Wandoo Crown Decline

Situation Statement, July 2006

Prepared by the Wandoo Recovery Group

Department of
Environment and Conservation

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Acknowledgments

The Wandoo Recovery Group (WRG) has produced this Situation Statement on wandoo crown decline and acknowledges the Department of Environment and Conservation's (formally the Department of Conservation and Land Management) Science Division for contributions of previous research studies, vegetation mapping, and wandoo decline research directions.

The WRG acknowledges the contributions of Mr Frank Batini, Mr Graeme Behn, Dr Mark Garkaklis, Paul Brown, Allan Wills, Kim Whitford, Jack Mercer, Lisa Bland, Robin Smith and Ella Maesepp.

The cover photograph was taken by Liz Manning.

Executive summary

Wandoo (*Eucalyptus wandoo* Blakely subsp. *wandoo*) is one of south-west Western Australia's most important eucalypts, and is endemic to the region. However, since the 1980s many wandoo trees and woodlands have suffered deteriorating health as demonstrated by a noticeable decline of the tree crown. Previous reports collectively suggest that wandoo has been in decline for perhaps 40 years, although the causes remain unclear. Land clearing, climate variability and change, altered fire regimes, increasing salinity, and activities of insects and fungal pathogens are likely contributing factors.

In February 2003, the Environment Minister, Dr Judy Edwards, formed the Wandoo Recovery Group (WRG) in response to growing community concern about wandoo's failing health. The WRG's role is to investigate the causes of crown decline and develop appropriate strategies and actions.

The WRG has been proactive in supporting research and initiating government and community-based actions to tackle the problem. An action and communication plan emphasising public participation has been developed and is being implemented.

The University of Western Australia (UWA) is conducting the principal research into wandoo crown decline. Based on the link between pests and pathogens and their environment, new research will focus on the relationships between climate, tree physiology and the wood-boring insect /fungal pathogen relationship as a priority.

The WRG is using its resources and knowledge to implement recommendations for survey, research and management. These include:

- surveying and mapping to determine the extent and severity of wandoo crown decline;
- conducting hydrological studies;
- supporting research focusing on the relationships between crown decline; environmental stresses, tree physiology, and the activities of insects and fungal pathogens;
- conducting communication and public involvement programs; and
- developing adaptive management options.

1 Introduction

1.1 Purpose of the Situation Statement

This Situation Statement provides government, stakeholders and the community with a view of wandoo crown decline in WA and the WRG's work.

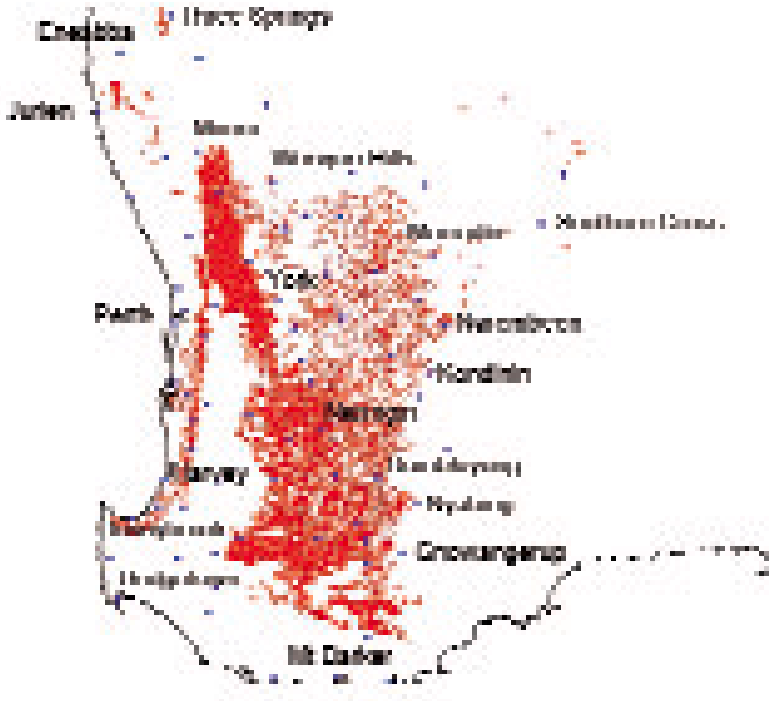
Research from the past 20 years, together with observations of wandoo decline, has been reviewed. Current research findings will broaden understanding of the causes of wandoo crown decline.

This report serves as a historic document, and a tool that can be used to gain support, guide future management decisions and protect wandoo for all its values.

1.2 Wandoo occurrence

Wandoo (*Eucalyptus wandoo* Blakely subsp. *wandoo*) is one of south-west WA's most important eucalypts, and is endemic to the region. It is distributed partially along the base of the Darling Scarp and is part of the jarrah forest in some of the medium rainfall areas. It grows south and eastwards into the wheatbelt. Wandoo is absent from the high rainfall areas between these regions. Within this distribution, it can span the topographic sequence from ridge to gully.

Clearing for agriculture has dramatically altered wandoo's current distribution. Many of the soil types on which wandoo grows have been taken up for farms, and the tree's range has been severely fragmented. Timber production, regeneration and silvicultural treatment have resulted in change to stand structure of the wandoo forest. Today it is restricted to areas of State forest, conservation reserves, isolated farmland remnants, paddock trees and roadside vegetation.



Map showing the distribution of *Eucalyptus wandoo* in south-west WA (provided by the Department of Environment and Conservation).

1.3 Importance of wandoo

Wandoo has made a considerable economic contribution to the State's development while conferring invaluable environmental benefits (White and Manning, 2005). It is one of the most important trees for wildlife in the south-west of WA, with many animal species using hollows in the tree and shed branches on the ground for habitat.

The foliage and bark support a myriad of spiders, beetles, thrips, native cockroaches, flies and other insects, making it a good habitat for insectivorous birds. Flowers produce abundant nectar, providing a source of food for birds and insects. The insects are important for recycling nutrients, seed dispersal and pollination and form an integral part of the ecological food web. The tree produces a fine honey that has long been the mainstay for the apiculture industry.

Wandoo is a first-class structural timber. It has been used extensively for heavy construction purposes such as poles, bridges, railway sleepers, wharfs and warehouse flooring. It is still in demand for joinery, flooring, stockyards and fencing.

Wandoo maintains popularity in landcare-oriented plantings, and is attracting renewed interest for timber production as a farm forestry species in medium rainfall areas.

However the wandoo forest is most valued for watershed protection and recreation. Most of the eastern or high salinity risk areas of Perth's forested water supply catchments are dominated by wandoo.

Change in tenure and purpose has resulted in altered management practices including such activities as beekeeping, timber production, prescribed burning, silviculture and access for experimentation and research (Batini 2005). Since the 1980s many wandoo trees have suffered deteriorating health as demonstrated by a noticeable decline of the tree crown. The exact geographical extent and severity of this crown decline is unknown.

1.4 Characteristics of wandoo crown decline

Early symptoms are characterised by an initial browning-off and death of the upper and outer twigs in the tree crown, commonly known as 'flagging'. Later, epicormic shoots sprout along the lower limbs to replace the dead twigs. These may then die, resulting in the progressive downward movement of the tree crown and redistribution of the canopy. Over three to five years the severity of decline often increases and, in some cases, the tree may die. However, the decline process can also stabilise and trees may recover as an epicormic crown replaces the lost canopy (Wills 2004).

The severity of crown decline can vary greatly within and between stands of trees. Older trees appear to be more severely affected (Batini 2004), but mature individuals with sound primary crown can be found interspersed with severely affected trees. Young trees are also affected. Decline symptoms have been noticed on wandoo and, to a lesser extent, on powderbark wandoo (*E. accedens*). Similar symptoms have been observed on jarrah and marri, but at present they are thought to be from different causes. The severity and duration of decline on other species appears different to those observed on wandoo. This decline event appears to be a relatively recent phenomenon (last 20-30 years). However, a comprehensive historical review needs to be undertaken to confirm this.

Healthy wandoo (photo by Pieter Poot).

Above Wandoo with severe flagging (photo provided by Ella Maesepp).

Right Epicormic shoots sprouting along the lower branches (photo by Liz Manning).

Wandoo in decline (photo by Pieter Poot).

Wandoo at Dryandra Woodland Reserve (photo by Mike Griffiths).

1.5 The community response

Increasing community concern about the failing health of wandoo, notably from the York Land Conservation District Committee (LCDC), influenced the State Government to take action and was the driving force for founding the WRG. In April 2002, the York LCDC conducted a seminar and field day to discuss wandoo crown decline. The LCDC prepared an action plan and presented it to the Environment Minister, Dr Judy Edwards. In February 2003 the Minister formed the WRG to investigate the causes of wandoo decline and devise appropriate strategies and actions.

1.6 Wandoo Recovery Group

The role of the WRG is to oversee strategic planning in relation to wandoo decline. This involves coordination of research, helping to secure research funds and community awareness programs. An action plan has been prepared and is being implemented. The WRG is focusing on four areas:

- research, to promote, support and facilitate research investigations into the causes of wandoo decline and recovery;
- mapping, to gain an accurate assessment of the extent and health of wandoo ecosystems through a coordinated vegetation mapping survey;
- communication, to increase public awareness of wandoo crown decline through an ongoing education program, while providing feedback on the WRG's progress; and
- collaboration to build partnerships with government, industry and community interest groups.

