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FOREST RESEARCH INSTITUTE

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PROJECT W.A.4

PROGRESS REPORT NUMBER 1.

This report considers a number of hypotheses advanced by earlier workers as explanations of the cause of jarrah dieback. These hypotheses were all erected on the basis of disturbance of the natural balance and in terms of the syndrome definition of Wallace and Hatch. Some of the investigation in this and two reports to follow, was carried out by the writer between 1959 and 1964. These earlier hypotheses and investigations have no where else been reported in a single document. They are documented here for future reference even though not one of the hypotheses advanced can satisfactorily account for the entire jarrah dieback syndrome as it is now known. Currently, explanation of the disease syndrome is made in terms of introduction to the jarrah forest of a primary pathogen, *Phytophthora cinnamomi*. Investigations of this last hypothesis are continuing and will be reported separately at a later date in the fourth progress report.

In this report, and the two to follow, hypotheses of jarrah dieback cause which are related to disturbance of the balance among intrinsic factors of the environment, are considered. The possibilities of nutrient decline and excess concentration of ions, is considered in the first report; in the second report drought, and in the third waterlogging are investigated.

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Review of Possible Causes of Jarrah Dieback.

There is a wide range of possible causes of disease in native forests. Of the many possibilities those based on disturbance of the balance among existing factors in the ecosystem seemed to give better account of the disease syndrome, as it was known in 1959, than did hypotheses based on the introduction of new factors, either living or abiotic. This view was consistent with the emphasis which Hamilton (1951) and Wallace and Hatch (1953) placed on the very strong association of the disease with logged stands on marginal sites, and the apparent stabilisation of many dieback areas.

Though serious disease of forest trees may be caused by exotic pathogens and by toxic wastes from industrial plants, consideration of these factors suggested that they were unlikely to be the cause of jarrah dieback.

The pathogenic importance of air pollution has been reviewed by Boyce (1948), by Scurfield (1960) and by Hepting (1964). Deleterious effects of industrial wastes are usually associated with proximity to large industrial plants, particularly those releasing heavy concentrations of sulphur dioxide (Boyce 1948). The quantity and composition of industrial waste gases from Perth would seem hardly sufficient to cause extensive and serious damage. Further, there is little sign of dieback in jarrah stands close to the major industrial complex of Cockburn Sound. By contrast, extensive dieback occurs in stands more than 50 miles distant from any significant heavy industry; a distance considerably in excess of the typical ranges given by Scurfield (1960). Even if these limits were exceeded it is difficult to envisage a pattern of deposition of such toxins which was consistent with the pattern of dieback occurrence, particularly the presence of healthy trees within a few feet of diseased trees, and the existence of sharp boundaries between healthy and diseased forest which occur in many dieback situations.

It was decided therefore, to examine those hypotheses which were based on disturbance of the natural balance and were consistent with a disease which :-

1. Affected the survival of a wide range, but not all, the flora.
2. Was closely associated with -
   (a) logging operations
   (b) forest of marginal quality
   (c) shallow infertile soils
   (d) specific topographic situations.

<u>Disturbance of the natural balance.</u>

Disturbance of natural balance is a factor influencing disease in natural communities of woody perennials. It may influence the health of plant communities directly by altering the values of physical factors of the environment, or indirectly by affecting the activity of biological agents - both those that may be beneficial and those which are pathogenic. The role of pathogenic organisms in this disease had been discussed by Harding (1949) and by Stahl and Greaves (1959). They found no consistent evidence of a known pathogenic organism. There are few, if any, reports in the literature to 1960 of microscopic pathogens which destroyed a wide range of species in a single plant community. It was considered at that stage therefore, that if pathogenic organisms were involved they were probably secondary.

In 1960 attention was therefore directed to hypotheses which accounted for the disease syndrome (as described by Wallace and Hatch) in terms of change in the physical environment. Where such changes represent a deterioration of the local environment in respect of the requirements for growth and survival of the plant community, the effects are embraced by the broad concept of site deterioration.

Site Deterioration.

