FORESTS DEPARTMENT

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MAY 80

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WESTERN AUSTRALIA

Preface

A study at the Agricultural University of Wageningen, combines $4\frac{1}{2}$ years theory with a 6 months period of more practical or fieldwork. Forestry is one of the studies to choose from and it can be divided in three sections:

- silviculture
- forest technics and forest products
- forest management

As a student of the silvicultural section, I worked 6 months with the Forests Department of Western Australia.
In this report, I try to show the things I have seen, learnt and experienced in the time I worked for the research branches of the department in Wanneroo, Manjimup and Dwellingup. For this reason it is not a complete description of the forestry activities in Western Australia. It is rather a selection of subjects, the research branches are working on. These subjects are discussed in the second part of this report. In the first part, a general description of the south-west region and the Forests Department will be given.

I am most grateful to mr. Beggs, conservator of forests, who made the necessary arrangements and to whom I was introduced by prof. Oldeman (silvicultural section). Furthermore, I want to thank the officers in command of the research branches in Wanneroo, T. Butcher, in Manjimup, P. Christensen and in Dwellingup, S.R. Shea and all the others who helped me to get along in my work as well as in daily life during my stay in Western Australia.

Piet Kamminga
Wageningen october 1982

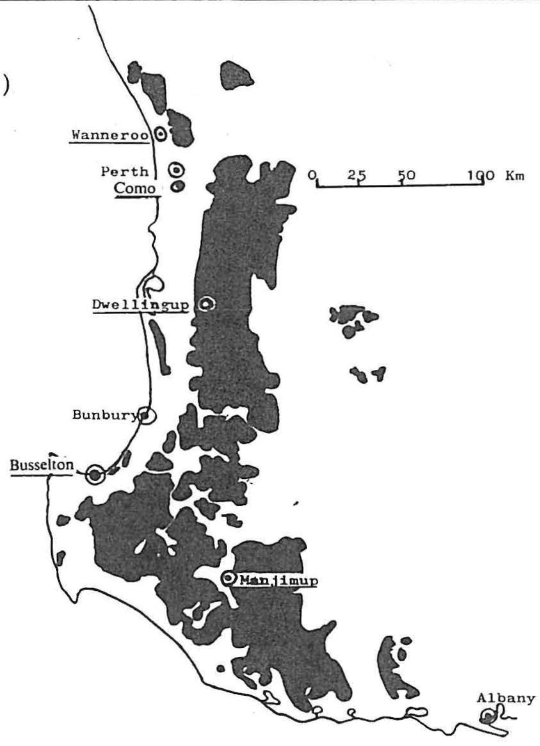
Contents

I GENERAL DESCRIPTION OF THE SOUTH-WEST

1,1 Introduction

Australia is a country with a relative small population, a little over 14 million inhabitants on an area of 7,7 million km^2, which is 213 X the area of the Netherlands. It consists of 8 states of which Western Australia is the largest with an area of 2,5 million km^2 and a population of only 1,2 million persons.
The capital city, Perth is situated in the south-western part of the state. This is the region where all major forestry activities take place and where 75% of the West-Australian population lives and works. (figure 1).
Nearly all the forests of the south-west belong to the Forests Department of Western Australia (figure 2). The total forest area is divided in several regions, each consisting of a few ($\pm$3) divisions. The projects of the research branch are carried out by 5 research centres, each covering projects relevant to their location. (These are : Wanneroo, Como, Dwellingup, Busselton and Manjimup)

Figure 2 : The state forests of Western Australia
(after western australian yearbook 1979)



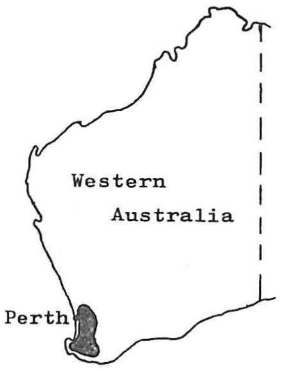


Figure 1 : The major forest area is situated in the south-western part of the state

Table 1 : Some statistics from the annual report 1979, of the Forests Department of Western Australia.

Forest area

total area of state forests	1 854 173 ha	
timber reserves	118 401 ha	
freehold land in the name of the conservator of forests	26 118 ha	
	1 998 692 ha	
of which:		
Jarrah	1 449 000 ha	
Karri	140 000 ha	
Wandoo	106 000 ha	
Pinus radiata	22 000 ha	
Pinus pinaster	24 000 ha	and others.

Fire protection

prescribed burning	: area in the 78/79 fire season	377 000 ha
	of which: aircraft burning	312 000 ha
wildfires	: total area burnt	3 000 ha

Table 1 continued

Log production (incl. sawlogs and logs for plywood, veneer and reconstituted wood and chipwood. excl. mining timber, firewood poles and piles.)

saw logs	: hardwood	858 474 m^3	other logs	: hardwood	454 096 m^3
	softwood	51 261 m^3		softwood	125 683 m^3

Employment		
forestry		
	professional officers	79
	general field staff	284
	clerical and drafting	92
cadets		
	professional	7
	field	27
full time wages employees		540
contractors and employees		20
		1049

1.2 Topography, Geology and Soils

Apart from an inconstant belt of coastal lowlands, the continent is broadly speaking divisible into three main topographic regions, of which the Great Western Plateau is one (figure 3). This plateau covers nearly the whole of Western Australia and the most part of the surface stands at less than 700m (2000 ft.). In the south western part of the state, the miocene surface, here forming what is known as the Darling plateau, is cut out of pre-cambrian granite and metamorphic rocks and is well dissected by rivers. On the west it is seperated from the Swan lowlands by the Darling scarp, which is thought to mark a fault or eroded warp (figure 4). Faulting can be traced for at least 550 km (350 miles) in a direction subparallel to the coastline.

