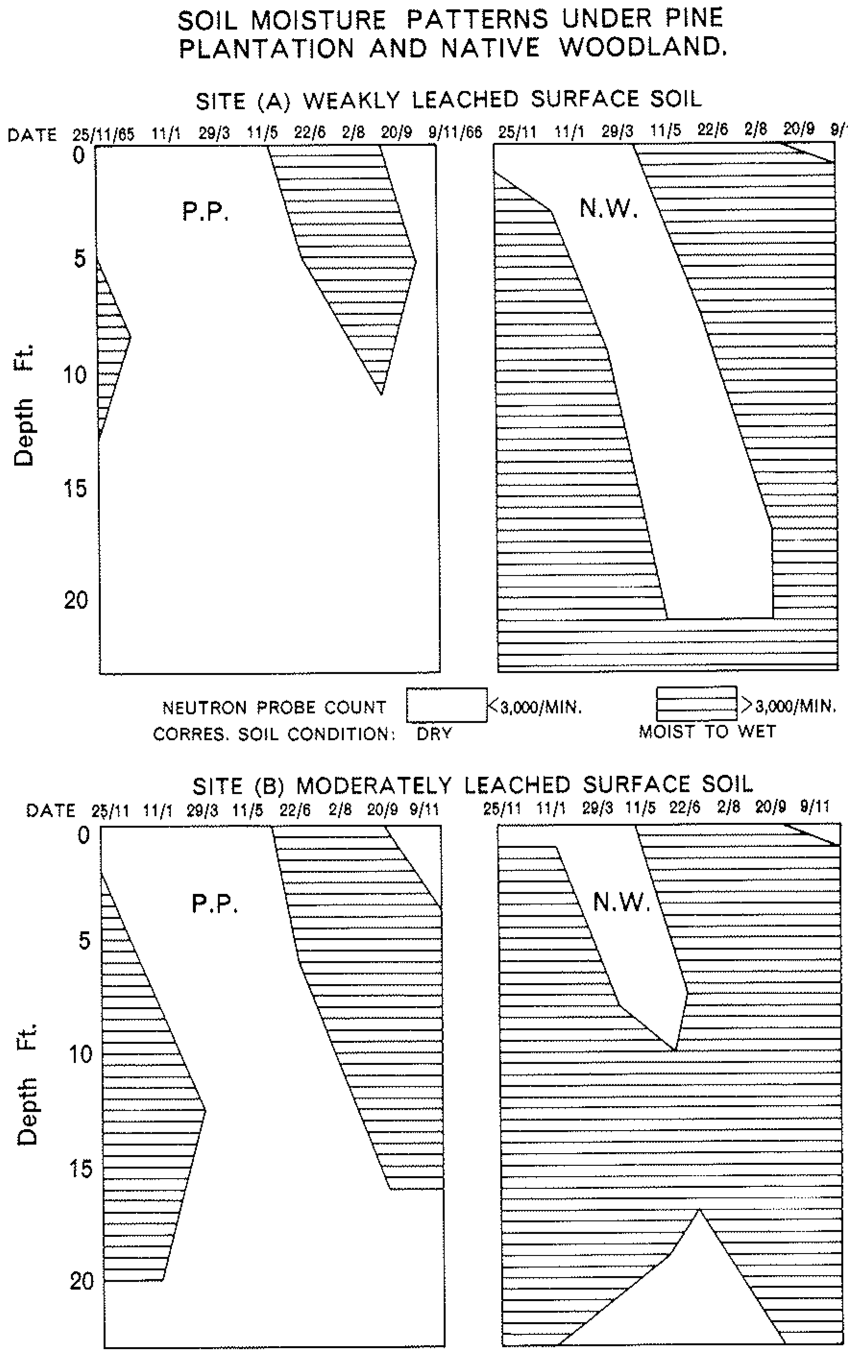


Figure 22.

Moisture patterns for the period from September 1965 to September 1966 under native woodland and pine plantation on two sites within the Spearwood Dune System.

Eremaea pauciflora. The native woodland consisted of an open stand of *Banksia attenuata* and *B. menziesii*, with a few stunted *Banksia grandis*. It was only 20 ft. high and had a basal area of 25 sq. ft. per acre. *Eremaea pauciflora, Melaleuca scabra* and *Calothamnus sanguineus* were prominent in the understorey.

The neutron probe readings were commenced in November 1965 and continued until January 1967. They began at the end of a very wet winter and spring, passed through a normal dry summer and drier-than-average winter and ended in the midst of a moderately severe summer drought. The readings were normally carried out at two-monthly intervals.

