Forestry and Timber Bureau.

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Internal Report.

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A REVIEW OF THE DISORDER JARRAH DIEBACK.

This Report reviews past work and presents a consideration of possible cause. Recommendations for future work are outlined.

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INTRODUCTION

Since 1926 the dying of patches of jarrah forest and the subsequent extension of many of these patches has been reported for almost the entire latitudinal range of the jarrah forest. This disorder is known locally as "Dieback". An even more common disordered condition in jarrah known as "Crown Deterioration" may be associated with dieback. The causes of these disorders are not known.

The total area affected by dieback has not been accurately determined, but it is considered to be small when expressed as a percentage of the total acreage of jarrah in State Forest. There is however a very real possibility that this disorder could become a serious obstacle to the attainment of management objectives. Dieback is spreading actively in many of its occurrences and in the past several years many new occurrences have appeared. A number of these are in good quality forest not previously regarded as susceptible. More or less continuous areas of up to several thousand acres have developed in parts of the northern jarrah forest.

At present it is not possible to predict how far dieback will develop or what will be its rate of spread, nor is sufficient information available to permit the confident definition of "no risk" areas. Until a risk classification is available as a guide to management an element of risk will be present in any treatment and in the calculation of the yield.

The experience of research into disorders of unknown cause in forest trees elsewhere suggests that the problem may require long research.

This report reviews past work, presents an appraisal of the problem in the light of our present knowledge and outlines proposals for the work of this station.

AN APPRAISAL OF POSSIBLE CAUSES.

SUMMARY :

Jarrah dieback which was first reported in 1926 is almost certainly a phenomenon of recent times. While the disorder may have been present prior to that date no evidence has yet been produced to show that it was a feature of the undisturbed forest.

The following features of dieback and the environment in which it occurs are important in a consideration of possible causes.

1. The disorder occurs on a wide range of sites through the greater part of the species range. The greatest incidence and the most extensive occurrences are along the western edge of the Darling Range in the northern jarrah forest.

2. All tree species as well as understorey species are affected by the disorder. These include Banksias, Persoonias, Eucalypts, Macrozamia (Cycadaceae) and Xanthorreaea (Monocotyledonae)

3. Jarrah occurs on poor lateritic soils as pure stands or in admixture with Marri (E. calophylla). Over much of the forest area massive laterite occurs at the surface or at shallow depth in the A horizon. This laterite restricts vertical root development; the major part of the jarrah root system is found in the surface shallow gravels and gravelly sands of low moisture holding capacity. It seems certain that during the almost rainless summer, jarrah depends on reserves of soil water held in the clay B & C horizons below the massive laterite.

In the course of past research no pathogen or insect has been established as the causative agent and in view of the wide diversity of plants affected it seems unlikely that a single pathogen is responsible. All alternative causes which have been suggested ascribe dieback to the effects of environmental changes.

The major changes known to have taken place in the forest in recent times are -

1. Cutting operations.
2. The complete exclusion of fires from many areas.
3. An increase in the incidence of severe fires.

The effect of repeated fires has been suggested as a causative factor through the removal of the litter layer, consequent exposure and a suggested decline in soil fertility. Various workers have shown that light fires do not have a serious effect on the level of major nutrients, soil microfauna or jarrah girth increment. It is believed that fire has always been a factor of the jarrah forest environment. The presence of dieback on burned as well as protected forest and its absence from many severely burned areas indicates that it is probably not an important causative factor of dieback.

Logging operations are perhaps the most drastic change that has been wrought on the forest. Hamilton has given a comprehensive list of changes which follow logging. His main points are :-

1. Reduction of canopy and protective vegetation exposes the site to increased insolation, evaporation and rain wash effects.

2. Reduction of litter results in decrease in organic matter and thence soil fertility.

3. A change in soil moisture relationships and reduction of moisture holding capacity. Drought conditions are greatly intensified.

4. A reduction in microflora and microfauna.

Soil fertility studies have shown little difference between healthy and dieback sites and it is likely that the most important changes are those affecting soil moisture availability and nutrient uptake.

Apart from the known environmental changes listed above, there is the possibility that dieback is associated with climatic change. Gentilli has presented evidence of a climatic change over a period of seventy years. The most important of his findings are a shift of the wettest month for Perth, from June to July, and a slight decrease in summer rainfall. These changes would slightly increase the duration and intensity of summer drought. The effects of changes due to climatic drift over a short interval are likely to be less marked than the effects of a sequence of adverse years during that interval. Such adverse sequences are known to occur, and have been shown to affect forest trees; the spread of Pole Blight of Pinus monticola has been related to series of years which were hotter and dryer than average.

The greatest incidence of dieback and the most extensive occurrences are on heavily cut over areas. There seems to be little doubt therefore, that cutting is a major factor even though occurrences are known in virgin forest. At the same time site exposure as an effect of cutting is not necessarily always involved since dieback has recently appeared in dense stands of formerly vigorous pole regrowth.

It is suggested that dieback may be primarily caused by climatic conditions which adversely affect the plant soil water relationships of the crop. The changes in site which Hamilton has outlined, each directly or indirectly affects soil water relationships.

The nature of dieback symptoms in individual trees may be regarded as an indication that death is directly due to physiological drought.

PAST RESEARCH IN THE PROBLEM "DIEBACK".

Dieback was first reported in 1926, but it did not cause concern until the late 1940's. A study of the disorder was initiated in 1948 and a number of aspects were investigated during the following 3-4 years. Since 1951 little work has been done.

In the course of research a broad description of the disorder was provided and several occurrences were described in detail. The chief lines of investigation concerned nutritional and pathogenic aspects, but no pathogen or nutritional deficiency was found to which the disorder could be attributed.

There have been a limited number of trials with both conifers and hardwoods to find suitable species and techniques for restocking affected areas. Pinus pinaster and Eucalyptus calophylla have shown most promise.

There has been no investigation of crown deterioration as a separate problem. Past work, which has been restricted to dieback, is treated in this report under the following headings:-

1) Description of the disorder.
2) Investigations of nutritional aspects.
3) Investigations of pathogenic aspects.
4) Restocking studies and trials.

1. DESCRIPTION OF THE DISORDER:

The results of studies to determine the occurrence and extent of the disorder and to describe its spread have been reported by Wallace and Hatch[2] and also by Hamilton[3]. A comprehensive and detailed description of the Teesdale occurrence was prepared by Hamilton.