In the south and south-east (of the south-west), where the elevation of the plateau is between 215 m (700 ft) and 275 m (900 ft), a number of conspicuous masses rise considerably above the general level, notably the Stirling, Porongorup and Mt.Barren Ranges. The miocene surface is intersected by the wide and very mature pliocene valleys of the Moore, Swan, Avon, Hotham, Murray, Williams and other rivers.

Near the coast the lowlands, which are some 25 km (15 miles) wide at Perth and nowhere rise above 60 m (200 ft), are covered with pleistocene and recent sanddunes, the former cemented by lime carbonate. Among the dunes are swampy areas and a series of lakes stretching along a meridional zone. Further inland the rivers emerging from the plateau have built up a gently sloping- and undulating piedmont plain of clay and sands. The lowlands extend for about 160 km (100 miles) south of Perth.

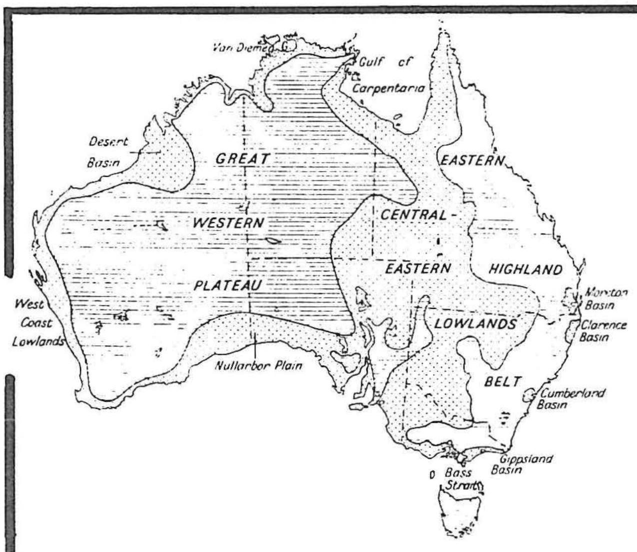
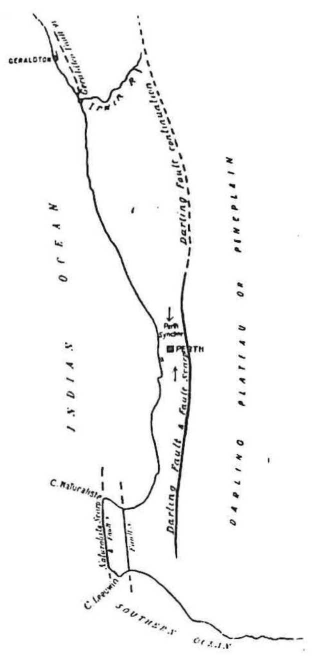


Figure 3 : The major topographic regions of Australia. (after David, 1950)

Figure 4 : The Darling Range 'fault' scarp. (after Maitland, 1919)



The relative high rainfall of the south-west is reflected in the characters of the rivers, which maintain a fairly constant flow to the ocean in valleys which are essentially water-worn. The upper courses are in very wide, highly mature valleys with a north-north- west south-south-east trend, parallel to the geological grain of the country, and carved in the old plateau to depths of 60 m (200 ft) and more. Downstream the rivers make right angled bends and flow west, occupying young to early mature valleys incised in the older valley-floors. (David,1950)

For the description of the soils, two classifications are used, the first is : the soil groups set out in the handbook of Australian soils, a classification in which the soil types are given in such an order, that with increasing numbers, they represent overall a progressive increase in degree of profile development and degree of leaching. (used in figure 5, Stace et al. 1968) The second one is the factual key notation (Northcote et al. 1975) where the soils are classified according to the uniformity of the texture profiles, (U=Uniform texture profile ; D=Duplex,with texture contrast profile) particle size (c=coarse) or colour (y=yellow; r=red).

Along the coast we find sandy soils: lithosols (3), calcareous- (4) and siliceous sands (5) with hardly any profile development (Uc 1 and Uc 2).
Soil type 17 represents the solodized solonetz and solodic soils in the group of the mildly leached brown soils (Dy, Dr and Db). They are rather infertile owing to severe deficiencies of nitrogen, phosphorus, calcium and a range of trace elements, poor physical conditions and difficult moisture relations. To the same group belong the soloths (18) and the non-calcic brown soils (21).
A very important soil-type is the lateritic podzol (35). The essential features of these soils are strong texture contrast with thick sandy A horizons (0,3 - 1,5 m) overlying mottled yellow-brown and red clay B horizons , an horizon of nodular pisolitic, or massive ironstone in the base of the A_2 and in the upper part of the B horizon, a thick zone of coarsely mottled white, red and yellow clay below the B horizon grading into dominantly white clay above the kaolinized parent rock, and acid throughout the profile. Soil type 46 does not belong to a real group but is related to the lateritic podzols. In the factual key notation it is KSUc 4.21 which is an ironstone gravelly variant of Uc 4.21 with soils of >60% by volume of ironstone gravel. Such soils usually overlie indurated lateritic materials and have a low available water capacity and low inherent fertility.

Figure 5 : The major soil types of the south-west, classification after Stace et al 1968, handbook of Australian soils.