Even the first reading showed marked differences in moisture patterns between the site and vegetation types (Figure 22). Of particular interest was the presence of very wet zones resembling aquifers at the depths of 15 to 22 ft. under the native woodland and ploughed firebreak on site A. In order to ascertain whether the absence of such a zone under the pine was due to chance or to the effect of the stand, a further access tube was sunk under the pine stand. A zone of strongly leached sub-soil, with an iron content one third of the less leached zones above, was found below 20 ft. Soil brought to the surface contained a high concentration of pine feeding rootlets, but was completely dry. It seemed that the moist zone, though once present, was by now exhausted and became part of a dry sub surface zone below 15 ft. in which moisture was no longer being replenished by winter rains. The soil profile under the ploughed firebreak and native woodland was moist down to the full depth of 23 ft. on both sites.

The progress of moisture exhaustion and replenishment on the two sites, both under pine plantation and native woodland, is shown in Figure 22. In presenting the observations, the neutron probe count of 3000 per min., corresponding to approximately 3.0 per cent. of moisture by weight or 3.9 per cent by volume, was chosen as an arbitrary division between moist and dry sand. It was chosen as being particularly well suited for showing the downward movement of the wetting front through the dry soil, but has no intended physiological meaning. The differences of moisture patterns between the two sites and the two vegetation types are so striking that there can be little doubt about their significance.

It is obvious that the pine stand has far greater moisture requirements than the native woodland on both sites. Under the present conditions, the moisture is not being adequately replaced at depth, and an increasing unbalance is developing between the moisture requirements of the pine stand and the capacity of the site to supply it. On both site types the inadequate reserves for the 1966-67 summer resulted in drought deaths of some trees and heavy needle cast by the remainder. The effects were particularly severe in another portion of the Hundred Acre Block where scattered small limestone outcrops occur.

The moisture requirements of the pine stand on site A were greater, and the replenishment of moisture poorer than on site B. This would suggest that the progressive depletion of water reserves is a function of stand density and reflects not only higher transpirational loss, but also greater rainfall interception due to denser crown cover. Similar relationship existed between the native woodland on the two sites.

The postulate that the summer deaths are the result of an unbalance between the water requirement of the pine stand and the water resources of the site is supported by the above findings. On sites with weakly leached surface soils, the initial growth is more rapid and the unbalance more acute, than on sites with strongly leached surface soils.

At present it is difficult to assess at what stand density the annual moisture replenishment would take place. The figures lie somewhere between those for the pine stand and those for the native woodland. This corresponds to the range of 60-100 sq. ft. of basal area per acre on site A, and to 25-70 sq. ft. of basal area on site B.

In order to obtain a more definite indication of the carrying capacity, two experiments have already been established. One of these, consisting of the three large pilot plots, has already been referred to. It is a 3 x 3 factorial experiment in three localities, in which the treatments are three topographical positions and three grades of thinning. The three localities cover the full climatic range within State Forest No. 65. The second is a basal area thinning experiment established in the Hundred Acre Block, adjacent to the neutron probe sampling sites. It has a randomised block design with 4 treatments, in which the blocks are site types ranging from site index 13 to site index 20, and the treatments thinning to constant basal areas of 31, 47, 71 and 107 sq. ft. per acre respectively.

It is proposed to combine the experiments with a detailed hydrological study. Rain-gauges and self-recording pluviometers have already been installed in the large pilot plots. Ultimately information on water usage in pine stands up to the age of 15 years will be provided in the first experiment, and in stands 15 years and over in the second experiment. It is considered that the study will provide the key to sound management of pine plantations on the Spearwood Dune System north of Perth.

ASSESSMENT OF PINE PLANTING POTENTIAL

The exact determination of total plantable area within State Forest No. 65 would require detailed mapping, beyond the present resources of the research branch. However, an approximation utilizing the detailed site-mapping already completed, is possible at this stage. In 1966, 8169 acres were mapped as a test of the practicability of site-vegetation mapping on a large scale and were the basis for delineation and clearing of 6000 acres in that year. The approximation can be arrived at by combining the detailed mapping which covered 6.5 percent of the total unplanted area, with ground reconnaissance and photo interpretation of the remainder.

The detailed mapping was carried out on five sample areas (Figure 23) covering the full physiographic and edaphic range from the Spearwood Dune System in the west to the Bassendean Dune System in the east. By matching the sample areas with physiographically equivalent assessment areas, and by applying the proportion of the various site-types found in the former on a proportionate basis to the latter, a reasonable, though not exact assessment can be obtained.