WRG membership includes representation from the York LCDC, Department of Environment and Conservation (DEC), Forest Products Commission (FPC), Water Corporation, University of Western Australia (UWA) and the World Wide Fund for Nature, (WWF – Australia). Community and business interests are also represented.

Observer status during WRG meetings has been accorded to the Conservation Council of Western Australia, the peak non-government conservation organisation in WA. Interested citizens are welcome to attend meetings as observers.

2 Threatening processes

Tree decline is often the result of a number of interacting abiotic and biotic factors.
Numerous conceptual models have been proposed, with some applying to more general theories of wandoo and others based on particular observations of wandoo. These frameworks are useful for comprehending and providing structure to observations and theories of wandoo decline (Appendix 1).

2.1 Factors influencing tree decline

There are many potential factors predisposing trees to decline, some primary and others that act as secondary opportunistic invaders. Although the causes of wandoo crown decline are unclear, a number of factors are thought to be involved. These include:

- reduced annual rainfall;
- reduced soil water in forested areas;
- changed understorey structure from altered fire regimes; and
- the activities of wood-boring insects and fungal pathogens.

In the wheatbelt the issues of wandoo decline are additionally complicated because of:

- rising saline water tables as a result of clearing for agriculture;
- changes in environmental conditions due to clearing; and
- agricultural management factors such as chemical usage, soil tillage, stock, grazing and stubble burning.

Clearing and environmental change predispose trees to decline (Crombie 2000). Before clearing, trees occurred in groups with a host of other species. The direct impacts of sun and wind were felt primarily by the tops of the canopies. Lower parts of canopies and soils were protected from the full drying power of the wind and sun. Below the ground, roots were most prolific near the surface. A system of deep roots in the lower horizons drew water from deep in the soil during summer droughts. Water tables were either absent or likely to be stable at the bottom of the rooting zone. In the post-clearing environment, sun and wind affect all parts of the canopy and the soil beneath the tree. Water tables may have risen causing deaths of those parts of the root system now permanently inundated. The volume of rainwater available in unsaturated storage is reduced.

3 Previous studies into wandoo decline

3.1 Brown *et al.* (1986-1990)

Biotic agents associated with branch 'flagging'

This study was carried out on wandoo decline. The aim was to collect detailed descriptions of diseases of wandoo across its distribution, collate a photographic record of symptoms and evaluate their role in its decline. Observations indicated that wandoo trees are not killed outright, but individual branches suddenly die resulting in a brown-leafed 'flag' in the tree crown. Flagging was found to be a major symptom of decline in wandoo and a key attribute in the model that was used in the study (Appendix 1). The study concluded that canker fungi, in association with specific borer insect larvae, could cause flagging in wandoo, both in the wheatbelt and the Darling Scarp.

The role of defoliating insects and fungi.

Curry (1981) implicated defoliating insects as a possible cause of decline in wandoo in some sites. The focus of this series of studies carried out between 1986-1990 was to evaluate the extent of foliage damage done by insects and fungi to wandoo and to identify some of the key species groups in the woodlands of WA's Upper Great Southern. This work indicated that defoliating insects and fungi were not the causal agents of the broadscale decline of wandoo in this region.

3.2 Mercer (1991, 2003)

Mercer (1991, 2003) investigated the decline of wandoo in areas of the central wheatbelt. He included in his study a wide variety of factors including rainfall deficit, fire history, 'connectivity' of remnants, changes in landuse, salinity, insect damage, and decomposition processes. Mercer reported that the role of these factors in the decline of wandoo was unclear but that general causes and effects of wandoo decline did not appear to be consistent with those reported for woodlands in eastern Australia. Much of what was observed in 1991 was considered to have probably resulted from an event 15 to 20 years earlier.

Mercer (2003) undertook transect surveys to establish the extent of active decline and the role of various potential causes. General trends along the transects and some comparisons of the 1991 data indicated several factors.

- The present decline pattern is broadscale, variable and not continuous across the landscape.
- Long-term cyclical decline has possibly been occurring over several decades and is often not related to the present decline. The present pattern is characterised by cyclic decline and recovery over an intermediate period of three to 10 years. The rapid crown defoliations documented in 1991 and due to extreme summer temperatures were considered an isolated event.
- Stands and individual trees often displayed very little or no decline symptoms while decline was evident nearby. Young regeneration stands were generally unaffected.
- Insect damage, specifically lerp damage may be implicated as a contributory factor.
- Crown health improved with longer periods without high intensity fire. Hot fires damaged tree crowns, suggesting that these fires brought disturbance that allowed decline patterns to develop (indicated by two recent and intense fire events in the Stirling Range followed by the acceleration of the present decline pattern).

- Crown health progressively improved at higher positions in the landscape and on steeper slopes. These areas have generally not been cleared or affected by rising watertables and their deeper root systems are resilient to soil moisture loss.
- Distinguishable decline events were long-term dieback greater than 10 years (dated several decades), not; salinity related dieback (recent and long-term) and present decline pattern (last 10 years).
- Three sites classed as degraded, intermediate and undisturbed in 1991 were compared in 2002 and similarly classed. The degraded and intermediate sites were affected by the present decline symptoms while the undisturbed site was unaffected. Old decline symptoms generally remained much the same.

3.3 Shearer *et al.* (1997)

Shearer *et al.* (1997) reviewed the distribution and impact of the root decay fungus, *Armillaria luteobubalina*, in wandoo woodland in WA. Rates of extension of disease centres, host susceptibility, site characteristics associated with disease centres and changes in community diversity following infection were also assessed. Although *Armillaria* caused high mortality in wandoo in the low annual rainfall belt of the wheatbelt (500-700 mm), infected areas were discrete, localised and small (mean 1.2 ha). The fungus spreads within sites mainly by root-to-root contact and moves extremely slowly. The direct impact of *Armillaria* in wandoo woodland was evident as mortality of trees when the infection reaches the tree collar rather than progressive crown decline. Shearer concluded that *A luteobubalina* was not the causative agent in this decline event.

3.4 Hooper (2003)

Hooper (2003) completed an honours project that aimed to assess the nature of damage to wandoo canopies and determine links with foliage loss and other organisms involved. He developed a model describing the relationship between a wood-boring insect (Type 1) and fungal pathogens causing canker likely to be responsible for the damage found in declining wandoo canopies.

The study found a constant association between Type 1 borer damage and fungal cankers on every declining branch sampled, but never on healthy trees. The findings suggest those fungal pathogen dispersal mechanisms, and/or the population dynamics of the Type 1 borer may hold the key to where the crown decline syndrome is expressed from year to year (Hooper and Sivasithamparam 2005).

4 Other reports

4.1 Batini (2005) A review of possible causes, with recommendation for survey, research and management.

In 2005, the WRG commissioned Mr Frank Batini to:

- review appropriate literature on crown decline in Australia;
- review and analyse the threatening processes that may contribute to crown decline;
- review and analyse current research into wandoo crown decline; and
- recommend options for survey, research and management.

Batini suggests trees are very long-lived and have developed multiple strategies to cope with threatening processes. However, because of their great age these older trees may not always be in balance with their current environment. Environmental changes such as temperature, soil moisture, and predator numbers may favour the build-up of insects and fungal pathogens.

Batini concluded the primary driver for wandoo decline in forest areas is a chronic drought stress over the past 25 to 30 years. This has been accentuated by an accumulation of litter, a build-up of understorey species and the increasing demands for water from the regrowth forest that was regenerated after timber production operations 30 to 45 years ago or, in some cases, after intense wildfire. Batini recommended a number of options for survey, research and management (see 11. Recommendations).

5 Observations of wandoo decline

Wandoo crown decline has been observed in the early 1980s in the wheatbelt, in the late 1980s on the Darling Scarp and again in the late 1990s in the wheatbelt. To build a historical picture and identify the extent of decline, the WRG reviewed a number of anecdotal reports describing instances of decline throughout wandoo's natural range. Many reports collectively suggest that wandoo has been in decline for perhaps 40 years, with reasons largely unknown.