1 Soils showing no profile development
- 3 Lithosols
- 4 Calcareous sands
- 5 Siliceous sands

2 Soils showing minimal profile development

3 The mildly leached dark soils

4 The mildly leached brown soils
- 17 Solodized solonetz and solodic soils
- 18 Soloths
- 20 red brown earths
- 21 non-calcic brown soils

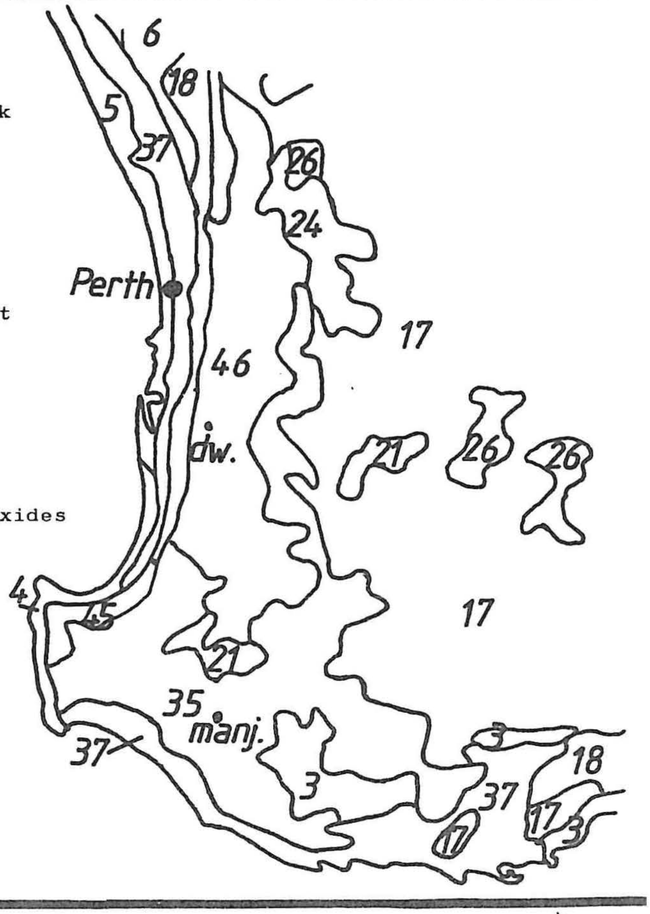
5 Soils with profiles dominated by sesquioxides
- 24 calcareous red earths
- 26 yellow earths

6 The mildly to strongly leached highly differentiated soils
- 35 lateritic podzolic soils
- 37 podzols

7 The organic soils

Scale

0 50 100 Km



1,3 Climate

The climate is determined by its proximity to the Indian ocean, by its latitude and by local topographical configuration. It is a typical Mediterranean climate, oceanic with winter rain (Köppen classification Csa in the northern part of the region and Csb in the south; a : warmest month $>22^{o}C$, b : $<22^{o}C$) .
The highest rainfall is recorded along the Darling scarp, between Mundaring and Collie, inthe southwest near Margaret-river and along the south coast up to Denmark. The strongly seasonal rainfall is reflected in the ratio of winter (april to october) to summer (october to april) rainfall, which is 3,7 : 1 in Manjimup, 5,3 : 1 in Dwellingup and 5,8 : 1 at Perth regional office. The summer drought is the chief limitation to plant growth. (table 2 and figure 7)

Station	Length of dry spell in months									Break of season	Length in
	1	2	3	4	5	6	7	8	9		months
Perth	100	100	100	99	90	65	16	1	0	mid april	6,3
Dwellingup	100	96	92	85	35	12	0	0	0	early april	7,6
Manjimup	100	96	81	65	28	7	0	0	0	late march	8,0

Table 2 : Percentage of years in which dry spells equal to or greater than various lengths occur and the average date of break and length of growing season (Bureau of meteorology, region 16, south-west, 1965)

In the south-west the air-temperature has less influence on plant growth than rainfall and though in winter growth slows down, it doesn't actually cease.(figure 6) Frosts range from less than 10 along the west-coast to over 50 per annum further inland. The frequency of occurence of frosts is locally accentuated by topography, being highest in the upland depressions.
Cyclones are most common in the tropical parts of Australia and not so much in the south-west, but they do occur. The last one, Cyclone Alby on 4 april 1978, caused considerable damage, resulted from wind and from fires which escaped,mainly from incomplete burning-off on private property.

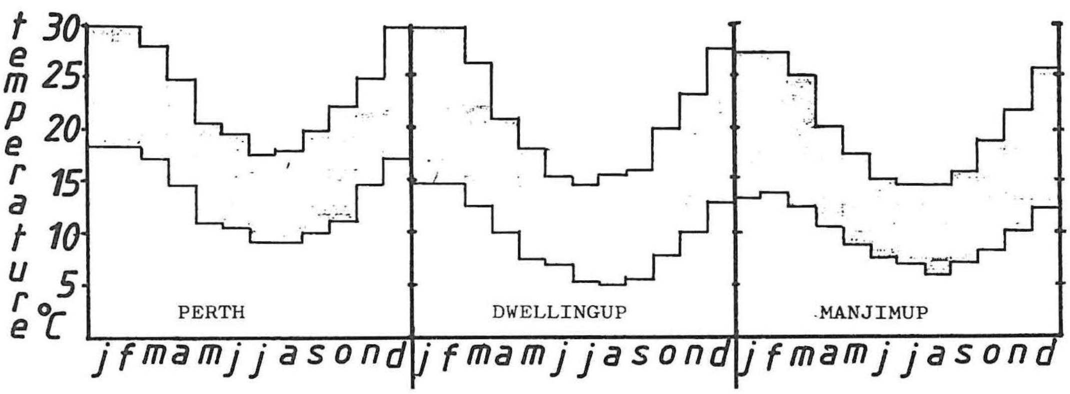


Figure 6 : The mean daily maximum and minimum air-temperatures of three places in Western Australia. (bureau of meteorology, region 16, south-west, 1965)

1,4 Vegetation

The distribution of vegetation-types in Western Australia is determined mainly by climate and to a lesser extent by soil-type. In the south-west too, the occurence of forest types is mainly determined by the annual amount of rain. (figure 7).
The structure and species composition of the south-western natural forests and woodlands are much more complicated than figure7may do believe. The structure and species composition of the Jarrah forest near Perth is very different from the identically named forest type around Manjimup.
The majority of tree-species of the south-west -and the rest of Australia as well- belong to the Proteaceae and Myrtaceae, with Eucalyptus (Myrtaceae) as the genus with most of the tree-species of commercial importance.

