Second Survey of *Eucalyptus wandoo* decline

Final Report

June 2008

Second survey of *Eucalyptus wandoo* decline

Jack Mercer

A report on wandoo decline on behalf of
the Wandoo Recovery Group,
Department of Environment and Conservation
and WWF - Australia

ACKNOWLEDGEMENTS

I sincerely thank the following:
Liz Manning (Wandoo Recovery Group) for coordination and assistance throughout the last 12 months. This included development of the funding submission, assistance in the field, long and arduous correspondence with funding proponents and document reviews.
Marilu Vaz for long days of field support and logistical assistance throughout the project.
Members of the Wandoo Recovery Group for support and guidance for the survey.
Landholders throughout the Wheatbelt who have shown interest in wandoo decline and allowed access to their properties once again. Tracy and Brett Smith for providing 100 years of rainfall averages for their farm.
Allan Wills and Ryan Hooper for their advice and direction on many questions.
Dr Erik Veneklaas (UWA) for generous time and expertise given to reviewing this report. Also Allan Wills (DEC) for comments.
John Hengstridge and John Dickson of Data Analysis Australia for statistical analysis and mapping.
Rob Doria from DEC's GIS- IMB for granting the licence to use DEC cadastre.
Chris Curnow and WWF-Australia for administrating funds and managing the contract.
Alan Sands and Emma Fiorentino (DEC), Rebecca Palumbo (Avon Catchment Council), David Stapleton (Southwest Catchment Council) and Deon Utber (South Coast NRM Inc) for their support in providing the funding contributions for this project.
Australian Government and the State Government of Western Australia for funding the survey through the Natural Heritage Trust and the National Action Plan for Salinity and Water Quality.

Cover photograph: Site at Julimar in 2008. Insert is six years previous.

Table of Contents

APPENDICES:

1. INTRODUCTION

The health of many iconic tree species, including wandoo, is in serious decline, occurring on a regional scale across a range of climatic zones and landscapes, and is a source of significant concern. Although several factors have been implicated in wandoo decline, no definitive cause or set of causes has been isolated to satisfactorily explain wandoo episodic declines. The most recent appears to be the worst recorded. Collective reports suggest wandoo has been in decline for perhaps 40 years, with reasons largely unknown. Podger (undated), Kimber (1981), Curry (1981), Brown et *al.* (1990), Mercer (1991, 2003), Wills et *al.* (2000, 2001), Hooper and Sivasithamparam (2005) and others have contributed knowledge to the health status of wandoo and there are other studies under way in association with the Wandoo Recovery Group (WRG) and University of Western Australia. A summary of various works up to 2002 was presented in the 2002 survey report (Mercer 2003). Although other research on wandoo decline is continuing, it was considered a need to establish a reliable set of base data across the range of wandoo woodland. The 2002 survey of *Eucalyptus wandoo* decline initiated the establishment of a consistent record over several parameters to create a "snapshot" of wandoo health on over 600km of transects including 129 sites. The aim of the 2008 survey was to build on this data in order to begin establishing a recorded trend in wandoo health.

2. SUMMARY

In 2008, although there have been regional changes in wandoo crown decline (WCD) across the survey area and along transects, several parameters analysed in both surveys have stayed much the same. In 2002, an indicator of healthier wandoo sites was a higher percentage of trees showing minimal or no impact, despite the presence of trees in severe decline. This was evident where epicorms were either absent or older than five years and there was an increasing presence of fruit and buds. This indicator was still strongly relevant, however, the number of unaffected or slightly affected trees has decreased due to WCD. As in 2002, foliar insect damage increased as crown health decreased, remained low to moderate but less variable and chewers were predominant. Trunk and large branch damage from borers significantly increased since 2002, indicating that wandoo are likely under ongoing stress. Wandoo were still healthier the longer a site was without high intensity fire suggesting that hot fire brings disturbance that may initiate tree decline. Excessively intense fire in 2007 on one transect showed that standing trees can be killed and ashbed regeneration can be low. This may be either due to low seed counts or destruction of seed capsules in canopies. Between 2002 and 2008, there was evidence such wildfires were followed by slow recovery and other decline agents may have become active. As in 2002, several trends in crown health were evident. Crown health improved: where insect damage decreased; the longer a site was without fire; from lower to higher position in the landscape; in remnants on privately owned land and in road reserves, but was less healthy in National Parks and Nature Reserves; in sites isolated or adjoining bushland, but was less healthy inside bushland; on land with gradients of 4-6 degrees; in association with the presence of older epicorms (or none at all) as well as increasing presence of fruit, buds and new leaves.

In 2002, temporal and spatial trends in decline across the survey area were evident. The decline pattern was broad scale, variable and not continuous across the landscape. Canopy loss was both recent and long term. In 2008 this was still evident but with more wandoo affected by decline in some districts while other districts were recovering. Increased decline was mainly new, post 2002, affecting what were previously healthy trees, or where post 1990 decline was worse. In 2002, zones between the rainfall isohyets of 400-450 mm and 600-650 mm showed the most marked crown decline on the

southern and central transects. This was no longer the case in 2008 where the eastern and western extremities of the southern and central transects exhibited post 2002 decline. The northern transect also showed a similar time frame of decline on the eastern extremity. In 2002, zones of marked crown decline also roughly coincided with areas where marked rainfall deficits were recorded. This was less defined in 2008, mainly because of post 2002 declines at the transect extremities. Comparison of data from 3 sites assessed in 1991 and 2002 showed that previous site condition may have predisposed trees to greater impacts from the present decline. In 2008, the healthy site has declined and the intermediate and degraded sites have marginally improved. It was suggested in 2002 that the cumulative impact on the remaining wandoo population was likely to be an increasing rate of decline and death across its range as older trees capitulated and little recruitment took place. Understorey decline, assessed only in 2008, was low and showed no significant correlation with increasing or decreasing wandoo decline. There were incidences where ascendance of understorey species and some limited wandoo recruitment may be related to severe decline of mature wandoo. The trends were for woody species and native monocots (grasses and sedges) to display less cover as wandoo crown health improved. On the other hand, litter cover increased as crown health improved.

3. TAXONOMY AND DISTRIBUTION OF WANDOO

Eucalyptus wandoo subsp. *wandoo* (wandoo), is endemic to the south-west corner of Western Australia. Wandoo distribution is approximately bounded by Mt. Barker in the south, Corrigin in the east, and the Darling Scarp in the west. However, wandoo grew on parts of the Pinjarra Plain before European settlement (Capill 1984). In the north, its distribution is bounded by Bencubbin and Moora. Outlying enclaves occur near Three Springs and south of Eneabba in the Gardiner and Herschel Ranges (Capill 1984; Brown et *al.* 1990); near Denmark on the Hay River and near Narembeen (Brooker et *al.* 2002). Wandoo is mainly restricted to elevations between 210 and 340 m above mean sea level which places it below the main topographical distribution of *E. accedens,*(powderbark), *E. marginata* (jarrah) and *E. calophylla* (marri) (Campbell 1956). Its general distribution falls between the isohyets of 350 mm and 1000 mm mean annual rainfall (Capill 1984).

Wandoo woodland is classified as a dry savannah open woodland (Beard 1990) with the upper strata having less than 40 per cent cover (Hewett and Underwood 1963). It originally occupied most of the extra dry and western part of the dry Mediterranean climate zones (Beard 1990). Other characteristics influencing the distribution of wandoo are soil types and topography. Exposed parent rock (granite, gneisses and dolerite) of the Yilgarn block has weathered to produce red-brown clayey loams (Capill 1984). It is in these areas that wandoo mostly grows, among a non-uniform woodland (Campbell 1956) by preferring the sandy loams, loamy sands and sometimes soils of higher clay content that are found in the upper, middle and lower valleys (Capill 1984). The species predominated on the more gentle slopes before clearing.

To the east of its range, wandoo has a loose association with the mallets, *E. falcata* (silver mallee), *E. gardneri* (blue mallet) and *E. astringens* (brown mallet), that usually radiate downslope from lateritic outcrops (Campbell 1956). In the eastern wheatbelt region wandoo grades into *E. capillosa* (wheatbelt wandoo). Although often confused with wandoo, seedlings and juvenile leaves of *E. capillosa* are hairy scabrid whereas those of wandoo are glabrous (Brown et *al*. 1990, Brooker et *al*. 2002). *E. capillosa* has more orange than yellow in its bark, has green rather than blue-green leaves, glaucous branchlets and a more spreading mallee appearance. The two species are associated in a belt stretching from Kellerberrin south to Corrigin. Other related species are *E. livida* (mallee wandoo), located east of *E. capillosa*, and *E. nigrifunda* (desert wandoo), located east of Kalgoorlie (Brooker and Kleinig 1990). North of Gingin, *E. wandoo* subsp. *wandoo* is replaced by *E. wandoo* subsp.

pulverea according to Brooker and Hopper (1991) and Brown et *al.* (1990). The latter differs only slightly from the former by having a more-or-less powdery bark, glaucous branchlets and less consistent yellow bark. It occurs on the alluvial silty loams of the Moore and Hill River valleys. Wandoo also has a loose association with *E. loxophleba* (York gum) over its range (Campbell 1956) and further south, with *E. occidentalis* (flat-topped yate) and *E. cornuta* (swamp yate). In the lower gullies and creek beds, *E. rudis* (flooded gum) is predominant and marks the lower topographical limits of wandoo. In the west, wandoo is associated with poorer forms of *E. marginata* and *E. calophylla* but more generally occupies the deep valleys that penetrate westward into the Darling Scarp (Capill 1984). Wandoo may be associated with *E. accedens* further upslope with the latter assuming dominance as elevation increases. *E. accedens* is not of the same taxonomic group as *E. wandoo*, *E. capillosa*, *E. nigrifunda* and *E. livida*. (Brooker et *al.* 2002).

