J. W. Gottstein Memorial Trust Fund

The National Educational Trust of the Australian Forest Products Industries



OBSERVATIONS OF EUCALYPT DECLINE IN TEMPERATE AUSTRALIAN FORESTS AND WOODLANDS

VIC JURSKIS

2004 GOTTSTEIN FELLOWSHIP REPORT

JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are,

- Fellowships and Awards each year applications are invited from eligible candidates to submit a study programme in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.
- 2. Seminars the information gained by Fellows is often best disseminated by seminars as well as through the written reports.
- 3. Wood Science Courses at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.
- 4. Study Tours industry group study tours are arranged periodically and have been well supported.

Further information may be obtained by writing to,

The Secretary, J.W. Gottstein Memorial Trust Fund, Private Bag 10, Clayton South, VIC 3169, Australia The information contained in this report is published for the general information of industry. Although all reasonable endeavour has been made to verify the accuracy of the material, no liability is accepted by the Author for any inaccuracy therein, nor by the Trustees of the Gottstein Memorial Trust Fund. The opinions expressed are those of the author and do not necessarily represent the opinions of the Trustees.

Copyright © Trustees of the J.W. Gottstein Memorial Trust Fund 2004. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior written permission of the Trustees.



Vic Jurskis graduated from Australian National University with a Bachelor of Science (Forestry) in 1976. He has been employed as a fieldworker, forester, researcher and manager in New South Wales' forest service, and is a member of the Institute of Foresters of Australia. He has worked in rainforest, eucalypt and cypress forests as well as plantations of native and exotic conifers and hardwoods on the coast, tablelands and western plains. In his current position as Silviculturist, he is particularly interested in the role of low intensity fire in maintaining health, productivity and biodiversity in eucalypt forests and woodlands. He is concerned at the increasing problems of forest decline and high intensity fire regimes in multiple use forests and conservation reserves.

EXECUTIVE SUMMARY

This is a report of a brief study tour of forest and rural tree decline in south-western Australia, Tasmania and south-eastern Australia. There were many similarities amongst the different cases examined, even though a wide range of pests, pathogens and parasites were associated with them. Unfavourable climatic conditions, especially drought, were associated with many cases, however decline typically occurred low in the landscape on sheltered or water-accumulating sites. Acute drought stress was apparent on some more exposed sites. There were often contrasts in the health of the same tree species in the same climatic conditions under different management, especially different fire and grazing regimes.

Forest decline is a major issue that must be addressed to achieve sustainable forest management in both conservation reserves and multiple use forests. It is recommended that management adapts by reinstating more frequent fire regimes to better protect the health of eucalypt ecosystems, and that research focuses on factors such as fire and grazing regimes, that can be managed, rather than on particular pests that are symptomatic of declines. To restore degraded or cleared eucalypt ecosystems it is necessary to establish vigorous eucalypt regeneration. Competition from other vegetation must be minimised. Exclusion of fire and grazing does not generally appear to be a successful technique for ecological restoration, except in the seedling establishment phase.

SCOPE OF THE STUDY

I visited Western Australia, Victoria and Tasmania over three weeks between 23rd February and 23rd April 2004 to examine and discuss eucalypt decline in native forests and woodlands, seeking an improved understanding of its fundamental causes. A list of individuals and organisations consulted is appended to this report. Tuart decline, wandoo decline, flooded gum dieback, *Phytophthora cinnamomi*, jarrah decline, *Armillaria luteobubalina* in karri, and Mundulla yellows were examined in Western Australia. In Victoria I examined red gum decline in East Gippsland, decline in various reserves around Melbourne including bellbirds, sheoak invasion, koalas, and *Phytophthora cinnamomi*, also *Armillaria luteobubalina* at Mount Cole, and rural/roadside decline. In Tasmania, I examined 'regrowth', 'gully', 'high altitude', 'east coast', and 'rural dieback' as well as decline and shrub invasion in dry forests.

This report outlines background information that was provided to me or discussed during the study tour, and my own observations of the various situations, before drawing some general conclusions and making some recommendations. The background information does not necessarily concur with my views, nor do my conclusions necessarily concur with the views of those I consulted. I have not specifically acknowledged each source of background information because there are so many that it would make this report difficult to read. However, the discussions and information so generously provided will contribute to a detailed review that I expect to complete in the future.

CASE STUDIES OF EUCALYPT DECLINE

Tuart decline

Background information

Since the mid 1990s, tuart (*Eucalyptus gomphocephala*) forest and woodland around Yalgorup, south of Mandurah, has suffered severe attack by the tuart borer (*Phoracantha impavida*) and the bullseye borer (*P. acanthocera*). These borers may girdle stems and branches causing crown deterioration and some death. There was a particularly severe outbreak in 1997. Some of the suggested causes are tree stress due to reduced winter rainfall (including an especially dry period in 1993/4), lowered fresh water tables and/or increasing salinity due to low rainfall and/or water extraction for agriculture, increased understorey competition due to reduced grazing and/or burning, exposure due to clearing, changes in nutrient uptake by tuart as a result of changed hydrology, changes in ecological balance between borers and their predators, and an unusual frost in 1997 (Anon. 2002).

Tuart decline was first noticed in the early 1990s around Martins Tank where decline is now most severe. Stands further north and south at Yalgorup are less affected. Tuart decline is not regarded as a problem at Yanchep and Ludlow. At Yalgorup decline may be most severe in low lying areas and on shallow soiled limestone ridges, and less severe on deeper sands. There is a view that tuart decline at Yalgorup is connected with the 'unique' hydrology, and different to areas further north and south where there is 'background decline' or decline that is clearly attributable to human management. Long term measurements by the Waters and Rivers Commission apparently do not indicate any lowering of water tables or thinning of freshwater 'lenses', however there appears to be some suspicion of these measurements in sections of the community. Runoff from the tuart forest around Yalgorup drains either to the lakes or to the Harvey Estuary. An artificial opening has been created to the Indian Ocean through the Dawesville Channel to reduce eutrophication and algal blooms in the Harvey Estuary.

Another view is that decline is associated with competition from dense understoreys that developed following reduced burning in the 1950s and removal of grazing in 1968. Parallels have been drawn with high altitude dieback in Tasmania and structural changes, pests and disease problems in formerly open ponderosa pine forests in USA. Development of dense peppermint understorey was seen as a problem from the early years of forest management, but has become more prominent since the 1960s. On the other hand it has been suggested that competition from dense peppermint understoreys is not an important factor in the decline, because stands with grassy understoreys are also declining, and because peppermint is a natural component of tuart forest. David Ward's investigations indicated that fires occurred in the tuart at about 3 yearly intervals prior to the 20th Century, and that this regime was maintained by graziers in some parts until the 1960s.

Tuart regeneration in the 1996 wildfire area at Yalgorup supports high populations of borers. Young and vigorous regrowth of tuart has survived heavy borer attack in the past (Bradshaw 2000). Some mature tuart stands around Perth recovered from episodes of borer attack during drought in the late 1960's. Large, healthy epicormic derived trunks are now growing from old trunks with dead leaders. Similar trees are visible around Yalgorup indicating that dieback and recovery episodes have previously occurred there as well. There appears to be some ambivalence towards borers as either an inciting or contributing factor in tuart decline (e.g. Anon. 2002).

The Tuart Response Group has published an atlas that categorises and tabulates canopy density and understorey condition of tuart on the Swan Coastal Plain. A three year, \$ 0.5 million research program is investigating tuart decline. It aims to understand the physiology of tuart in relation to water and nutrient use; describe and compare the morphological and physiological condition of healthy and declining tuart in relation to soil type, salinity, and water tables; determine whether pathogens are associated with tuart decline; describe the insect fauna of healthy and diseased tuart; examine the impacts of planned fire, and understorey competition, on health of tuart. The research findings will be used to adapt the Yalgorup National Park Management Plan, and to develop strategies that will provide land managers and community groups with appropriate tools to reduce and manage the impact of tuart decline (D. Haswell pers. comm.).

Bradshaw (2000) has recommended schemes to establish tuart regeneration and to create and maintain a range of understorey structures. All the schemes include substantial mechanical disturbance and burning because tuart regeneration is heavily dependent on ashbed (Bradshaw 2000). Managers would need to specify the desired mix of areas of savannah and scrub understoreys.

Field observations

In Yalgorup National Park, tuart in lower topographic positions generally appeared to be more severely declining than in higher areas. A very low quality stand with a dense heathy understorey on a limestone ridge appeared to be healthy. Decline did not appear to be as severe in mixed-species stands, but jarrah (*E. marginata*) appeared to be similar in health to tuart, whereas marri (*Corymbia calophylla*) was relatively healthy. At Preston Beach, two tuart trees with bitumen seal over their roots right up to their trunks were very healthy.

Tuart saplings in declining stands appeared to be generally healthy. The 1996 wildfire area had a high density of vigorous saplings (10-15 cm dbh) which did not appear to be adversely affected by the high numbers of borers that they supported. There was a pronounced 'mounding' effect where regeneration in small hollows and depressions was spindly (1-2 cm dbh), heavily attacked by *Mycosphaerella*, and appeared to have no future. Dense regeneration of understorey species had also occurred and there was a deep litter layer. Fuel levels appeared to be extremely high, and there was a dense ladder of green fuel between the ground fuels and the regenerating tuart canopy.

The 'epicentre' of tuart decline at Martins Tank had the appearance of typical rural dieback followed by regeneration after 'destocking'. It had fencing and other 'improvements', and widely spaced dead eucalypts with relatively young regrowth of understorey species, as well as some jarrah and marri.