Earlier workers had proposed that jarrah dieback might be explained by the deleterious effects of trade cutting and fire in critically altering the values of site factors in locations already marginal for the growth of jarrah. Hamilton (1951) proposed a very broad and complex hypothesis involving increased erosion, leaching and insolation in the surface soil leading to increased evaporation and decreased capacity for storage of nutrients and water. Loneragen (1962) considered that cutting increased the amplitude of variation between summer dessication and excess soil moisture in the winter, with adverse effects on the root systems of susceptible species. Wallace and Hatch (1953) reported detailed examination of soil nutrient levels and soil physical factors but found no marked evidence of soil degradation. Waring (1950) emphasised poor aeration and possible mobilisation and accumulation of toxic ions in water-gaining situations.

These changes could affect root growth, and thus plant health, through their effects on soil temperature, availability of soil moisture, and physical and microbiological factors influencing nutrient cycles.

The importance to the plant community of disturbance in the level of factors which affect plant growth will depend upon the degree of disturbance in relation to the factor compensation or "buffering" capacity of the whole site and upon the tolerance of the plants involved.

Site deterioration thus is necessarily a complex phenomenon. No single factor in a natural system may be adjusted without effects on other interdependent factors. A single factor, however, may play a dominant role in plant health where that factor approaches the extreme value tolerated by the plant (Daubenmire 1959). This situation is most likely to arise on sites with near limiting values in several factors since such sites have poor buffering capacity. In any one plant community the particular combinations of factors and their relative values vary in both time and space. In some situations relatively small changes may be sufficient to initiate a general decline.

Hamilton suggested such critical changes were the results of cutting and burning on sites "which are marginal for the growth of jarrah". He did not define, however, which of the site factors or plant growth determinants were most sensitive to change. Since there was little knowledge of the tolerances of jarrah to specific ecological factors it was not immediately possible to single out specific conditions to which jarrah might be particularly sensitive. Some of the single factor hypotheses suggested by earlier workers were therefore examined with the purpose of finding a basis for a more precise statement of the site deterioration hypothesis. These single factor analyses were made in the knowledge that no one factor may be actually separated from the ecosystem and appreciating that factor analysis is but "an expediency to permit a complex interdependent and continuous system to be investigated with present procedures", (Hopkins 1963).

Among the many changes leading to site deterioration which had been advanced as likely to be important in the development of jarrah dieback were :-

i) Decline in nutrient availability

ii) Soil toxicity

iii) Excessive soil temperature

iv) Moisture deficiency

v) Excess soil moisture

None of these changes alone could account for the whole syndrome, but they are examined because dieback, in some places, might be due to one cause, and in other places to another of the changes, or combination of changes.

Decline in nutrient availability as a possible cause of jarrah dieback.

Plant nutrient levels may be reduced on a site by :-

1) Removal from the site in processes of leaching, erosion or combustion.

2) Conversion to compounds which are less readily absorbed by the plant.

3) Incorporation in other organisms within the ecosystem which renders them temporarily unavailable.

4) Removal from the site by man.

Hamilton (1951) suggested that cutting might reduce the availability of nutrients by accelerating some of these mechanisms.

Such an hypothesis of dieback cause was consistent with the effects of cutting and with the reported restriction of dieback to poor quality forest on infertile and marginal sites, and with its marked association with cutting. These conditions were regarded as characteristically occurring in specific topographic situations such as gully heads. Nothing was known, however, of the relative tolerances to nutrient deficiencies of the various species in the flora so that it was not then possible to determine whether the nutrient deterioration hypothesis was consistent with the observed range of reactions of the species.

This hypothesis, however, was amenable to test on the basis that the levels of available forms of plant nutrients in soils or plant tissue should be lower in dieback affected trees or soils than from unaffected forest. Wallace and Hatch (1953) reported that in leaf ash analyses for Ca, Mg, K, Mn, P and N and soil analyses for Ca, N, P, K, there were no differences which could not be accounted for by a reduction of litter accession following the death of trees. In other words, such differences as did exist were more likely a consequence of dieback than a cause, (Hatch 1964).

The nutrient deficiency hypothesis is further weakened by the later discovery of extension of dieback on to more fertile and deeper soils.