4. APPROACH TO SURVEYS OF WANDOO DECLINE

The approach taken for the 2002 and 2008 surveys was a reconnaissance style survey that covered the main geographical extent of wandoo, excluding populations north and east of Julimar. Three transects were established in the wheatbelt and state forest and multiple sites along these transects were assessed for several semi-quantitive and descriptive parameters. It was assumed that the set of parameters used would identify those factors that warranted further investigation. The parameters were also comprehensive enough to give a reasonable profile of site history and change over several years. General trends observed along the transects and some comparisons of 1991, 2002 and 2008 data from three sites are presented.

4.1. Hypotheses

The central hypothesis tested in 2002 was that environmental disturbance had caused wandoo decline on a wheatbelt-wide scale over the last decade, evidenced by crown defoliation, loss of twigs, branchlets and branches and ultimately some deaths of trees. Factors potentially causing this decline, and tested in this study, were: (i) rainfall deficits, that may incite decline higher in the landscape and on steeper slopes, and where high stem density may result in tree water deficits; (ii) fire history, where optimum fire frequencies and intensities may not be occurring; (iii) connectivity in the landscape, with land clearing and consequent fragmentation predisposing wandoo to decline; (iv) changes in land use; (v) secondary salinity; (vi) insect damage; and (vii) changes in understorey and litter structure.

The central hypothesis for 2008 was that environmental disturbance continued to cause wandoo decline. Factors tested were: (i) rainfall deficits were inciting decline in the landscape; (ii) high stem density resulted in water deficits; and (iii) associated understoreys had similar or related decline patterns.

4.2. Methods

4.2.1. Revisiting quadrats on three transects in 2002

Three transects comprising a total of 126 sites were reassessed (3 sites not being found). Transects were oriented in an east-west direction in 2002, with most sites having relatively easy access for future observations, if required. The extent and approximate latitudes of the transects were:

- the northern transect extending from just east of Kwolyn to Helena Valley along the 31st parallel, with some additional sites included further north in Julimar;
- the central transect extending from just east of Kulin to Collie along the 32nd and part of the 33rd parallel; and
- the southern transect extending from Chillinup to just west of Manjimup along the 34th parallel.

4.2.2. Establishment of quadrats

Usually one but up to three quadrats were established in 2002 at each site, depending on the variability of the landscape, and sites were sometimes clustered in an attempt to encompass landscape variability. Quadrats were $2500m^2$ (50m by 50m) and, where possible, were oriented with a GPS ground position reading (easting and northing) on the north-west corner of the quadrats with the first 50 metres paced in an east to west compass direction and the quadrat positioned south of this line. Road reserves or narrow creek lines were given the standard dimensions of 25m by 100m and oriented parallel to the roads. In 2008 pegs were established on the north-east corner of each quadrat where the 2002 and 2008 GPS readings were taken. Additional GPS readings were also taken in 2008 for each photo point, generally north of and central to quadrats to gain the most representative image.

4.2.3. Semi-quantitive assessment

- Semi-quantitive parameters, except for crown assessment, insect damage and salinity, were assessed on a common scale as: (1) none present; (2) low (1-25%); (3) moderate (26-50%); (4) high (51-75%); and (5) very high (76-100%). Parameters assessed were as follows:
- Crown condition. Crown condition as a measurement of tree health was assessed using a method by Abbott (1992) adapted from Grimes (1978). It involved rating the leaf density (0-9), incidence of dead branches (0-9) and contribution of epicormics to foliage (0-6), giving a maximum aggregate of 24 for undamaged crowns. In this survey, this method was used to establish average crown rating of the stand within each quadrat rather than that of individual trees. This method was then aligned with the recently developed WRG (2005) crown decline stages of C1, healthy, through to C6, dead trees (Appendix 1, Table 1).
- Percentage of dead trees due to present decline. The proportion of dead trees was estimated within each quadrat. Trees that appeared to have been dead a long time were omitted, since the survey aimed to assess the present decline pattern.
- Percentage of trees unaffected by or showing minimal impact from, the present decline. The proportion of trees unaffected by or showing minimal impact from the present decline was estimated within each quadrat.
- Insect damage to leaves. Insect damage to leaves was assessed for each quadrat from 3 or 4 random “grabs” of 20 to 25 leaves from tree canopies within reach. Approximately 50% of leaves assessed were young and the other 50% were older leaves. Damage was allocated into three main groups as a percentage of leaf area that (i) was chewed or missing, (ii) was browned, mined or scarred; (iii) had lerp builders attached and; (iv) had gall damage. Abnormal levels of other damage types were noted, in particular the presence of borers (see also section 4.2.5). Insect leaf damage groups were: (1) none or very little (0-5%); (2) low (6-10%); (3) moderate (11-25%); (4) high (26-50%); and (5) very high (>50%). Actual % damage was also calculated for each quadrat in 2008.
- Vegetative cover under tree canopies. For each quadrat, vegetative cover under tree canopies was estimated as a percentage covering the ground (using projected foliage cover for plants present).

Three categories were recorded: (i) native woody vegetation; (ii) native grasses and sedges; and (iii) exotic weeds.

- Litter layer cover. Cover of the litter layer for each quadrat was estimated as the percentage of ground covered by litter.
- Soil salinity. Soil salinity (as mSm^{-1}) was measured using an EM-38 salinity meter at 50 cm and 100 cm soil depths in the approximate centre of each quadrat. Salinity groups relative to south-west woodlands were: (1) none or very little (0-50 mSm^{-1}); (2) low (50-100 mSm^{-1}); (3) moderate (100-150 mSm^{-1}); (4) high (150-500 mSm^{-1}); (5) very high (500-1000 mSm^{-1}); and extreme (>1000 mSm^{-1}) (Agriculture WA 2002). Salinity measurements were not recorded for 2008 apart from random samples on the southern transect.

4.2.4. Descriptive assessment

Descriptive parameters assessed were as follows:

- Age of epicormics. Age of epicormic growth was an estimate of how many years since epicormic response had occurred, with the dominant age group recorded and other age groups noted. There were 6 groups: (1) no epicormics present; (2) <1 yr; (3) 2-3 yr; (4) 3-4 yr; (5) 4-5 yr; and (6) >5 yr old. The 2002 photograph record was used to improve estimates in 2008.
- Land use. Land use was allocated to one of 6 groups: (1) paddock; (2) parkland cleared; (3) private remnant; (4) road reserve; (5) State forest; and (6) National Park or Nature Reserve.
- Soil types. Soil types included a general description of soil depth of the A-horizon and percentage composition of gravel, if relevant. Groups were: (1) sandy loam or loamy sands; (2) duplex soils (>30 cm over clay); (3) duplex soils (<30 cm over clay); (4) stony duplex; (5) shallow soils over laterite/granite; or (6) other soil type. A small hole was dug to inspect the soil profiles.
- Position in landscape. These categories were: (1) valley floor; (2) low to mid slope; (3) mid to higher slope; (4) ridge; and (5) outcrop.
- Connectivity to reserve or remnant. Connectivity to a reserve or remnant was classed for quadrats as: (1) isolated, surrounded by >50m of cleared land; (2) adjacent/close by, surrounded by <50m of cleared land; (3) adjoining; and (4) inside.
- Tree density for each quadrat. Density of stems per quadrat was used to estimate tree density of all age groups of wando. Other tree species were included in the estimate, if present. Groups were; (1) <10; (2) 11-20; (3) 21-30; (4) 31-40; (5) 41-50; and (6) >50 stems/quadrat.
- Average tree diameter at breast height over bark. Average diameter of wandoo trees in each quadrat was approximated from a quick sampling of 6 to 10 trees at breast height over bark (DBHOB). Groups were: (1) 5-10; (2) 11-20; (3) 21-30; (4) 31-40; and (5) >40 cm.
- Fire history. Fire history for each site was assigned to categories of: (1) <5 yr; (2) 5-10 yr; (3) 10-20 yr; (4) 20-30 yr; and (5) >30 yr. The date of the last fire was recorded if known, estimated by studying fire damage or regrowth, or, listed as a missing value if unknown. Fires considered were those that were intense enough to scorch tree crowns.
- Slope type, aspect and gradient. Slope type was described as uniform, convex or concave. Slope aspect was approximated as direction of fall relative to magnetic north. Slope gradient was estimated as from: (1) 0-2; (2) 2-4; (3) 4-6; (4) 6-8; (5) 8-10; and (6) >10 degrees fall.
- Phenology. Phenology was estimated using a similar method to that of Mercer (1991): binoculars were used to observe the presence of fruit, buds, new leaves and flowers and the density and

uniformity of each of these was recorded as: (0) none present; (1) few present; (2) sparse and uneven; (3) sparse and even; (4) moderate and uneven; (5) moderate and even; (6) dense and uneven; and (7) dense and even.