Figure 1

Stands with dense peppermint (*Agonis flexuosa*) understorey were in poor condition, however open, grassy stands varied from healthy to dying. Contrasts in stand condition between different 'paddocks' were visible (e.g. Figure 1), apparently as a result of different management rather than environmental differences. A tuart stand in what appeared to be a regularly mown suburban reserve at Mandurah was very healthy. Within the 'nature strips' along the highway, mature eucalypts appeared to be generally healthy in open grassy stands compared to denser stands containing shrubby understoreys, regrowth or planted trees.

In categorising understoreys, the Tuart Atlas apparently does not recognise some management regimes (such as exclusion of natural fire regimes) that have created unnaturally dense understoreys as disturbances. For example, the 1996 wildfire area appears to be classed as undisturbed. It may be that a considerable proportion of the

36% of tuart forest classed as having undisturbed understorey actually has an unnatural structure.

The status report on tuart decline (Anon. 2002) indicates that the core area of decline is over a shallow water table, where there is relatively little fluctuation in groundwater, and that decline has spread to areas high above the water table, and that trees on ridgetops almost certainly don't access groundwater. Although there is a possibility that reduced recharge of groundwater as a result of climate change could eventually lead to increased salinity at the water table (Anon. 2002), there does not appear to be any evidence that climatic and hydrologic changes are causing the current decline.

Mundulla yellows

This 'disease' may involve a virus or mycoplasma, or it may be connected with herbicides or pollutants. It is apparently a problem of highly disturbed areas, especially suburban and agricultural roadsides and parklands, rather than forests. It mainly affects eucalypts in WA but is not confined to eucalypts. Diagnosis is not straightforward, but the main early symptom is interveinal chlorosis in leaves, patchily distributed within crowns. Leaf abscission may typically occur very soon after leaves die. Affected branches die back and this condition spreads gradually through the crown over several years. It appeared to me that the patchy distribution of symptoms in crowns may reflect problems in particular branches of the root system.

Wandoo decline

Background information

There has been a general decline in the health of stands of wandoo (*E. wandoo*) throughout its range over the last two decades, and particularly in the last decade. No particular pest or pathogen has been nominated as a primary agent of decline, however folivorous insects, borers and fungi are apparently involved in the deterioration of the tree crowns. Some structural changes have occurred in the woodlands over recent decades, for example formerly grassy wandoo flats are shrubbing up, rock oak (Allocasuarina huegeliana) is expanding outwards from its restricted natural habitat of rock outcrops, and parrot bush (Dryandra sessilis) is invading formerly open grassy stands. Flooded gum (E. rudis) stands along creeks have increased in density. One symptom of wandoo decline is 'autumn flagging' when leaves at the ends of branches suddenly turn brown and whole branchlets all through the crown die simultaneously. Patch death of wandoo associated with Armillaria root disease has occurred sporadically over many decades. Flooded gum (E. rudis) stands along creeks have suffered chronic defoliation by the native leaf miner *Perthida glyphopa* over many decades. This tree is able to repeatedly recover from severe defoliation.

Changed fire regimes and a decrease in annual rainfall together with a change towards more summer rainfall have been suggested as the factors underlying wandoo decline. Some recent measurements have found water tables in wandoo that are three to nine metres lower than they were in 1975 (F. Batini pers. comm.). Decline has also been associated with localised soil salinity, but this is mostly in agricultural situations. By examining grasstrees, David Ward has found evidence that fire regimes in wandoo stands before and after European settlement have been similar to those in tuart and jarrah. Since the 1980s many stands have remained unburnt for long periods. A Wandoo Recovery Group has been formed, incorporating agency and community members. It has produced an Action Plan and is seeking funding. The top priority is research into the causes of the problem.

Field observations

In mixed species stands, mature jarrah appeared to be declining at least as severely as wandoo, whereas saplings of all species appeared to be relatively healthy. However, at one site, saplings and young trees appeared to have been recently affected whilst older trees appeared to have been declining for some years, and marri was also affected (Figure 2). This situation appeared similar to episodes of drought scorch overlaid on chronic decline that I have observed in New South Wales. On a nearby flat, a solitary wide crowned semi-mature wandoo appeared to be in excellent health (Figure 3). Long skirts of thatch on grasstrees and a fairly heavy and continuous grass layer (Figure 3) suggested that the general area had not seen fire for an extended period, nor much grazing in recent times.



Figure 2





At another long unburnt site, a wandoo stand on a low rise appeared to be healthy whereas a stand lower down in a cowal appeared to be declining in health. However saplings and younger trees in the cowal were healthy. Open stands of wandoo in farmlands varied from healthy to severely declining. Open flooded gum stands on flats in farmlands were often reasonably healthy, whereas dense stands along creeks where there was obvious eutrophication had severe dieback in their crowns (Figure 4). A small 'exotic' plantation of salmon gum *E salmonophloia* on cracking clay soil in the wheatbelt was in good condition and had completely suppressed the grass leaving bare soil underneath. Jam (*Acacia acuminata*) regrowth on an abandoned gravel pit/picnic area was also in good health. On the other hand, jarrah forest in the Darling Ranges appeared to be generally unhealthy.

obvious evidence of recent fire, and a very heavy groundlayer of grasses, sedges and small shrubs.



Figure 4

Jarrah decline and Phytophthora cinnamomi

Background information

Jarrah decline was not nominated as a problem by most of my contacts, and was not specifically included in my itinerary. Dieback of jarrah and/or understorey death caused by *Phytophthora cinnamomi* has long been recognised as a problem. More recently there has also been dieback of coastal heathlands associated with *P. cinnamomi*. Despite many decades of intensive research on *P. cinnamomi*, views still differ on the relative importance of inoculum compared to suitable environmental conditions for expression of disease. Davison (1997) reported a case where waterlogging killed jarrah trees on a site containing *P. cinnamomi*.

Increasing runoff in the ~15,000 ha Wungong catchment was correlated with the area of dieback and with the area burnt each decade (Batini *et al.* 1980). By 1976 dieback had affected 3,700 ha of the catchment. In the 1960s and 1970s an area equivalent to the entire catchment area was burnt each decade.

Some jarrah dieback sites have been converted to exotic plantations and some mixed stands have developed into marri woodlands. Detailed mapping of dieback is carried out before logging or mining operations and quarantine is used to prevent spread of inoculum into generally healthy areas of forest.

Poor crowns in jarrah forest have been attributed to dieback associated with *P. cinnamomi*, infestations of leaf miners, overstocking, and long term reductions in rainfall. It has been suggested that competition from persistent suppressed trees in overstocked stands may reduce the vigour of entire stands.

Reliable long-term fire history records are available for the jarrah forests, and detailed satellite imagery of wildfires and prescribed burns has been routinely collected in recent years. A wildfire in the Monadnocks Conservation Park in January 2003 exhibited extreme behaviour, probably as a result of large accumulations of fuel. Many old trees were killed by this fire.



Figure 5



Figure 6

Field observations

The jarrah forests that I visited appeared to be in generally poor health, most pole stage and older trees having many dead branches and thin epicormic crowns. Most regrowth stands appeared to be densely stocked with residual and coppice stems, and often understorey shrubs. In mixed stands, marri generally had better crowns, especially the regrowth stems. *P. cinnamomi* 'graveyards' can be distinguished by their sedge understoreys and abundance of dead trees and shrubs. However declining stands beyond the 'green walls' surrounding the graveyards appear similar to declining stands that are not adjacent to graveyards (e.g. Figure 5).

A recent prescribed burn in John Forrest National Park had burnt patchily with low flame and scorch heights. Low intensity patchy burns are unlikely to have any impact on tree stocking and understorey structure once regeneration and understoreys are established. There was no obvious difference in health between a long (60 years) unburnt and a regularly burnt stand of jarrah in Chandler block. This was a good quality site and the trees were in generally better health than at other sites. However the old trees in the unburnt stand were in poor condition. There were no old trees in the regularly burnt stand.

There were some contrasts in the health of jarrah trees and stands growing in different situations. For example an old roadside tree near Manjimup was in remarkably good condition (Figure 6), as was an even-aged regrowth stand in a paddock. Near Kirup, a regrowth stand in farmland appeared healthier than the nearby regrowth forest (Figure 7 right side middle distance compared to left side background). Within a reasonably healthy forest stand that appeared to have been regularly burnt, lignotuberous regrowth stems appeared relatively healthy compared to coppice regrowth, and mature crowns were relatively poor.



Figure 7

Armillaria in karri (E. diversicolor)

Background information

Armillaria luteobubalina is a widespread native fungus that causes scattered deaths and windthrow in native forests in south-western Australia. In 'undisturbed' forest, *Armillaria* root disease appears to kill only scattered, suppressed or 'overmature' trees. Logging (including thinning) is thought to increase the incidence of disease by providing a large food base, in stumps and roots, that increases the inoculum in the forest. The fungus can survive in stumps and roots for at least 25 years. It spreads when 'clean' roots contact infected roots. Young trees are more susceptible to disease than old trees, and stress increases susceptibility. Above-ground symptoms are often not evident in infected trees. It is thought that veteran trees may be infected for centuries before senescence or drought stress makes them vunerable to disease. Trees may die suddenly or decline gradually over several years.

Although forest pathologists are concerned about its potential impacts on timber production (growth reduction, defect and mortality), some managers apparently don't see *Armillaria* root disease as a serious problem. There is a view that *Armillaria* root disease may assist in 'self-thinning' of dense regrowth and that infection or disease may decline with stand age.

Armillaria is common in the wetter stands of karri, however only one substantial 'disease centre' (<1 ha) has been observed in an unthinned and unburnt 70 year old regrowth stand. *Armillaria* appears to be ubiquitous in the 1972 regrowth that is currently being thinned. Here the infection rates of live trees are much higher than those reported from central Victoria. A reserved area of old forest in the same block is also heavily infected. A thinning experiment in the 1972 age class indicated that disease and death after 10 years was correlated with intensity of thinning. There was a correlation of disease, but not mortality, with application of nitrogen in light and heavy thinnings but not in moderate thinnings and unthinned stands. The 1975 age class (the next younger age class) has not been surveyed for *Armillaria*.