Occurrence and Extent of the disorder:

In 1949 district offices of the Forests Department provided plans on 80 scale of the occurrences within the districts. These were to be revised each six months and descriptive notes provided for each occurrence. The plans were submitted in early 1950, but were not regularly revised. They have not been brought up to date within the last three years at least.

Wallace and Hatch summarised the 1950 position as follows:-

a) The extent of dying patches was of comparatively minor significance and amounted to less than 0.2% of the jarrah forest area.

b) The greatest incidence was in the northern part of the forest area, but the disorder occurred as far south as Kirup.

c) It generally occurred on cut-over forest, but several occurrences were reported in virgin forest.

d) The disorder was confined to certain topographic features, notably, heads of gullies and slight saddles in ridges. It was most common on black laterite soils.

e) The spread of the disorder seemed to be limited by the slope of the land.

Progress of the disorder:

The spread of the disorder has been described in broad terms by Wallace and Hatch and also by Hamilton. The detailed description of the Teesdale area by Hamilton was intended as the basis for a study of changes on this site. Unfortunately this work was not followed up after his departure and no detailed description of the spread of the disorder is available for Teesdale or any other occurrence.

The following sequence in the development of the disorder has been noted by Wallace and Hatch.

a) The first readily noticed deaths are in Banksia grandis. These may occur up to two years prior to the death of jarrah.

b) The gradual death of jarrah follows.

c) Deaths of Macrozamia reidlii and Xanthorea preissii accompany these changes.

d) A considerable change in the ground flora follows.

e) The disorder appears to have little effect on marri, occasional overmature trees die.

Since 1950 a number of exceptions to several of these observations have developed. These are discussed in the second part of this report.

Mapping from Aerial Photographs:

The first attempt to map dieback from aerial photographs was made in 1950. The Forest Department's forest type mapping from aerial photographs now includes a dieback class although there are a number of difficulties in interpretation. In some cases it is difficult to distinguish affected areas from poor quality or fire damaged forest. Many small areas cannot be recognised on the photographs and the full extent of large patches cannot be accurately defined in all cases.

Photo interpretation and field checking will be invaluable in an examination of the extent and occurrence. Those areas which have been photographed two or more times will be particularly valuable in a study of the spread of the disorder.

2. NUTRITIONAL ASPECTS:

The fertility of the laterite soils of the jarrah forest is extremely low. This has led to the suggestion that certain factors such as site changes following logging and burning had reduced soil fertility to a critically low level on the poorer sites in the jarrah forest and that this was responsible for dieback on those areas.

Fertility studies initiated in 1949 were concerned with two main aspects.

A. The investigation of differences in soil fertility of dieback affected areas and adjacent green forest.

B. Trials with fertiliser amendments in both healthy and unthrifty forest.

A number of experiments were carried out on each aspect. These are discussed briefly under A) and B).

A) The investigation of differences in soil fertility.

Following detailed soil surveys on each of the Teesdale, Huntly and Farleys Study areas, samples were taken from within soil types for comparison of certain soil fertility factors of affected and adjacent green areas. Samples were taken from the gravelly A horizon and the mottled clay B horizon. It was generally not possible to sample the bleached clay C horizon. As the clays of the C horizon are known to contain little reserves of plant nutrients this was not regarded as important.

Analyses of soil reaction, cation exchange capacity, organic matter and major essential elements were carried out.

The conclusion of this work as reported by Wallace and Hatch are :-

a) No outstanding difference appears to exist between the soils of the dying jarrah areas and those of adjacent healthy areas.

b) Many of the differences between the soils of the two areas can be explained by difference in leaf litter accumulation following the disorder.

c) The phosphate levels of the two areas appeared to be identical, of the order 20 - 170 p.p.m. P_2O_5.

At the time of their report, Wallace and Hatch considered the die-back patches studied to be stabilised. Each of these areas has again become active within the last three or four years and many of the areas sampled as healthy in 1950 are now disordered. If the areas deemed to be healthy, did not have an incipient stage of the disorder the spread may be regarded as evidence in support of Wallace and Hatch's conclusions since development of a critical decline in soil fertility is unlikely in four to five years.

Leaf Ash Analyses.

Following on the soil fertility analyses, work was initiated to determine whether there were differences in nutrient uptake by trees on healthy and affected areas. Leaf ash analyses were carried out for the major plant nutrients for both marri and jarrah leaves. Although the results varied considerably Wallace and Hatch found no evidence for a marked deficiency of any one of the major plant nutrients.

Trace Elements.

There has been no investigation to date of the comparative levels of minor or trace elements in the soils or plants of affected and healthy areas.

B) Trials with Fertilizer Amendments.

1. Phosphates.

Soon after World War II developments in agriculture led to the farming of the laterite soils of the Ridge Hill series at the foot of the Darling Scarp. Following clover establishment and superphosphate application to part cleared paddocks there was often a vigorous development of jarrah and marri crowns. This attracted the attention of Dr. Stoate who suggested similar results might be obtained under forest conditions if soil fertility was increased by clover establishment and phosphate application.

A number of controlled trials were established in both healthy and unthrifty forest. The following are the main results of these trials.

a) Phosphate applications of up to 20 cwts of superphosphate per acre per annum for several years produced no measurable response in diameter increment or in crown vigour.

b) Leaf ash analyses have shown that there was no outstanding uptake of the applied phosphorous.

c) Hatch[1] has shown that practically all of the phosphorous applied at the rate of 2 cwt per acre for 7 years is retained in the surface few inches in a fixed form.

d) There has been no response to combined phosphate and clover establishment experiments though fair growth of clover was produced.

2. Mixed Fertilisers.

A mixed fertiliser trial with the following annual dressings was maintained for 4 years.

Replication 1.

10 cwts of agricultural lime per acre.
4 cwts of superphosphate per acre
1 cwt K_2SO_4
1 cwt $MgSO_4$
10 lbs $CuSO_4$
10 lbs $ZnSO_4$
10 lbs Boracic Acid
10 lbs $MnSO_4$

Replication - as for replication 1 but with 20 cwts of Lime.

After 4 years there was no response to these applications.