- Average annual rainfall. In 2002, annual rainfall for each site was manually interpolated from isohyets generated from rainfall data using Weaver (1997). Section 4.2.6 explains the procedure for 2008.
- Broader observations. Additional observations for each quadrat were: associated vegetation communities, including nearby farmland as a defined association; dominant understorey species; and the presence of any notable features within or around each quadrat. Also, type and nature of tree decline was a short description for each stand based on whether crown symptoms were typical of the present decline pattern (post 1990), including: whether this decline event was recent (post 2002); whether there was evidence of older decline events; or whether decline was not typical (fire, other). These observations were not included in data analysis.

4.2.5 Additional parameters for 2008

Additional parameters for 2008 were:

- The assessment of understorey decline with decline categories of: none or very little (0-5%); low (5-10%); moderate (10-25%); high (25-50%); and very high (.50%). The assessment of understorey decline with decline categories of: none or very little (0-5%); low (5-10%); moderate (10-25%); high (25-50%); and very high (>50%). Categories used for native woody vegetation and native grasses/sedges cover were too coarse to establish a reasonable estimate for decline, therefore, a more descrete set of categories was formed.
- Borer damage to trunks and large branches measured as an average number of lesions per tree for each quadrat. Categories were: none (0); moderate (<5); and high (>5). Quadrats were traversed diagonally (or lengthwise for elongated sites, e.g. road reserves) to make estimations.
- Further identification of common understorey species over the survey area.

4.2.6. Recording of general trends in rainfall and mapping 2008

General trends of crown decline were recorded to present a wider profile of the wandoo decline patterns along the transects. Comparitive thematic grid maps were produced using Mapinfo “ER Mapper” to illustrate the spatial pattern of wandoo decline for 2002. In 2008, the 2002 map was reproduced to improve interpolation by using geostatistical points to display the data points and the optimally fitted model. Crown ratings, interpreted as colours for each site, were mapped using standard triangulation techniques to generate interpolated values. Average crown rating values for each site were grouped into five colour categories. Dark green indicated the highest ratings for crown health progressing in an order of declining crown health through light green, yellow, orange and finally red which represented the lowest rating for crown health. Areas were excluded where insufficient data was captured. The exercise was repeated for the 2008 data to create comparative maps. To explore any potential relationship between rainfall and wandoo crown condition, crown ratings for each site were plotted against 1976-2007 rainfall for each station. Also, change in crown ratings (2002-2008) were plotted against 2002-2007 rainfall. BOM data for both periods of average annual rainfall was used for stations along each transect that were geographically relevant to quadrats.

4.2.7. Comparison of 1991, 2002 and 2008 data on wandoo decline

Comparison of 1991 and 2002 data was undertaken at three sites (Boyagin, Noombling and Popanyinning on the central transect) used by Mercer (1991) to assess wandoo decline in the central wheatbelt. Sites were re-visited in 2008 to further assess the impact of the present decline and its relationship with any past decline. Sites photographed in 1991 and 2002 were done again in 2008. Subject trees on the south end of Albany Highway were similarly updated (Appendix 2).

4.2.8. Data collection and analysis 2002 and 2008

Within each quadrat, several semi-quantitive and descriptive parameters (independent variables) were assessed in 2002. Average crown condition rating was tested against this set of variables (continuous and categorical) using an initial univariate approach. A multivariate model based on those variables identified as being significantly ($p<0.05$) or marginally significantly ($p<0.15$) related to crown health was then developed using a step-wise linear regression model and the model building strategy of Hosmer and Lemeshow (1989). For all sites, parameters showing significance against average crown condition were divided into those related to potential causes of decline and those related to site location and history. The latter group was for interpretation purposes only that may act as indicators of crown health. With respect to potential predictor variables for crown decline for 2002 and 2008, variables with a non-ordinal pattern (such as "Land use") or where it was judged that the response may not be linear (such as "Fire history") were reduced to a set of "dummy" variables (hence LUSE1-LUSE6, FIRE0-FIRE5) as indicated in Appendix 1, Table 2. In 2008, similar analysis investigated the relationship that the wandoo crown condition had with each of the semi-quantitive and descriptive assessment (indicator) variables. To test whether the relationship between crown condition and each individual variable was statistically significant, separate ANOVA models were created. In addition, ANOVA models were created to test any significance between changes in crown ratings between 2002 and 2008 with all variables. A summary of these models is presented in (Appendix 1, Table 3).

5. RESULTS

5.1. 2002 results revisited

5.1.1. Parameters related to potential causes of crown decline

In relation to wandoo crown rating, the continuous variable of average annual rainfall was marginally significant and significant ($p<0.15$). Overall insect damage was significant and showed an inverse relationship, of increasing damage with decreasing crown ratings. Lerp insect damage was also significant, but no correlation was evident to suggest this parameter clearly related to crown health trends). Fire history was significant with increasing crown ratings directly correlating to increasing years since the last intense fire. Position in the landscape ($p<0.15$), showed a distinctive trend where crown ratings increased with higher position in the landscape. Land use ($p<0.05$) had no discernible trend, although highest crown ratings were in private remnants and road reserves. Isolated sites or those adjoining bushland typically exhibited high crown ratings, with the lower ratings being inside and adjacent to/close by bushland ($p<0.05$). Sites within National Parks and Nature Reserves had the lowest average crown ratings. Gradient slope ($p<0.05$) also showed no distinctive trend, with slopes of 4-6 degrees having the highest average crown ratings.

5.1.2. Parameters related to indicators of crown condition - 2002

Significant parameters relating to these indicators and showing correlations were % of trees with minimal or no impact ($p<0.05$); presence of fruit ($p<0.05$); and presence of buds ($p<0.05$). All three parameters increased with increasing crown health, the first being a direct correlation and the others a more general correlation. Where epicorms ($p<0.05$), were not present or growth was >5 years old there were higher crown ratings. Initial analysis confirmed that the main factor related to decline severity was the proportion of dead trees at a site. This confirmed that crown rating was an effective replacement for the level of tree death and so was a useful means of assessing and rating decline, although, uninformative in identifying potentially causative factors. Thus, data was re-analysed without this variable as a potential predictor. Longitude was significant ($p<0.05$).

5.1.3. Multiple regression - 2002

The multiple regression analysis in 2002 showed that crown decline rating was significantly related to the predictors ($F_{7,119}=6.47$, $p<0.0001$) but only poorly predictable ($R^2=0.28$). Variables identified as statistically significantly related to crown decline score were (in order): insect damage group ($p=0.0033$); isolated stands ($p=0.0047$) and those adjoining reserves ($p=0.0097$)); litter cover group ($p=0.0116$); and fire interval >30 yr (0.0169). All except insect damage were positively correlated with crown decline score.

5.2. Statistical correlations - 2008

5.2.1. Parameters related to potential causes of crown decline - 2008

In relation to wandoo crown rating, average annual rainfall and longitude were not significant in 2008, as in 2002. Wandoo crown rating and latitude was significant to ($p<0.1$). Overall insect damage was not significant but still showed a relationship of increasing damage with decreasing crown ratings (Fig. 1). There were negligible recordings of lerp and gall damage in 2008. Fire history was not significant but again the trend was for increasing crown ratings with increasing years since the last intense fire (Fig. 2). Position in the landscape, again showed a distinctive trend where crown ratings increased with higher position in the landscape (Fig. 3). Land use ($p<0.1$) had no discernible trend, although highest crown ratings were again in road reserves as in 2002. Again, sites within National Parks and Nature Reserves had the lowest average crown ratings (Fig. 4). Connectivity results maintained the same trend in 2008 but with no significance. Sites adjoining bushland exhibited higher crown ratings, lower ratings being inside bushland (Fig. 5). Gradient slope was less significant ($p<0.1$), again with slopes of 4-6 degrees having the highest crown ratings (Fig. 6). Slopes $>10^o$ had high rating but there were few sites on this gradient. There was no significant relationship regarding site density and crown health.

5.2.2. Multiple regression – 2008

Although the model again achieved a relatively poor fit with the data ($R^2 = 0.25$) the relationship between crown assessment and the predictor variables used in the model was significant ($F_{13,108} = 2.979$, $p<0.001$). Multiple regression showed that crown rating decreased as native woody vegetation and native grasses/sedges cover increased. High cover of the former and high and very high of the latter were all significant ($p=0.05$). Crown rating increased with the level of increasing litter cover with this group also significant ($p=0.05$).