After thinning operations, trees and stumps are surveyed, and stumps within 25m of centres of infection are pulled to kill the fungus by dessication and to reduce the spread of infection through the residual stand. There have been proposals to leave infected stands unthinned, or pull trees, rather than felling them, in thinning

operations. Chemical treatment can reduce infection of karri stumps by *Armillaria*, but is not operationally feasible.

The unlogged karri forests are about half evenaged and half multiaged. Integrated logging for pulpwood as well as sawlogs commenced in 1975. Prescribed burning on about a 13 year cycle is considered desirable to manage fuels in mature karri forests. Unthinned regrowth forests have not had routine prescribed burning. Karri is considered to be fire sensitive until about 13-15 years of age, by which time heavy fuel loads can sustain intense fires under moderate conditions. There are accounts from early settlers that some karri forests were open and grassy. There are contradictory views as to whether frequent burning may promote a bracken understorey.

Field observations

Armillaria infection was evident in an unthinned 130 year old regrowth stand that regenerated after clearing for agriculture, and in older trees nearby. (It was interesting that the 130 year old trees still had distinctly different crowns from the older trees, so it was quite easy to identify different age classes.) The dense shrubby understorey appeared to be much younger than the trees.

The 'centre of infection' in a 70 year old regrowth stand was recognised before the recent thinning operation. It was on a flat or slightly concave section of a broad spur. The topography, ground vegetation of tall bracken and vines, and compaction of the soil surface where there appeared to have been few passes of harvesting machinery, suggested that this was a patch of boggy ground. An older tree that had obviously been present as advance growth when the stand regenerated was infected and was declining (Figure 8). In one stand in the 1972 age class, deep rutting of the soil had been caused by harvesting machinery during recent thinning operations.



Figure 8



Figure 9

It is possible to carry out routine prescribed burning in older regrowth stands that have dense shrubby understoreys without scorching tree crowns (Figure 9).

Red gum (E. tereticornis) decline on the Bairnsdale plains

Background information

Problems in the Bairnsdale region (as with most of the well-known cases of rural eucalypt decline) were first reported in the late 19th century following the initial wave of agricultural development. Less than 1% of the pre European distribution of red gum woodlands in the region remains relatively intact. Decline in roadside and paddock trees has been increasingly apparent in the last two decades. Decline is not apparent in the largest reserve within the region (Moormung Flora and Fauna Reserve of 400 ha). This reserve has not been grazed by domestic stock since it was gazetted about 15 years ago, however prescribed burning is still carried out routinely in a mosaic pattern through the reserve. The severity of decline is said to increase with increasing distance of remnant vegetation from retained forests.

Decline is thought to be caused by insect damage as a result of reduced numbers of predators (because the predators' habitat has been reduced), increased soil nitrogen levels (from agricultural inputs), and changed hydrology, including increased salinity (due to clearing for agriculture and opening of the lakes to the sea in 19th Century). Compaction of soil and ringbarking of trees by livestock, use of weedicides, and mistletoes are also stressing the trees. Noisy miners (*Manorina melanocephala*) are thought to exclude other predators of insects and thereby contribute to tree decline. Stands of red gum on Raymond Island that are occupied by a dense population of koalas were classified in the medium category of dieback by a 1999 survey.

Conservation authorities consider that the role of changed fire regimes in tree decline is unknown and that trials are needed. Frequent burning trials are being conducted in railway reserves to conserve native grasses and herbs, including rare orchids. Eucalypt and shrub regeneration in these reserves are considered undesirable, but recent burning does not appear to have substantially reduced the density of regenerating trees and shrubs.

It has been proposed to counteract tree decline by: creating habitat for sugar gliders (which eat Christmas beetles) by planting black wattles (*Acacia mearnsii*) and installing nest boxes; planting shrubs to feed wasps, ants, beetles and birds that also eat folivorous insects; allowing fallen timber to accumulate and provide habitat for various ground-dwelling insectivores; planting wildlife corridors; fencing to exclude stock and allow regeneration. It is considered that some grazing or burning of fenced off regeneration areas may be necessary to reduce fire hazards and prevent dense red gum regeneration.



Figure 10

Figure 11

Figure 12

Field observations

Healthy red gum stands in Moormung flora reserve comprised mostly regrowth trees with very few shrubs or hollow trees (Figure 10). Roadside stands with dense shrub understoreys (Figure 11) or with dense grass swards (Figure 12) were declining severely. The most severely declining stands were those containing old hollow bearing trees (e.g. Figure 11). Many long unburnt stands contained exotic and native weed understoreys that would prevent low intensity burning. Some stands with evidence of recent burning were relatively healthy. Noisy miners were not evident in any red gum stands at the time of my visit. Travelling west from Bairnsdale towards Melbourne I saw some very healthy paddock trees and stands of red gum that were remote from any retained forests and had no shrubs, accumulations of fallen timber, or hollow bearing trees (e.g. Figure 13). The severity of decline in paddock trees and stands appeared to be related to the extent to which pastures had been 'improved'.



Figure 13

General observations near Melbourne

A declining stand of mountain ash (*E. regnans*) near Powelltown had a moderately dense shrubby understorey and appeared to have suffered repeated defoliation. The trees had sparse epicormic crowns. Another stand near Powelltown had recently been burnt. The understorey was completely scorched or burnt but there was no crown scorch.

There were numerous examples of severely declining stands of dry forest where fire and domestic grazing had been excluded. They occurred on both private (e.g. Figure 14) and public lands including Healesville Sanctuary, Yellingbo Nature Reserve, Cardinia Reservoir and many Roadside Conservation Areas. Most of these stands had dense understoreys of native shrubs, but some had dense grass and/or exotic shrubs such as blackberry (Figure 15). Near Cardinia Reservoir, individual trees of *E. ovata* in a slashed paddock were healthy compared to a retained clump with fallen timber and a dense growth of sedges under the trees.



Figure 14



Figure 15

Understorey plantings in Yellingbo (Figure 15) will certainly succumb to competition from grass and blackberry. The declining stands were mostly low site quality forests. Similar forests that were grazed by cattle or horses were usually healthy. There were obvious contrasts between forest structure and health in Yellingbo Nature Reserve (Figure 16) compared to some adjoining private properties (e.g. Figure 17). However there were some healthy regrowth saplings in most declining shrub-infested stands (e.g. Figure 14, 16). Some riparian reserves with moist, tall forest were also declining. On the other hand, a messmate stand on a good quality hillslope site in the Silvan Reservoir was healthy.



Figure 16



Figure 17

Healesville Sanctuary

Background information

The Coranderrk Reserve is 144 ha of native forest and woodland adjoining Healesville Sanctuary. It is enclosed by a high netting fence topped with barbed wire, and native animals are allowed to graze and browse in the reserve. There had been bellbirds in the reserve before 1938, but there were none for twenty years until immediately after a wildfire in 1962. The reserve hasn't had any substantial prescribed burning. Bellbirds were removed from a declining stand in 1993, and other birds flocked in to eat the psyllids. The number of psyllids decreased dramatically and stayed low for nearly a year, but a few bellbirds moved back in after 6 months. The health of the trees did not improve over two years after the bellbirds were removed. In another declining stand, psyllid numbers decreased as many peppermints (*E. radiata*) died, and the bellbirds moved on. Candlebark trees remained healthy and did not support psyllid plagues. *Phytopthora cinnamomi* was present in both of these declining stands. Experimental removal of noisy miners from a declining woodland remnant at another study site in Victoria did not improve the health of the trees (M. Clarke pers. comm.).

Field observations

Forest throughout the reserve is declining, and some of it has dense shrubbery (Figure 18), whereas some has a dense, continuous grassy sward (Figure 19). Bellbirds occur in some patches, others have no bellbirds, but are infested by mistletoes. There is a contrast where the reserve adjoins land held by the Local Aboriginal Land Council. Decline is more severe and there is relatively dense shrubbery in the Wurundjeri land. It appears as though grazing and browsing by macropods in the reserve may have helped to maintain tree health and retard shrub development relative to the Aboriginal land which appears to be unstocked.



Figure 18

Figure 19

Armillaria at Wombat and Mt. Cole Forests

Background information

Tree decline and death associated with *Armillaria luteobubalina* has been observed in forests in central Victoria since about 1960, and may have been observed in the 1930s. It was intensively investigated in the 1970s and 1980s, but apparently managers are generally unconcerned about its impact on timber production at present. Kile (1981) suggested that *A. luteobubalina* was a primary cause of decline and death of trees that had not been stressed by any factors other than infection by this native fungus.

The geology at Mt. Cole is mostly granite and dying trees tend to occur in patches, whereas the geology at Wombat is mostly metasediments and dying trees tend to be in scattered groups. As in Western Australia, it is suggested that logging promotes *Armillaria* root disease because the better quality food resource provided by stumps supports a buildup of inoculum that is able to infect live trees. A study at Wombat found that stumps were much more likely to be infected than trees, except in an area that had been severely burnt by wildfire and salvage logged, and in another area with a history of repeated selective felling. Trees near infected stumps were more likely to be infected to the proportion of stumps in a stand.

In contrast to studies in Karri regrowth, the level of infection was not related to residual basal area or logging intensity but may have been related to the frequency of harvesting operations. Only 5% of retained overwood trees were infected three to ten years after selective logging. In a study of site preparation methods, intensive treatment, including tree pushing and ripping did not reduce mortality of planted trees caused by *Armillaria* root disease. Infected trees may remain healthy until drought or other stress initiates decline or death. Blue gum (*E. bicostata*) is prone to sudden death whereas messmate (*E. obliqua*) often declines gradually. Prescribed fire has not been used in even aged regrowth stands established since the 1950s.