For the purpose of this assessment the unplanted portion of the State Forest is divided into 9 assessment areas, characterized by a specific combina-

TABLE 5

OVERALL ASSESSMENT OF PINE PLANTING POTENTIAL IN STATE FOREST NO. 65

Area	Distance From Perth (miles)	Total Acreage (un-planted)	TYPE A* S.I. (not tested)	TYPE B S.I. Inadequately tested, 15–20	TYPE C S.I. 16–20	TYPE D S.I. 14–18	TYPE E S.I. 14–20	TYPE F S.I. 11–14	TYPE G S.I. 7–13	TYPE H S.I. 13–17	TYPE I S.I. 17–26	TYPE J S.I. 15–20	TYPE K S.I. Inadequately tested
1	18–20	2,960				600 Acres mainly BA, BM, some EM low drought		755 Acres mainly BA, BM, low drought	1,001 Acres mainly BA, BM, ET v. low drought	414 Acres mainly BA, BI Nil	9[illegible] Acres mainly EM Nil	93 Acres mainly MP, ER low-mod. flood	
2	18–26	20,300							14,333 Acres mainly BA, BM, ET v. low drought	2,464 Acres mainly BA, BA Nil	367 Acres mainly EM, BI Nil	2,667 Acres mainly MP, ER low-mod. flood	529 Acres treeless low BL, MP, ER extreme flood
3	26–34	13,120	1,483 Acres treeless extreme drought	708 Acres scattered EG, BA, NF v. high drought	4,815 Acres EM, BG CF, EG low-mod. drought	5,209 Acres EM, BA, BM low drought	748 Acres EM, BI Nil			65 Acres BI, BA Nil		92 Acres mainly ER, MP low-mod. flood	
4	27–37	12,670				3,801 Acres mainly BA, BM, EM low drought		4,434 Acres BA, BM low drought	3,168 Acres BA, BM, ET low drought	1,014 Acres BA, BI Nil	253 Acres EM, BI, BA Nil		
5	34–48	14,890	1,861 Acres treeless extreme drought	1,325 Acres scattered BA, NF v. high drought	10,066 Acres chiefly BG, CF, BA mod. drought	1,415 Acres chiefly BA, BM, ET low-mod.	223 Acres BA, BI some EM low drought						
6	34–48	17,470	1,974 Acres treeless extreme drought	943 Acres scattered BA, NF v. high drought	6,412 Acres chiefly BG, CF, BA mod. drought	6,936 Acres chiefly BA, BM, ET low-mod.	996 Acres BA, BI some EM low drought			87 Acres BA, BI Nil		122 Acres MP, BR, EL low-mod. flood	

7	36–43	13,500				2,741 Acres chiefly BA, BM, ET low-mod.		3,443 Acres BA, BM, ET low drought	4,563 Acres BA, BM, ET low drought	1,890 Acres BA, BI Nil	418 Acres BI, BA, EM Nil	445 Acres MP, ER low-mod. flood	
8	40–44	6,140							4,323 Acres BA, BM, ET low drought	743 Acres BA, BI Nil	110 Acres BI, EM Nil	804 Acres MP, ER, BL low-mod. flood	160 Acres low MP, BL or treeless extreme flood
9	56–71	25,700	2,914 Acres treeless extreme drought	1,305 Acres scattered BA, NF v. high drought	9,465 Acres BA, BM, ET high	10,238 Acres BA, BM, ET moderate	1,470 Acres BI, BA low-mod.			120 Acres BI, BA Nil		181 Acres MP, ER mod. flood	
Total Acreage ...		120,000	8,232	4,350	30,758	30,940	3,437	8,632	27,388	6,806	1,240	4,409	[illegible]
Of this, within 26 Miles of Perth 50 miles of Perth 75 miles of Perth		 6,702 56,107 75,500			 0 21,293 30,758	 600 20,702 30,940	 0 1,967 3,437			 2,878 6,677 6,806	 459 1,240 1,240	 2,765 4,228 4,409	

* For definition of Types A to K inclusive see Appendix II.
S.I.=Site Index.