3. Trials with nitrogenous fertilisers have not yielded a response. Applications of 2 cwt per acre of Blood and Bone and Potato Manure E were used in a 3 x 3 latin square experiment and girths were recorded on ten codominants on each plot. After three years there was no response to treatment. There was however a marked improvement in the vigor of the ground flora.

3. INVESTIGATION OF PATHOGENIC ASPECTS :

Work on pathogenic aspects of the disorder has been limited. A report of preliminary investigations in 1949-50 has been prepared by J.H. Harding. The following are the major points made in that report.

a) There was no evidence to suggest insect attack as the cause.

b) While several fungi have been isolated these were not considered to be responsible for the disorder.

c) Virus and bacterial infection if present was not transmitted by inoculation and grafting techniques.

d) No serious abberration was found in the anatomy of samples taken from affected plants. Root, leaf, twig, branch and bole samples from one affected sapling were compared with similar material from healthy areas

1 Hatch, A.B. Typed report F.D.

In September, 1959 W.Stahl and R. Greaves of the Forestry and Timber Bureau visited Western Australia to examine pathological and entomological aspects. They have reported separately on their findings.

4. RESTOCKING STUDIES AND TRIALS :

The natural recolonisation of dieback sites by Marri has been reported by Wallace and Hatch. A recent re-assessment of a regeneration transect on the Teesdale area has shown :

a) Marri regenerates as dense groups within 0-1½ times tree height of seed trees. These seed trees are veterans of the old crop.

b) No regeneration was found outwards from the perimeter of these groups even though the saplings were up to 25' high and carried some fruit.

c) The crowns of the marri saplings are not dense and vigorous. They are yellow-green in colour in most instances on this transect.

d) The saplings have made height growth of up to 2' - 2½' per annum over ten years.

Although occasional Marri veterans are found on most sites affected by dieback they are usually too widely scattered to satisfactorily restock the affected areas in a reasonable time. Sowing and planting trials have been established to find suitable species and techniques for quickly restocking dieback areas with a useful tree crop. A number of Eucalyptus and several Pinus species have been tried.

A) EUCALYPT PLANTING AND SOWING TRIALS :

a) PLANTING TRIALS - have been made with a number of eucalypts - none of these have produced very good growth. In most cases potted 1 - 0 nursery stock was planted in cultivated spots usually 18" x 18" and 6"-9" deep. van Noort has shown that cultivation is the most important requirement in the establishment of 1 - 0 jarrah stock on similar sites. He believes that loosening of the compact sandy gravels is essential for optimal root development and is at least as important as the reduction of competition due to cultivation. It is likely that a more extensive and thorough cultivation than that usually given would promote a more rapid development with most eucalypts.

The following species have been tried.

E. calophylla - establishment satisfactory, poor subsequent growth.
E. marginata - established plants die before becoming dynamic.
E. crebra - establishment satisfactory, but all plants remain in prostrate form, 5 years after planting.
E. saligna)
E. microcorys) Height growths of 1' - 2' per year, but all
E. camaldulensis (species have sparse shallow crowns.
E. sargenti)

E. robusta - Failed to survive first year in the one trial where it was used. A possibility for wet situations.
E. occidentalis - very slow growth.

Jarrah wildings were taken from good quality forest and planted at Teesdale, but failed completely. Young jarrah seedlings develop a marked vertical root system and it is likely that severe root pruning was responsible for this failure.

Although dieback areas are usually poor sites they show considerable variation. Very dry sites as well as areas which are waterlogged through much of the winter are common. Marri grows naturally throughout the range of sites and has shown tolerance of these varied conditions when planted.

During 1959 the planting of dieback areas was started in the Gleneagle Division. Species were selected which were considered suited to the various sites. Among a number of species not tried before are E. accedens, E. astringens and E. maculata. The development of these trials is to be followed.

b) SOWING TRIALS:

Trials have shown that Marri can be successfully established by sowing. The best results have been obtained by spot sowing particularly on ashbeds. Broadcast sowing was tried but did not give satisfactory results. Where sowings have been made with other eucalypt species on sites without prior seed bed preparation complete failure has resulted.

B) PLANTING TRIALS WITH PINUS

Trials of varying size with several species of Pinus have been established on laterite soils in the past. Large scale trials were generally concerned with plantation possibilities of these soils. A number of smaller trials however have been established specifically to find species which will grow on dieback sites.

a) Pinus radiata has been planted in plantations on laterites at Mundaring, Gleneagle, Harvey and Collie. Unthrifty, chlorotic, spindle or dead topped stands have invariably resulted. The same results have followed planting trials with this species on dieback areas.

b) Pinus pinaster has been planted on a larger scale on laterites than any other tree species. This species can be established and will grow on most laterite soils, and does not develop the unthrifty conditions described for P. radiata.

At Gleneagle 600 acres have been planted and there growth is variable; plantings have failed in soils which are wet throughout winter and growth is slow on soils with massive laterite near the surface. On the deeper soils which occur mainly on middle and lower slopes, growth has been good. Height M.A.I's for 5-9 year old stands are of the order 2½ - 4 feet.

Good site preparation and an initial dosage of 2 ozs. of superphosphate per tree have been found to be essential for satisfactory growth.

The results of trial plantings of Pinus pinaster on a range of dieback sites are encouraging and it seems certain that Pinaster can be grown satisfactorily to an age of 25 at least on all but wet and very rocky sites.

c) Pinus elliottii - fair results have been obtained with this species at Gleneagle on better soils, but this species has not been tried yet on dieback sites.

d) Pinus halepensis - has grown very slowly and is not healthy. It is not likely to be useful on dieback areas.

e) P. coulteri, P. ponderosa, P. canariensis and P. muricata have all been grown on laterites at Mundaring Weir, but none of these can be regarded as a prospect for dieback planting.

POSSIBLE CAUSE IN THE LIGHT OF PRESENT KNOWLEDGE.

Jarrah dieback is a disorder of unknown and probably complex cause. A solution of the problems of this disorder may involve long term investigations in more than one field. The two best known disorders of unknown cause in forest trees elsewhere, Pole Blight of Pinus monticola and Dieback of Birch, have been the subjects of many years research by a number of workers in both the U.S.A. and Canada. Despite their efforts the exact cause of each of these disorders remains unknown. Pole Blight research has engaged a number of workers over a period of twenty years and has produced recommendations for white pine management in the Pole Blight affected region, but has not established the cause of Pole Blight. Leaphart[1] has suggested that a further ten to fifteen years of research and observation of trends of the disease may be necessary to show if their recommendations for management are in fact real. The planning of research in jarrah dieback must take the possibility of similar experience into account.