Jarrah zone

Karri zone

Wandoo zone

Tuart zone

635

Isohyets

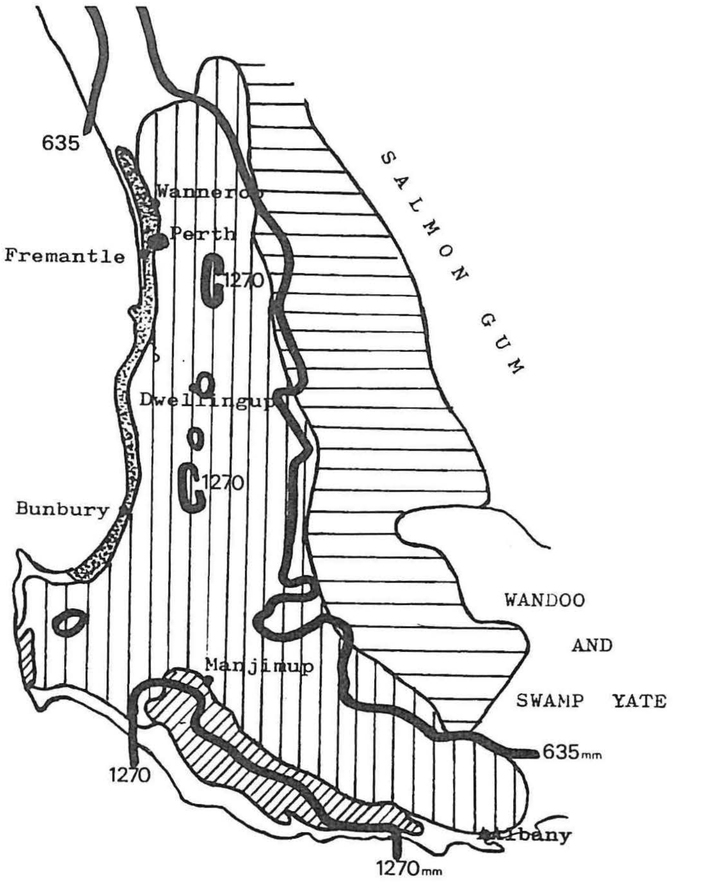


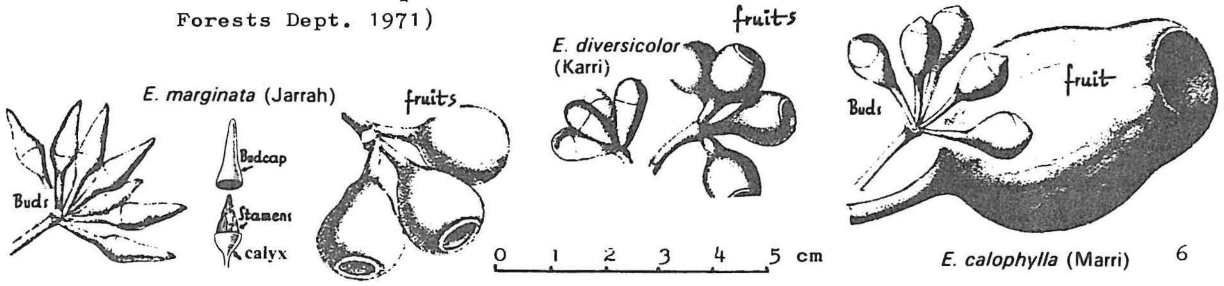
Figure 7 : The major forest types of the south-west of Western Australia (after Forestry in Western Australia, Forests Dept. 1971)

Natural softwoods are rare and confined almost exclusively to the genus Callitris.

The Eucalypts

The eucalypts are all -except one- evergreen trees or shrubs. The name of the genus is derived from two greek words : eu (well) kaluptos (covered) and applies to the bud-cap or operculum, that protects the stamens of the unopened flower. Other characteristics of the eucalypt flowers are the absence of both sepals and petals and the presence of an inferior ovary and the stamens of indefenite number.
The fruit developes out of the calyx (fig 8).
The eucalypt trees are light demanding and they reach maximum development only then, when there is adequate crown-space. The crowns do not intermingle, not only because of light requirements, but also because of 'pruning' : abrasion of tips caused by the swaying of the trees. This pruning is very marked in eucalypts because their growing tips consists of naked buds, unprotected by scaly bracts.
The growth habit connected with it, is called crown shyness.
Another feature of the eucalypt crowns is the arrangement of the leaves. They are situated towards the extremeties of the branchlets, because normally leaves are only formed on the growing tips and are shed after a certain length of time. The leaves are retained on the crowns for ½ - 2½ years, depending on species and vigour.
Fast growing, vigorous trees shed their leaves much faster than slower growing-ones.
Another factor in this is the seed production which differs greatly from year to year.
When the crown of a tree is partly or fully destroyed by fire or wind, the eucalypts have another way of forming leaves. Leafy shoots known as epicormics or epicormic shoots develop from dormant buds, which are present in the cambium layers of the woody stems throughout the crown and trunk of the tree.