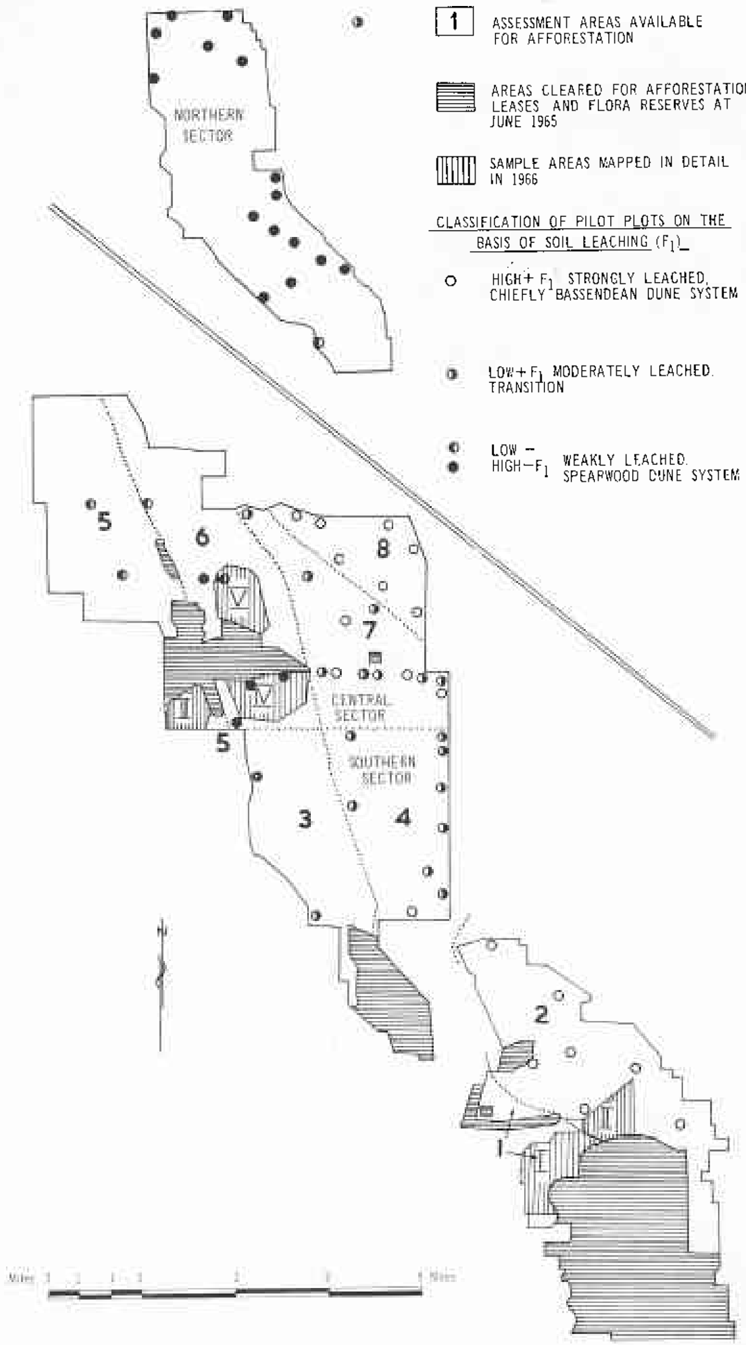


Figure 23.
Location of pilot plots, sample and assessment areas used in the evaluation of pine planting potential of State Forest No. 65.

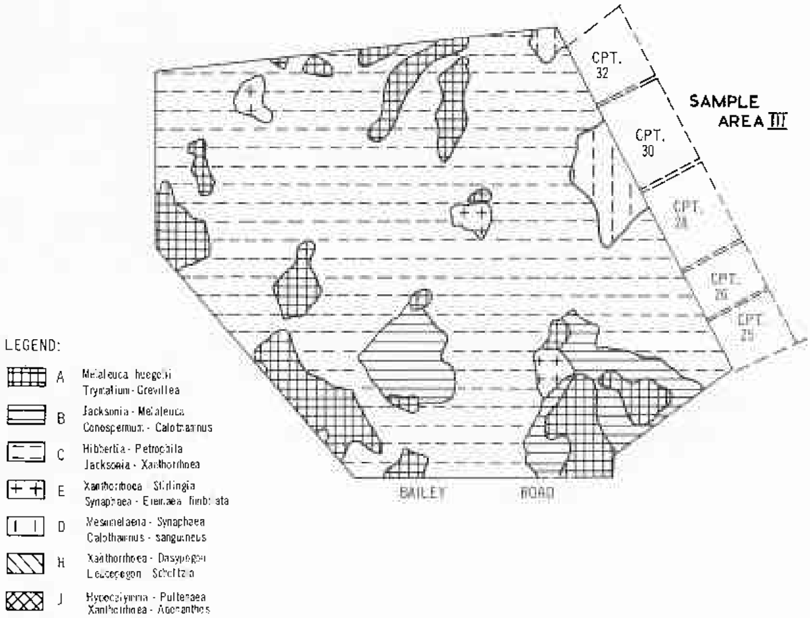
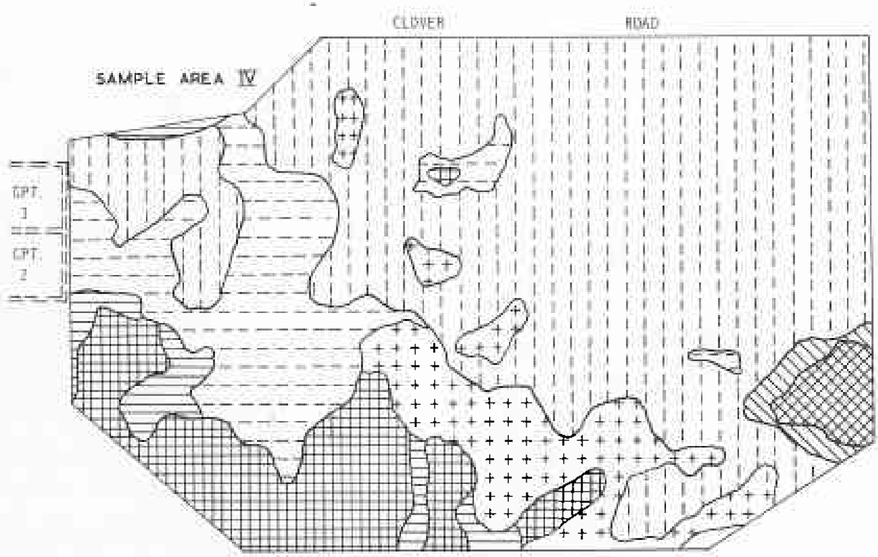