The obvious aims of research are :-

1. To determine the cause.
2. To produce at the earliest a risk classification as an aid to management.
3. To provide, if possible, a remedy where dieback is incipient and prescriptions for preventative practise on risk areas.

A description of the occurrence and an understanding of the factors affecting spread are necessary before soundly based research can proceed. Recent developments in the spread of the disorder have resulted in considerable change in the situation from that described by Wallace and Hatch[2]. There is a need for basic descriptive information such as -

1. The extent and occurrence of the disorder.
2. The seasonal incidence of spread.
3. Variation in the rate of spread between various geographically and topographically distinct occurrences.
4. Relation of the rate of spread to climatic variation.
5. The symptoms of disorder in individual trees including root mortality studies.

The attainment of this information is a prime requirement and will involve the establishment of permanent plots through the geographic range of the disorder. Following the initial establishment of this work, it will be possible to commence exploratory investigations into the cause of dieback. As the scope of investigations will be limited by practical considerations it is necessary to select for more detailed study any factors which in the light of present knowledge are most closely related to the disorder. The investigation of dieback and soil water relationships is recommended. This recommendation is based on a consideration of the occurrence, the overall symptoms of the disorder and some recent observations of symptoms in individual trees.

The Occurrence of Dieback.

The outstanding features of dieback occurrence are its relatively recent appearance, the wide range of conditions in which it occurs and its occurrence through almost the entire jarrah forest region.

Dieback has developed in less than 35 years from virtual absence into a prominent feature in the jarrah forest. It is certain that the disorder, if present at all, was not an important feature of the virgin forest, at least within the last two hundred years; there is no evidence of treeless barrens or pure marri stands on sites which could be regarded as suited to jarrah. It is possible that small areas had appeared in the past but have subsequently restocked with jarrah.

Dieback occurs in a variety of situations, covering a wide range of topography, stand composition, fire and cutting history. It is no longer restricted to certain topographic situations or to poor quality forest as previously reported, although there are many more occurrences in those situations than elsewhere. The occurrence of dieback in good quality forest, in dense, formerly vigorous pole stands, on ridge tops and on steep slopes, seems to be a recent development. At the present time, with the possible exception of forest on the fertile young soils derived from acidic and basic rock, it is not possible to confidently define any set of conditions which can be regarded as risk-free.

The disorder occurs over almost the entire latitudinal range of the jarrah forest. It has been recorded over a north to south range of 165 miles of the total 180 miles of jarrah in State Forest. Although the majority of occurrences are found along the western side of the Darling Range, scattered small occurrences are found eastwards for up to thirty miles in the Dwellingup district. From north to south there is an increase in the number of wet days and a decrease in the average maximum temperature.

	Jan. Average Maximum Temp.	Average No. Wet Days.	Average Monthly Summer Rain.
Dwellingup	82.6	~~100 - 150~~ 134	½" approx.
Manjimup.	77.8	150 - 170	1"

The disorder occurs through a west to east rainfall range from 51" at Dwellingup to about 28" south of Boddington.

There is no record of occurrences in the Pemberton and Shannon River districts in the main Karri forest region where the climate is slightly wetter and milder than at Manjimup.

Gross Symptoms of the Disorder.

Unlike most other diseases of forest trees, dieback has drastic effects on the whole of the plant community. Every tree species present is affected, and all but E. calophylla (Marri) eventually die. In the case of Marri, veterans are adversely affected and become thin crowned or stagheaded, but young marri saplings often produce a vigorous response to the reduced competition. Of the other species, trees of every size and age are affected and die. The following list illustrates the diversity of plants affected.

Tree strata :

Jarrah.

Understorey tree species :

Banksia grandis)	
Persoonia longifolia)	Family Proteaceae
Persoonia elliptica)	
Casuarina fraseriana	Family Casuarinaceae

Other understorey :

Macrozamia reidlii	Family Cycadaceae
Xanthorrea preissii	Family Lilliaceae

There is a marked change in the understorey associated with dieback . This may be due in whole or in part to secondary effects.

Hamilton[3] has described the changes in the vegetation in disordered areas. The main points of his description are -

1. The actual death of the jarrah is preceded by mass death of the Banksia grandis and Persoonia understorey.

2. Banksia deaths usually commence before the onset of summer, but jarrah deaths occur in late summer and autumn.

3. Jarrah may become stag-headed and die in several years or the entire crown may die in one year.

4. In general the crown dies first at the top and is partly replaced by epicormics which eventually die.

5. No size or age is immune.

Further to this there seems to be a marked decrease in the size of leaves formed prior to death.

The formation of kino sheets in the crown and upper part of the bole close to the cambium were noted by Stahl[4]. The affected trees were unthrifty poles occuring at the edges of small dieback patches of recent origin.

POSSIBLE CAUSES.

In the course of past research no parasite has been established as the causative agent and in view of the wide diversity of plants affected it seems unlikely that a single pathogen is responsible. Various theories have been advanced ascribing dieback to one or another environmental change. The forest environment and the changes which have taken place are now considered.

Environmental Change.

The Jarrah Forest Environment.

Jarrah occurs naturally as pure stands or in association with Marri on a wide range of sites. Some of these are marginal - and jarrah has probably spread to many sites to which it is not well suited.

The majority of jarrah forest soils are of low fertility and of poor physical properties. Although the soils are generally deep, an impeding layer of more or less continuous cemented laterite gravel is generally found. The lower surface of this impeding layer marks the boundary between the gravelly sands of the A horizon and the mottled clays of the B horizon. On many sites massive laterite occurs at shallow depth or at the surface. The sandy gravels of the A horizon therefore usually have a very limited water storage capacity. The root systems of Banksias, jarrah and marri have been shown to have two distinct parts, shallow spreading laterals and a deep vertical system[5].

The summer environment of the jarrah forest is hot and dry. Of the total annual rainfall, about 5% only is received in the four months December to March and this is the period of active crown extension. Except for intermittent and unreliable rain received in these months, the entire summer water requirement of the forest must be drawn from reserves built up during the winter months and retained in the subsoil clays of the B and C horizons. It seems certain that the development and survival of these trees depends largely on their ability to establish and maintain a healthy root system in these horizons. Any changes which seriously deplete the moisture reserves in this zone or reduce ability of the trees to draw on them, must have serious effects on tree health.