<u>Soil Toxicity.</u>

The health of a plant may be disturbed by the effects on its metabolism of toxic concentrations of inorganic ions absorbed by the plant from the soil; by toxic exudates of other living organisms and microbes and by accumulation of toxic concentrations of by-products of the breakdown of organic residues in the soil. These effects may be grouped as soil toxicity effects, though they may be part also of the broader concept of soil sickness. Such effects may be generally phyto-toxic or specific depending upon the concentrations and upon the nature of the agent involved.

Toxicity due to increase in ion concentration.

Increased mobilisation of various ions and their accumulation in soluble forms at lower points in the topography have been suggested as possible causes of dieback. Stoate (1948) considered that jarrah dieback might be related to the deaths of native vegetation on salt encroachment areas in the farmlands to the east of the jarrah forest. Waring (1951) considered this to be unlikely but agreed the possibilities warranted investigation. He suggested the possible mobilisation of heavy elements such as chromium and vanadium and their accumulation in water gaining situations. Stahl (personal communication) had suggested the role of aluminium and manganese toxicity should be investigated.

There are few references in the literature to such effects in natural stands of forest trees or other natural vegetation although in undisturbed conditions the distribution of plants is determined, inter alia, by the tolerances of individuals to the various constituents of the substrates on which they occur. Thus salt sensitive plants are naturally excluded from saline soils. In some situations the concentrations of soil constituents may be so phytotoxic to all plant forms that the areas remain barren of vegetation (Daubenmire 1959). Since plant communities tend to a dynamic balance with their environment or disappear, the tolerances of various species to specific soil conditions, including ion concentrations, determines their natural distributions. For example, Winterhalder (1963) has demonstrated Mn toxicity responses in E.gummifera grown experimentally on rain forest soils from which the species is excluded in nature. E.saligna, which occurs naturally on the higher Mn rain forest soils, showed no toxicity symptoms.

Serious disturbance of plant metabolism in a community growing naturally on a soil to which it has adapted is, therefore, unlikely to be caused by excess ions (Walker 1951), (Wilde 1957). Such disturbance may, however, occur where plants are grown on sites other than those on which they naturally occur or where there has been disturbance of the natural environmental balance. Woods (1955) has attributed deaths of P.radiata to salt toxicity. Nemec (1948) has described a growth stagnation of Scots Pine (Pinus sylvestris), which is associated with toxic levels of aluminium in degraded soils of poor aeration and increased acidity. There are many examples in crop husbandry and horticulture of the association of plant disease with accumulation in plant tissues of toxic levels of ions such as Boron, Manganese and Aluminium in acid and in poorly aerated soils. In all cases plant ranges of tolerance occur (Walker 1957). Walker concludes also that these effects "are in the main chronic and appear as the result of gradual increases in inimical concentrations of one or more ions so that growth depression may progress slowly for a long period without marked symptoms developing".

The possibility of increased soil salinity.

There are a number of similarities between jarrah dieback and the soil salinity problem of the higher rainfall zone. This is particularly apparent in the association of the troubles with logging on the one hand, and clearing on the other. There was also at the time, similarity in the association of both troubles with defined topographic situations and soil types and with the apparent extension of the areas in the early stages.

This problem affects the native vegetation where it has been retained in susceptible areas. Perhaps the earliest references of wide-spread dying of native vegetation in south western Australia, refer to mass dying of Eucalyptus woodland in the 11" - 25" rainfall zone. This dying followed extensive clearing of adjacent higher country and was associated with increase in the amount and salinity of ground waters and the development of bare patches on which grows only salt tolerant samphire (Salicornia sp) (Wood, 1923, Burvill 1946, 1955). All other vegetation, including eucalypts, eventually dies out. Among the many species affected are Salmon Gum (E.salmonophloia.F. Muell), York Gum (E.loxophleba. Benth), and E. wandoo. Blakely).