- In 1963, small patches of wandoo deaths were occurring on the middle to lower slopes in the Dale region and east of the Gleneagle Forest Division (Podger undated). Declining trees were noted near settlements in logged areas and in unlogged stands within the woodland belt. Regeneration seemed unaffected. Fire damage, salinity and fungal infections were not considered relevant.
- A photograph by Chippendale (Chippendale 1973, p. 69), taken pre-1973 appears to show early stages of decline in wandoo. The location of the site is unknown.
- Kimber (1981, 1984) reported that wandoo and other trees had been declining within the wheatbelt since the early 1970s, with affected trees more common on road verges and in paddocks and less frequent in remnant woodlands. Drought, together with agricultural practices and opening up the woodlands, was implicated.
- Curry (1981) reported increased dieback in wandoo in the wheatbelt during the drought years of 1975-1980. Older trees were more affected than the young. Drought, salinity, defoliating and sap-sucking insects were thought to be causal factors.
- Davison and Tay (1983) reported that insect attack, drought and frost events were often associated with canker fungi in trees and all are known to affect wandoo.
- Brown *et al.* (1990) reported that instances of what is today called wandoo crown decline were first officially recorded from the Dryandra State Forest in the mid-1980s.
- Mercer (1991) noted the symptoms of wandoo decline probably dating back to the 1970s and 1980s in the central and southern wheatbelt. Decline was noted on road reserves, steep gullies, high elevations and mid to low slopes. Canopy loss was both recent and long-term.
- A conference was organised in Kojonup in 2000 due to increasing concern over the instance of declining tree health in WA (Conference proceedings, 2000).
- Underwood (2001 unpublished report) first noted decline in bushland north of the Great Southern Highway between the Lakes and York in the early 1990s. By the late 1990s, wandoo was declining throughout its range (Appendix 3).
- Reports to the WRG in 2004-2005 indicate that flagging was occurring near Dumbleyung. Decline and, in some cases, recovery of wandoo was observed in the adjoining districts of Wagin and Katanning (White and Maesepp pers. comm.).
- Wills (2005) took a series of photographs of wandoo crowns at Wundabiniring Brook from 1999-2005. At present, the trees appear to be rebuilding their crowns. Observations from this site have been published in a series of reports and used to develop the brochure, *Surveying Wandoo Crown Decline: A guide for assessors* (Appendix 4).
- McGregor (pers. comm. 2005) observed crown decline in wandoo trees in 1995 on the Great Southern Highway, about three kilometres east of Inkpen/Yarra Roads. The decline spread east and reached his farm (near the western boundary of the York Shire) in 1997 with two trees affected. In 1998, 20 per cent of trees were affected, increasing to 75 per cent by 1999. Most of the trees on the property are young (30 to 35 years old) and affected trees were situated from valley floors to hilltops. Ten years later, the trees seem to be recovering.
- White (pers. comm. 2005) became aware of wandoo decline in the Harrismith-Moulyining area in early 1980, in the Narrogin area in 1991 and in the Williams area in 1993-94. Through the 1990s, reports confirmed widespread decline through the southern part of the wheatbelt, particularly Tambellup and Kojonup (Appendix 5).

6 Current research

UWA is conducting the principal research into wandoo crown decline. Two lines of study are being examined:

(i) ecophysiological research to examine wandoo's response and tolerance to a range of environmental stresses such as changing climatic conditions, salinity and waterlogging; and

(ii) phytopathological research to determine the relationship between crown decline and the activities of insect borers and fungal pathogens.

6.1 Environmental (ecophysiological) studies

6.1.1 Survey of 30 populations

In 2004 an initial survey of 30 populations (Appendix 8), was conducted covering the entire wandoo distribution range to identify possible environmental, plant physiological or soil chemical factors that may be involved in the decline. At each site, 12 trees were chosen randomly, their health status classified, and leaves and soil samples were taken for further chemical analysis (leaf and soil macro and micronutrients, soil EC, soil pH). On sites where other species of eucalypt were co-occurring with wandoo, samples of these species were also taken. Results did not provide clear indications of specific factors causing the current crown decline. This indicates that crown decline may be caused by a multiplicity of factors, with the relative contribution of each factor depending on specific site conditions.

6.1.2 Water relations of wandoo compared to co-occurring eucalypt species

Since the mid-1970s a continuing decrease in annual rainfall over WA's south-west (Indian Ocean Climate Initiative 2002) has led to a considerable lowering of the groundwater table in several catchments containing wandoo woodlands in the Darling Range, east of Perth (Batini 2005). In contrast, many areas of cleared land have rising water tables. Both situations may lead to drought stress especially when this condition persists for many years. It is thought that chronic drought stress may be involved in wandoo crown decline either directly or indirectly by making the trees more vulnerable to their natural enemies (leaf chewers, wood borers, pathogenic fungi and other micro organisms). However, other tree species co-occurring with wandoo (marri, jarrah, powderbark, york gum, salmon gum) generally seem less affected. Wandoo's vulnerability could be related to its position in the landscape (valleys), the soils it grows on (heavy clays) or its physiology (least adaptive to a change in climate, most vulnerable to insect/pathogen attack).

To assess whether wandoo is more vulnerable to drought than some of its main co-occurring tree species (marri, jarrah, powderbark) the water relations of these four species are being studied in the Julimar Conservation Park, near Bindoon (north-east of Perth). Pure stands of wandoo woodland, powderbark woodland and jarrah/marri woodland, plus a mixed species stand, are being monitored to determine the water status of selected trees (leaf water potentials) as well as their transpiration rates (leaf gas exchange). Additionally, sapflow probes are continuously monitoring the flow of water through the trunks of several individuals for each species. The initial results show that wandoo is the biggest 'water user' of all four species, especially when compared to jarrah and marri trees. Diurnally, they open their stomates earlier during the day and close them later than the other species, whereas seasonally, they close their stomates to a lesser extent than the other species during the hot and dry summer months. More research (e.g. to understand root-soil interactions and assess the effect of insect damage) is needed to gain a better understanding of wandoo's vulnerability to drought relative to its co-occurring species.

6.1.3 Glasshouse experiments

Glasshouse studies are testing the salt tolerance and drought tolerance of 30 geographically distinct wandoo populations. The use of provenances with improved salt and/or drought tolerance will also be useful for future landcare programs. Initial results of the salt experiment indicate a large variation in salinity tolerance among the 30 populations.

6.2 Insect and fungal (phytopathological) studies

In 2003, a study was launched investigating possible biotic disease factors involved in the decline of wandoo. Intensive sampling of wandoo canopies close to the Great Southern Highway, revealed that an interaction between a wood-boring insect, named Type1 borer and decay forming fungi were responsible for declining canopies. Numerous infestations were found per declining branch. The study concluded that Type 1 borer damage and associated decay columns were the primary damage-causing agent in declining canopies.

Investigation of branch ultrastructure showed decay affected functionality of conducting tissues. Declining trees were clearly distinguished from healthy trees on the basis of the damage characteristics of Type 1 borer, various canker types (dominant "fusiform", "cracking" and perennial "fusiform") and associated decay columns. Cankers on primary branches in declining canopies were found to be larger and more severe.

Investigations to understand the taxonomy and biology of the organisms involved and the specific interactions between insect, decay-fungi and the environment are underway (Hooper and Sivasithamparam, 2005). The condition of the wandoo forest has not been monitored with any rigour since local communities along Great Southern Highway first observed crown decline in the early 1990s. Both spatial and temporal patterns of decline remain unclear. The study (part of a PhD program) will provide a platform for long-term monitoring of crown decline symptoms and populations of Type 1 borer throughout the wandoo region.

7 Future directions for research and management

Research into wandoo decline is being guided through consultation with the aim of:

- developing priority research proposals and management options for regenerating and maintaining wandoo woodlands;
- ensuring government, scientific, industry and community viewpoints are represented in developing future research directions; and
- providing opportunities for government and non-government organisations, Natural Resource Management groups, universities and business to participate in and contribute to future research programs.

7.1 Wandoo Science Workshop

To fulfill these aims a Wandoo Science Workshop was held in July 2005 to set direction and priority for future research. The workshop focused on the key scientific and operational research needs as well as identifying knowledge gaps in current information. Outcomes arising from the workshop identified research priorities, funding sources and the need to develop a research strategy and decision-making framework (Appendix 9).

7.2 Research strategy framework

As a result of the workshop the WRG asked Dr Ian Abbott (Science Division, Department of Environment and Conservation) to recommend an approach to developing a research strategy. Dr Abbott proposed a sequence of steps which should be addressed in assessing a sudden change (as happened with decline of crowns of wandoo trees in the 1990s), together with an outline of resource management. With assistance from Dr Abbott and Dr Erik Veneklaas (UWA), a research strategy framework that captures current research hypotheses and guides future resource management is being developed (Appendix 9).

8 Mapping

Wandoo has been extremely difficult to identify and map from aerial photographs and initial distribution maps were prepared by ground survey. The WRG identified a need to develop a method of rapidly and consistently assessing crown condition in wandoo trees suffering from crown decline. The methods fall into two classes:

1) remote sensing (e.g. aerial photographs, Landsat, airborne thematic mapping); and
2) ground survey (e.g. photo points, plots, road reconnaissance, visual assessment along transects).

8.1 Remote sensing

The Department of Environment and Conservation (DEC) and CSIRO are using remote sensing technology and trend analysis of satellite imagery to assess changes in vegetation cover at a landscape-scale over a period of 18 years. DEC is coordinating a wandoo canopy assessment project which aims to:

- map the distribution of wandoo decline and recovery at various sites using remote sensing technology; and
- identify changes in vegetation cover from 1988-2005 using trend analysis of Landsat imagery data.

Field data have been collected at sites including Helena catchment (including Talbot Block), Julimar Conservation Park, Drummond Nature Reserve, and Dryandra Woodland Reserve. Maps have been produced for each of these sites.

Findings so far indicate that in some areas the forest and woodland canopy has declined. There are also areas of recovery. The project is currently examining the decline to recovery ratios for each of the survey regions (Appendix 10).

8.2 Ground survey

Wandoo decline has been described qualitatively on a number of occasions. The WRG elected to develop a simple, repeatable survey procedure based on sequential photography of a number of trees over four years (Wills 2004). A technique trialled by Batini (2004) consisting of a visual assessment of tree crowns was adapted by the WRG and used as a guide to develop their own survey procedure.