Changes in the Environment.

The major changes which are known to have taken place in the jarrah forest are -

1. Man's sawmilling operations.
2. The complete exclusion of fire from many areas.
3. An increase in the incidence of severe fires.

The occurrence of dieback in 1926 and its appearance in locations remote from settlement, lend little support to the possibility of toxic effects of industrial waste gases. Of the effects due to man, cutting and fire are the most important, and each of these has been suggested separately or jointly as the cause of dieback.

Fire.

That fire alone is a cause is most unlikely, since dieback has not developed on many sites which have been severely fire damaged. Further, dieback has occurred on sites which have never been badly burnt and have not had fire of any intensity for periods up to twenty five years. Gardner[6] has described the vegetation of Western Australia as pyrophilous and listed fire resistant adaptations for a number of native plants.

Additional evidence that fire has been a natural factor of the jarrah forest environment for at least the last three hundred years, has been presented by Harris and Wallace[7]. Light fires of the order which Harris and Wallace consider were typical of the natural occurrence have been shown to have no important effects on either the level of major nutrients in the soil[8], soil microfauna[9] or jarrah girth increment[10].

Cutting.

Although a number of occurrences of dieback are known in virgin bush, the great majority of patches and all of the more extensive occurrences are to be found on cutover forest.

Hamilton[3] has described those changes which he considers follow heavy cutting and fire, and attributes dieback to these changes.

Recently dieback has appeared in situations which cannot be explained by the effects of logging alone. Dieback patches have appeared in dense and formerly vigorous pole regrowth stands which were cut over up to forty five years ago. These are in forest of high site quality near Dwellingup. Other small occurrences are now known for mixed regrowth and veteran stands of high quality which were very lightly cutover. These facts plus the presence of dieback in virgin forest and the development of a similar disorder in both virgin and cutover wandoo forest indicate that some widespread change may be involved.

Climatic Change.

It is suggested that dieback is due to physiological drought induced by the effects of adverse seasonal conditions and that these effects are greatly magnified, but not dependent on site changes following cutting operations.

Leaphart[1] considers that the development of Pole Blight in Pinus monticola is related to a period of dryer than usual seasons from 1917 to 1949. McMinn and Molnar[11] have studied the effect of climate on Pole Blight affected White Pine, and have reached the conclusion that even occasional hot dry summers in the cool part of a climatic cycle could delay the recovery or promote further decline in trees at a low state of vigour. They report that in these circumstances vigourous trees are little affected because reserves carry them through to the following growing season.

Adverse seasons are known in the jarrah forest. In the five months December - April of 1949-50, only forty nine points of rain fell at Dwellingup, a centre which has an average of 545 points for this period. Even when total annual rainfall is equal to average the distribution can be unfavourable for tree growth. The winter of 1958 for instance, was typified by a very uneven distribution of rainfall.

	March	April	May	June	July	August	September
Average monthly	0.98	2.62	6.84	10.70	10.40	7.90	5.52
1958.	0.16	1.96	7.18	4.10	18.70	5.98	1.18

Gentilli[12] has presented evidence that climatic changes have occurred during the last eighty years in Western Australia. From data for Perth, he has shown an increased total rainfall with a slight decrease in summer incidence. There has been a shift of the wettest month from June to July. Such changes, if they extend even slightly the period of summer drought and increase its intensity, would be unfavourable to plant growth.

How Cutting May Intensify Unfavourable Conditions.

Heavy cutting and associated burning must have considerable effects on factors controlling soil water balance. Whilst no quantitave studies have been made, the following changes are suggested as being of importance.

The reduction of canopy by logging and the reduction of ground cover (which is usually temporary) by damage during logging and burning, will result in :-

1. Increased evaporation losses at the surface, but decreased transpiration draw. The increased evaporation losses may be an important factor in summer.

2. The reduction in canopy and litter will result in decreased interception of rain and therefore -
   a) Lower evaporation losses from the canopy and litter.
   b) Greater infiltration.
   This will have an important influence on the effectiveness of light summer showers.

3. Run-off and lateral drainage during heavy showers will be increased and this will lead to a decrease in soil water recharge at high points and increased waterlogging lower in the drainage system. In soils with impeding layers at shallow depth, this will be an important factor.

   Both water shortage and water-logging produce internal water deficits and when prolonged, death will result[14].

4. Following logging there is, on many sites, a vigourous development of weed species, particularly Banksia grandis. Such weed growth must place a large additional draw on soil moisture reserves of the A horizon, thus depleting these reserves at an earlier stage in the summer. Of the total rainfall from summer showers the jarrah crop will receive a reduced proportion as the weed crop develops. The transpirational draw by weeds will be increased as well as the losses due to interception. The tree species may therefore be forced to draw substantially on the B and C horizon soil water reserves at a relatively early stage in the summer.

These changes following logging, are not necessarily critical, but if the effect of these influences is superimposed on the fortuitous occurrence of a series of adverse seasons, soil moisture reserves may well be reduced to a critically low level for considerable periods. In the U.S.A. both citrus and alfalfa have been grown on sites of marginal rainfall for several seasons. This growth has been shown to be dependent on ground water supplies which had accrued over many years and once these reserves were depleted it was no longer possible to grow these crops on the same site[13]. Grieve[5] has shown that jarrah on the coastal sand plain near Perth, continues to transpire at a high rate throughout the summer and concludes that this species is dependent for its survival on water reserves at depth.

The widespread occurrence of jarrah on a range of sites, the associated disorder Crown Deterioration and the death of wandoo, seem to indicate that some major widespread change other than cutting is involved. This change is one affecting plant soil water relations is suggested as following symptoms in disordered jarrah.

1. The deterioration of the crown usually proceeds from the topmost branches back, until a stagheaded crown of epicormics only is left.

2. The leaves formed on unthrifty crowns appear to be much smaller than those on healthy trees and have a dry appearance. The reduction in size and density appears most marked toward the top of the crown.