The manifestations of this trouble vary in different parts of the agricultural area (Burvill 1946). In the higher rainfall (15" - 25") areas the affected areas commonly occur on or near drainage lines "either near the sources of gullies or along their edges or on extensive flats". Limited examples of this type may be seen within the jarrah forest zone close toward its eastern boundary. Problems of salt accumulation, however, are generally problems of semi-arid areas. Similar troubles have been reported from semi-arid areas of Victoria (Leeper 1957).

Increasing soil salinity in Western Australia has received considerable attention as an agricultural and soil conservation problem, (Teakle and Burvill 1938, Burvill 1946, 1955), and as a water purity problem (Wood 1923, Anonymous 1951). There have been more detailed investigations (Smith 1962, Bettenay, Blackmore and Hingston 1964) to determine its cause. These latter reports confirm the earlier conclusions of Teakle and Burvill but give a more detailed account of the probable mechanism. Clearing has disturbed the natural equilibrium present under native vegetation, by increasing run off and recharge of aquifers. This leads to more frequent rise of salt bearing ground waters to the surface, and the deposition of salts, predominantly sodium chloride, in the previously "salt free" surface horizons. Leeper (1957) has offered a similar explanation for the development of salt encroachment in semi-arid Victoria.

In view of the general absence of an agricultural soil salinity problem in the areas with rainfall exceeding 30" per annum it is necessary to postulate that jarrah and its susceptible associates are sensitive to lower concentrations of salts than are either the resistant species in dieback areas or the agricultural crop and pasture species commonly grown in these higher rainfall areas. Plant species are known to vary considerably in tolerance to soluble salts (Russell 1950, Leeper 1957). Although there are no data available for the species of the jarrah forest, it has been suggested (Ridley personal communication) that eucalypts in the subgenus Renantherae (Pryor 1959), to which jarrah belongs, are intolerant of relatively low concentrations of soluble salts. Ridley states that he has found no record of members of the Renantherae occurring on soils undergoing salinisation. It is possible that jarrah is so sensitive to salts that disease may occur at concentrations lower than those necessary to cause efflorescence of salts on the soil surface.

The hypothesis would be supported by evidence of :-

1) A higher level of soluble salts in dieback soils than in adjacent unaffected soils, and accumulation of higher levels of specific ions, e.g. chloride in plant tissues from dieback areas.

2) A positive correlation between stream salinities and the proportion of diseased areas on dieback affected catchments.

3) A clear pattern of association of the disease with logging and a low incidence, or its absence, in extensive undisturbed areas.

The evidence on these points as shown below, is in fact, to the contrary.

Levels of soluble salts in field soils.

Hatch (1964) carried out a series of analyses on a range of lateritic soils from the jarrah forest which showed that water soluble salts were low in all surface horizons. He found a mean value (n=72) of 0.014% and a SD = ± 0.005. Of this total chlorides, calculated as sodium chloride, comprised from one-third to one-half. In a separate study (Wallace and Hatch 1951), soils from diseased forest and from nearby unaffected forest were examined at three localities. Their data for water soluble chlorides (expressed as sodium chloride percent) in the A and B horizons are shown in Table 1.

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Table 1 (Extracted from the data of Wallace and Hatch)

Water Soluble Chloride expressed as Sodium Chloride.

	Healthy Forest			Dying Forest		
	Mean	Range	No.	Mean	Range	No.
Teesdale	0.008	0.007	9	.008	0.023	13
Huntley	0.002	.005	16	.004	.011	13
Farleys	0.017	.066	21	.014	.043	18

Wallace and Hatch (1951) concluded that there was no evidence of salt accumulation in the soils examined, despite annual accretions of salt from rainfall of the order of 100 lbs/acre/annum in this area, (Hatch, unpublished 1953). These levels are well below the limits of tolerance for general crop purposes of 0.1% suggested by Leeper 1957.

Analyses of soils from pot trial number 1, Project W.A.4, indicate that jarrah will tolerate higher levels of total soluble salts. In that trial jarrah seedlings were grown in the greenhouse in 6" pots of field soil taken from a dieback area and fertilized at weekly intervals. Seedlings died in the untreated soil but grew well in steam sterilised soil. Three pots of each soil were air dried, screened to 2 mm and specific conductivities of 20 gram (air dry weight) samples determined on a Philips measuring bridge and converted to total soluble salts % after the methods described by Piper (1942). The data are presented in table 2.