8.2.1 Wandoo assessment guide

The WRG has developed a simple survey procedure for assessing the health of wandoo trees. This explains how to assess the severity and the progression of wandoo decline in stands of trees in relation to their size, canopy condition and presence of flagging (Appendix 11). Community groups, land managers, students and researchers can use this procedure to survey wandoo trees in their local area. Results from these surveys will provide knowledge that is locally informative and will develop an understanding of the geographic extent and severity of wandoo decline, and its progression over time. The data will be collated by the WRG and made available for research and monitoring. Information gained will complement the broad-scale mapping project being undertaken by the DEC.

9 Communications

9.1 WRG Communication Plan

The WRG acknowledges that community engagement is essential to achieve its objectives and implement protection and recovery measures. A communication plan has been developed and is steadily being implemented (Appendix 12). The plan focuses on:

- regular reporting to the Minister, key stakeholders and interested groups on the progress of research and WRG activities;
- community education and awareness-raising to enhance knowledge and understanding about wandoo;
- consultation, joint planning and opportunities for community participation; and
- establishing and maintaining networks and partnerships with government, industry, research and community sectors.

9.2 Community participation

The WRG encourages community engagement in its projects and activities. Opportunities for involvement can be through:

- participation in community fora;
- surveying wandoo crown decline using the WRG Assessment Guide;
- assisting researchers with their work; and
- attending WRG meetings.

9.3 On-ground activities

Volunteers are needed at regular times throughout the year to conduct wandoo crown assessment surveys to record the health of wandoo trees and woodlands in their local area. Calls for volunteers will be made using community, government and research networks.

9.4 Website and links to other interest groups

A wandoo web link to the DEC's NatureBase website will provide information about wandoo decline, research and WRG activities.

9.5 Achievements

Since its establishment, the WRG has supported researchers and land managers who are tackling the problem on the ground. This support adds encouragement and provides important connections and access that enable things to happen. The WRG has developed an action plan and is steadily implementing this to achieve its goals. Achievements are listed below:

- News bulletins explaining wandoo crown decline and details about research investigations and WRG activities have been widely circulated.
- Stories and information about wandoo have appeared in *LANDSCOPE* Vol. 20 No. 3 Autumn 2005; *Western Wildlife*, Vol. 8 No. 4 October 2004; *CALM Conservation News*, No. 55; *Australian Association of Bush Regenerators* (AABR), Vol. 13 Issue 1 March 2005 as well as Natural Resource Management (NRM) and rural media.
- Community information days and field trips to raise public awareness about wandoo decline and the WRG have been strongly supported by farmers, landcare professionals, scientists and representatives from government and non-government organisations.
- WRG members have given presentations to community groups including the Toodyay Naturalists Club, Central South Naturalists Club (Narrogin), Talbot Brook Land Management Association, and the York Society.
- A community forum on wandoo decline was held in June 2005 to provide participants with an opportunity for community input and feedback. Representatives from tertiary institutions, government and non-government organisations and community groups attended.
- A Wandoo Science Workshop was held in July 2005 to set direction for future research.
- The WRG provided advice and input into the South West Catchments Council (SWCC) and Avon Catchment Council (ACC) NRM Strategy and Investment Plans. Reference to wandoo crown decline appears in both strategies and there is increased opportunity for future projects relating to research and conservation management.
- Regular reports on the progress of research and WRG projects have been circulated to the Minister, interested groups and active partners of the WRG.
- The WRG Assessment Guide has been developed to assist ground survey of wandoo decline.
- Networks and partnerships continue to be formed and strengthened between groups with interests in wandoo.

10 Partnerships

The WRG continues to build partnerships and strengthen existing ones through a collaborative approach to projects that cover the WRG outcomes and those of partner organisations. Partnerships can be formed between government, industry, research institutions and community groups.

10.1 Government

Commonwealth Government

- The Commonwealth Government provides links to the Natural Heritage Trust (NHT2), and National Action Plan (NAP) programs. Regional projects are delivered through Natural Resource Management (NRM) Councils. The Northern Agricultural Catchments Council (NACC); Avon Catchment Council (ACC); Swan Catchment Council (SCC); South West Catchments Council (SWCC); and South Coast Regional Initiative Planning Team (SCRIPT) have interests in wandoo. The WRG has provided input and advice into the ACC and SWCC Investment Plans. The Australian Research Council (ARC) Linkage Program provides funding for long-term research.

State Government

- Partnerships and funding is mainly through agencies. Projects that cover the WRG outcomes and those of partner organisations will help to achieve corporate goals. The WRG supports the proposed establishment of a WA Centre of Excellence for Tree Decline Science and Management.
- The DEC is the lead agency provider for the WRG, assisting with weblinks, finance, publications, executive support and mapping technology.

Local Government

- The WRG is seeking the support of local government authorities (LGAs) in WA's south-west.

10.2 Private business / industry

Additional research partners and sponsors are being sought from business and industry. Potential partners include the Water Corporation, mining companies and agribusiness. Projects require well defined outcomes within three years. Efforts to find common ground and establish support for ongoing research will continue.

10.3 Research

UWA is the WRG's main research provider. In the area of tree biology, a partnership between the School of Plant Biology and the former Department of Conservation and Land Management (CALM) led to an ARC Linkage grant (2003-2005), allowing a part-time postdoctoral appointment. In addition, a PhD project is funded directly by the DEC and supplemented by the Cooperative Research Centre for P lant-based Management of Dryland Salinity. In the area of plant pathology, a PhD student works on wandoo decline with a UWA scholarship, receiving in-kind support from the DEC and the WRG.

Increased synergies are being sought between UWA's wandoo research and Murdoch University's tuart research. An expression of interest to establish a State Centre of Excellence for Tree Decline Research was submitted in October 2005.

At the national level, the interests of the WRG are represented by UWA's involvement in a bid for a Commonwealth environmental research facility, hosted by the University of Tasmania. This was to bring together several scientific disciplines to address the conservation of iconic eucalypt woodlands of rural Australia (this bid was unsuccessful).

10.4 Community

The WRG acknowledges local communities who have the knowledge and passion required to manage local assets. Such partnerships with community interest groups are vital to ensure the success of recovery projects. The York LCDC has been the principal driver in influencing the State Government to establish the WRG. The WRG draws considerable input and advice from the York LCDC who is well represented on the WRG. The Beverley, Toodyay and, South Central Naturalists Clubs as well as a number of Friends Groups have given considerable support to WRG projects. Volunteers are encouraged to participate in WRG projects that involve research, mapping and monitoring.

11 Recommendations

The WRG is using its resources and knowledge to implement recommendations for survey, research and management suggested by Batini. These include:

- continued surveys and mapping to determine the extent and severity of wandoo crown decline, using a standardised assessment procedure for evaluating crown condition, Landsat imagery and remote sensing technique with input from volunteers. Comparisons between the health of the remaining areas of bush and of the wildfire area in the eastern Helena catchment will be considered;
- hydrological studies that will see several boreholes in the eastern Helena catchment remeasured at three to five year intervals;
- support for research focusing on the relationships between crown decline, environmental stresses, tree physiology, and the activities of a wood-boring insect and associated fungal pathogens;
- adaptive management treatments involving combinations of do-nothing (control), thinning, scrub-rolling and frequent fire regimes implemented on State forest. These sites would prove useful for more detailed research studies on tree physiology, nutrient status and susceptibility of wandoo under different silviculture/fire regimes to insect/fungal attack; and
- communication and public participation in survey, photography and monitoring programs.

Options for research topics were explored at the Wandoo Science Workshop and these are being given further consideration by the WRG (Appendix 9).

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Appendix

1: Shows four conceptual models of decline:

1. The disease spiral – Manion 1981
2. Clearing and environmental change – Crombie 2000
3. Disease triangle model - traditional
4. Wandoo disease model – Brown *et al.* 1990

The disease spiral (Manion 1981)

There are many potential factors predisposing trees to decline, some primary and others that act as secondary opportunistic invaders (as recognised by Manion 1981).

Predisposing factors

These are long-term factors that weaken trees, or in the wheatbelt where site changes are so diverse they may no longer be suitable for the existing trees. Examples include:

- reduced annual rainfall;
- rising groundwater;
- increasing salinity;
- increased nutrient supply;
- position in the landscape; and
- agricultural pressures (fertilisers, herbicides, soil compaction, stock grazing, increased exposure of the foliage to wind).

Inciting factors

These are short, sharp shocks of either a physical or biological nature, from which trees have difficulty recovering. Examples include:

- frost;
- defoliation by locusts and other insects;
- very high temperatures;
- unseasonal rainfall; and
- herbicide drift / mechanical damage.

Contributing factors

These are long-term factors that have been present at a low level, but which invade weakened host trees. They are often very conspicuous and indicate severely stressed or dying trees. Examples include:

- canker fungi;
- insects: borers, leaf skeletonising caterpillars, scale, psyllids; and
- root rot fungi e.g. *Armillaria*.

Clearing and environmental change predispose trees to decline (Crombie, 2000)

Prior to clearing

- trees occurred in groups with a host of other plant species;
- had ectomycorrhizal and endomycorrhizal fungal associations;
- accessed a deeper water table; and
- lived in an environment with an intact invertebrate and vertebrate fauna.