3. The presence of kino sheets under but close to the cambium in many unthrifty poles. As was reported by Stahl and Greaves, these kino sheets are found chiefly in the lower crown and upper part of the bole. There was no evidence of fire or insect damage. Day[15] reported the presence of similar gum vein formation in E. camaldulensis on Cyprus, and advances evidence from the anatomy for a hypothesis of drought cause.

4. The splitting of marri bark on twigs, branches and bole and the exudation of kino from these splits. Greaves found a small wasp and larvae in such splits in twigs but was of the opinion that this was secondary. Day[15] describes a similar bark splitting in E. gomphocephala on Cyprus and attributes it to drought.

5. Although marri is severely affected in most cases on dieback sites, and also in areas of jarrah crown deterioration, it rarely dies. Jarrah almost invariably dies. This difference may be due to marri's ability[5] to reduce transpiration during hot conditions, whilst jarrah continues to transpire vigorously.

CONCLUSION.

From the foregoing arguments it is suggested that changes in microclimate following on logging and burning, may not be the major factor. Studies of the plant-soil water relationships are recommended as likely to be of major importance in an understanding of the disorder. Detailed proposals for work in the immediate future, which are based on this conclusion have been outlined in the next part of this report.

PROPOSED PROGRAMME OF RESEARCH.

A description of the occurrence and of the symptoms of dieback is a basic requirement for each of the research aims previously outlined. This work will require priority in the programme as the sound planning of further research will be largely dependant on its results.

There are large gaps in our knowledge of the plant and environment relationships in the jarrah forest, but there is evidence which suggests that an understanding of the problem requires further investigation of plant and soil water relationships.

No method of ensuring the satisfactory restocking of affected sites has yet been devised. Since there is no evidence of a decline or cessation of dieback spread, solution of the problem could become increasingly urgent. Methods are needed for extending the natural recolonisation by marri and increasing its rate of development.

The investigation of each of these problems requires considerable work, but until further staff and resources are assigned to dieback and crown deterioration research, work must be limited to a few aspects. For this reason the proposals set out below do not provide for direct research on crown deterioration. While it will be possible to commence exploratory investigations of growth and water relations, the major work for the next several years will be to produce a comprehensive and detailed description of dieback. Work on restocking will be restricted almost entirely to the maintenance of existing trials.

Before going on to discuss the individual proposals in detail, consideration should be given to the following summary in order that each proposal can be seen in its proper perspective. In this summary, aspects other than those proposed for immediate study, are briefly discussed. These will require attention at an early date and are essential to the formulation of an hypothesis of cause, but cannot be attended to at present.

SUMMARY OF ASPECTS REQUIRING INVESTIGATION.

1. Description of the disorder dieback of jarrah.
   - 1.1. Occurrence and extent - work is proposed, see detailed proposals.
   - 1.2. Symptoms and progress of the disorder - work is proposed, see detailed proposals.

2. The cause of dieback.
   - 2.1. Pathological studies - preliminary work suggests that a pathogen is not likely to be responsible. However, the possibility of a virus cause has not been eliminated - no work is proposed.
   - 2.2. Environmental change.
     - 2.2.1. Correlation studies of dieback spread and environmental changes.
       - 2.2.1.1. Dieback occurrence and spread with fire history and cutting intensity - no work is proposed immediately, but a study could be planned within the area mapped in proposal 1.1.2. see appendix.
       - 2.2.1.2. Dieback spread with variation in climatic factors.
         - 2.2.1.2.1. Permanent plots to be established under proposal 1.2. will provide basic information for such a study - no work proposed at present.

2.2.1.2.1. Stem analyses and meteorological records. If the effects of cutting and adverse seasons are the cause we may expect to find this reflected in poor growth on trees which have survived. Jarrah is diffuse porous but it may be possible by suitable technique to examine cross sections for correlation with climatic indices (net water balance? etc.) calculated from meteorological records. No work is proposed at present.

2.2.2. Studies of the relationships of growth and the spread of dieback with variations in available soil moisture. It will be necessary to establish considerable basic information concerning the water use of certain of the plants in the jarrah forest if their differences in behaviour in dieback are to be understood. A sound hypothesis must offer an explanation for these differences.

2.2.2.1. Root studies - both root habit and root mortality studies are required. Work will be limited for the present to excavations in association with the leader test of proposal 2.2.2.2.1. Later it will be possible to extend this work probably in association with the plots of proposal 1.1.2.1.

2.2.2.2. Water relations and growth. A comprehensive study will be designed following initial results from 1.1.2. and the results of an exploratory study to provide some basic information on water use and growth. Initially the marches of transpiration, growth and soil moisture will be investigated - as outlined in proposal 2.2.2.2.1. below.

3. Risk Classification - no work will be possible for a number of years since the direction of work will be determined largely by the results of preliminary work as above.

4. Restocking of affected sites.

4.1. Natural recolonisation by marri.

4.1.1. Seed production studies - no work.

4.1.2. Seedling survival and development maintain Teesdale Transect.

4.1.3. Subsequent development - the very poor condition of mature marri and some pole and pile size trees suggests that later disorders may appear in regrowth stands in the future. No work is proposed on this line.

4.2. Artificial restocking.

4.2.1. Sowing and planting with marri - required where marri recolonisation is absent or inadequate. No work proposed at present.

4.2.2. Other species - P. pinaster has been established as suitable on some sites, but useful, tolerant fire resistant species are preferable if suitable species and techniques can be determined.

DETAILED PROPOSALS.

1. DESCRIPTION OF THE DISORDER.

1.1.1. Occurrence and Extent for the whole of the forest area.
Object. To provide an estimate of the extent and information concerning the geographic and situation range of the disorder.

Method. Forests Department district offices are to maintain plans of dieback occurrence within their areas of control. These plans are to be submitted at regular intervals to Dwellingup, together with descriptive information for the individual occurrences mapped. A form has been designed for field description which will ensure standardised description and allow collation of the information on punched cards.

1.1.2. Occurrence and extent on a large representative area.

Mapping from aerial photographs of 130 square miles of Dwellingup area by Division of Forest Management Research.

1.2.1. Symptoms, Development and Spread.
Object. To provide a detailed description of the disorder over the range of its occurrence and covering the major situation variation.

Method. Strip line permanent sample plots will be established in small recent occurrences. If large actively spreading occurrences are avoided, it should be possible to follow the progress of the plots for five or more years.