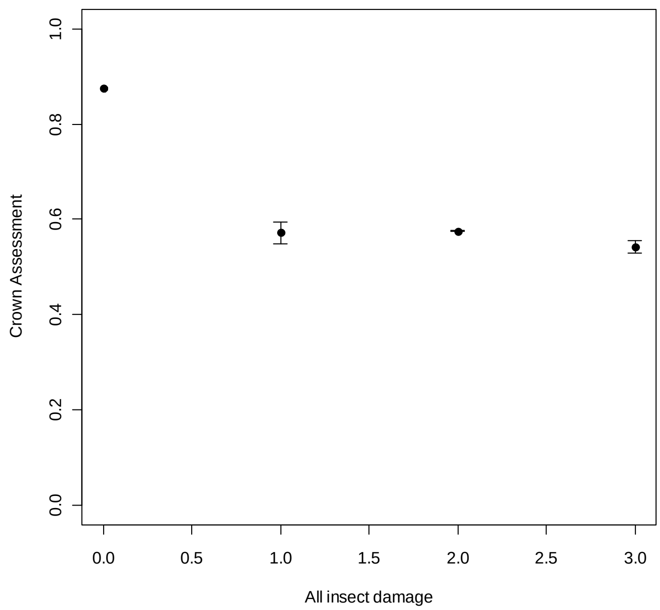


Fig. 1: All foliar insect damage against average crown rating. Insect leaf damage categories were: (1) none or very little (0-5%); (2) low (6-10%); (3) moderate (11-25%); (4) high (26-50%); and (5) very high (>50%).

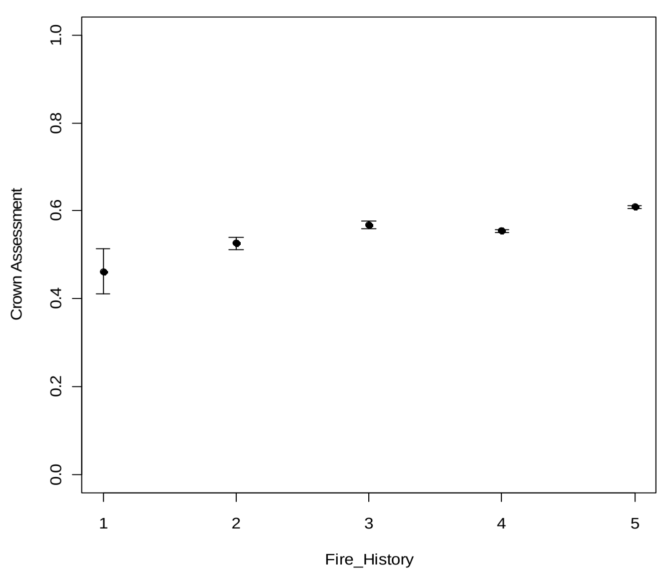


Fig. 2: Increasing time without fire against average crown rating. Categories are: (1) <5 yr; (2) 5-10 yr; (3) 10-20 yr; (4) 20-30 yr; and (5) >30 yr.

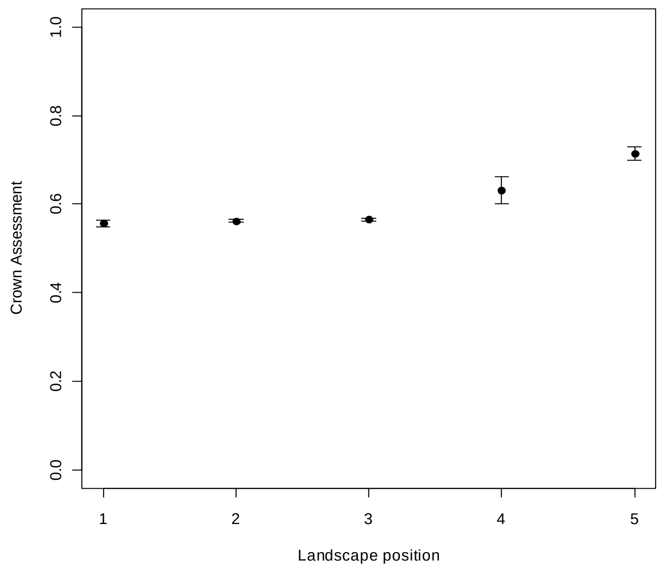


Fig. 3: Position in the landscape against average crown rating. Categories are: (1) valley floor; (2) low to mid slope; (3) mid to higher slope; (4) ridge; and (5) outcrop.

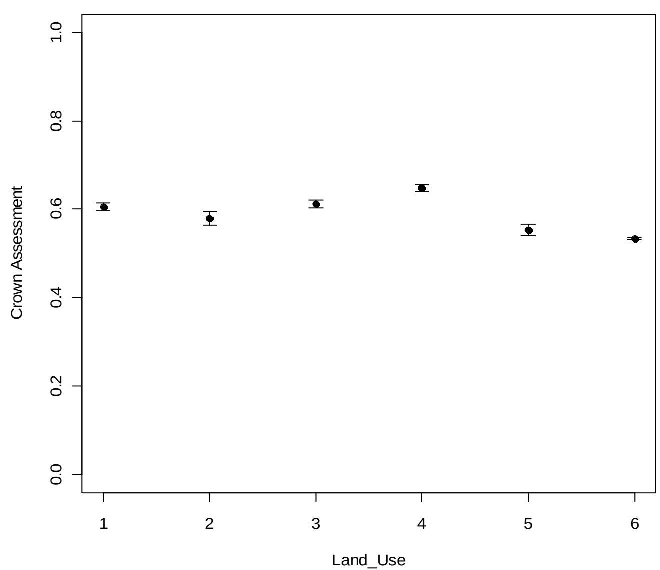


Fig. 4: Land use against average crown rating. Categories are: (1) paddock; (2) parkland cleared; (3) private remnant; (4) road reserve; (5) State forest; and (6) National Park or Nature Reserve.

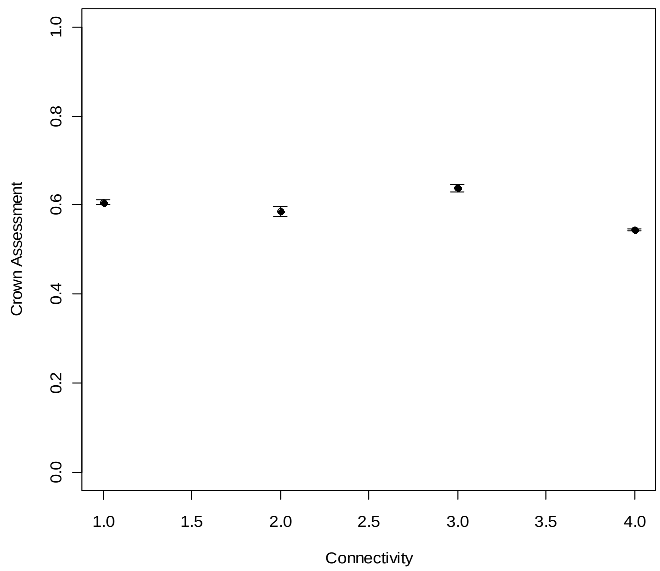


Fig. 5: Connectivity against average crown rating. Categories are: (1) isolated, surrounded by >50m of cleared land; (2) adjacent/close by, surrounded by <50m of cleared land; (3) adjoining; and (4) inside.

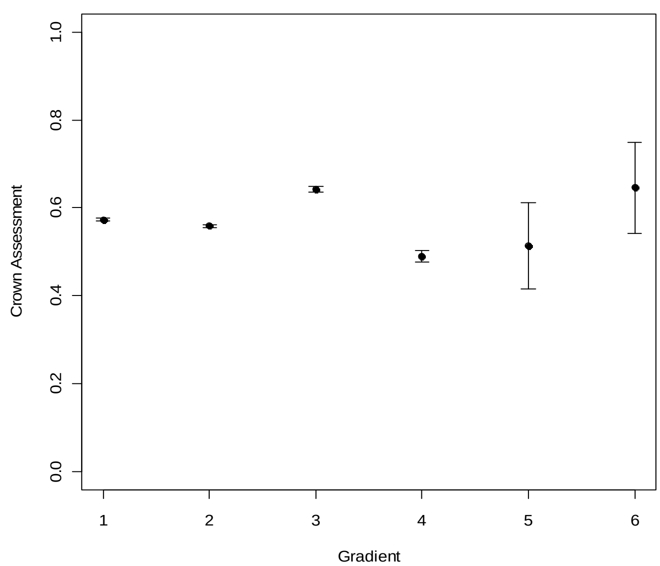


Fig. 6: Slope gradient against average crown rating. Slope gradient was estimated as from: (1) 0-2; (2) 2-4; (3) 4-6; (4) 6-8; (5) 8-10; and (6) >10 degrees fall.