In an attempt to explain how a widespread naturally occurring organism could cause extensive disease, Florence (1996) suggested that soils were eroded and depleted after heavy cutting of timber and repeated burning in the gold mining 'era' and that unnaturally dense regrowth stands may have outstripped the site resources so that individuals could not gain dominance over their competitors. This supposedly increased their susceptibility to pathogens. Florence (1996) also suggested that heavy cutting may have encouraged messmate to regenerate outside its normal (relatively high quality) environment, where it was more vulnerable to stress.

Field observations

Patches of dieback occurred on good quality sites that were fully stocked with regrowth. Even though the tree species were relatively shade tolerant and basal areas generally high, sorting of crowns into varying dominance classes and self-thinning had occurred (e.g. Figure 20). One stand in a steep, sheltered gully had the typical appearance of 'mesic dieback' in New South Wales or 'gully dieback' in Tasmania (Figure 21). However most declining stands were devoid of shrubbery and had very heavy litter (Figure 22) or grass (Figure 23) cover on the ground. There was a patch of dieback in a high quality 100 year old regrowth stand that had not been thinned.



Figure 20



Figure 21



Figure 22



Figure 23

Sheoak invasion at Ocean Grove

Background information

Ocean Grove Nature Reserve is 143 ha on the Bellarine Peninsula near Geelong. It was open eucalypt and *Allocasuarina verticillata* woodland with scattered shrubs but is mostly 'succeeding' to a scrub of sheoak (*Allocasuarina littoralis*), wattle (*Acacia pycnantha*) and ti tree (*Myrtaceae*) scrub. It remained unburnt for over 100 years, but recently parts have been affected by prescribed burns and arson. Reasons for lack of eucalypt recruitment were investigated in the 1970s. It was thought that predation of seed by ants, allelopathy by sheoak litter and the physical impediment and competition of dense grass cover impeded recruitment. Lunt (1998) documented sheoak invasion, failure of eucalypt seedlings to establish successfully, and decline of eucalypt trees between 1971 and 1996. The superior competitive ability of sheoak and wattle in the absence of frequent low intensity fire prevents establishment of eucalypts. Healthy, grassy woodlands on adjoining private property are destined for residential development.

Field observations

Research has addressed sheoak invasion and failure of eucalypt regeneration, but has not addressed the decline in health of established eucalypt trees. About half the reserve appears to be relatively undisturbed and half has had considerable clearing and amenity plantings. Mature *Allocasuarina verticillata* appear to be declining and some have been killed by recent fires, whilst thick sheoak is regenerating from coppice and seed. Healthy open woodlands adjoining the reserve (Figure 24) are maintained by grazing. Some plantings of exotic eucalypts within the reserve are healthy and have not been 'invaded' even though they are surrounded by a wall of scrub.



Figure 24

Brisbane Ranges National Park

Field observations

Much of the park appears to be long unburnt and there are large areas of heavy and continuous litter and low shrub cover. There is widespread decline with different symptoms in different types of forest. For example, declining ironbark stands are infested with mistletoe (Figure 25), gum and peppermint stands are infested with koalas (Figure 26), and broad leaved peppermint (*E. dives*) trees, grasstrees and *Hakea* have apparently been killed by *P. cinnamomi*. A recently burnt area appeared

to have a diverse layer of low shrubs and sedges compared to an area on the opposite side of the road where there had been no fire for a long time.



Figure 25



Figure 26

North-eastern Victoria, NSW south-western slopes, Snowy Mountains *Field observations*

Trees in ungrazed and unburnt roadside strips were usually declining, however saplings were healthy (e.g. Figure 27). In some cases there was evidence that activities such as drainage works, batter stabilisation or weed spraying had affected trees. However, in many cases, the declining roadside stands were above or distant from long established road formations and were unlikely to have been affected by the construction and maintenance of the roads. The roadsides usually had dense understoreys of native and/or exotic shrubs or grasses. Trees in adjoining grazed paddocks were often relatively healthy. On a rocky outcrop near Euroa, both trees and shrubs had been drought scorched, whilst surrounding trees on exposed rocky slopes were reasonably healthy (Figure 28). At the same time, roadside trees on relatively deep soils downslope from the rocky outcrop were declining (Figure 27). Red gum in improved pasture at Corryong were also declining (Figure 29). Many stands of alpine ash (*E. delegatensis*) in the Snowy Mountains area were eliminated by the 2003 fires.

Apparently they had no effective seed reserves in their canopies because of their young age or poor health.



Figure 27

Figure 28



Figure 29

Rural tree declines in Tasmania

Background information

All dry forests and woodlands in Tasmania are affected by 'dieback' (Neyland 1996). White gum (*E. viminalis*) is the worst affected species because it has nutritious and palatable leaves that are attractive to foliovores. Drought is thought to be the main cause of tree decline. Central and eastern Tasmania have been in drought since the mid 1970s. Tree decline is severe in areas with average rainfall below 625 mm and moderate where rainfall is 625 - 1000 mm. Exposure of remnant trees and trees at the edges of remnant stands is considered to stress trees by accentuating fluctuations in temperature and increasing wind speeds near the ground. Trees in denser stands are thought to be generally healthier than scattered trees because they suffer less exposure.

Possums are contributing substantially to tree decline. There was a dramatic decline in harvesting of possums for fur in the 1990s, although there was a dramatic increase at the same time in the issue of crop protection permits to shoot possums. There was no evidence that commercial hunting was regulating possums before the decline in the fur trade, however spotlight surveys detected a 70% increase in possums over about 20 years from the mid 1970s, most of the increase occurring after 1989. Moving

'fronts' of possum plagues have killed whole stands of trees in the midlands and the central plateau.

Locally severe outbreaks of insects are regarded as a natural phenomenon that has recurred over thousands of years. The outbreaks are thought to decline naturally as predator populations build up. More than a thousand hectares of dry forest around Hobart were severely defoliated by caterpillars in the late 1970s. Gum leaf skeletonisers (*Uraba lugens*) caused widespread and severe damage in the Midlands in 1962, 1975, and 1990-1991. Chrysomelid beetle plagues occurred on the central plateau in 1995-1996 and 2001-2002.

Clearing and agricultural management are considered to contribute to tree decline by stressing trees through soil compaction, nutrient enrichment, exposure, and increased browsing as a result of reduced densities of trees. Proposed management actions are directed towards obtaining regeneration through fencing, and exclusion of grazing, and/or planting/sowing. Exclusion of grazing for up to five or six years is recommended. Patch burning is recommended to encourage regeneration. There is a view that regeneration of shrubs such as wattle, oak or bursaria may pave the way for eucalypt regeneration by improving soil conditions and providing shelter and protection from weather and browsing animals.

Field observations

The low rainfall zone (< 625 mm) where decline is most severe appears to correspond with the open woodland zone that was the focus of post-European agricultural development.

Declining stands of cider gum (*E. gunnii*), snow gum (*E. coccifera*), or *E. delegatensis* on the central plateau often had dense low shrub understories. One declining stand of *E. delegatensis* had a dense grass sward with patches of low shrubs. In this respect the declining stands were similar to a declining stand of *E. delegatensis* near Kiandra (NSW) that has now been extinguished by wildfire. A stand of cider gum that was recently killed by a wave of possum attack had some nearly dead trees with weak epicormic shoots on their trunks, some recently dead trees that still had twigs and small branches attached and some trees that had died over previous years and had lost their twigs or small branches. It appeared as though there had been a period of decline before the final demise of this stand. Some low, open woodland stands of *E. archeri* near Paradise Plains in the North East Highlands were being invaded by a dense tall shrub layer of ti tree.

A stand of white gum forest near Mathinna was being 'invaded' by cherry (*Leptomeria* sp.) On the fringes of the Fingal Valley between Fingal and St. Marys, woodland remnants on lower slopes were declining whereas dry forests on upper slopes and ridges were healthy. Many dry forest stands on the east coast were scrubbed up and dying (e.g. Figure 30) as were remnant stands in the hills along the Midlands Highway between Tunnack and Hobart. Many paddock trees in the Midlands were resplendent with possum guards but did not appear to be recovering in health.

A fenced regeneration area in the Midlands north of Tunnack had some eucalypt regeneration and some dense wattle regeneration. Heavy grass and wattle regeneration had occurred since a recent intense fire, but no new eucalypt regeneration. A trial plantation of *E. nitens* included wattle plantings, however there was also natural regeneration of wattle and oak. Vigorous grass and weed growth in the plantation suggested that the soil contained high levels of nitrogen.



Figure 30

Forest Declines in Tasmania

Background information

There is a view that unnecessarily large efforts and resources went towards investigating forest declines in the 'glory days of dieback' after *P. cinnamomi* was identified as a cause of dieback in Western Australia and Victoria. The lack of any evidence of a 'primary pathogen' in the case of regrowth dieback, after considerable effort and expenditure, has encouraged this view. It is also widely considered that forest diebacks are the result of many different factors in different places, interacting in very complex ways. On the other hand, Wardlaw (1990) considered that 'east coast dieback', 'gully dieback', 'Calder dieback' and 'regrowth dieback' were all caused by extreme climatic events.

The work of Ellis and Pennington (1992) indicated that 'high altitude dieback' of *E. delegatensis was* caused by changes in soil microbiology, especially mycorrhizae, that accompany changes in understorey as a result of exclusion of fire. Felling and burning understoreys can improve eucalypt health and growth rates. Periodic prescribed burning has been suggested as a way of maintaining forest health. On the other hand it has been suggested that burning causes loss of timber values by inciting wood decay. High altitude dieback is regarded as secondary succession to rainforest. Some declining stands have been converted to plantations.