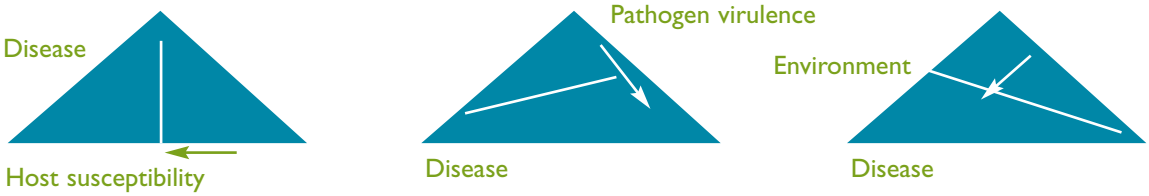
After clearing

- trees now occur singly or in small groups in the landscape;
- diversity and abundance of beneficial mycorrihizal fungi have decreased;
- habitat for fauna and diversity of fauna species have decreased;
- water tables have risen;
- salinized water is encroaching in lower parts of the landscape;
- agricultural pressures are pervasive (95 per cent of the wheatbelt has been cleared); and
- mature trees are not being replaced with young seedlings because sheep consume them.

Disease triangle (as mentioned in Hardy 2000)

The Disease Triangle incorporates the factors that affect the development and destructiveness of disease, and includes the susceptibility of the host population, the virulence of the pathogen, and the environment favourable to the pathogen.

This model requires the host to be present with the 'right' pathogen(s) and under the appropriate environmental conditions to result in disease expression. All three elements must be in place for the disease to be expressed.



If the three sides of the equilateral triangle represent the maximum effect of each factor, then the area within the triangle represents the maximum severity of the disease. If the susceptibility of the host, virulence of the pathogen or environmental conditions favours disease then the potential and severity for decline will increase.

Environment	Host	Pathogen
Temperature	Susceptibility	Adaptability
Rainfall	Growth stage and development	Presence of pathogens
Salinity	Reproductive fitness	Pathogenicity
Soil water content	Population density and structure	Dispersal efficiency
Soil fertility	General health	Survival efficiency
Wind		
Fire history		

WANDOO DECLINE DISEASE MODEL (Brown *et al.* 1990)

CYCLIC CLIMATIC CONDITIONS SUITABLE
(Early 1980s and late 1990s)

↓

Wandoo present

↓

Borer larvae common and attacking branches

↓

Fungal spores introduced into bark and/or wood by borers or through borer damage

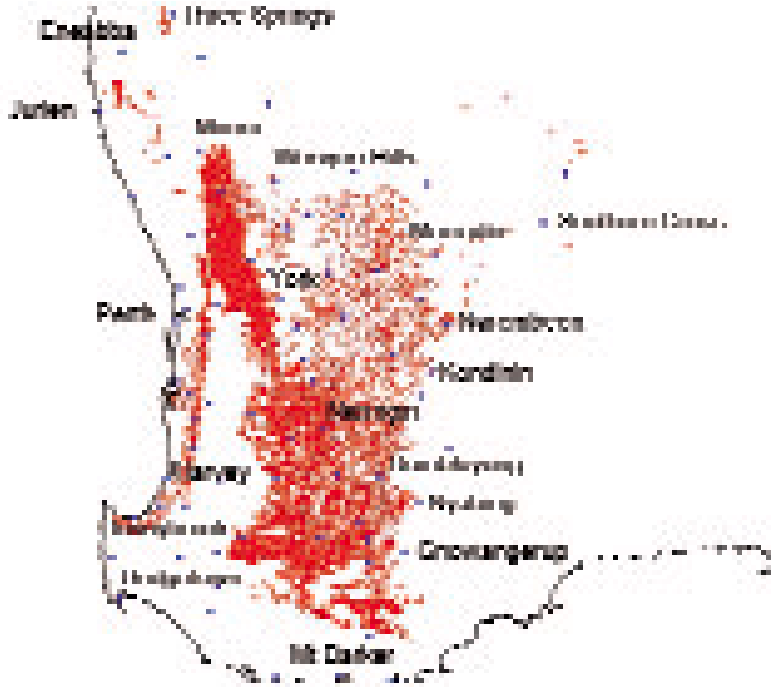
↓

Local environmental factors affect impact on stands and trees

↓

Disease expression through branch flagging

2: Map showing the distribution of *Eucalyptus wandoo* in south-west WA



3: Extract from an unpublished report by R.Underwood (2001)

"I have been interested in the wandoo forest since 1963 when I became a forester in the Mundaring district. This encompassed the bulk of the northern wandoo State forest. I was involved in the great wandoo mapping project, which took in the whole of the wandoo forest in the Helena catchment as well as Julimar Forest. Previous dieback in wandoo was investigated and found to be caused by *Armillaria meila* (now known as *A luteobubalina)*, (honey fungus). I cannot remember seeing this current decline syndrome in the forest in those days. In the early 1960s the wandoo forest was far more open and grassy than it is today. Up until the late 1960s there was no regular prescribed burning of wandoo bush in the eastern part of the Helena catchment, but there were very frequent and usually quite mild fires. They were allowed to burn as they did not necessarily represent a threat. Periodic control burning began in the mid 1960s. This change in management practices resulted in less frequent fire and a woodier, shrub understorey replaced the native grasses. Since the 1960s, the number and diversity of large native fauna has declined, due possibly to a change in vegetation structure, drier seasons, illegal shooters and the explosion in numbers of the European fox. The change in understorey from grass to shrub-land has allowed a build-up of leaf-eating insects that were previously controlled by frequent summer fire and has changed the hydrological cycle. My observations over the past 40 years indicate that older stands of wandoo are less healthy and more susceptible to this decline than younger trees".

4: Wills, 2005. Crown decline in wandoo at Wundabiniring Brook, 1992 – 2005

The Science Division of the then Department of Conservation and Land Management (CALM) was alerted in early 1999 to foliage death in an extensive area of wandoo (*E. wandoo*) in the Talbot forest block. Although unclear, the cause of foliage thinning was initially attributed to below average winter rainfall in 1997 (Wills *et al.* 2000). Leaf feeding insects and salinity did not appear to be factors detrimentally affecting wandoo at this site (Wills *et al.* 2001).

A series of wandoo crowns in open woodland near Wundabiniring Brook were photographed in 1999 and then re-photographed in subsequent years (2000, 2001, 2002, 2003, 2004 and 2005). At the outset of monitoring, there was already variation between trees in time of onset and severity of decline symptoms; the amount of 'flagging'; loss of terminal foliage; growth and death of epicormic clusters; and subsequent death or recovery of the tree. Flagging of epicormic foliage was most abundant in late May 2001. By late autumn 2003 and 2004 flagging had become relatively uncommon at this site and remained so during 2005.

At present, with some exceptions, trees appear to be rebuilding their crowns at this site. Epicormic clusters initiated after the loss of terminal foliage continue to grow and most trees now have dense canopies. Trees that were most severely affected, those that completely lost their first flush of epicormic foliage, appear to be those most likely to die suddenly. The ultimate cause of death of those trees that die is not clear, although the decline process probably weakened them.

Long-term (seven years) observations at this site clearly indicate that individual trees respond differently with regard to the abundance and extent of development of branch dieback. The mechanisms for differences between tree crowns are unknown at this stage. Observations from this site have been published in a series of reports and have been used by the WRG in preparing the brochure; "Surveying Wandoo Crown Decline: - A guide for assessors".

5: White (pers. comm. 2005)

Observations detailing presence and severity of decline were recorded from 2000 in areas between Narrogin and Perth, Burekup, Albany and Merredin. Emerging pattens include:

- a strongly seasonal pattern of decline and recovery;
- visible symptoms appear usually after first autumn rains ie. late March to April;
- a lull in the expression of symptoms over the winter period, with new symptoms visible from September to October; and
- symptoms appear to reach a peak around December followed by a strong growth flush of epicormics.

Landscape position or soil type does not appear to influence the instance of wandoo crown decline. Some of the areas previously affected e.g. Burekup, have not displayed any fresh symptoms for the last three years.

- Several sites e.g. areas around Toolibin, Dongolocking, Quairading/Corrigin, Namulkatchem etc, appear unaffected by wandoo crown decline. However, this is not always consistent, as the outlying trees on the Corrigin–Kulin Road have been severely affected.
- The severity of wandoo crown decline can differ between forest areas and cleared land where the Brookton Highway emerges from the forest. The severity of damage changes from that of individual dead branchlets to C4 crowns in the space of under one km.
- Some areas, which were badly affected in the previous decline event (ie. studies by Brown *et al.* 1990) e.g. Quinns Block near Narrogin, do not appear to display symptoms anywhere near the same severity in this decline event.

This decline relates primarily to *E. wandoo* subsp. *wandoo*. There are some reports of similar symptoms being observed in the unrelated *E. accedens*, though it is by no means as widespread as in wandoo. *E. capillosa* subsp. *capillosa* has been reported as suffering and, while I have observed thinning crowns on this species, the symptoms of wandoo crown decline have been absent. Occasional flagging symptoms have been observed in cultivated *E. gardneri* around Narrogin. The northern form of *wandoo*, subsp. *pulverea*, does not appear to be affected.

Conflicting accounts of decline appear to be related to lack of observers who can make timely and consistent observations (Mercer 1991). People often "discover" new areas, but this can be more a case that they had not travelled through the area recently, rather than a "spread". There is an attempt (not unreasonable either) to link wandoo crown decline with falling rainfall. However, this appears to be at odds with some of the available evidence of repeated events of decline and recovery, e.g. Smith's work at Flynn's farm. In some areas, still affected by an overall rainfall deficit, there appear to have been no signs of wandoo crown decline.