5.2.3. Parameters related to indicators of crown condition - 2008

Significant parameters in 2008 relating to site history and showing correlations were % of trees with minimal or no impact ($p<0.0$), presence of buds ($p<0.001$) and presence of new leaves ($p<0.01$). All three parameters increased with increasing crown health, the first being a direct correlation as in 2002 and the others a more general correlation. Presence of fruit was not significant but generally increased with increasing crown rating (Figs. 7, 8, 9 and 10). Regarding age of epicorms (no significance in 2008), none present or growth greater than five years old still related to higher crown ratings (Fig. 11). There was, however increased crown ratings for ages of 2-3 years and to a lesser degree 1-2 years but there were few recordings of those age classes. There was no significant relationship with crown condition and tree density (Fig. 12).

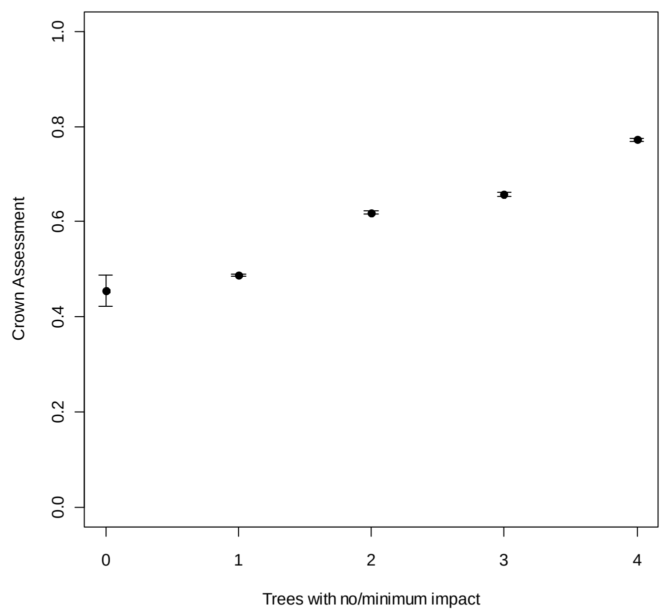


Fig. 7: Trees with no/minimum impact against average crown rating. Categories are: (1) none present; (2) low (1-25%); (3) moderate (26-50%); (4) high (51-75%); and (5) very high (76-100%).

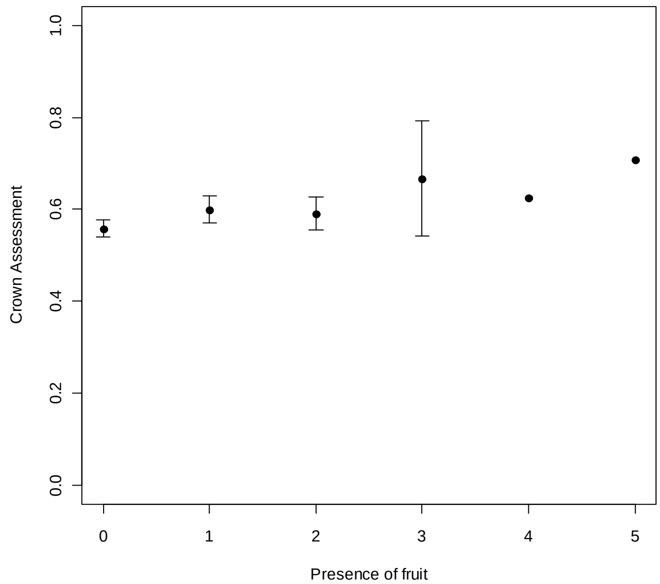


Fig. 8: Presence of fruit against average crown rating. Categories are: (0) none present; (1) few present; (2) sparse and uneven; (3) sparse and even; (4) moderate and uneven; (5) moderate and even; (6) dense and uneven; and (7) dense and even.

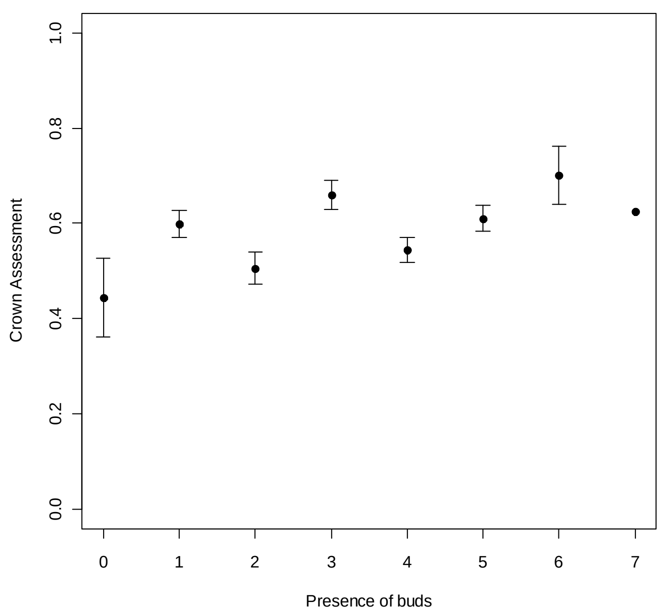


Fig. 9: Presence of buds against average crown rating. Categories are: (0) none present; (1) few present; (2) sparse and uneven; (3) sparse and even; (4) moderate and uneven; (5) moderate and even; (6) dense and uneven; and (7) dense and even.

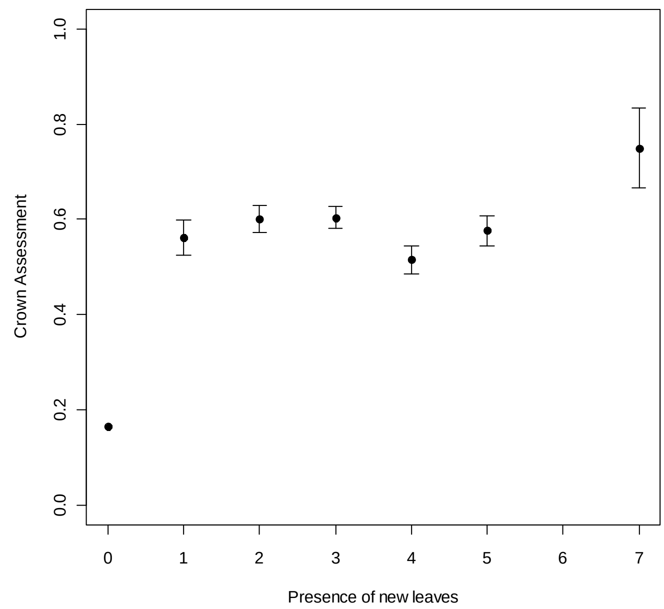


Fig. 10: Presence of new leaves against average crown rating. Categories are: (0) none present; (1) few present; (2) sparse and uneven; (3) sparse and even; (4) moderate and uneven; (5) moderate and even; (6) dense and uneven; and (7) dense and even.

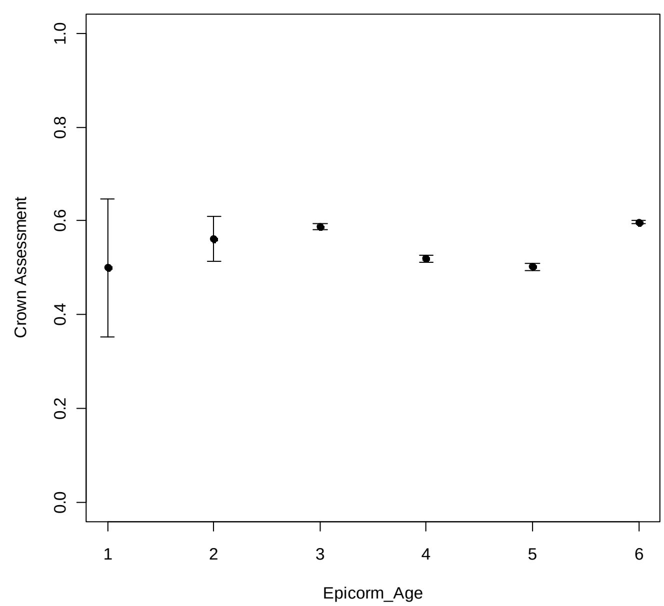


Fig. 11: Age of epicorms against average crown rating. Categories are: (1) no epicormics present; (2) <1 yr; (3) 2-3 yr; (4) 3-4 yr; (5) 4-5 yr; and (6) >5 yr old.