Figure 8 : the buds and fruits of three W.A. eucalypt trees (from Forestry in Western Australia, Forests Dept. 1971)



the forest types (Fig 7)

- the jarrah forest

The jarrah forest is a sclerophyllous forest-type with eucalypts such as jarrah (E. marginata), marri (E. calophylla) and blackbutt (E. patens) as dominant species. Some understorey species are: sheoak (Casuarina fraseriana) and bull banksia (Banksia Grandis), below this : blackboy (Xanthorrhoea preissii) and zamia palm (Macrozamia reidlei). The distribution of jarrah is limited to the east an north by low rainfall and the species becomes progressively smaller as the rainfall decreases. Eastwards it gives way to wandoo (E. wandoo). On the coastal strip, west of the Darling Range, it occurs in open formation as a tree of low height and poor form. In the extreme south it is replaced by karri (E. diversicolor) and marri on the better soils.
The jarrah forest was originally found scattered throughout the south-west of the state over 5,3 million ha. with some 1,6 million ha, of prime forests.
Jarrah is closely associated with soils of lateritic origin, but reaches its greatest size in the red loam soils of the deeply dissected river valleys, but most of these areas have been cleared for other uses.
The virgin jarrah forest is a fire climax vegetation. The majority of plants and trees have adaptive traits to protect them from fire (thick bark) or enables them to recover after fire (lignotubers,epicormics). Another type is the species adaptation, where the individual might be killed, but the species will continue to exist (seeds) (Gill, 1975)
The virgin forest was not just fire-adapted but was adapted to a certain fire-regime, which consists of the components fire intensity, fire frequency and season of burn. There is no virgin jarrah forest left, most areas have been logged once, twice or even more often in the last 100 years. By cutting trees and changing the fire regime changes in the understorey took place. The relation with the spread of Phytophthora cinnamomi, an important threat to the jarrah forest community, will be discussed in the second part .

- the karri forest

The karri forest is a temperate eucalypt rain forest with karri (E. diversicolor) as main tree species. Other important tree species which occur in mixture with karri are : jarrah, marri and the red and yellow tingle (E. jacksonii ; E. guilfoylei). Karri is one of the tallest hardwood species of the world with a total height of 60 - 80 meters.
The karri forest occurs in the extreme south-west of the state in areas receiving an annual rainfall in excess of 1000 mm. Within the distribution limits of 400 000 hectares, the pure karri, the karri/marri and the karri/jarrah,tingles stands occupy some 120000ha. The actual distribution of karri is determined mainly by soil type. Karri soils have textures varying from fine sands to sandy loams, are of low nutritive value and have been proved deficient in trace elements such as zinc,ccopper and cobalt.
In the virgin forest, karri tends to occur in even-aged patches which vary in size from several to many hectares in extent. There is some evidence that this is the result of both rare catastrophic fires and irregular milder fires caused by lightning strikes or resulting from peripheral burning carried out by the Aborigines. (Underwood 1978).
Unlike jarrah and marri, karri regenerates from seeds only and does not form lignotubers. Nowadays, fire is still an important tool, and is used for the regeneration after logging. These regeneration burns will be discussed in the 2nd part.

- the tuart forest

In the tuart zone along the west coast, the forests are of the savannah type, open forests with a scanty undergrowth of some legumes and a well developed understorey of small trees such as Banksias, the ground covering consists of grasses and herbs. Tuart (E. gomphocephala), the principal species of the zone, attains heights of up to 35 m. and is confined to limestone formations. Tuart normally grows in pure stand but can be found associating with other eucalypts, such as jarrah and marri. Because of its rigid site limitations, and the past use of its natural grass understorey for grazing, there is very little tuart forest remaining.

- the wandoo woodland

Wandoo (E. wandoo) occasionally grows in forest formation but more commonly is a true savannah woodland species with an understorey predominantly of native grasses. It is generally found between the 300 - 600 mm. rainfall limits on dark brown loamy sand or sandy loams containing some gravel. Wandoo may occur as a pure woodland or in mixture with jarrah, marri or powderbark wandoo (E. accedens).

II THREE RESEARCH STATIONS: WANNEROO DWELLINGUP MANJIMUP

In this part I will try to explain a few of the problems where the three research stations are working on, or have been working on in the past.
Wanneroo research station concentrates on pine silviculture, with all its different aspects. The research stations of Dwellingup and Manjimup were established to investigate silviculture and protection of the jarrah and karri forest respectively.

2,1 Wanneroo pine-plantations

By the end of the 19^{th} century, it was realised that the timber production of the indigenous forests alone would not meet the demands of the future population. Softwood species, imported from all over the world were tried and two proved suitable to Western Australian conditions : Pinus pinaster from the coasts of France and Portugal and Pinus radiata from California.

Pinus pinaster

Pinus pinaster proved especially suitable for planting on the infertile sands of the Swan coastal plain. Provenance trials showed that a Portugese race, from the forests of Leiria was the most suitable and was markedly superior to provenances from France from the vieuwpoint of total height, merchantable volume and volume of the pruned section (Hopkins, 1960). From 1960 on, it was decided to select plus - material within the forests of Leiria and to forward vegetative material to Australia for propagation, because the phenotypic selection within the Australian plantations did not produce enough plus material to commence an orchard programme. (Perry and Hopkins, 1967).
In the Mullaloo seed orchard near Wanneroo which was established between 1970-1972 a cross breeding program was carried out, and was nearly finished in 1979, when I worked in Wanneroo for two months. This cross breeding was carried out by means of controlled pollination, which means that certain receptive female cones were pollinated with certain known pollen. To be sure of that, the female cones were well covered with cellulose bags and the pollen were injected into the bag by a hypodermic syringe. The plants raised from these seeds were planted in the pine plantations and are monitored for as long as necessary. The normal routine measurements include diameter, height and a form assesment. The spacing used in these progeny trials is 3,0 X 3,0 m. (1100 per ha.). After 10 years the plots are heavily thinned, 60 % is cut. The reason for this is the low availability of water and the result is an open forest where thick branches develop if the remaining trees would not be high pruned up to 7m. Some other measurements in the pine plots, related to this water availability are: soil moisture down to a depth of 8,5m. with a neutron probe and stress measurements during the hot and dry summer months.