6: Batini (2005). Hydrology studies in Helena catchment

Since the mid 1970s, records show that rainfall in the Perth metropolitan water catchments has decreased by about 15 per cent and that run-off has been reduced by about 50 per cent. It is possible that the reduction in rainfall has been even greater in the eastern parts of these catchments, where wandoo is more common.

During the mid 1970s, the Forests Department commenced some paired catchment studies in the Helena catchment (Hutt, Wellbucket and Talbot subcatchments) to investigate the effects of timber cutting on salinity. The catchments were predominantly comprised of jarrah-marri with wandoo on the lower flats. Rainfall, run-off, salt discharge, salt storages in the soil profile, groundwater depths and salinities and shallow water-table depths and salinities were recorded. Nine deep bores were established in each catchment to measure the salinity and depth of the confined groundwater (Batini, Hatch and Selkirk, 1977). Tree felling and logging of the experimental catchments resulted in no rise of the deeper groundwater table. In fact, data from deep bores between 1975 and 1979 showed that the minimum water levels recorded were already falling in all catchments.

Prior to winter 1976, a further nine deep/shallow bore combinations were drilled close to the eastern margin of the catchment, in the 500-600 mm rainfall zone within predominantly wandoo forest in the Talbot forest block. Depths and salinity were recorded usually at monthly intervals, commencing in June 1976 and continuing for three to four years. During that time (when the average rainfall recorded was 450 mm), two of the forest bores showed a decline of about 1.5 m, two remained at about the same level and a further three were always dry.

In 2004, the WRG requested these bores be remeasured. These valuable records now span a period of over 25 years. Maximum difference between recorded bore levels in the mid to late 1970s and recent remeasurements show that the water level fell in all bores. The greatest observed reduction was nine m, with the average over 10 bores exceeding four m. The data indicates that groundwater levels have been in decline since *at least* 1975. The soil water storage has also been depleted during the past 30 years. These conditions suggest that the trees in the eastern Helena catchment have been under a chronic drought stress over this extended period.

7: Smith (2003). Preliminary assessment of rainfall and groundwater trends in areas of wandoo

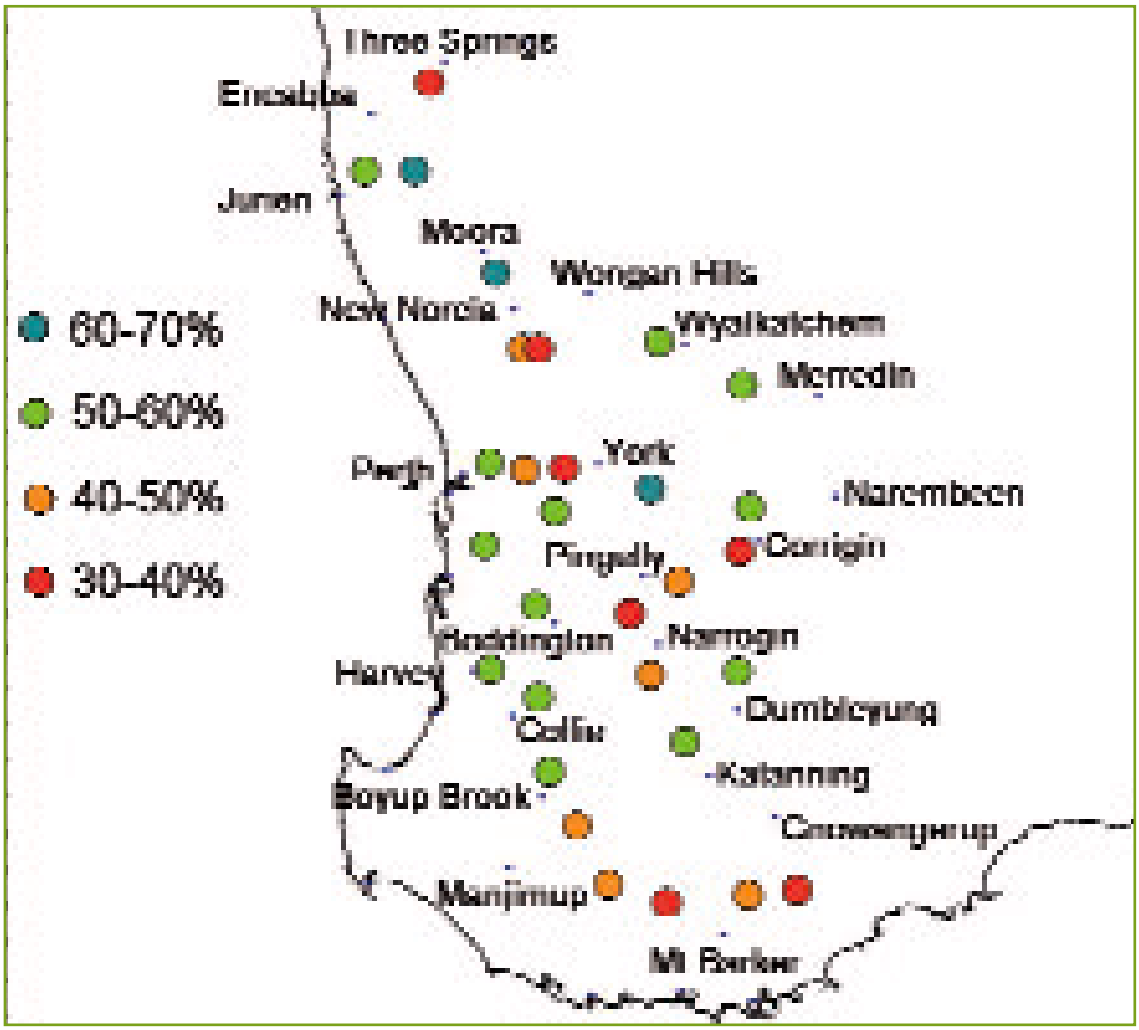
A report by Smith detailed a preliminary assessment of rainfall and groundwater trends in areas of wandoo at Flynn's Farm, Helena catchment. Smith noted that wandoo woodlands are generally located on soils that have accumulated significant salt storage from rainfall. On forested slopes groundwater tables have declined in response to decreased rainfall. Soil moisture is thought to be the source of most water transpired by wandoo, especially where wandoo occur above saline groundwater. Results from trend analyses indicated that wandoo crown decline is not directly related to, and the result solely of, groundwater decline.

8: Ecophysiological (environmental) studies undertaken by the University of Western Australia

The map below shows the health status (percentage of maximum possible score) and approximate location of 30 wandoo sample populations.

The results indicate that there is no clear regional pattern of the health status of wandoo. However, the survey was limited in that:

- only 12 trees per population were sampled;
- active crown decline was relatively rare during the assessment period; and
- indicators at the time of sampling may not represent health problems at different times.



The following table summarises the main results of this initial survey:

Some crown decline was observed in all populations, but no clear geographic or rainfall-related pattern emerged. Active flagging, a symptom of current decline, was only observed in a few populations.
At sites where wandoo co-occurred with other eucalypt species (powderbark, jarrah, marri, salmon gum) wandoo generally had the lowest health status.
Possible changes in plant mineral nutrition (shortage, toxicity, imbalance), as assessed by leaf nutrient levels, were weakly associated with population health for Fe (r=0.49) and Zn (r=0.38), whereas no association was observed for any of the other nutrients (N, P K, Mg, Ca, Mn, B, Cu).
Surface and subsoil electrical conductivity, as an indicator of possible salinity problems, was not correlated with population health, although subsoils of some populations did show moderately high salinity levels (0.4 – 0.9 dS m-1). However, leaf Na concentration was weakly negatively correlated with population health (r=-0.49), suggesting that salt-related problems cannot yet be excluded. There were no consistent differences in soil pH between healthy and unhealthy sites.
Wandoo population health was not correlated with the carbon-isotope discrimination value ($\delta^{13}C$) of their leaves. This suggests that, at least at the time of leaf growth, unhealthy populations were not more drought-stressed than healthy populations.

9: Wandoo Science Workshop outcomes

The Wandoo Science Workshop focused on scientific and operational research needs as well as identifying knowledge gaps in current information.

Research proposal by Dr Ian Abbott, 2005

Sequence of steps

- Step 1: establish whether the change is part of natural variability or a result of anthropogenic factors. This will often involve interviewing a large number of old-timers, distributing a structured questionnaire to persons who may be able to contribute historical information, systematic searching of historical literature, studying scientific literature for precedents, and initiating dendrocronological research.
- Step 2: conceptualise the problem. Avoid hasty rejection of factors and premature favoring of other factors. Apply clear thinking to understanding mechanisms and patterns of decline. Consider the full range of relevant environmental disturbances. Passive observation in the field is useful at this stage.
- Step 3: form appropriate working hypotheses. Apply Ockham's razor and hypothesise a single overarching cause rather than multiple causes but think in terms of causation chains. Avoid the ecwee ('everything connected with everything else') mindset and 'spaghetti' diagrams. Distinguish between indirect/secondary/contributing factors from those that are direct/primary/inciting. Simplify for the time being by setting aside second and third order interactions. Work out major cross linkages.
- Step 4: test the working hypothesis. Avoid unstructured, ad hoc surveys and general collecting of fungi, bacteria, viruses and invertebrates. Favour active observation by imposing a variety of relevant disturbances (as replicated experimental treatments) – these might include thinning, a range of fire frequencies and intensities, irrigation, fertilisation etc, at an appropriate scale (several to many tens of hectares). The approach should be cross disciplinary, coordinated and integrated (i.e. performed on a common set of plots).
- Step 5: revisit Steps 2 and 3.