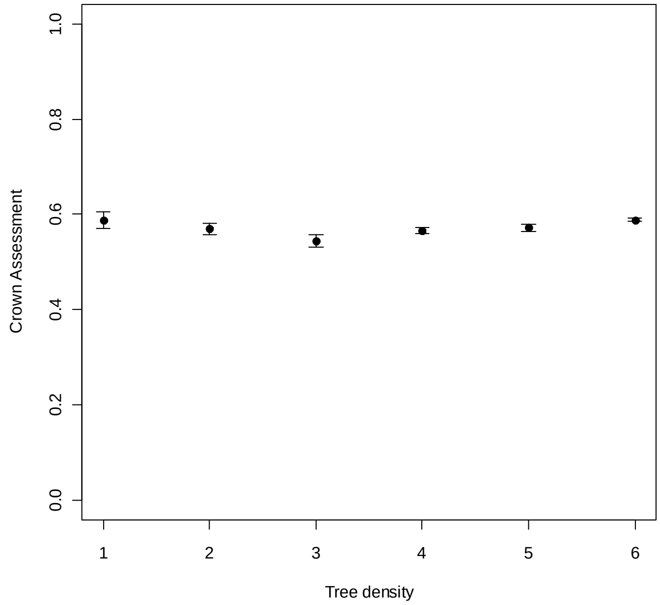


Fig. 12: Tree density for each quadrat against average crown rating. Categories for density are: (1) <10; (2) 11-20; (3) 21-30; (4) 31-40; (5) 41-50; and (6) >50 stems/quadrat

5.2.4. Parameters relating to other strata - 2008

In 2008 native woody understorey cover (p<0.1) and native grass cover generally decreased as wandoo crown rating increased (Figs. 13 and 14). Alternatively, litter cover showed an increasing trend with increasing crown rating (Figs. 15). Understorey decline was not significant and with no trend evident. Multivariate analysis also showed the significance of decreasing crown rating with higher levels of native woody plants, grasses and sedges and lower levels of litter.

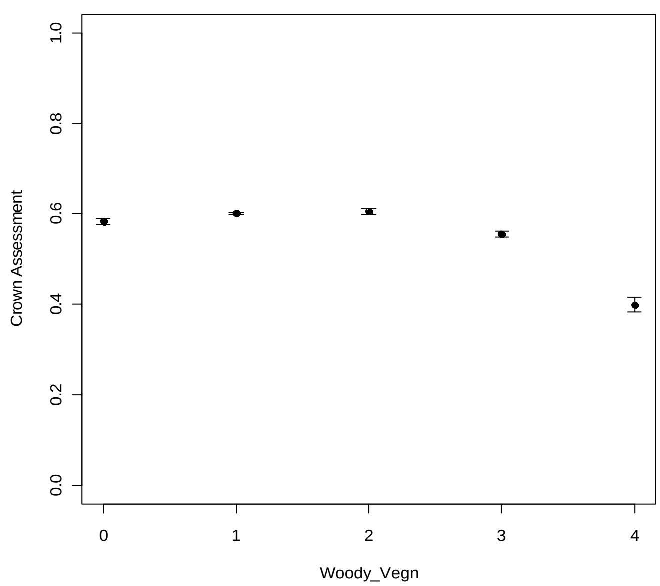


Fig. 13: Native woody understorey cover against average crown rating. Categories for cover are: (0) none present; (1) low (1-25%); (2) moderate (26-50%); (3) high (51-75%); and (4) very high (76-100%).

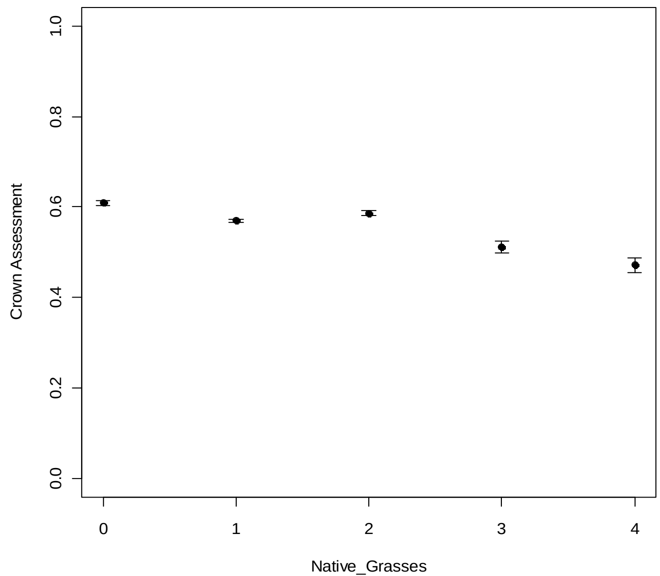


Fig. 14: Native grass/sedges cover against average crown rating. Categories for cover are: (0) none present; (1) low (1-25%); (2) moderate (26-50%); (3) high (51-75%); and (4) very high (76-100%).

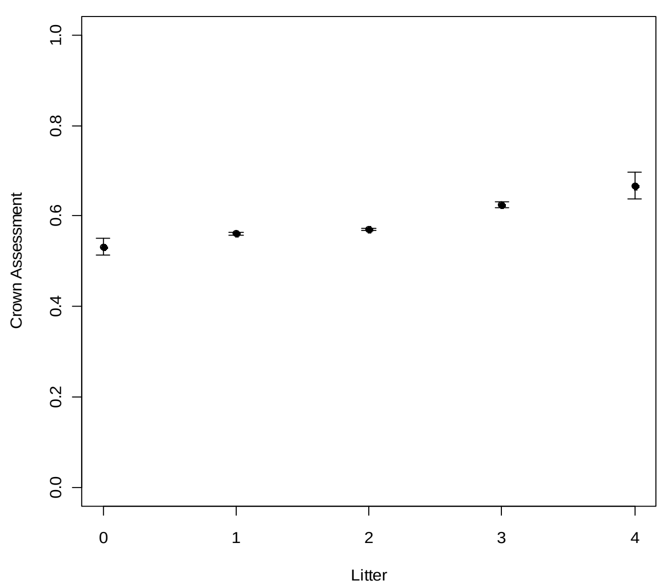


Fig. 15: Litter cover against average crown rating. Categories are: (1) none present; (2) low (1-25%); (3) moderate (26-50%); (4) high (51-75%); and (5) very high (76-100%).

5.2.5. Changes in crown rating from 2002 to 2008

Most variables showed no marked relationship between the category level and the change in crown rating. A relationship between the change in crown rating and the longitude of sites is noted with the change in crown rating exhibiting a slight negative trend as the longitude increases (Fig. 16). In addition to this a positive trend in the change in crown assessment was observed with the change in crown rating increasing with increasing long term (all data to 2007) and short term (2002-2007) average annual rainfall (Fig. 17). There was an increasing trend in the change in crown rating with age of epicormic growth (Fig. 18). Sites with no epicormic growth present had an average change in crown assessment of approximately -0.2 with the average change decreasing towards zero as the age of epicormic growth increased from <1 year to between 4 and 5 years. Sites with epicormic growth that was >5 years old had a small positive average change in crown rating. A pattern is also observed between the average change in crown rating and the position of the site in the landscape (Fig. 19) with sites located on mid to higher slopes and on ridges having a greater average decrease in crown assessment than sites located on valley floors or on outcrops. Sites at which the last recorded fire occurred less than five years ago had a much larger (negative) change in crown assessment than sites belonging to any of the remaining categories of fire history (Fig. 20).

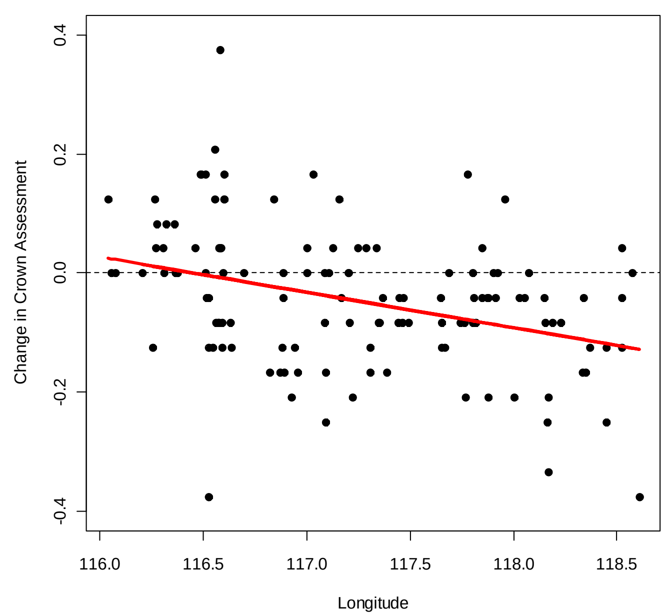


Fig. 16: Longitude (west to east) against change in wandoo crown rating. Change is from 2002 to 2008 for all transects.