About thirty plots 10 chain x ½ chain will be required. On these plots all trees will be enumerated and classified into crown health classes. In addition the following observations will be made -

1. Dendrometer records of radial growth at breast height for a small number of selected trees on each plot.
2. Detailed description of crowns for those trees selected for measurement of radial increment.
3. Description of changes in ground flora on a number of quadrats on each plot.

Since dieback affects not only jarrah, but the plant community as a whole it is important that the changes that occur in each of the layers of the stand are known.

The plots will be inspected at six month intervals in most cases but quarterly in the case of those near Dwellingup.

2. THE CAUSE OF THE DISORDER.

2.2.2.2.1. The relation of tree health and growth to available soil water.

Fraser (16) has carried out a study of the relations of growth, tree health and soil moisture variations for a hardwood stand in Ontario. Work on similar lines for jarrah is required, but there are several features of the plant, soil, climate complex which differ markedly from the Canadian conditions. These are the presence of a marked summer drought, the xerophytic nature of the jarrah forest and the presence in most jarrah forest soils of an impeding layer within or at the surface of the soil profile.

Certain basic information concerning plant water use and the determination of a suitable technique for soil moisture measurement is required. The following leader test is proposed.

Object.

a. to investigate the seasonal marches of transpiration, growth and moisture content of the upper A horizon in a jarrah marri pole stand.

b. to determine the suitability of the electrical resistance (gypsum block) method for the measurement of soil moisture content of the B and C horizons.

Method. A fifty foot tower will be erected in a group of young jarrah and marri poles. From this it will be possible to measure water loss in transpiration by the quick weighing method of Huber (as described by Grieve (5))

Growth will be measured as radial increment at 4'3 by dial guage dendrometer and as crown extension on selected crown units.

The soil moisture measurement of B and C horizons by the placing of gypsum blocks in drilled access holes will be investigated. This will be carried out within the group so that the data derived will be applicable to the study if the method is satisfactory.

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16b.	Fraser, D.A.	1959. Nine Years of Observation on the Condition of 241 Yellow Birch. Canada Research Division. Tech. Note 69.

Plate 1.

Banksiadale Compartment 6. Shallow spreading root system of jarrah veteran growing on shallow soil of a laterite ridge top. Note the large roots above the surface close by the crosses. This is typical of many trees growing on the rocky shallow A1 horizons common on many ridge tops.

Plate 2.

A windblown pile on the same ridge. This tree had developed in less than 18" of sandy gravel over massive laterite.

Plate 3.

The root system of the pile of plate 2. Note the complete ramification of the soil.

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Plate 4.

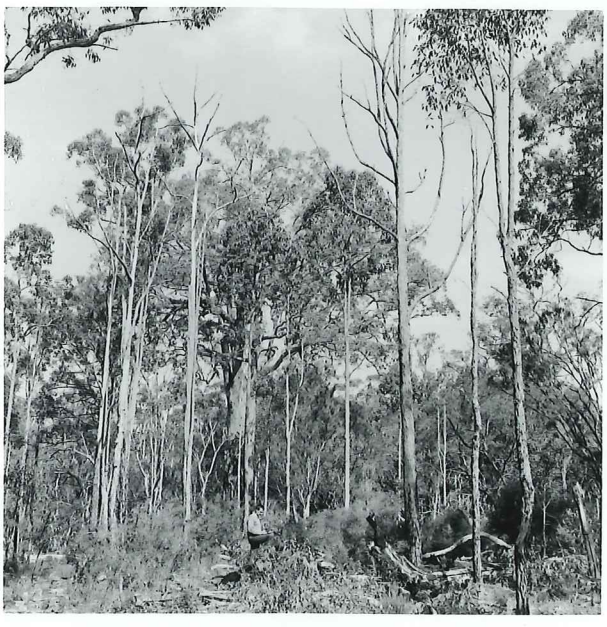
Banksiadale Compartment 6. Stagheaded condition in a jarrah tree in the area of plate 5. The crown is almost entirely composed of secondary epicormic growth. This is typical of the nature of veteran and tree crowns in many places. Where this condition is not associated with dieback it would be described as "crown deterioration" by Western Australian foresters.

Plate 5.

A disordered pole in the dieback occurrence shown in plate 6. Here much of the epicormic growth as well as the primary crown has died.

Plate 6.

A dieback occurrence of recent origin in a mixed pole and veteran stand. This occurrence is on a ridge top at 1,100 feet elevation - a high point in this locality. The poles have died in the last 2 - 3 years. The dense crowned saplings are marri and the scrubby fastigiate tree in the background is Casuarina fraseriana. Dead Banksia grandis can be seen to the left of the figure.



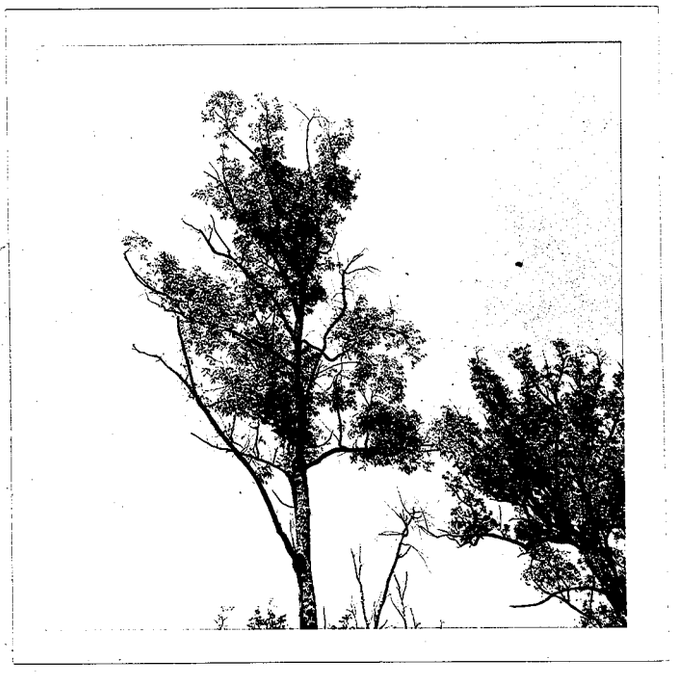


Plate 7.