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Table 2. Total soluble salt content % of soil containing healthy and dying jarrah seedlings grown on steamed and untreated soil.

	Steamed Soil	Untreated Soil
Replication 1	0.18	0.26
" 2	0.36	0.16
" 3	0.42	0.16
Mean	0.32	0.19

Stream salinities in relation to extent of dieback.

The forests on most catchments which rise in the eastern parts of the jarrah forest and discharge into larger streams before reaching the western zone have relatively little dieback. By comparison, forests on many of the more westerly catchments are severely affected with dieback. Stream salinities are, however, inversely related to the extent of dieback in the forests on their catchments. The catchments listed in table 3 are ranked for extent of dieback. Mean annual stream salinity values (in grains per gallon) are shown for the years 1955, 57, 58 and 60-63. This data has been derived from Department of Public Works' analyses of regular monthly samples taken at fixed gauging stations. These years are the only years available to 1963 when monthly data for all stations was available.

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Table 3. Dieback rating in relation to stream salinities in grams per gallon for five jarrah forest catchments for the period 1955, 1957-58 and 1960-63.

Catchment	Dieback Rating	Mean Max.	Absolute Max.	Absolute Min.
Bancells Brook	Severe	9	11	4
Logues Brook	Severe	10	14	4
North Dandalup River	Moderate	17	22	6
Davies Brook	Very Low	19	20	8
Yarragill Brook	Low	43	52	12

It is recognised that certain species are more highly susceptible to soil salinity than others. Churchill (1961) regards the Restionaceae as a salt sensitive group; their ecological position on saline soils is taken by members of the Cyperaceae. Representatives of the Restionaceae family, particularly species of Loxocarya, dominate many old dieback areas. Further, the good health and regeneration of the normally salt susceptible species, E. wandoo and E. rudis on jarrah dieback areas at the 46 mile and 45 mile pegs on the Brookton Highway in the 25" rainfall zone, is not consistent with soil salinity as a cause of dieback. These species succumb in saline areas less than ten miles further east near the Dale River.

Dieback has more recently appeared in areas where there has been little recent disturbance by clearing or cutting. The main examples of this are in the low plateau of the Blackwood, an area which receives regular winter rainfall of high intensity - conditions which give rise to podsolisation processes and which are generally regarded as not conducive to the accumulation of soluble salts within the profile.

In not one of the aspects tested does the soil salinity hypothesis satisfactorily account for the observed phenomena.

Metal Ion Toxicity.

Waring (1950) suggested toxic concentrations of elements such as manganese, chromium vanadium and titanium might be responsible for dieback. He considered that cutting may have brought about changes which increased the mobility of these elements and allowed their concentration in basin-like and water gaining situations in which dieback generally occurred. Stahl (personal communication) had suggested aluminium and manganese toxicity might be responsible for deiback. Many elements may be toxic to plant growth where they occur in excess concentrations in the ionic state (Meyer and Anderson 1939). Such toxicity is, however, rare in natural forests (Wilde 1957).

Boron toxicity has been reported for horticultural crops, including apples and pears (Grasmanis 1958, Berg, Clulo-Berg and Orton 1958). It is unlikely, however, that toxic levels of Boron occur in jarrah dieback areas since boron sensitive crops, e.g. apples and pears, grow well on cleared jarrah dieback sites in the Pickering Brook area. Boron levels in lateritic soils in South Western Australia have been shown to be low and to progressively increase eastward (Hingston 1966).

Iron, manganese and aluminium toxicity are typically problems of highly acid soils or poorly aerated soils (Leeper 1952, Russell 1950, Meyer and Anderson 1939). There are many references to aluminium and manganese toxicity which refer to disease of crop plants on flooded soils (Tarasova and Khlebnikova 1950), (Gasser 1956), (Grasmanis 1958). On highly acid soils legumes (Rovison 1958), kale, lettuce, sugar beet and potato (Hale and Heintze 1946) and conifer seedlings (Duchaufor and Rousseau 1959) are reported to be affected by toxic levels of these ions.