Pinus radiata

Pinus radiata, which has been succesfully planted in the eastern states and other parts of the world, requires the more fertile river valley sites. For maximum growth it requires deep fertile loams but with liberal dressings of superphosphate and some

zinc and manganese, this species can also be grown on some less fertile sandy soils of good depth.
The breeding of Pinus radiata in Western Australia is less advanced than that of Pinus pinaster, due to a later start. Superior trees from New Zealand, the eastern states as well as from local plantations were used to establish seed orchards. Progeny trials are carried out, measuring height and diameter and assesing the form. In such a form assesment numerical expressions for buttsweep, straightness, thickness and angle of branches and the form of the tree are given to each individual and therefore allow easy computer processing.
In 1979 and 1980, the resistance of several progenies of radiata pine to Phytophthora cinnamomi was tested in the glasshouse of Wanneroo.

2,2 Dwellingup 1. jarrah dieback

Jarrah dieback is a plant disease caused by the introduced soil-borne fungus Phytophthora cinnamomi Rands. This pathogen has the capacity to kill jarrah and many of the components of the forest almost throughout its geographic range.
The area of crown land affected by jarrah dieback was 280 000 ha. in december 1977 and is increasing by 20 000 ha. a year (Shea, 1978). Besides the loss of timber, recreation and conservation values, the disease poses a threat to the major water supply system of the south-west of Western Australia. (see: 2.2.2)

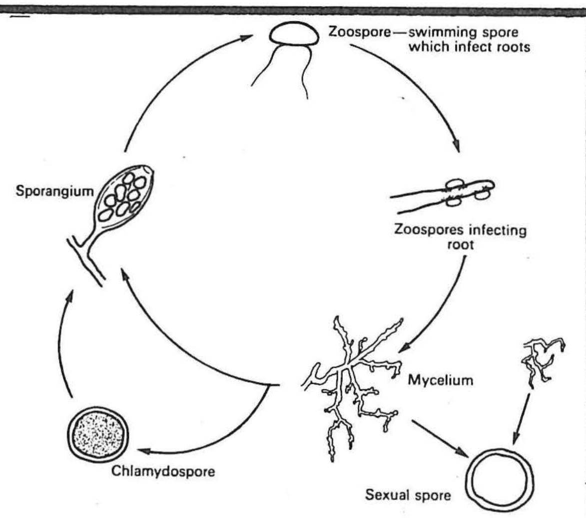


Figure 9 : The life cycle of Phytphthora cinnamomi Rands. (from Forest Focus no 14)

Phytophthora cinnamomi occurs in the soil and roots in various forms, which make up its life cycle (Fig 9).
Zoospores are considered to be the main agent of spread and infection. Soil temperature and soil moisture affects sporulation and zoospore motility and are thus two important limiting factors in the spread of the disease. Soil moisture levels equivalent to field capacity and soil temperatures of 15°C are assumed to be the critical limits below which infection does not take place. (Shea, 1977). Studies in the northern and southern forest types showed that upland, well drained sites have relatively short periods, mainly in spring, when both soil - moisture and - temperatures are suitable for infection. Lowland sites, such as moist gullies and swamp edges, seldom have periods when moisture levels are critical but soil temperatures can be limiting here, especially in the southern forest types. Canopy, shrub and litter cover have a significant effect on the period during which soil temperatures and moisture levels are suitable for infection (Shea,1975;Kristensen, 1975).
P. cinnamomi causes damage to plants by attacking their root systems. In the case of jarrah, only the fine feeder roots are attacked and the tree slowly dies, which takes sometimes more than 10 years, this in contrast to the highly susceptible bull banksia (Banksia grandis Wild.). P. cinnamomi invades large banksia roots and mortality results from girdling of the stem and therefore occurs rapidly. Bull banksia is usually the first species to die and because of its susceptibility and the presence of dense stands of this species, it is one of the major factors contributing to the spread and intensification of P. cinnamomi. Banksia roots provide a large foodbase, pathways through which the pathogen can spread and a place where the fungus can survive during the remainder of the year, particularly during the dry summer.
The spread of P. cinnamomi upslope is slow, some 50 cm. per year and is probably mainly caused by mycelium growth through the horizontal root system of bull banksia and root contacts.

The fungus spreads rapidly downslope because spores are distributed in drainage lines. In the past artificial spread resulted from moving large quantities of soil like that adhering to bulldozers or moved in road building operations.

How to control jarrah dieback ?