Teesdale Block.
A small recent occurrence in part of a area of several hundred acres throughout which small groups or individuals have died. This type of situation is most common on low ridges where extensive older occurrences are found in the gullies and gully heads. See plate 9 which is within 200 yards. The occurrence shown here would be too small to be mapped as a seperate unit by air photo interpretation.

Plate 8. Marrinup Compartment 12.
Part of an extensive occurrence. Here in a low lying area there is a considerable stocking of marri veterans. None of the jarrah is now alive and the marri is unhealthy.

Plate 9.

Teesdale Block.
A completely dead area in what has been good quality forest. Note that many of the Xanthorea priisii specimens are alive even though this occurrence is more than ten years old.

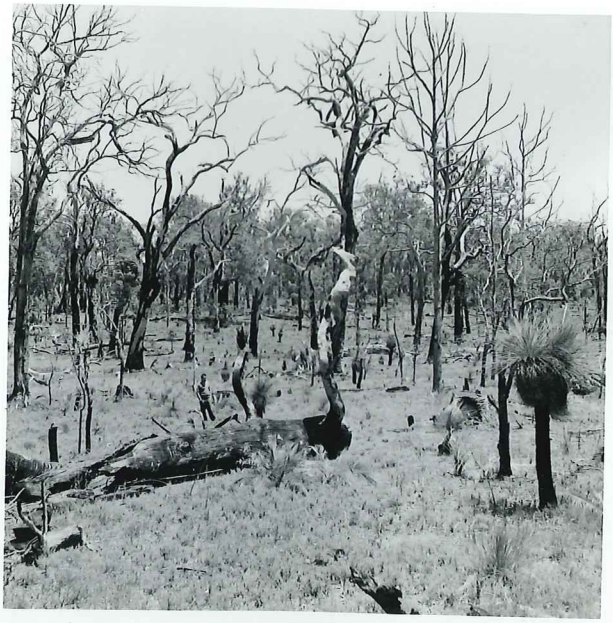


Plate 10.

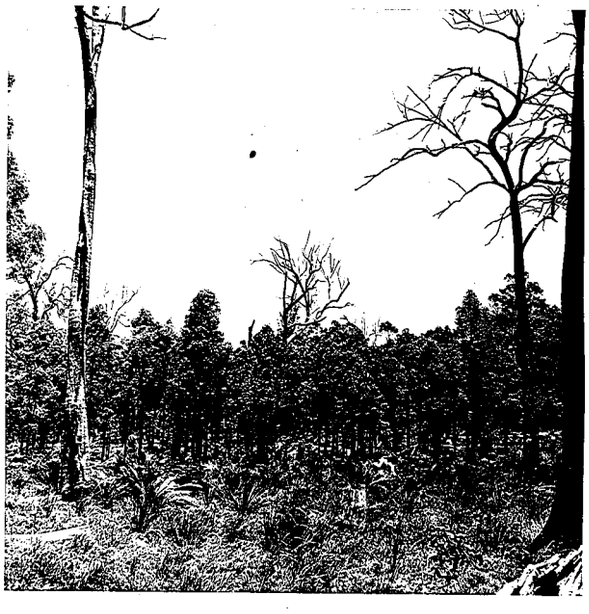
Teesdale study area.
Disordered marri veteran. Almost the entire crown is epicormic and much of this growth has already died. This condition is common in much of the marri around Dwellingup this year.

Plate 11.

Bark splitting in a marri pole. The top of this crown is extremely unhealthy and carries only a few senile yellowed leaves.

Plate 12.

A dense group of young marri saplings on the Teesdale study area. These have arisen from a veteran seed tree which grew in the centre of this group, but has now fallen.



SCADDAN
SWAN
PERTH
COLLIER
FREMANTLE
SOMERVILLE
ARMADALE
MUNDARING WEIR
YORK
BEVERLEY
BERAKING
MT DALE
GLENEAGLE
JARRAHDALE
PINJARRA
DWELLINGUP
MURRAY
RIVER
DWARDA
DRYANDRA
HAMEL
Mc LARTY
NARROGIN
WILLIAMS
HARVEY
HARVEY WEIR
MYALUP
BUNBURY
COLLIE
BOWELLING
WACIN
STIRLING
BUSSELTON
COOLILUP
DONNYBROOK
J.C. WILLCOCK
KIRUP
GRIMWADE (E. KIRUP)
KATANNING
METRICUP
Jalbarragup Road
BOYUP BROOK
KEENAN
MARGARET RIVER
NANNUP
BRIDGETOWN
BLACKWOOD
JALBARRACUP
BORANUP
DONNELLY
MANJIMUP
RIVER
CRANBROOK
AUGUSTA
WARREN R.
PEMBERTON
FRANKLAND
NORTHCLIFFE
PARDELUP
MT BARK
DEEP R.
NORNALUP
ALBANY

Major Developement

Other Occurences

Deaths
endoo.

JARRAH DIEBACK.

To illustrate main occurence and spread
(not complete nor precise.)

NORTHAM
YORK
SWAN RIVE
SCADDAN
NANGARA
PERTH
COLLIER
MUNDARING WEIR
FREMANTLE
SOMERVILLE
BEVERLEY
ARMADALE
BERAKING
MT DALE
GLENEAGLE
JARRAHDALE
PINJARRA
DWELLINGUP
MURRAY
DWARDA
DRYANDRA
RIVER
HAMEL
NARROGIN
Mc LARTY
WILLIAMS
HARVEY
HARVEY WEIR
MYALUP
BUNBURY
COLLIE
BOWELLING
WACIN
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STIRLING
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BRIDGETOWN
BLACKWOOD
JALBARRACUP
BORANUP
River
MANJIMUP
CRANBROOK
DONNELLY
WARREN R.
FRANKLAND
AUGUSTA
PEMBERTON
PARDELUP
NORTHCLIFFE
DEEP R.
NORNALUP
ALBAN
Major Developement
Jarrah Dieback
Other Occurences
Patch Deaths Wandoo.
JARRAH DIE BACK.

PINJAR
GNANGARA
SCADDAN
SWAN RIVER
NORTHAM
YORK
PERTH
MUNDARING WEIR
COLLIER
FREMANTLE
SOMERVILLE
BEVERLEY
ARMADALE
BERAKING
MT DALE
GLENEAGLE
JARRAHDALE
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NARROGIN
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ALBAN

Major Developement

Other Occurences