Resource management

A project coordinator will oversee the research by:

- planning, site selection, plot installation, treatment application etc in consultation with interested parties and with the endorsement of the WRG, as well as conducting research reflecting this person's discipline base;
- seeking partnerships and funding opportunities with universities, NRM groups, non-government organisations (NGO's) etc, as well as liaison with other groups studying decline in tuart, flooded gum and marri; and
- collating reports, ensuring that the research program proceeds smoothly, maintaining focus of single-discipline scientists on the cross-disciplinary and integrated purpose of the study, identifying information gaps, publicising progress etc.

Wandoo crown decline

Research priorities

Research	Comments
Ecophysiology • Genetic variation – within site variability, glasshouse studies – PhD to be finalised February 2007. • Roots. Sub-surface exploration to identify depth and health of fine roots and their loss. • Water relations – where does the water come from and how is it used? • Comparison of sites with healthy and unhealthy crowns. • Structure of soils and how this influences growth of wandoo.	Current research projects - high priority and will be continued. A vital component of this research.
Climate research • In relation to wandoo decline/recovery. • Evidence of decline during a good rainfall year. • Collation and re-activation of previous hydrology research. • Re-evaluate water relations – site specific interactions.	Could be factored into research identifying drought stress.
Phytopathology • Fungi / insects / borer relationships.	A current research project - high priority and will be continued.
History of previous cycles of decline/recovery • Research early reports of decline (pre 1980s). • Look for cycles (use aerial photos, interviews, literature, and palaeo/dendro time). • Compile an archive (paddock trees versus remnants). • Link decline events in space and time. • Link life-cycle of decline (ups and downs).	High priority, suitable as honours project.
Mapping areas of decline at landscape levels • Trend analysis. • Overlay rainfall data with canopy data. • Use a high rainfall year – better detect rainfall signal. • Analysis of other factors e.g. fires.	High priority. Current data will provide information to assist intervention trials.
Management trials • Fire – intensity, frequency. • Stand density – logging / timber harvesting. **Other intervention trials** • Irrigation/'drought' by interception. • Understorey competition.	High priority. Fire trials to test response to changed fire regimes. Not a current priority.
Network with other tree decline groups • Tuart Response Group, Phytophthora Response Group, Centre Phytophthora Science, Management.	Underway and ongoing.
Modelling • Long-term change scenarios. • Spatial models of environmental management variables implicated in wandoo decline.	Not able to be done at present.
Biotic factors • Mycorrhiza. • Armillaria in wandoo (build on previous work). • Predation. • Nutrient relations/recycling. • Other faunal relationships.	Not a current priority.
Meta Analysis • Scientific data.	Not a priority at present.

Extract from the Wandoo Research Strategy

Objectives of the research strategy

Future research needs to be planned in order to ensure that:

- research focuses on identifying the cause(s) of wandoo crown decline;
- research aims at identifying management options for wandoo crown decline;
- the chances of funding are increased;
- co-ordination and integration of research projects are maximised locally and nationally; and
- all stakeholders are encouraged to participate fully.

Elements of research into wandoo crown decline

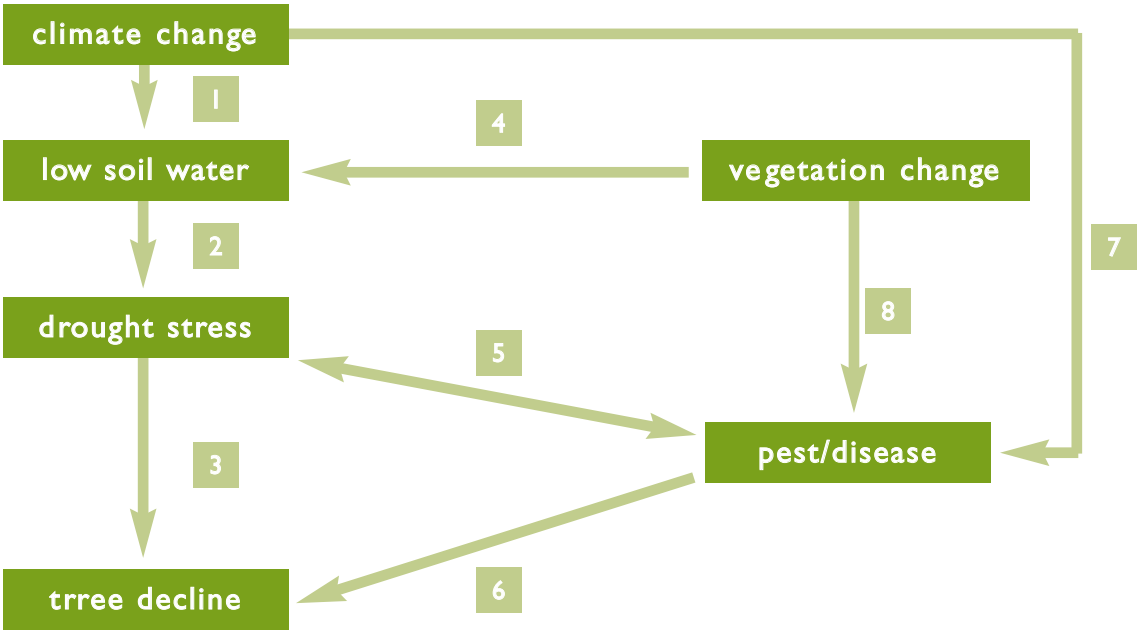
1. Historical research: retrieve and document historical information, oral or written, on wandoo health in order to relate this to climatic and anthropogenic factors;
2. Monitoring/mapping: use remote sensing and field surveys to analyse current and long-term (multi-year) trends in wandoo woodland health. This assessment is at the landscape to regional scale and includes any historical surveys/aerial photos/satellite images. The monitoring of wandoo woodlands has previously been classified as "mapping" as distinct from "research" but it should be an integral part of research; and
3. Hypothesis-driven research: specific well-defined projects that address major or partial research questions in the context of a larger conceptual research framework.

All three areas of research are essential and need to be investigated concurrently.

Conceptual framework

Research into wandoo crown decline should be based on a central hypothesis (or limited number of alternative hypotheses). This provides the framework for a research strategy. It needs to be as simple as necessary (focusing on the major factors, as indicated by current evidence) and not prematurely exclude plausible alternative hypotheses. The research should not be limited to observational studies but rather aim at testing hypotheses by experimentation at appropriate spatial scales.

The diagram is a simple representation of the framework that captures current research hypotheses.