Figure 24.
Pattern of distribution of ground vegetation types within sample areas III and IV (Spearwood Dune System).



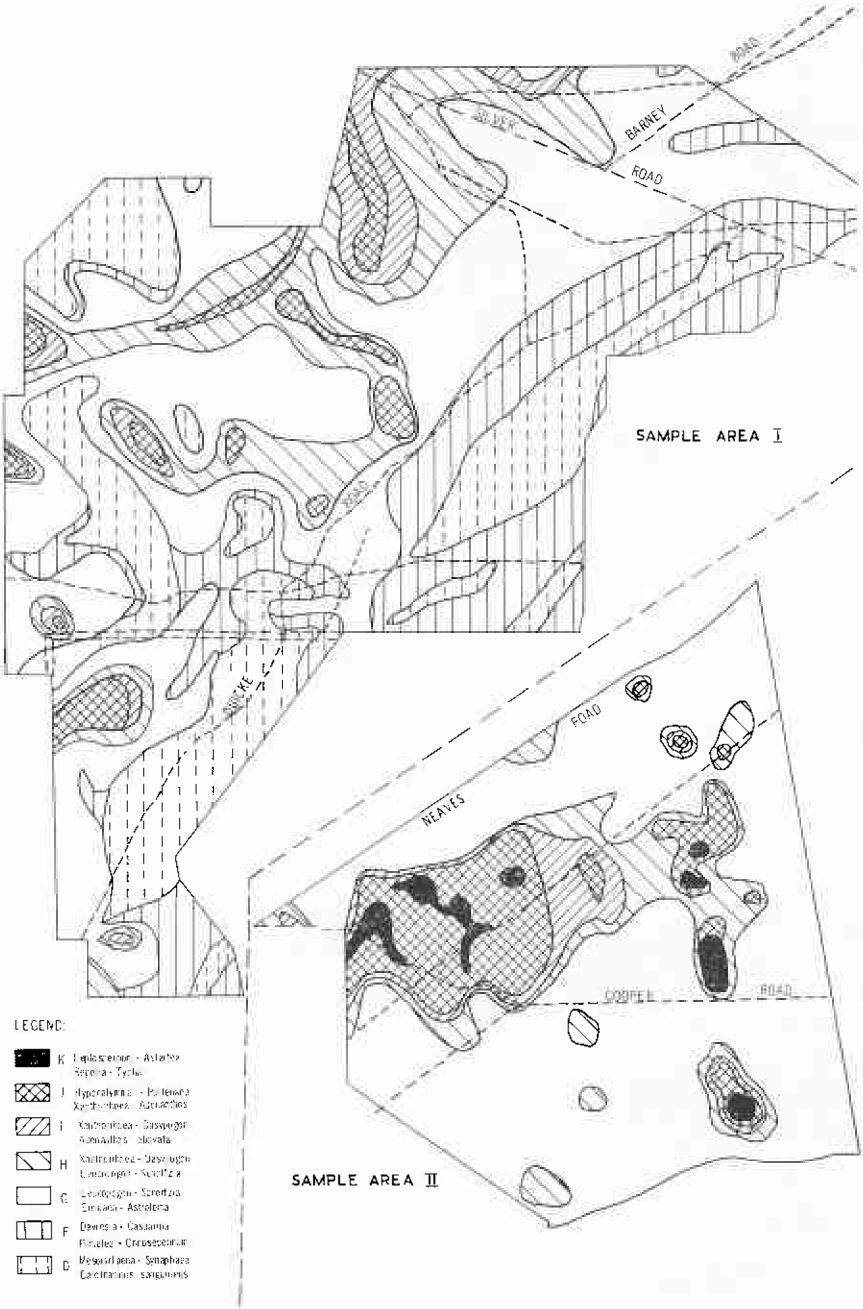


Figure 25.
Pattern of distribution of ground vegetation types within sample areas I and II (Bassendean Dune System and Transition).

tion of physiography and distance from market. Though the climatic factor cannot be assessed directly, it can be inferred from the nature of the tree stratum in the native woodland, which has been shown to have a strong climatically induced north-south variation.