'East coast dieback' associated with *P. cinnamomi* affected small areas of dry forests on poorly drained sites in 1973 after the break of a year-long drought that had been preceeded by 3 consecutive wet years. One stand that was affected was clearfelled and regenerated successfully.

'Gully dieback' was the death and decline of about 2800 ha of *E. obliqua* in narrow bands in steep gullies near Fingal and Scamander. Understoreys were not affected, nor were *E. viminalis* and *E. sieberi* on the sides of the gullies. The main episode in the late 1960s was attributed to an extreme drought in 1967 and another episode in 1988 followed a drought in 1987. Palzer (1981) found no evidence that chemical or biotic

factors were involved. Since *E. obliqua* occurred on wetter sites and deeper soils than other eucalypts, and was more sensitive than *E. viminalis* to deprivation of water in pot trials, he concluded that drought was the cause of gully dieback. Severe defoliation by *Uraba lugens* occurred during the 1967 drought, and *Armillaria luteobubalina* was associated with gully dieback as a secondary pathogen. 'Calder dieback' affected possibly 3000 ha of *E. obliqua* in strips near the bottoms of valleys in the Inglis catchment during the early 1970s. It was attributed to an epidemic of the leaf fungus *Aulographina eucalypti* as a result of unusually frequent valley fogs. *Armillaria luteobubalina* may have been associated with Calder dieback as a secondary pathogen.

'Regrowth dieback' causes crown decline and deaths of *E. regnans* and *E. obliqua* (*Monocalyptus*) in regrowth forests older than about 30 years. *E. globulus* and *E. viminalis* (*Symphyomyrtus*), in the same forests, are highly resistant to the problem. Regrowth dieback is different from the normal self-thinning process because dominants and codominants are affected. In northern Tasmania, *E. regnans* is apparently more susceptible than *E. obliqua*. Regrowth dieback was first observed in 1964 in the southern forests where it has affected scattered trees through about 16, 000 ha. It was attributed to droughts between 1959 and 1963 and again in 1972. In the north-east about 5, 000 – 10, 000 ha of regrowth dieback were attributed to droughts in 1967, 1972 and 1982 as were about 1000 ha in the north-west. Investigations of regrowth dieback in relation to site factors (Podger *et al.* 1980) were based on 36 x 0.1 ha plots in dense even aged regrowth stands, covering the major parent materials and soil types, and the range of site indices in the southern forests. No correlations were identified. Investigations of possible fire impacts were abandoned because it was difficult to distinguish crown decline from fire damage.

Although drought is generally accepted as the trigger for regrowth dieback, there has been no satisfactory explanation why it does not affect regrowth stands younger than about 30 years of age, nor why it does not affect understoreys. However there are suggestions that the age threshold relates to a change from a helical to an axial transpiration pathway and a change from vertical sinker roots to a taproot system as the trees develop (T. Wardlaw pers. comm.).

The leaf beetle *Chrysophtharta bimaculata* and the root/butt rot fungus *Armillaria hinnulea* may be contributing factors, however no pest is constantly associated with the disease. There is a good relationship between lost increment and crown dieback ratings over 40%, but not with crown dieback ratings below 40%. Regrowth dieback is not affected by stand density. Thinning and fertilizing may encourage increased defoliation by leaf beetles. Regrowth dieback is not generally regarded as an ongoing management problem provided that yield predictions are periodically adjusted for growth losses.

It could be argued that regrowth dieback is an example of 'secondary succession' in the absence of fire, similar to 'high altitude dieback', however this is not the accepted view in Tasmania. The southern forests are mostly wet forests that had a natural regime of occasional high intensity fires. However, sixteen percent of the tall wet eucalypt forests at Warra have a mature stand height less than 34 m, and less than half the area burnt since 1850 was burnt by stand replacing fires.

Field observations

On the Western Tiers (Cluan Tiers Coupe 314) a stand of *E. delegatensis* that was thinned in 1991 and affected by drought and leaf beetles in 1995, still had unhealthy looking crowns. This stand had a moderately dense shrubby understorey. Destructive sampling had shown that half the trees in this stand had columns of defect arising from (mostly occluded) fire scars. The lack of signs of recent fire on the trees suggested that the shrubby understorey and the defect may be attributable to occasional moderate to high intensity fires.



Figure 31

In the north-east highlands, some selectively logged stands have regenerated to silver wattle (*Acacia dealbata*). The remains of dead eucalypts can be seen in well-developed rainforests around sheltered gullies. In some slightly less sheltered positions there are developing rainforests under declining stands (e.g. Figure 31). Eucalypt saplings in these situations are relatively healthy (e.g. Figure 31). In more exposed and apparently poorly drained situations there are ti tree scrubs, whilst some well drained ridgetops carry healthy open *E. delegatensis* regrowth stands. Some midslopes carry healthy plantations.

I saw two patches of 'gully dieback' from a distance (Figure 32 middleground), and one close up (Figure 33). They were on the lower and midslopes of southerly aspects. In the stand that was closely inspected, both the mesic understorey and the patch of dead trees on the southerly aspect stopped abruptly in the bottom of the gully and did not extend up the northerly aspect. On the upper northerly aspect, some regrowth trees and one old tree of *E*, *obliqua* around a slight drainage depression were declining (Figure 34). A small clump of mesic shrubs was developing in this slight depression (Figure 35). The rest of the northerly slope had a thick litter layer and no signs of recent fire, but the trees (*E. sieberi*) were healthy.



Figure 32

Figure 33



Figure 34



Figure 35

Nearby stands of *E. sieberi* on dry, exposed aspects showed dead tops and branches indicating fire damage, but the replacement crowns appeared healthy, having normally developed foliage distributed on the ends of the new branches (e.g. Figure 32 foreground).

Some dry forest stands on moderately sheltered aspects in the foothills of the Fingal valley were declining. They had moderately dense shrub understoreys, often of cherry (Santalaceae).

Many stands of tall wet regrowth forest appeared to have unhealthy crowns. Some of these were predominantly *E. obliqua* x *E. regnans* 'intermediates'. A ridgetop stand of *E. obliqua* had relatively little understorey but very high levels of eucalypt litter. There were some relatively dry looking forests around the Warra 'aggregated retention' coupes, but they often had dense understoreys of titree, or other dry

sclerophyll shrubs, and gahnia. A post logging burn propagated through one 'aggregated retention' clump under mild conditions without any canopy scorch. Some very low quality sites had open to dense sclerophyll shrub understoreys and some 'moist' forests had open to dense pomaderris understoreys. Many of these drier mixed aged stands of *E. obliqua* had a similar structure to stands on New South Wales' southern escarpment (where the pre-European fire intervals estimated from dendrochronology averaged 18 - 25 years).

In a Continuous Forest Inventory plot at Hastings Caves, where studies of regrowth dieback had been done in the 1970's, there were relatively few dead trees and a fairly full stocking of live trees with unhealthy looking crowns. Some patches had large diameter (> 80cm) dominant trees while some were relatively small (~ 40 cm).

DISCUSSION OF FACTORS IN EUCALYPT DECLINE AND ITS MANAGEMENT

Climate and weather

Climate change or weather extremes were proposed as inciting factors or contributing factors in most cases of eucalypt decline or dieback that I examined. White (1986) considered that climatic extremes were the general cause of tree declines because stressed trees provide better than normal food that allows herbivores to build up. White (2004) used "herbivores" in the broadest sense to include all kinds of foliovores, parasites, pests and diseases. Stress due to climate change or weather extremes would favour all of the herbivores that were implicated in the cases that I examined (e.g. White 2004a). However the contrasts in health that are commonly visible between stands experiencing exactly the same climatic regime suggest that climate and weather are not the fundamental problems.

Lowered water tables and increased groundwater salinity as a result of climate change have been implicated in tuart decline, however measurements by the Waters and Rivers Commission indicate that these impacts have not yet occurred. On the other hand, some dramatic increases in depth to watertable have recently been measured in wandoo woodlands. Most eucalypt ecosystems in New South Wales do not interact with water tables. Eucalypts are mostly unable to exploit sites with shallow groundwater and many stands have been killed by rising water tables as a result of clearing, intensive logging, intense wildfires, dam construction or other earthworks, and weather extremes. *P. cinnamomi* has been associated with some of these cases in Western Australia, Victoria and Tasmania. Chronic decline in forests and rural lands is usually associated with low lying, water accumulating sites, or other poorly drained sites where waterlogging is more likely to cause problems than falling water tables.

In the wandoo I saw a case where a higher and drier stand appeared to be healthier than a stand lower down in a cowal. Crown dieback in *E. rudis* appeared to be most severe in creeklines with lush grasses and weeds (e.g. Figure 4). Rural tree decline is typically most severe in depressions and low-lying areas (e.g. 'New England Dieback' and red gum decline on the 'Bairnsdale Plains'). Tuart decline was particularly associated with shallow water tables. There does not appear to be any convincing evidence at this stage that lowered water tables are causing forest decline. Trees planted as exotics can grow much faster than they would in their native habitat because they escape most of their native pests, pathogens and parasites. Eucalypts planted in Australia outside their natural habitat may also perform very well. Nevertheless, the performance of exotics can be used as an indication of the degree of climatic stress that is affecting natives. Where native trees are declining but exotic trees (that are adapted to similar or less severe climates) show no signs of climatic stress, it suggests that something else is stressing the natives. Lush native understoreys in drought affected stands may indicate underlying problems in tree health, and the presence of healthy saplings amongst declining trees also suggests that something other than weather is causing decline.

There is often a clear distinction between drought impacts and chronic decline. For example, near Euroa, trees and shrubs on a rock outcrop had suffered drought scorch, whereas surrounding trees on rocky exposed slopes were healthy at the same time as roadside trees on deeper soils were declining (Figures 28, 27).