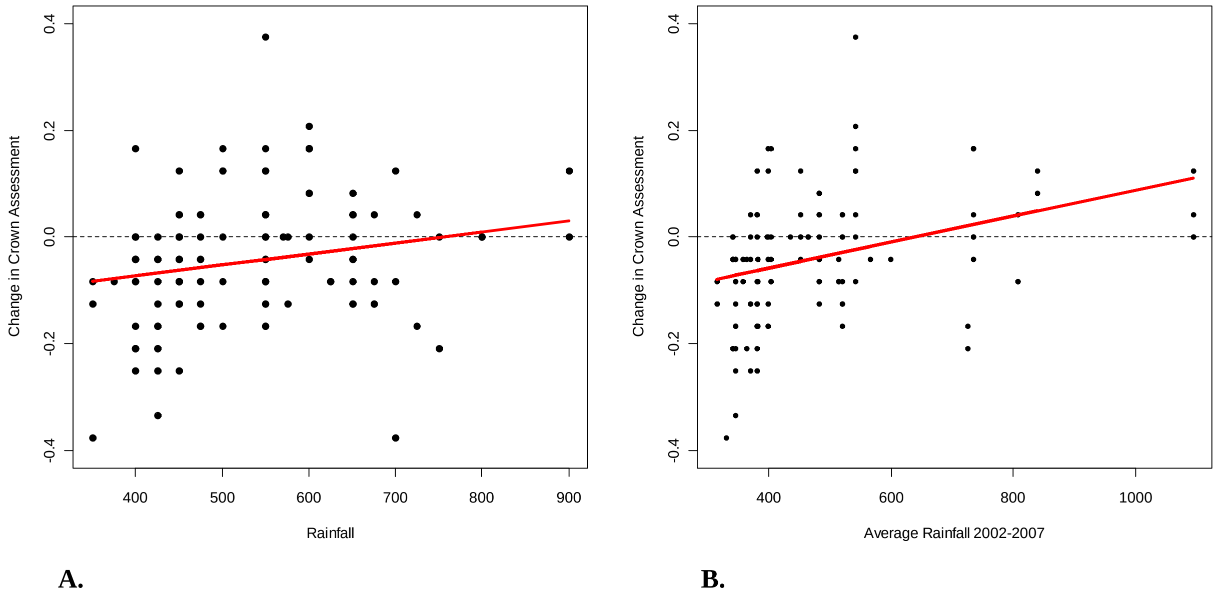


Fig. 17: Long term (A) and short term (B) annual rainfall against change in wandoo crown rating. Change is from 2002 to 2008 for all transects.

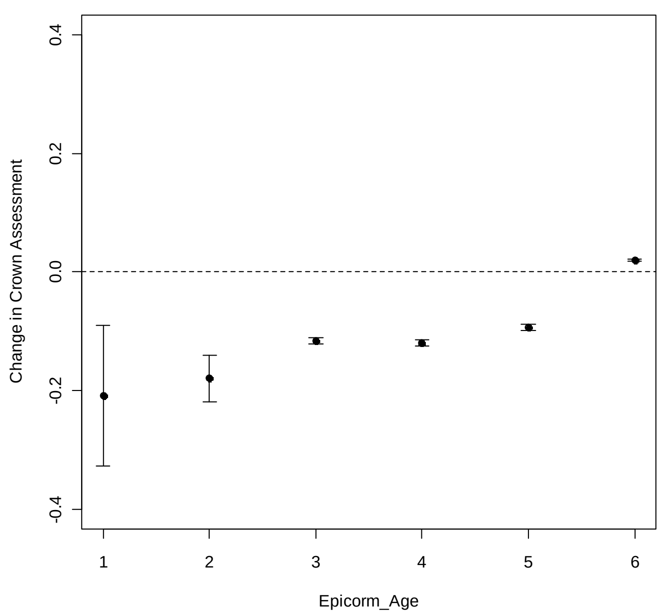


Fig. 18: Age of epicorms against change in crown rating from 2002 to 2008. Categories are: (1) no epicorms present; (2) <1 yr; (3) 2-3 yr; (4) 3-4 yr; (5) 4-5 yr; and (6) >5 yr old.

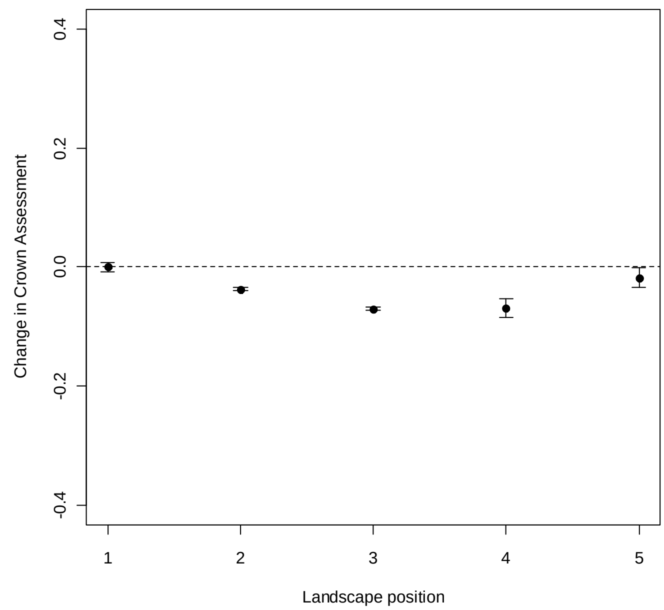


Fig. 19: Position in the landscape against change in crown rating from 2002 to 2008. Categories are: (1) valley floor; (2) low to mid slope; (3) mid to higher slope; (4) ridge; and (5) outcrop.

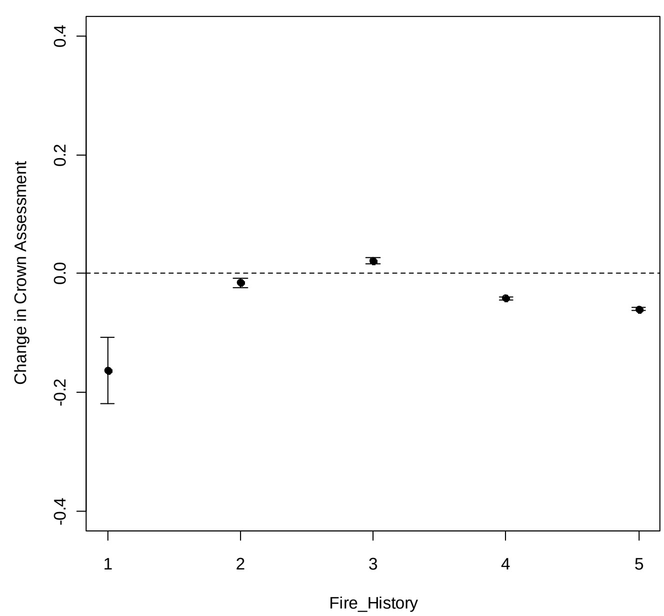


Fig. 20: Fire history against change in crown rating from 2002 to 2008. Categories are: (1) <5 yr; (2) 5-10 yr; (3) 10-20 yr; (4) 20-30 yr; and (5) >30 yr.

5.3. Rainfall and crown condition – 2008

In 2008 there were no obvious marked patterns on individual transects from plots of 1976-2007 average annual rainfall and crown ratings, or 2002-2007 average annual rainfall and change in crown ratings (2002-2008). Therefore the plots were not presented in this report. Of interest is the change in crown ratings for each transect, without rainfall, which are presented in section 5.11. Change in crown condition over all transects (all sites included) against average annual rainfall (ANOVA plot) did show a trend of decreasing crown rating with decreasing rainfall moving west to east.

5.4. Insect damage

5.4.1. Foliar insect damage

In 2008 foliar insect damage remained consistent across all transects at 11-25% or at moderate impact. This was similar to 2002 but with less variability. There was a marked decrease in incidences of high levels of damage. Chewing larvae and insects were primarily responsible, contributing to 80% or more of leaf damage. Leaf mining and browning was the second largest contributor (<20%), followed by minimal damage (<1%) from skeletonising and galls. There was negligible lerp insect activity when compared with 2002.

5.4.2. Damage to bark and cambium

Borer damage to bark and cambium tissue increased markedly across all transects, with lateral damage to wandoo trunks and larger branches evident at many sites. Larger trees were less susceptible than smaller trees to defoliation, branch loss and occasional deaths. Borer damage, noted in 2002 as a sporadic occurrence having little impact, was quantified in 2008 to reveal a more uniform occurrence across the survey area. Borer damage could be attributed to the cossid moth or *Phoracantha sp*. Large entry points recorded were likely due to bullseye borer, *Phoracantha acanthocera* (Brown et *al.* 1990, Allan Wills, DEC, pers. comm., Ryan Hooper, DEC, pers. comm.). Bark feeding areas were also observed in large primary branches, lesions possibly made by *Bimia bicolor*. Damage to trees similar to that described by Brown et *al.* (1990) was of the longicorn beetle larvae of *Tryphocaria punctipennis*. Widespread damage was the dying back of smaller branches and branchlets often characterised by lesions and epicormic growth at the base of dead wood. A twig borer species was reported by Hooper and Sivasithamparam (2005) as an agent causing or contributing to WCD (see section 6.2.2). Large longitudinal lesions were observed at a few sites (Rocky Gully, Stirling Range N.P. and York) on the trunks of smaller wandoo or branches of larger trees (diameter 10-20cm).