A brief description of the five sample areas is as follows:

Sample area I—2214 acres in the transition zone between the Spearwood and Bassendean Dune System.

Sample area II—1174 acres in the Bassendean Dune System.

Sample area III—877 acres in the Cottesloe Soil Association of the Bassendean Dune System.

Sample area IV and V—1749 and 2157 acres respectively, in both the Cottesloe and Karrakatta Soil Association of the Spearwood Dune System.

In Figure 23 the location of sample and assessment areas is shown. Details of the assessment are contained in Appendix II and a general summary of the data extracted is contained in Table 5. These provide a basis for the planning of plantation establishment in the region.

Overall results (Table 5) form a basis for discussion of the economic factors involved. From this point of view it is important to note that the bulk of the area which can be expected to give satisfactory initial growth rates falls within the Spearwood Dune System, which is orientated from south to north. Within this system, the increase in drought susceptibility in northern areas, demonstrated earlier, is aggravated by an increase in the haulage distance to Perth. Since the drought susceptibility can, on present indications, be only avoided by early non-commercial thinnings and overall lower stockings, a drop in intermediate, (and probably also final) yields is inevitable. This, in combination with increased haulage costs, will have an adverse effect on plantation profitability, which will be only partially offset by lower clearing costs. The seriousness of this effect will depend on the profitability of thinning operations and the internal demand for timber.

CONCLUSIONS

It is considered that the theoretical soundness and practicability of the ecological approach to site classification has been demonstrated for areas lacking information on environmental factors but carrying relatively undisturbed native vegetation. In respect to the application of the findings, there are two possibilities:—

(a) The direct elimination of unsuitable sites in the field.

(b) Overall site mapping, followed by elimination of unsuitable sites in the office.

The direct approach is less costly, but cannot be used as a basis for subsequent management of cleared and planted areas.

The sample areas which have been mapped in detail will serve as a future check on the accuracy of the predictions.

RECOMMENDATIONS

The work so far completed has opened up many new avenues for research on various aspects of plantation establishment on the coastal plain north of Perth. The most important of these is the study of the limitations imposed by drought susceptibility within the Spearwood Dune System, and involves the determination of the stand density at which there is adequate replenishment of moisture reserves. It is likewise important to investigate if the drought resistance of *Pinus pinaster* can be improved genetically. Consideration also needs to be given to the economic implication of the drought problem.

Within the Bassendean Dune System it is desirable to investigate the methods for amelioration of the excessively wet sites, and the fertilization of the *Xanthorrhoea preissii-Leucopogon conostephioides* type, in which the lack of nutrient holding capacity prevents the full utilization of the relatively favourable moisture conditions.

Finally, the methods developed should be applied to site quality assessment on the remainder of the coastal plain, and in the jarrah forest on the lateric soils of the plateau.

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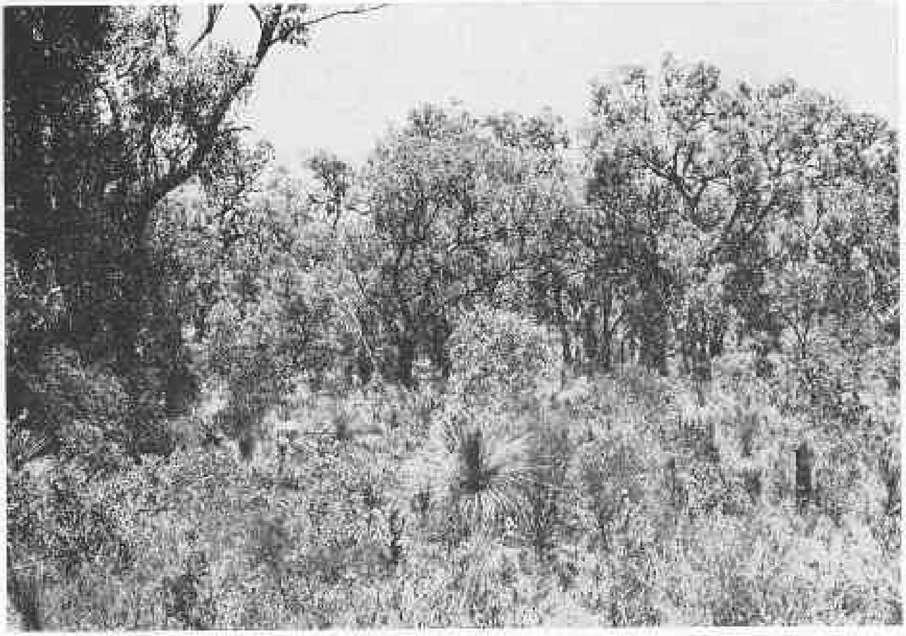

Figure 26.
(a) Relatively dense stand of *Eucalyptus marginata* — *E. calophylla* on deep, moderately leached sands in a depression, indicative of very low drought death probability. (b) Very open stand of *Eucalyptus gomphocephala* on shallow, weakly leached sand over limestone on a slope, indicative of high drought death probability.