It seems unlikely that drought caused gully dieback in Tasmania, because dieback affected the most sheltered sites, with the deepest soils. *E. obliqua* in higher and drier positions or on more exposed aspects than the dieback sites were not affected, nor were mesic understoreys in dieback areas. Similarly, there appears to be no reason why drought would incite 'regrowth dieback' without affecting the mesic understoreys. Chronic tree decline proceeds through good seasons and bad. Climatic extremes exacerbate tree decline, but the trees do not improve when conditions ameliorate. Many people do not recognise decline until it is well advanced, and declining trees are likely to die during droughts, so decline is particularly evident when there is climatic stress.

Sometimes there is overlap between chronic decline and acute drought stress. This was evident in New South Wales during 2002 when some trees with thin epicormic crowns suddenly turned brown at the same time as healthy trees in more exposed positions were affected. This may have also been the case in a mixed wandoo stand where saplings and young trees had died back and reshot and a mature marri was in decline (Figure 2).

Eucalypts have evolved to cope with extremes and have survived them in the past, mostly by resprouting. Some *E. obliqua* in gully dieback areas developed epicormic crowns. This species usually develops epicormics, and declines gradually, when it is affected by *Armillaria* in central Victoria. If drought caused gully dieback many trees would be expected to recover as was the case with drought scorch in otherwise healthy stands of monocalyptus after recent droughts in New South Wales.

In most cases of forest decline, including tuart decline with peppermint scrub, gully dieback, and sheoak invasion, eucalypt seedlings cannot establish without human intervention. If declines had been caused by climatic fluctuations prior to European settlement, there would be extensive treeless scrubs on good soils. However, the distribution of treeless scrubs and heaths corresponds closely with rock outcrops and swamps that cannot support trees even when climatic conditions are favourable.

The three gully dieback sites in Tasmania and the three largest centres of *Armillaria* root disease in Victoria and Western Australia had much in common with mesic forest

dieback sites throughout coastal New South Wales. They all occurred on sheltered water accumulating sites, the understoreys were not droughted, and fires had been infrequent or absent during the life of the stands. Palzer (1981) argued that the occurrence of gully dieback on sheltered sites with deep soils indicated that extreme drought was the cause, whereas Kile (1981) and Edgar *et al.* (1976) appeared to imply that drought could not be the cause of *Armillaria* root disease because it occurred on the best sites.

In the case of Calder dieback, an abundance of fog supposedly favoured a fungal infection in the foliage that killed *E. obliqua*. In gully dieback, drought was considered to have killed *E. obliqua*, and *Armillaria luteobubalina* was regarded as a secondary pathogen of its roots. On the other hand, this fungus was regarded as a primary cause of dieback in central Victoria and south-western Australia. However, in Western Australia, it was considered that infection may not have caused disease until some stress such as drought affected the trees.

Pests, pathogens, parasites, predators and ecological balance

Day (1981) suggested that identifying pests or pathogens as 'causes' of decline only puts the problem back one step. What causes the outbreaks of pests and pathogens? White (1993) explained that stress improves the food quality of trees for their 'herbivores', and incites dieback or decline. He provided a compelling argument, based on detailed examples from around the world, that predators are limited by the abundance and quality of their prey. The principle applies equally to the herbivores that attack the trees and to the predators that attack the herbivores.

I saw much evidence supporting both facets of this principle. It was particularly evident in the contrasts between ungrazed and unburnt reserves and roadsides, where trees were heavily attacked by herbivores and parasites, compared to adjoining grazing lands where the trees were relatively healthy. There was no barrier to the herbivores and parasites that could account for the differences. The trees in the unmanaged areas must have been more stressed, however the primary stress could not have been climate or weather because the contrasting stands were experiencing the same conditions. The declining stands often had an abundance of the habitat features that support the predators that are supposed to control the herbivores and parasites. Rural landholders are being encouraged to create habitat for predators that will supposedly prevent pest outbreaks and tree decline. This strategy has little prospect of success.

Identification of *P. cinnamomi* as a cause of dieback in jarrah allowed pathologists, at least for a while, to concentrate on the pathogen rather than the cause of outbreaks, since an exotic pathogen might be expected to run rampant. However the lack of expression of disease in many situations where *P. cinnamomi* has been found, and the lack of specific pathological symptoms in many cases where trees are declining leads back to questioning the cause of outbreaks and declines. There is still some argument whether *P. cinnamomi* is a recent introduction to Victoria and southern New South Wales. There have been many outbreaks in East Gippsland associated with hydrological impacts of logging and wildfire. There have been no outbreaks in similar forests in southern New South Wales, where phytopthora is common but the logging and fire management history and practices are different.

Jarrah is susceptible to *P. cinnamomi*, whereas marri is not. Although *P. cinnamomi* is not implicated in the decline of mixed tuart forests, jarrah appear to be declining in these forests, whilst marri are generally healthier. There are many other examples of differences in the susceptibility of species in mixed stands to dieback and decline. *E. viminalis* was not affected by gully dieback but was the species worst affected by rural dieback in Tasmania. In New South Wales, even the most resistant species such as tallowwood (*E. microcorys*) or monkey gum (*E. cypellocarpa*) eventually succumb as mixed stands decline. *Monocalyptus* roots appear to be succumb quickly when unfavourable soil conditions develop, whereas *symphyomyrtus* roots apparently continue to function under stress whilst their crowns decline and attract various pests. Corymbia seem to have less sensitive roots than monocalyptus and less palatable and nutritious leaves than symphyomyrtus.

The high susceptibility of *Monocalyptus* and low susceptibility of *Symphyomyrtus* to regrowth dieback suggests that it stems from problems with root function. Although changes in the proportions of even aged and mixed aged forests in the landscape during the 20th century could have caused hydrological changes, dieback is independent of stand density, indicating that the cause is not water stress due to high transpiration rates of regrowth stands. The changes in the forests may have increased the overall food resources for folivorous insects, and the potential for outbreaks under stressful climates, but this would be more likely to affect *Symphyomyrtus*. Perhaps increases in proportions of even aged regrowth have upset some fine genetic matching of trees to site conditions. For example, monocalyptus may have invaded some microsites that were naturally occupied by symphyomyrtus.

Armillaria luteobubalina is a native fungus that is common and widespread in relatively undisturbed old forests as well as intensively managed regrowth forests. Like all 'herbivores' it must be limited by the quality of its food (White 2004a, 1993). Stumps are better food for *Armillaria* than healthy trees, so they are more likely to be heavily infected. According to the 'germ theory' (Manion and Lachance 1992), when the inoculum builds up in response to better food in logged forests the living trees are more likely to be infected (e.g. Kile 1981). However, the germ theory is not sustainable (White 2004a, White 1993), since in its logical conclusion the entire range of *Armillaria luteobubalina* would eventually be occupied by dead trees and dead fungus.

The amount of harvesting activity in the forest, rather than the number of stumps in the forest, may govern the expression of *Armillaria* root disease. This may explain the association of disease with logging intensity in karri regrowth as well as its association with logging frequency at Wombat. The most likely cause of stress associated with harvesting, that could make tree roots more susceptible to disease is soil compaction. Compaction of soil can reduce its permeability, aeration and drainage making it a more stressful environment for the roots of trees. Differences in the pattern of *Armillaria* disease expression on different geological substrates at Wombat and Mt. Cole may be due to differences in their susceptibility to compaction. The unusually strong expression of *Armillaria* root disease within a coupe at Wombat where timber was salvaged after a wildfire might be related to an increased susceptibility of burnt ground to compaction. The two best developed 'centres of disease' that I saw in Western Australia and Victoria were gently concave sites that appeared to be boggy and susceptible to compaction.

On the other hand, these stands were 70 and 100 years old and had not been thinned prior to the outbreaks of disease. Erosion, depletion of nutrients and inability of trees to establish dominance over other trees (Florence 1996) were obviously not the factors underlying the disease in these high quality stands. However, if compaction caused by harvesting operations was a problem, it took a long time to become apparent.

Restricted drainage or aeration on concave sites might have predisposed the sites to disease problems. Soil compaction caused by harvesting could have exacerbated the situation. Unnatural exclusion of fire may have gradually induced changes in the soil that eventually incited disease in these stands. However there does not appear to be any substantial evidence of the potential impacts of different fire regimes on expression of disease associated with *Armillaria* because most of the regrowth forests that are affected have not seen fire. In declining forests on similar sites in three states, *Armillaria* was considered to be a primary pathogen in Victoria and Western Australia, a secondary pathogen in Tasmanian gully dieback, and was not considered as a contributing factor in New South Wales.

Fire regimes, grazing, soil conditions and nutrient cycling

Ellis *et al.* (1980) restored the vigour of stands suffering from 'high altitude dieback' by felling and burning their understoreys. Ellis and Pennington (1992) demonstrated that changes in soil microbes caused by exclusion of fire could affect tree health. Jurskis and Turner (2002) referred to a number of studies indicating that unnatural exclusion of low intensity fire from forests can change the physical properties, chemistry and biology of their soils. They suggested that the changes would stress eucalypts, leading to chronic decline. The particular pests, pathogens and parasites that contributed to the decline of the trees would vary with the species of trees and their environment (Jurskis 2004). Soil properties can also be changed by agriculture, by the hydrological impacts of earthworks or intensive logging, and by the hydrological and chemical impacts of wildfires. All these factors have been associated with forest decline (Jurskis *et al* 2003, Jurskis and Turner 2002).

Whether changed fire regimes have any role in regrowth dieback is difficult to say. The tall wet forests are not all tall and wet, for example, sixteen percent of Warra is relatively dry. Current fire regimes may be different to those that shaped the evolution of the trees. About half the fires in Tasmania's wet forests since 1850 have been stand replacement fires, but it is not clear whether this represents an increase, a decrease, or any change compared to the pre-European environment. Bowling and McLeod (1968) examined the fire history and health of stands in 80 Continuous Forest Inventory plots in southern Tasmania. They reported that plots that had been burnt were less affected by regrowth dieback than plots that had not been burnt.