A few short term measures were taken and a large research team is working on a more defenite and long term control of the disease.
Between 1976 and 1978, a large portion (40%) of the state forests was declared quarantine area. Within the quarantine areas vehicle movements were restricted and all forest operations were relocated outside these areas for the period of three years. Quarantine provides short-term control because it restricts spread of the fungus in contaminated soil and permits detailed mapping of the distribution of the disease.
Theoretically there are a few ways to control the disease in the long-term.
First : attack the pathogen, for instance by spraying with a fungicide. Techniques like that are usually not practicable in a forest situation. By replacing the susceptible host, the disease could be controlled, however there is little evidence that there are strains of jarrah which are resistant. Replacing jarrah with an alternative,resistant species is another method, but further research is neccesary before broadscale rehabilitation is possible and even then, it will be very expensive.
Another control option is to change environmental conditions in such a way as to inhibit fungal pathogenicity : the fungus and the host co-exist but environmental conditions are unsuitable for the pathogen.(Shea,1979)
The promotion of native leguminous species and at the same time a reduction of the banksia density, create environmental conditions which are unsuitable for activity and survival of the fungus. The present density of the banksia understorey is mainly the result of the broad scale mild prescribed burnings carried out after 1954; in the upland virgin jarrah forest, it occured only as a minor component of the understorey. Mild burns in spring had little effect on the banksia understorey, but they provided an excellent seedbed for the seeds which were released from the cones, the following autumn. Thus under a mild burning regime banksia population levels increased. Medium to high intensity fires in autumn and late summer, when banksias are under drought stress can kill over 50 % of the banksia population.(Shea,1979)
Native legumes of the jarrah forest failed to regenerate under the mild burning regime, but appear in dense stands after burns of higher intensity. Studies showed that ants buried the leguminous seeds in their nests and therefore the seeds do not receive enough heat to stimulate germination during normal, mild spring burns.
A benificial effect of the leguminous understorey is that sporangial production and infection is markedly reduced, because of a change in the soil microbiological environment. Although these studies are very hopeful, long-term field trials are to be carried out before the legume approach can be implemented on a operational scale.
A number of large scale trials have been initiated to determine the practical problem of high intensity burning and they ensure that if it is found that a legume understorey will confer permanent resistance of the forest to dieback, the technique can be implemented rapidly.
An example is the medium intensity burn of Hakea D25 near Dwellingup on 24/3/80, where an area of 22 km^2 was burnt. The ignition was carried out by an airplane, dropping incendiary canisters in a grid pattern and the fire was monitored by some 70 men.

2,2,2 Salinity and water balance

The Dwellingup research station of the Forests Department is definitely not the only place where the salinity problem is being investigated, but the problem itself is important enough to mention.
In many parts of the south-west, large quantities of salts are stored in the soil. Salt storage is relative low along the high-rainfall edge of the Darling Range and increases rapidly going inland from the coast. The native forests and woodlands of this region maintain a balance between the incoming and outgoing water and salts, so even though storage of salt is high, the river salinities remain low. Permanent clearing for agriculture disrupts these water and salt balances.

In the figures 10 and 11 we see which changes takes place following clearing in the high and low rainfall areas respectively

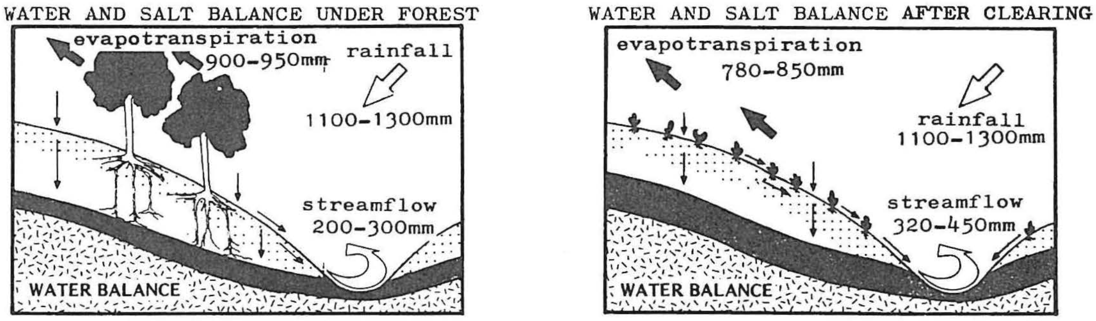


Figure 10 : Water and salt balance in highrainfall areas (1100 - 1300mm)

The evapotranspiration decreases after clearing, because crops and pastures transpire water only from shallow soils and the trees draw on moisture to depths in excess of 20 metres (!). The groundwater discharge into the rivers is slightly higher after clearing, but the major increase of the streamflow occurs as increased surface runoff during winter.

In these areas, where salt storage is low, 2 to 3 times the annual input of salt are discharged by streamflow following clearing. Stream salinity is not significantly increased as the salinities of the increas d groundwater seepage are low and these are diluted by increased surface runoff. (after publ. works dept. 1979)

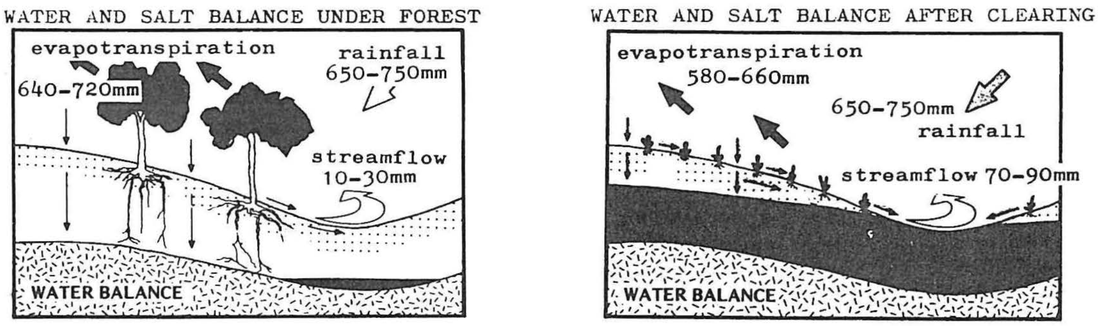


Figure 11 : Water and salt balance in low rainfall areas (650 - 750 mm)

The evapotranspiration decreases for the same reason as in fig 10. In these areas the groundwatertable is often more than 10 metres below the valley bottom. After clearing, the groundwaters rise and after a number of years (sometimes more than 10) they intersect the soil surface and flow into the streams. Most of the increased streamflow however occurs as increased surface runoff during the winter.