The possibility that such toxicity causes jarrah dieback is not consistent with the mildly acid condition of the jarrah forest soils or with the occurrence of dieback on well drained sites. Hatch (1964) has measured a measured pH of a range of jarrah forest soils and found a mean pH of 6.40 ± 0.32 for n = 72. In an earlier study Wallace and Hatch (1953) compared with pH of soil solution at several points in the profile on ten dying sites with ten unaffected sites. They found a pH range 5.5 to 6.8 in dying areas and 6.1 to 6.9 in unaffected areas. These pH levels are well above those normally associated with toxicity by iron, manganese and aluminium. Leeper (1957) has suggested that levels of 15 p.p.m. at pH 4.5 is a level which many plants will not tolerate. The only reference to toxic accumulation at pH greater than 5.5 seen, is that of Grasmanis (1958) who reported association of Mn excess with bark necrosis in apples. This uptake occurred in anaerobic conditions under constant waterlogging in soil with pH values in the range 6.3 to 7. Jarrah forest soils contain very high levels of iron and aluminium and, in places, commercial grades of hydrated aluminium ores are mined. There was early interest by mining exploration geologists in the dieback barrens because of the association of high grade bauxite ore deposits and natural barrens in the West Indies. Elkington (personal communication) reported that contrary to expectation, high grade ores were found mainly under ridge tops and not in the typical dieback gullies. If site disturbance had in some way caused toxic levels of these ions to come into solution without reducing pH markedly, then higher levels would be expected in the tissues of plants growing in dieback areas than those in unaffected areas.

Wallace and Hatch (1951) found for folia manganese the opposite to be the case. In colorimetric determination for manganese on acid digested dried leaves they found the values of table 4.

Table 4. Foliar manganese in parts per mission of two species growing in dieback and in unaffected areas (extracted from data Wallace and Hatch).

	E.marginata		E.calophylla	
Replication	Dieback	Unaffected	Dieback	Unaffected
1	62	204	87	121
2	82	164	40	192
3	228	293		
4	132	112		
5	104	114		
6	128	150		
Mean	122	173	63	156

Foliar manganese was also determined on seedlings grown on untreated and on unsterilised soil from a dieback area in which seedlings had failed and grown well respectively, i.e. seedlings from Experiment 1, Project W.A.4. The data presented in table 5 are consistent with Hatch's earlier field data.

Table 5. <u>Foliar manganese in p.p.m. in jarrah seedling leaves grown on (a) sterilised, and (b) unsterilised soil from a dieback area.</u>

	Replication 1	2	3	Mean
Sterilised	307	157	367	277
Untreated	144	110	106	120

The evidence of higher levels of Mn in healthy plants than in diseased is not consistent with the view that levels of Mn in dieback soils may be toxic to jarrah. By contrast, aluminium toxicity is not necessarily associated with accumulation of Al ions in foliar tissues; Russell (1950) states that it accumulates in the roots and interferes with phosphorous absorption. Because of the high levels of Al occurring naturally in jarrah forest soils the chances of obtaining root material free of surface contamination were considered too high to warrant analysis of root tissues for absorbed aluminium. However, early good growth of aluminium sensitive species on dieback soil would require rejection of the hypothesis that dieback is due to aluminium toxicity. Barley is reported to be particularly sensitive to aluminium (Meyer and Anderson 1939, Hewitt 1947). According to Hewitt (1948), oats is tolerant of high aluminium; Foy and Brown (1964) by contrast, consider oats to be a sensitive test plant. Two 4" pots of unsterilised soil of Experiment 1, Project W.A.4, in which jarrah seedlings had died, were therefore resown to three species jarrah, Mugga oats and Prior barley. The jarrah died in the seedling stage but both cereals grew well, produced healthy root systems, set seed and matured.

It is concluded that jarrah dieback is not due to aluminium, manganese or boron toxicity. Because of the evidence of other investigations reported elsewhere, are now so strongly indicative of the role of a soil borne pathogen, the toxicity of other elements has not been considered.

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