Tuart decline associated with peppermint scrub, and the decline of tuart trees in pastures are both consistent with the model of Jurskis and Turner (2002). However the model did not deal explicitly with the differences that can be observed in the health of trees in rural lands under different management regimes. The stark contrasts in the health of roadside trees compared to paddock trees, and between trees in paddocks under different management (e.g. Figure 1) suggested that the intensity of grazing regimes, like that of fire regimes is critical to the health of the trees. High intensity

fires have different impacts on soils and tree health than low intensity fires (e.g. Jurskis *et al* 2003). Intensive grazing and pasture improvement will have different environmental impacts than low intensity grazing of semi-natural pastures.

Sometimes roadside trees were healthier than paddock trees, sometimes the reverse applied. Trees in areas that were maintained by slashing often appeared healthier than trees with dense undergrowth. It appears that low intensity grazing, or even slashing, can substitute for low intensity fire and maintain healthy woodlands, whereas exclusion of fire and grazing, pasture improvement, or high intensity fire can accelerate the changes in soils and nutrient cycling that cause tree decline (e.g. Jurskis *et al* 2003).

Contrasts in health were sometimes visible down to the scale of individual trees and small clumps, and some observations were surprising, for example, the healthy tuarts that were surrounded by bitumen at Preston Beach. But even this example may be consistent with the model because the root environment under bitumen seal might be closer to the natural condition than the eutrophic soil in scrub infested forests or improved pastures. The healthy Wandoo tree on the flat in Figure 3 may serve as a 'kangaroo camp' that benefits from regular grazing around it. There was some evidence that the Coranderrk Reserve benefited from grazing and browsing by native macropods compared to adjoining unstocked land. Reasons for sharp contrasts in tree health are not always immediately apparent. The management history of a site may not be readily discernible, and recent changes in management may have occurred. Nevertheless, there were many widespread examples indicating that grazing or even slashing regimes can substitute for the natural, low intensity fire regimes that maintained the competitive ability of eucalypt trees and kept them healthy prior to European settlement.

Competition

Day (1981) suggested that pasture improvement could have profound impacts on trees, and that we should look to competition between plants to explain tree decline. Landsberg *et al.* (1990) confirmed the connection between pasture improvement and eucalypt decline. Tree decline is mostly associated with dense shrub or grass understoreys, including improved pastures. However, younger trees sometimes outcompete older trees of the same species, particularly during droughts. In this respect jarrah and wandoo appeared to be similar to sheoaks and cypress (*Callitris*) in the east. Older trees lose their ability to control sites when unnatural fire regimes create an unfavourable environment for their roots. This weakens the trees and promotes understoreys and/or regeneration which reinforce the site changes and further weaken the old trees.

Interspecific competition drives self-thinning in densely stocked regrowth stands. In healthy stands, dominant trees compete more strongly than suppressed trees, and larger trees outcompete smaller trees (e.g. Bi 2004). This is not the case in declining forests where dominant trees decline along with subdominant trees, and mature trees are choked out by regrowth long before they reach their natural lifespan.

Changes in soils may tip the balance in competition between plants. Shrubs, pastures or weeds can outcompete eucalypts because they are favoured by rich soils. Unnatural disturbance allows young plants to outcompete old plants because their physiology is different. Young trees grow very quickly, using resources made available by disturbance to extend their roots and crowns. Mature trees hoard resources, depriving their competitors and using the resources only to maintain their established roots and crowns. Frequent, low intensity fires assist this process by preventing an accumulation of the resources that are shed by the trees in the form of old leaves, bark and branches. Without fire these resources become available to competing plants or soil microbes. Long term exclusion of fire favours shade tolerant, moisture loving and nitrogen loving species. It does not stimulate eucalypt regeneration, but it may give young trees an advantage compared to older trees.

Senescence, clearing, and exposure

Regrowth dieback doesn't affect stands younger than about 30 years of age. This also applies to most cases of forest decline in Australia. *Armillaria* and phytopthora apparently kill young natural seedlings in the forest, however it is not clear whether these are the weak seedlings that would inevitably succumb to interspecific competition. The age threshold in forest decline is presumably connected with changes that occur in their physiology as trees mature and move from the rapid expansion phase towards the phase where they maintain their established root systems and crowns. Other changes that occur about this time are initiation of heartwood (Turner 2004) and decline in the sapwood area increment of regrowth stands (Bi 2004). These changes will affect the leaf area, and water use of the trees as well as nutrient cycling and competition between trees and understoreys. Any environmental changes that reduce the competitive ability of trees will have a greater impact on trees after these physiological changes have occurred (Bi 2004).

There is a widespread view that much rural tree decline is attributable to natural senescence of trees that were established before European settlement. However the relative age of trees is apparent from their crown architecture, and much of the rural tree decline that I observed was of young and mature trees (e.g. Figures 12, 29) that have regenerated since European settlement, rather than old trees. In any case, healthy old trees (e.g. Figure 6) have a different appearance than declining old trees (e.g. Figure 11). Exposure did not appear to be detrimental to the health of established trees. Exposed trees (e.g. Figures 3, 6) or trees in open stands (e.g. Figure 13) were often healthy whereas trees in dense stands (e.g. Figures 5, 12) were often unhealthy.

Regeneration

Different management regimes are necessary to regenerate forests compared to those that will maintain the health of established forests. Lack of regeneration should not be regarded as a problem in a healthy mature forest. However, in unhealthy or senescent forests, it may be necessary to exclude fire and grazing for a short period to establish regeneration. As soon as regeneration is established, fire and/or grazing should be reinstated to maintain the competitive advantage of the eucalypts over other vegetation. There is no process of succession where other plants may gradually pave the way for eucalypt establishment. The other plants compete directly with the eucalypts. In their natural environment of frequent fire, the eucalypts are the strongest competitors and they dominate the ecosystem. When human activities alter the environment and exclude fires, other plants may gain dominance.

There is no store of eucalypt seed in soil and eucalypt seed is dispersed a very short distance from standing trees. On the other hand, many native shrubs have large stores

of seed in the soil, as well as seeds that are widely dispersed by birds. Where management aims to restore eucalypt ecosystems, planting shrubs to increase diversity or create habitat for predators of herbivores may be unnecessary or counter productive.

When eucalypts are planted to rehabilitate areas affected by rural tree decline, they may be placed in environments with elevated watertables, high levels of soil moisture and nitrogen, and different microclimates compared to their natural habitat. They usually face competition from exotic plants, and sometimes natives, that are better adapted to these conditions. Control of competing vegetation is critical to the success of these plantings. Some planting trials on difficult sites in the NSW southern tablelands have indicated that application of nitrogen fertilizers depresses the survival of eucalypt seedlings, probably by encouraging soft shoot growth rather than root growth. This makes them vulnerable to frost, drought, browsing and weed competition. Broadcast application of Osmocote reduced the survival of *E. blakelyi* seedlings planted in grazing lands on the New England (Li *et al.* 2003). Nitrogen applied as ammonium is less likely to encourage soft growth than nitrate. Addition of phosphorus may improve the survival of eucalypt seedlings.

Investigations of forest decline

Investigations of forest decline have focussed on particular tree species, forest types or geographic areas. They have also focussed on contributing factors such as pests, pathogens and parasites, even single organisms, rather than searching for the underlying cause of stress to the trees (e.g. Day 1981). For example investigations of 'Ourimbah dieback' (Bird *et al.* 1974) in New South Wales over several decades led to suggestions that forest decline was associated with a few types of moist regrowth forest, and with psyllids and bellbirds. However these investigations were virtually confined to a narrow range of moist regrowth forests that were within the natural range of bellbirds and had been deliberately 'protected' from fire (Jurskis 2004). A wider range of observations now suggests that dieback is associated with a variety of dry and moist forests that have been affected by reductions in the extent of prescribed burning in recent decades. A variety of pests, pathogens and parasites are contributing to the declines. All ages are affected except for young regrowth stands less than about 30 years old.

The reported lack of correlation between 'regrowth dieback' in Tasmania and site factors was based on limited evidence. Podger et al. (1980) established 36×0.1 ha plots in dense even aged regrowth, covering the major parent materials and soil types, and the range of site indices in the southern forests. As well as the limited replication in this sample, there were difficulties in distinguishing crown decline from fire damage, and there were no surveys in unlogged mature forests.

It would be better to consider a wide range of situations when formulating hypotheses, on forest decline so that those based on spurious associations derived from restricted sampling can be quickly discarded. Clear hypotheses can then be rigorously tested by tightly focussed research (White 2004b).

RECOMMENDATIONS

Management

Five key principles of ecologically sustainable forest management under Australia's National Forest Policy are: maintenance of all ecological communities and processes; public accountability; maintenance of ecosystem health and vitality by reducing threats from diseases, weeds and unnatural fire regimes; the precautionary principle; and adaptive management. In accordance with these principles there is a need to adapt our forest management immediately rather than waiting for some possible answers from current research into forest decline. Forest managers (including managers of Roadside Conservation Areas) should reintroduce low intensity fire regimes into dry and moist forests where early signs of structural changes and/or decline in tree health are apparent.

Urgent action should be taken to reduce fire hazards and restore a healthy open forest structure in most of the area of recently burnt and regenerated tuart forest at Yalgorup. Part of the area should be retained as an 'undisturbed' reference area. Monitoring is an essential component of adaptive management, and reference areas are necessary for effective monitoring. Management plans should not aim to perpetuate unnaturally shrubby forests (e.g. Bradshaw 2000), rather they should aim to restore more natural open conditions (e.g. Jurskis 2002).