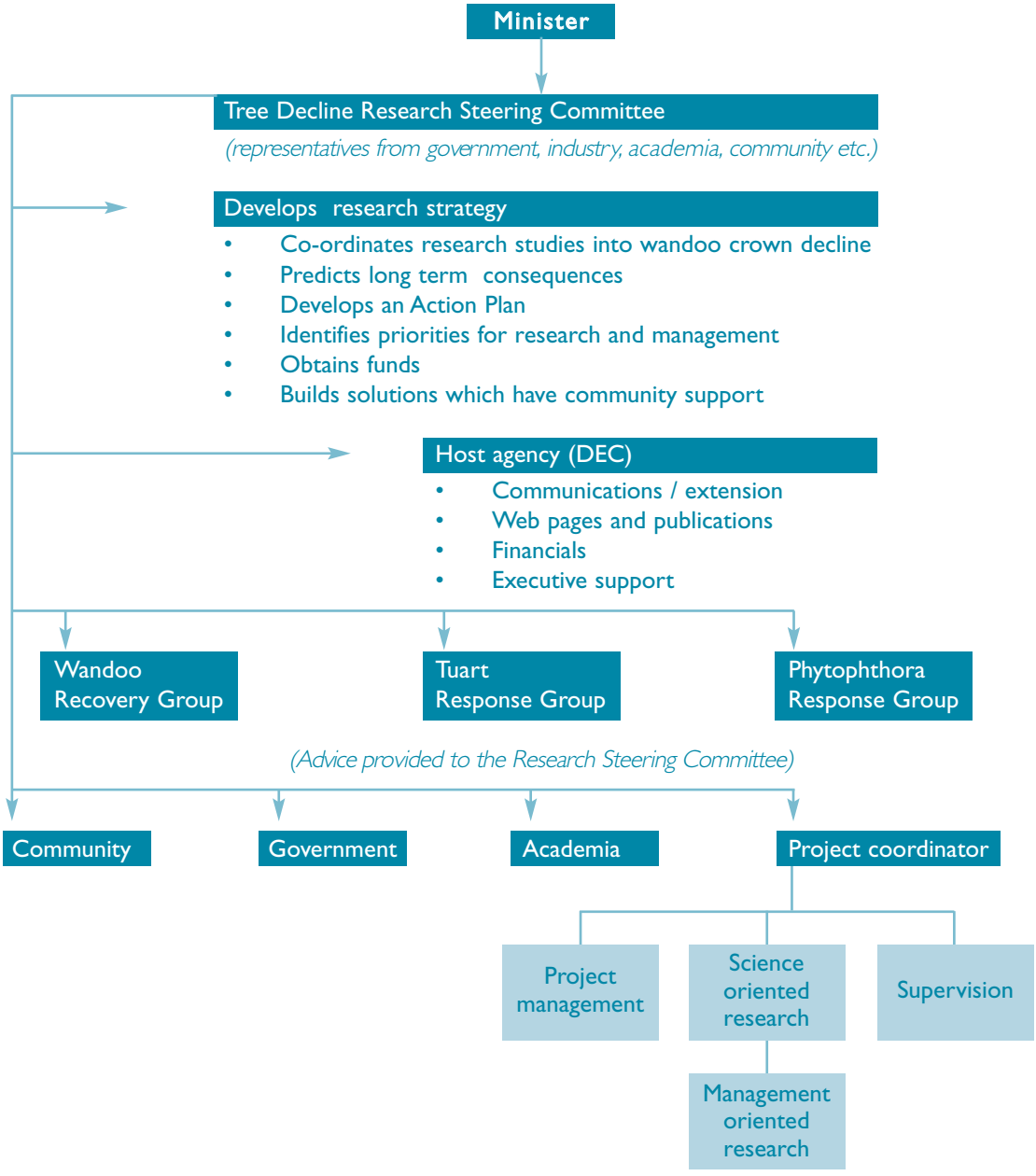


The project on wandoo response to drought (P. Poot) focuses on the drought stress of trees (arrow 3), and to some extent on how this relates to soil water (2). Research into the climatic (1) and vegetation (4) drivers of drying soils is not being directly addressed at present. The project on pathology (R. Hooper) studies the direct impact of borers and fungi (6), the impact of climate change on pest and disease, both directly (7) and indirectly (5), and the impact of vegetation change on pest and disease (8).

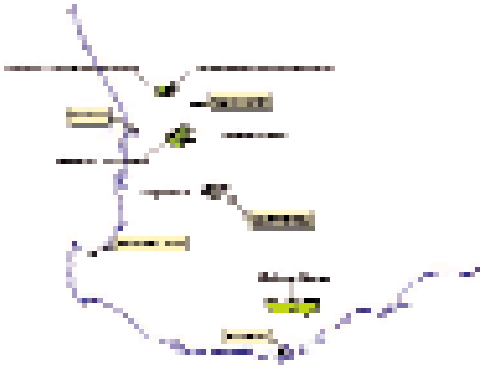
This diagram does not address alternative hypotheses such as direct effects of fire regime on soil biology or chemistry, local (fox-driven) extinction of marsupial species etc. Research projects into such hypotheses are of interest but are not the logical priority at this stage. If specific funding opportunities for such research exist, they are worth pursuing.

Decision-making framework

A conceptual model to unify research into tree decline and assist the implementation of the Wandoo Recovery Group Action Plan.



10: Map showing wandoo canopy assessment sites

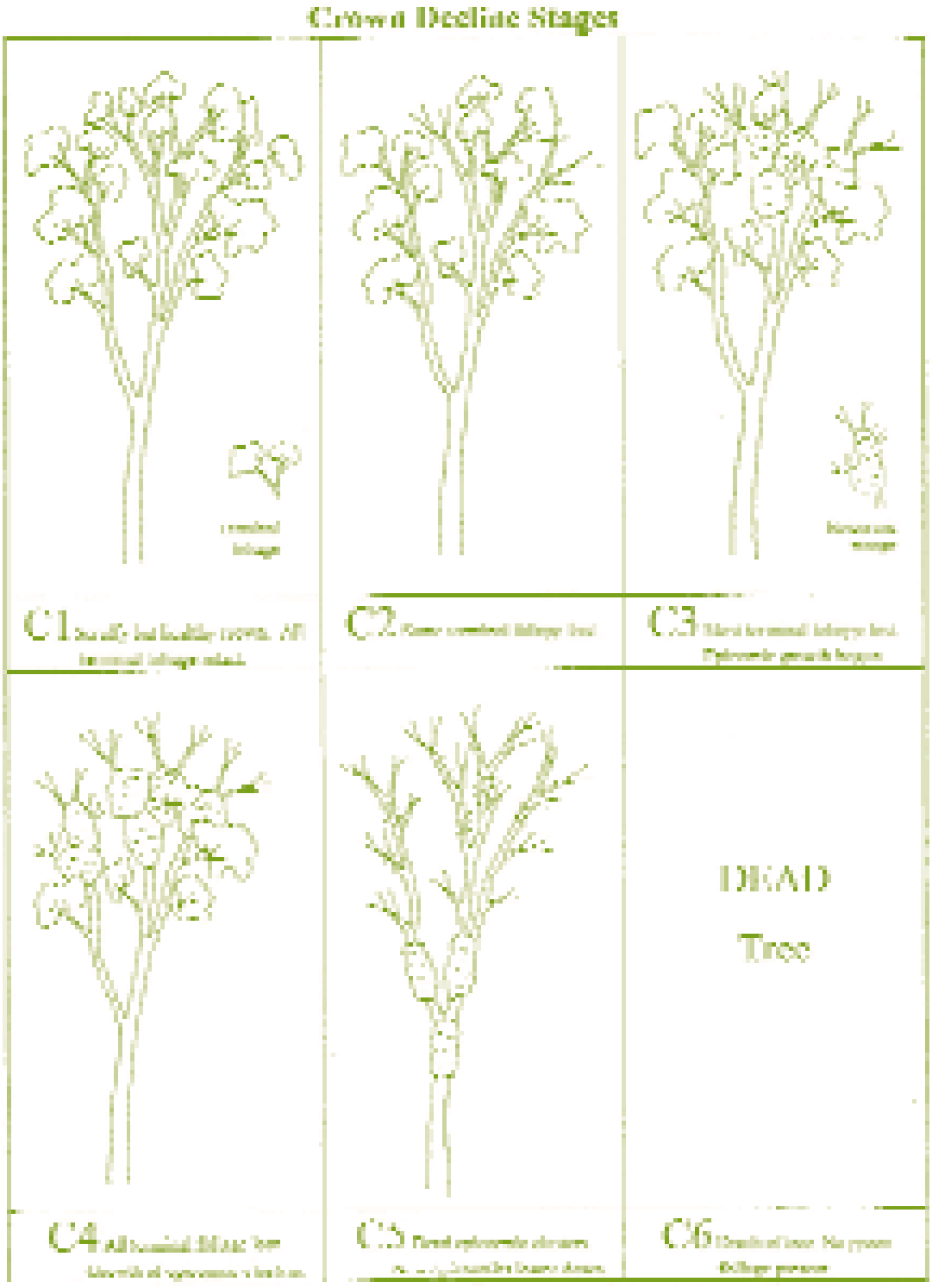


11: WRG assessment guide – survey sheet and line drawings depicting crown decline stage.

Survey Sheet – Wandoo Crown Decline

Return completed surveys to Wandoo Recovery Group, Department of Environment and Conservation, PO Box 1167 Bentley Delivery Centre, BENTLEY WA 6983

Date Tree Species	Transect length Transect bearing				Transect location (Please also draw a map on the back of this sheet showing location and orientation of the transect line) GPS reference: Name of recorder:								
Crown decline stage	Diameter 10 - 25 cm % of crown currently flagging				Diameter 25 - 50 cm % of crown currently flagging				Diameter > 50 cm % of crown currently flagging				
	0% -20%	< 50%	20 - 100%	50 -	0% -20%	< 50%	20 - 100%	50 -	0%	< 20%	20 - 50%	50 - 100%	Totals
C1 No decline													
C2 Some terminal foliage absent													
C3 Most terminal foliage absent													
C4 All terminal foliage absent													
C5 Epicormic death													
C6 Dead tree													
Totals													


Crown Decline Stages
C1
C2
C3
C4
C5
C6
DEAD
Tree

12: Indicative schedule for achieving targets relating to the WRG Communication Plan 2005-2006

Activities	2005				2006			
	Jan. / March	April / June	July / Sept.	Oct. / Dec.	Jan / March	April / June	July / Sept.	Oct. / Dec.
WRG bulletins distributed	■		■	■		■		■
Stories feature in *LANDSCOPE*		■			■			
Other media articles appear in rural press	■	■	■	■	■	■	■	■
Reports on progress of WRG forwarded to Minister and key stakeholders	■		■		■	■		■
Link with the DEC's NatureBase website to provide information on wandoo			■	■	■	■	■	
WRG meetings	■	■	■	■	■	■	■	■
Distribute other information as required	■	■	■	■	■	■	■	■
Information days and personal presentations to community groups	■	■	■		■			
Plan run and report on information day at Dandaragan	■	■						
Plan, run and report on Wandoo community forum		■	■					
Plan, run and report on Wandoo Science Workshop		■	■					
Community/volunteer training to assess crown condition in wandoo	■	■	■		■		■	
Strategic planning and development between WRG and active partners	■	■	■	■	■	■	■	■
Wandoo research plan developed				■	■	■		
Input into Natural Resource Management Council Investment Plans	■		■	■	■	■		
Follow-up one-on-one meetings with various stakeholder groups			■	■	■	■		■
Research organisations	■	■	■	■	■	■	■	■
Industry partnerships				■	■	■	■	■

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