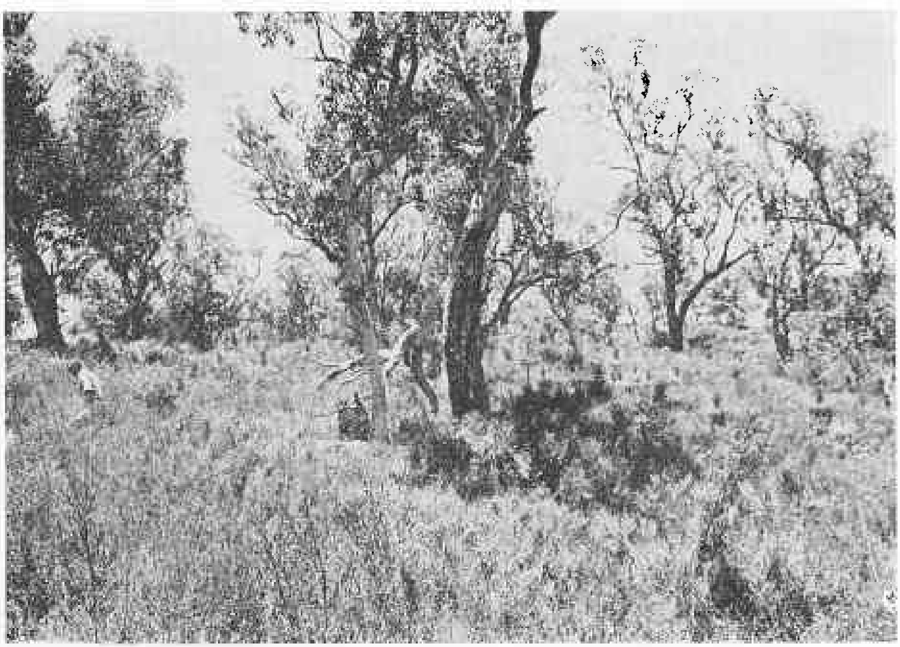

Figure 27.
(a) Scattered trees of *Melaleuca preissiana* on strongly leached sand with excessively high ground water table, indicative of unsuitability for plantation establishment. (b) Moderately dense stand of *Eucalyptus marginata* — *E. calophylla* on moist humusoid sand over organic deposition horizon, indicative of optimum condition for plantation establishment.

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APPENDIX I

Factor Analysis of Large Pilot Plots

Site types and corresponding species groups separated on the basis of scores on the first three factors may be summarized as follows:—

F.1	F.2	F.3	
mod. to high	low ±	mod. ±	Mid and upper slope in southern, upper slope in central sector, shallow weakly leached soils with overstorey of *Casuarina fraseriana, Banksia grandis, B. attenuata* and *B. menziesii, Eucalyptus todtiana* and understorey of *Mesomelaena stygia, Stirlingia latifolia, Hibbertia racemosa, Xanthorrhoea preissii* and *Gompholobium tomentosum.* In addition *Conospermum triplinervium var linearis* was common in the central sector, though absent in the south.
Low —	low +	low to high +	Depression in southern sector, deep weakly leached soils with overstorey of *Eucalyptus marginata* and understorey of *Bossiaea eriocarpa, Xanthorrhoea preissii* and *Mesomelaena stygia,* with some *Stirlingia latifolia* and *Gompholobium tomentosum.*
low to mod.	mod. to high —	low to high +	Depression in central sector; moderately leached deep soils with overstorey of *Banksia attenuata* and *B. ilicifolia* and understorey of *Calythrix flavescens, Conostephium pendulum, Patersonia occidentalis, Scholtzia involucrata, Xanthorrhoea preissii and Dryandra nivea.*
low to mod.	low to high —	low to mod. —	Transition between deep moderately leached and shallow weakly leached soils; mid slope of central sector; overstorey of *Banksia attenuata* with admixture of *Banksia grandis* and *B. menziesii* and *Casuarina fraseriana,* and understorey of *Acacia stenoptera, Hibbertia huegelii* and *H. hypericoides, Mesomelaena stygia, Patersonia occidentalis, Petrophila linearis, Scholtzia involucrata, Xanthorrhoea preissii* and *Dryandra nivea.*
low to mod. +	high +	low to mod. —	Mid and upper slope in northern sector; very weakly leached sands with overstorey of *Banksia attenuata* and understorey of *Bossiaea eriocarpa, Hakea costata, Hibbertia huegelii, H. hypericoides* and *H. racemosa, Jacksonia stenbergiana, Mesomelaena stygia, Synaphaea polymorpha* and *Xanthorrhoea preissii and some Conospermum triplinervium var linearis.*
low to mod. +	low to mod. +	low + to low —	Depression and lower slope in northern sector; deep weakly leached soils with overstorey of *Banksia attenuata* and some *Banksia ilicifolia* and understorey of *Bossiaea eriocarpa, Hakea costata, Conospermum stoechadis, Daviesia nudiflora, Mesomelaena stygia, Synaphaea polymorpha, Dryandra nivea* and *Xanthorrhoea preissii.*