Extension officers should recommend short-term exclusion of fire and grazing from woodland remnants only where there is a need for eucalypt recruitment to replace dying and senescent trees. In such cases they should recommend reintroduction of frequent low intensity fire and/or grazing as soon as eucalypt regeneration is visible above the grass layer. Only canopy trees should be used in rehabilitation plantings, as natural regeneration of subcanopy and shrub species is normally reliable and often excessive. Plantings of eucalypts on woodland sites should have intensive weed control until such time as fire and or grazing are reintroduced. Phosphorus should be the dominant element in fertilizers applied to rural eucalypt plantings, and nitrate fertilizers should not be used.

Research

The Bushfire CRC should initiate research into the connection between fire regimes and forest decline. There are many opportunities at sites where there are clear contrasts in the health of trees under different management regimes, to conduct tightly focussed research that has a good chance of providing management solutions for forest decline. Research should examine soil conditions, tree roots and the physiology of sapstreams and foliage at a range of sites where there are trees with contrasting health in a uniform environment subject to different management regimes.

Additional research should be initiated on the impacts on forest structure and health of introducing frequent low intensity fire regimes into dry and moist forests as soon as possible after regeneration events. Forest types that are susceptible to decline should be targeted. Trials of understorey reduction and burning (e.g. Bradshaw 2000) should be carried out in some stands where structural changes and tree decline are advanced, to see whether it is feasible to reintroduce low intensity fire regimes.

Additional burning trials should be initiated in regrowth stands in central Victoria and south-western Australia to test for differences in *Armillaria* infection and disease with different fire regimes. Distribution of *Armillaria* infection and disease should be compared with physical properties of soils as influenced by topography as well as harvesting impacts. Rates of infection of trees around chemically treated karri stumps should be compared with rates around untreated stumps.

Any future studies of regrowth dieback should examine more extensively its distribution in relation to site factors and fire history, should include surveys of mature forests, and should attempt to distinguish crown decline from previous damage by fires.

ACKNOWLEDGEMENTS

I am grateful for the support of the Gottstein Trust, especially the Secretary, Dr Adrian Wallis. State Forests, particularly Michael Bullen, also provided valuable support. I acknowledge the stimulating discussions, help and hospitality provided by all the individuals and organisations that are listed in the appendix. Special thanks go to the private consultants: Frank Batini, Jack Bradshaw, Bob Ellis, John Kellas, Roger Underwood and Dave Ward. Although our views differ, Glen Kile's constructive criticism of a draft report helped me to improve the presentation and argue more clearly against the 'germ theory'.

REFERENCES

- Anon. (2002) Status report. Tuart conservation and protection. Government of Western Australia
- Batini, F.E., Black, R.E., Byrne, J. and Clifford, P.J. (1980). An examination of the effects of changes in catchment condition on water yield in the Wungong Catchment, Western Australia. *Aust. For. Res.* **10**, 29-38.
- Bi, H. (2004). The self-thinning surface in relation to declining stands. In Fundamental causes of eucalypt forest decline and possible management solutions. Proceedings of colloquium November 18-19, 2003 Batemans Bay, NSW. (eds. T.C.R. White and V. Jurskis) pp. 23-5. State Forests of NSW, Sydney.
- Bird, T., Kile, G.A. and Podger, F.D. (1974). The eucalypt crown diebacks a growing problem for forest managers. *Australian Forestry* **38**, 173-187
- Bowling, P.J. and McLeod, D.E. (1968). A note on the presence of *Armillaria* in second growth eucalypt stands in southern Tasmania. *Australian Forestry Research* **3**: 38–40.
- Bradshaw, F.J. (2000). Recommendations for the regeneration and maintenance of the tuart forest in the Yalgorup National Park. Consultant's Report. F.J. Bradshaw, Manjimup.
- Davison, E.M. (1997). Are jarrah (*Eucalyptus marginata*) trees killed by *Phytophthora cinnamomi* or waterlogging? *Australian Forestry* **60** (2), 116-124.
- Day, M.F. (1981). Foreword. In *Eucalypt dieback in forests and Woodlands*. (eds. K.M. Old, G.A. Kile, C.P. Ohmart) CSIRO Australia.

- Edgar, J.G., Kile, G.A., and Almond, C.A. (1976) Tree decline and mortality in selectively logged eucalypt forests in central Victoria. *Australian Forestry* **39** (4), 288-303.
- Ellis, R.C., Mount, A.B. and Mattay, J.P. (1980). Recovery of *Eucalyptus delegatensis* from high altitude dieback after felling and burning the understorey. *Australian Forestry* **43**: 29-35.
- Ellis, R. C. and Pennington, P.I. (1992). Factors affecting the growth of *Eucalyptus delegatensis* seedlings in inhibitory forest and grassland soils. *Plant and Soil* 145: 93-105
- Florence, R.G. (1996). *Ecology and Silviculture of Eucalypt Forests*. CSIRO Australia.
- Hopkins, E.R., (1973) Crown dieback in eucalypt forests. In Eucalypt dieback in Australia. Proceedings of the Lakes Entrance seminar. (eds. G.C. Marks and R.M. Idczak) pp 1-16. Forests Commission Victoria.
- Jurskis, V. (2004) Overview of forest decline in coastal New South Wales. In *Fundamental causes of eucalypt forest decline and possible management solutions*. Proceedings of a colloquium at Batemans Bay 18th and 19th November 2003. (eds. T.C.R. White and V. Jurskis) pp. 4-7. State Forests of NSW. Sydney
- Jurskis, V. (2002) Restoring the prepastoral condition. Austral Ecology 27: 689-690.
- Jurskis, V., Bridges, B. and de Mar, P. (2003) Fire Management in Australia: the lessons of 200 years. In *Joint Australia and New Zealand Institute of Forestry Conference Proceedings 27 April – 1 May 2003 Queenstown, New Zealand.* Ministry of Agriculture and Forestry. Wellington. pp 353 – 368.
- Jurskis, V. and Turner, J. (2002). Eucalypt dieback in eastern Australia: a simple model. *Australian Forestry* **65** (2): 81-92.
- Kile, G.A. (1981) Armillaria luteobubalina: a primary cause of decline and death of trees in mixed species eucalypt forests in central Victoria. Australian Forest Research 11, 63-77.
- Landsberg, J. Morse, J. Khanna, P. (1990). Tree dieback and insect dynamics in remnants of native woodlands on farms. *Proceedings of the Ecological Society of Australia* 16: 149–165.
- Li, J., Duggin, J.A., Grant, C.D. and Loneragan, W.A. (2003) Germination and early survival of *Eucalyptus blakelyi* in grasslands of the New England tablelands, NSW, Australia. *For. Ecol. Man.* **173**, 319-334.
- Lunt, I.D. 1998. Allocasuarina (Casuarinaceae) invasion of an unburnt coastal woodland at Ocean Grove, Victoria: structural changes 1971-1976. Australian Journal of Botany 46: 649-656.
- Manion, P.D. and Lachance, D. (1992) Forest decline concepts: an overview. In *Forest decline concepts*. (eds. P.D. Manion and D. Lachance) APS Press St. Paul. pp 181-190
- Palzer, C. (1981) Aetiology of gully dieback. In *Eucalypt dieback in forests and Woodlands*. (eds. K.M. Old, G.A. Kile, C.P. Ohmart) CSIRO Australia. pp174-178.
- Podger, F.D., Kile, G.A., Bird, T., Turnbull, C.R.A., McLeod, D.E. (1980). An unexplained decline in some forests of *Eucalyptus obliqua* and *E. regnans* in southern Tasmania. *Australian Forestry Research* **10**: 53–70.
- Turner, J. (2004) Aspects of nutrient cycling and plant physiology in forest stands. In *Fundamental causes of eucalypt forest decline and possible management* solutions. Proceedings of colloquium November 18-19, 2003 Batemans Bay,

NSW. (eds. T.C.R. White and V. Jurskis). pp 15-7. State Forests of NSW, Sydney.

- White, T.C.R. (2004a) Natural factors limiting pests and diseases. In *Fundamental causes of eucalypt forest decline and possible management solutions*.
 Proceedings of a colloquium at Batemans Bay 18th and 19th November 2003. (eds. T.C.R. White and V. Jurskis) State Forests of NSW. Sydney. pp11-12.
- White, T.C.R. (2004b). Foreword. In Fundamental causes of eucalypt forest decline and possible management solutions. Proceedings of colloquium November 18-19, 2003 Batemans Bay, NSW. (eds. T.C.R. White and V. Jurskis). State Forests of NSW, Sydney.
- White, T.C.R. (1993). "The Inadequate Environment: Nitrogen and the Abundance of Animals" Springer-Verlag. Berlin
- White, T.C.R. (1986) Weather, *Eucalyptus* dieback in New England, and a general hypothesis of the cause of dieback. *Pacific Science* **40**, 58-78.

APPENDIX Organisations and Individuals Consulted

CALM W.A. Mark Garkaklis, Drew Haswell, Kevin Pollock, Robert Powell, Alan Sands, Rick Sneeuwjagt, Alan Walker

CALM W.A. Science Division Neil Burrows, Lachie McCaw, Richard Robinson, Mike Stukely

Murdoch University Paul Barber, Giles Hardy

University of Western Australia Pieter Poot, Erik Veneklaas

Curtin University Elaine Davison

DSE VIC Mick Bramwell, Ian Smith

Parks Victoria Lachie Jackson

La Trobe University Mike Clarke

ForestryTas Fred Duncan, John Hickey, Gary King, Mark Neyland, Tim Wardlaw

Forests and Forest Industry Council of Tasmania Trevor Bird

Private Consultants Frank Batini, Jack Bradshaw, Bob Ellis, John Kellas, Roger Underwood and Dave Ward.