Under forest cover salts are slowly accumulating as there are insufficient groundwaters to move them to the streams. Peak concentrations usually occur 5 to 10 metres below the surface. After clearing the annual output of salts can be 30 times the input, once the groundwaters have reached the soil surface. Additional water from increased surface runoff is far outweighed by the increased salt discharge and therefore major increases in stream salinities result. The salt storages are so high that leaching may continue for hundreds of years before stream salinities return to near preclearing levels. (after publ. works dept. 1979)

The potential average salinity of rivers in the south-west varies according to the degree that their catchments extend inland to areas having salt-laden soils.

The actual salinity of these rivers depends on how much of the inland low to medium rainfall sections of their catchments have been cleared.

The salinity of the rivers is one important factor in the water resource development. The increasing demand for water, the relative scarcity of divertible water resources and increasing land use conflicts on catchments has emphasized the necessity for the development of active catchment management strategies based on ecological and hydrological considerations. (Shea et al, 1978)

In 1957 it was determined that Darling Range laterites were rich enough in alumina to be considered as possible bauxite deposits. Agreements between the State Government and Alcoa of Australia, which permit bauxite mining operations were signed and mining started in 1963. Alcoa's mineral lease covers 700 000 ha. of state forests. At the current rate of production the company is clearing 280 ha. annually for mining which could rise to 400 - 450 ha annually by the year 2000 (Alcoa, 1978). The impact of mining will be greater than the area mined because bauxite mining operations will increase the spread and intensification of jarrah dieback (Shea and Herbert, 1977).

Rehabilitation begins with earth works to reshape the sharp pit features. Top-soil is replaced on the pit floor and ripping on the contour to 2 m. depth on 2 m. centres is carried out to break the compaction of the pit floor.

Revegetation practice includes planting of mixed species of trees and undersowing with native shrub species. Carryover of native seed in replaced topsoil is possible by seperate stripping of the upper 5 cm. of topsoil and immediate respreading.

The present spacing of the trees is 4 X 4 m. (625/ha.) and the fertilization consists of a spot application of 200 gr./tree (12:52) and an aerial application of 300 kg./ha. superphosphate (Bartle and Shea, 1979).

One of the most difficult problems associated with rehabilitation is ensuring that the species used, will survive in the long term. A drought during the first 10 years after establishment may have negligible effects on survival whereas a drought of similar intensity when the tree is larger and the canopy closed may result in catastrophic collapse of the whole stand. At this moment there are no long term data available that enables selection of a tree species which would grow, survive and perform the same hydrological function as jarrah.

2,3 Manjimup karri silviculture

All early cutting of karri was on an unrestricted exploitation basis with little or no thought given to the regeneration of the forest. The dedication of large areas as state forest in 1918 led to a change in attitude from exploitation to conservation, with planning to ensure regeneration.

A clear felling system was used, but the unsaleable or cull karri trees were retained as seed trees. After a mid summer burn, the cull trees were ringbarked.

From the mid 1930's onwards, the system changed to a selection felling system.

Since 1968 a clear felling with seed trees system is used again.

With the system currently used, some 4 high quality trees per hectare are left as seed trees and all unwanted stems are removed. A bulldozer rolls all scrub and understorey stems flat to the ground to produce the optimum conditions to favour germination survival. For optimum results, the regeneration burn must coincide with seed being present in the crowns of the seed trees. The aim of the regen burn is to obtain as high an intensity fire as possible. The burning technique is described in fig 12. A hot burn brings down all seed within several weeks. In good seed years stockings of 100,000 seedlings per hectare are common, germination takes place after the first rains, usually in mid-april. Unstocked areas, as indicated by surveys, are planted immediately they are known.

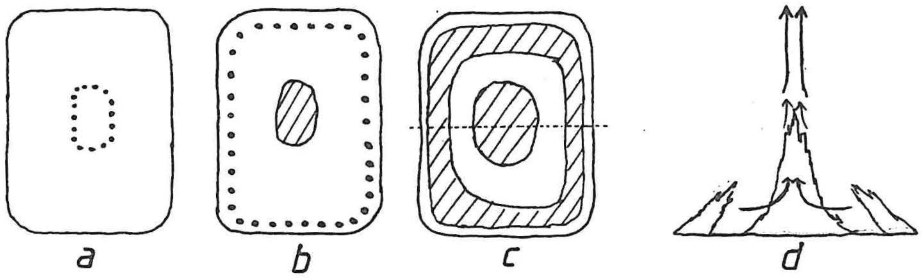


Figure 12: The burning technique used in regeneration burns. After center firing, a convection column developes (a). Then the edges are lit (b). The convection column serves as a stabilizer and the flames along the edges point inwards (c,d).

Thinning, though not essential, if carried out early in the life of the stand, improves its growth markedly. At the age of 10 - 15, the trees become tall enough and their bark thick enough to withstand a low intensity burn. From then on regular burning can keep fuel accumulation low and thus reduce the risk of damaging fires (White and Underwood, 1974).

Development of techniques for artificial regeneration is an important consideration for future karri forest management : the regeneration is not tied to the fou -year floral cycle of karri.

The regeneration by hand planting is used more and more. In the winter of 1978, 2000 ha were regenerated of which 1360 were hand planted, mainly because of a poor seed crop (annual report, 1979).

The costs of broadcast sowing is approximately 20% that of hand planting but at the moment, high seed collection costs make broadcast seeding as expensive as hand planting (Annels, 1980).

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