APPENDIX II

The continuous nature of variation in both soil and vegetation posed problems in mapping, in that the continuum had to be arbitrarily divided into segments. The following types or noda were recognised:—

Type A.—indicated by presence of *Melaleuca huegelii* and *M. cardiophylla*, *Acacia heteroclita*, *Trymalium ledifolium*, *Grevillea thelemanniana* and *G. vestita*, *Dryandra sessilis*, characteristic of bare limestone (travertine) outcrops with pockets of reddish-brown sand.

Type B.—indicated by presence of *Jacksonia hakeoides*, *Conospermum triplinervium var. linearis*, *Calothamnus quadrifidus*, *Melaleuca acerosa, and Leschenaultia linearioides* characteristic of shallow yellowish-brown sand with scattered limestone pinnacles, occurring on slopes below limestone outcrops.

Type C.—indicated by presence of *Hibbertia hypericoides* and *H. racemosa*, *Hakea costata*, *Petrophila serruriae* and *P. brevifolia*, *Jacksonia hakeoides* and *J. sternbergiana*, *Mesomelaena stygia*, *Xanthorrhoea preissii* and *Stirlingia latifolia*, characteristic of moderately deep yellow sands with weakly leached surface, occurring mainly on lower slopes below limestone outcrops.

Type D.—indicated by presence of *Mesomelaena stygia*, *Synaphaea polymorpha*, *Calothamnus sanguineus*, *Eremaea pauciflora*, *Melaleuca scabra*, characteristic of deep yellow sands with moderately leached surface, occurring on broad plains within the Spearwood Dune System.

Type E.—indicated by presence of *Eremaea fimbriata*, *Xanthorrhoea preissii*, *Synaphaea polymorpha*, *Stirlingia latifolia* and *Melaleuca scabra*, characteristic of deep, moist pale yellow to yellow sands in depressions within the Spearwood Dune System.

Type F.—indicated by presence of *Daviesia quadrilatera* and *D. juncea*, *Casuarina humilis*, *Pimelea sulphurea*, *Calectasia cyanea*, *Conospermum stoechadis*, *Acacia sphacelata*, *Eremaea pauciflora* and *Jacksonia floribunda*, characteristic of deep pale yellow sands with strongly leached surface, occurring on slopes and dune crests within the transition zone.

Type G.—indicated by the presence of *Leucopogon conostephioides*, *Scholtzia involucrata*, *Eremaea pauciflora*, *Melaleuca scabra*, *Boronia purdieana*, *Astroloma xerophyllum*, characteristic of deep, dry pale grey sands which are strongly leached throughout, and occur on lower slopes in the transition zone, and slopes and dune crests within the Bassendean Dune System.

Type H.—indicated by presence of *Leucopogon conostephioides*, *Scholtzia involucrata*, *Xanthorrhoea preissii* and *Dasypogon bromeliaefolius*, characteristic of deep pale grey sands, dry at the surface, moist at depth, strongly leached throughout; occurring on sub-flats and around swamps in transition zone and within the Bassendean Dune System.

Type I.—indicated by presence of *Xanthorrhea preissii*, *Dasypogon bromeliaefolius*, *Melaleuca seriata and Adenanthos obovata*, characteristic of moist soils with dark grey humusoid surface and organic deposition horizon at depth, occurring within the transition zone and the Bassendean Dune System.

Type J.—indicated by presence of *Hypocalymma angustifolium*, *Pultenaea reticulata*, *Xanthorrhoea preissii* and *Adenanthos obovata*, characteristic of wet dark grey humusoid sands, usually over a deposition horizon, occurring throughout the region in flat-swamp transition and in seasonal swamps.

Type K.—indicated by *Leptospermum ellipticum*, *Astartea fascicularis*, *Calothamnus lateralis*, *Regelia ciliata* and *Typha spp.* characteristic of water saturated sands and peats, occurring in permanent swamps throughout the region.

ALEX. B. DAVIES, Government Printer