5.5. Fire history

On the southern transect, fire damage has occurred at two sites since 2002. Fire at a Red Gum Pass site has burnt understorey and some buts of mature wandoo. *Armillaria* fungus may also be active on some trees, possibly as a post fire agent. At Wambellup, a recent summer fire was hot enough to scorch crowns. The central transect recorded only one incident of recent intense fire, apart from evidence of controlled burning. This fire burnt two sites west of Williams in 2007. Damage to wandoo was significant in that 25% and 30% of wandoo were fire-killed. Crown ratings of 17 and 16 (C2) recorded in 2002 have fallen to 3.5 (C5) and 7 (C4) in 2008. Understorey species have responded with both seed germination and resprouting. There was evidence of fire-killed *Xanthorrhoea sp*.

There has been no fire damage affecting quadrats on the northern transect intense enough to scorch crowns or destroy trees. Four sites, in Julimar, Mount Observation, Talbot Road and Helena Valley, had low intensity prescribed burns that damaged the lower trunks of small wandoo. A Talbot Road site did lose one large tree to fire. In 2002, an earlier intense fire was implicated in crown destruction at the Keaginine Nature Reserve site near Great Northern Highway (crown rating of 6) with the WCD active and afflicting the fire-related regrowth. This rating increased to 8 with moderate, even distribution of new leaves and further epicormic growth 1-2 years old.

In 2002 in the Stirling Ranges, a condition reported for three sites, after recent wildfires, was the destruction of a post-fire epicormic growth (Mercer 2003). A site on Salt River Road and two sites on Red Gum Pass, recorded deaths of approximately 25%, 40% and 50% of trees related to respective average crown ratings of 7, 6 and 3 (C4, C5). In 2008, tree deaths have increased to 35%, 60% and 60% respectively and related to crown ratings of 11, 5 and 7 (C3, C5 and C4). The first and third sites have stabilized and show recovery through what appears to be a second epicormic response, while the remaining site continued to decline. At all sites there was post-fire regeneration of wandoo. Following marked low rainfall years before the wildfires, water deficits were implicated at these sites, suggesting epicormic growth may have died back due to lack of soil moisture.

5.6. Position in the landscape, land use, connectivity and slope gradient

Regarding position in the landscape, land use, connectivity and slope gradient, results were similar to 2002 with crown ratings still progressively increasing from valley floors up to the higher landscape. The pattern has remained much the same since 2002. Road reserves had the highest crown ratings while National Parks and Nature Reserves had the lowest. Sites adjoining bushland exhibited higher crown ratings, lower ratings being inside bushland. Gradient slope was repeated with slopes of 4-6 degrees having the highest crown ratings.

5.7. Understorey and litter

Understorey was recorded at 98 quadrats across the study area. Predominant species present across all transects were *Xanthorrhoea sp*., *Hakea lissocarpha*, and *Lepidospernum sp*. In addition, *Olax benthamiana*, *Hakea marginata* and *Hypocalymna angustifolia* were common on the southern transect, while *Desmocladus species* (probably several native curly grass species over the survey area) were common on the northern transect (Fig. 21). Understorey decline was generally insignificant with: 50% of quadrats recording levels of 0-5%; 27% of quadrats were low (5-10%); 15% were moderate (10-25%); and 7% were high (25-50%) Although high decline levels were observed at sites with low to moderate crown ratings (5 quadrats = C3, 1 = C4 and 1 = C2) there appeared to be no siginificant relationship between understorey decline and lower crown ratings. From 2002 to 2008, there was little change on the transects of understorey cover (collectively woody species, grasses and sedges) that was of any significance.

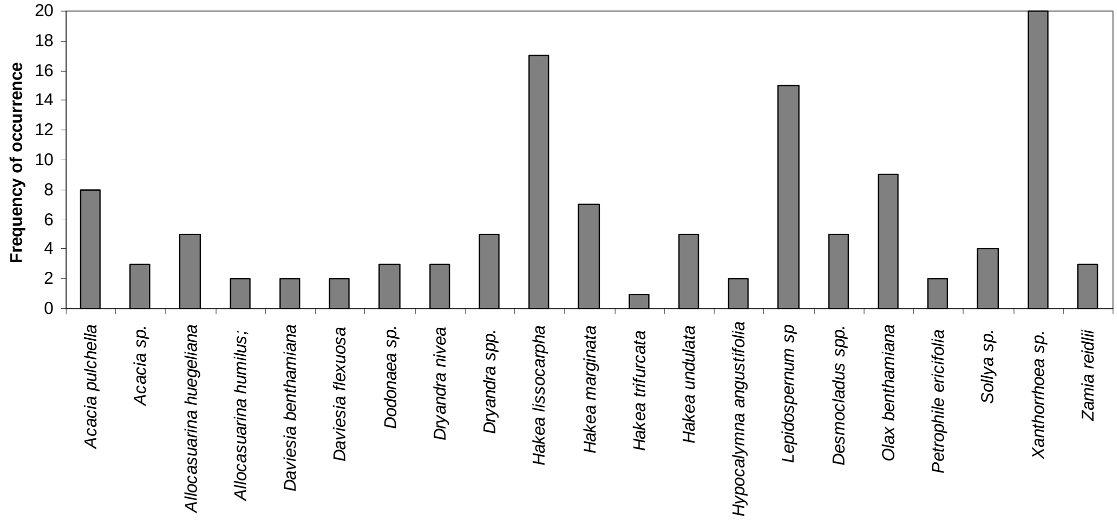


Fig 21: Understorey occurrence as the dominant species at 98 quadrats over the southern, central and northern transects.

5.8. Age of epicorms

All transects displayed significantly more older epicorms than in 2002. On the northern transect, epicorms >5 years old dominated at 22 sites compared to nil sites in 2002. The predominant ages of epicorms in 2002 were 1-2 and 2-3 years old while ages >5 years prevailed in 2008. On the central transect, epicorms >5 years old dominated at 19 sites compared to 4 sites in 2002. Epicormic growth across this transect was <4 years old in 2002 compared to >4 years in 2008. On the southern transect, epicormic growth dominated at 22 sites compared to only 3 sites in 2002. The predominant age of epicorms along the transect was <3 years old in 2002 and >3 years old in 2008.On all transects, younger epicorms were generally seen where a post 2002 decline event had occurred or where a post 1990 event had further deteriorated. Changes in crown rating over six years were generally less negative the older the epicorms were, with a marginal positive change for epicorms >5 years old (Fig. 18, section 5.2.4.).

5.9. Phenology

A feature in 2008 has been an increase in the presence of new leaves across the survey area. On the southern transect, the distribution of new leaf and bud growth in the crowns generally increased from sparse in 2002 to moderate in 2008. On the central transect, new leaf growth generally increased from sparse in 2002, to more even distribution in 2008. Bud growth decreased from moderate to sparse. On the northern transect, new leaf growth generally increased from sparse distribution in 2002, up to moderate in 2008. Sparse bud growth, however, decreased further in 2008. On all transects, fruit was generally very sparse in 2002 and very few were recorded in 2008. Flowering was rarely recorded in both surveys. There was very little bud or fruit abortion, although this was more frequent in 2002.

5.10. Comparison of 1991 and 2002 data at Boyagin, Noombling and Popanyinning

In 1991, Boyagin, Noombling and Popanyinning were classed as healthy, intermediate and degraded respectively. Data collected and photographs taken in 1991 and 2002 showed little change in the structure of wandoo canopies over 11 years at Boyagin, Noombling and, to a lesser degree, Popanyinning. In 2002, Boyagin showed little evidence of the present decline. Noombling showed some limited symptoms, mainly defoliation from about 3-5 years before 2002, with no cyclical pattern present. Popanyinning showed more advanced and active decline symptoms. The 1991 site photographs and several other images of wandoo from that time showed little evidence of active decline. In 2008, Boyagin was showing decline, falling from a crown rating of 18 to 14 (C2 to C3). The intermediate site, Noombling, showed marginal improvement from 18 to 19 as did the degraded site, Popanyinning, increasing from 13 to 14.

5.11. General trends along transects and decline patterns

Observations in 2002 showed that the present decline was often overlaid onto other earlier decline patterns. Temporal and spatial trends in decline were apparent and separate decline events had occurred, or were occurring, that may be distinct from one another. These were broad scale, variable and not continuous across the landscape. This was still apparent in 2008 but less clear as previously healthier stands and individual trees showed WCD. Six years ago healthy wandoo existed amongst declining trees, even in stands of marked decline. In 2008 this pattern was less variable with more decline evident.

Identified in 2002 were long term dieback greater than 10 years and likely decades old; salinity-related dieback, both recent and long term; and the present decline pattern (now implicating twig borers and associated canker fungi). The rapid crown defoliations in 1991, due to extreme summer temperatures, was considered a separate decline event and not witnessed in the 2002 survey. There has, however been a similar heat stress event in 2007 around Quairiding, Corrigin, Beverly, Wickepin and Narrogin (Peter White, DEC, pers. comm.). Salinity-related decline was observed in 2002 as trees that had died back some years before and now existed with a contracted crown. Some monitored trees have declined further while others have improved over a 17 year period (Appendix 2). Saline areas were often unaffected by the present decline pattern in 2002 but in 2008 the impact has increased. As would be expected, more trees have died in saline areas. Random sampling of sub-surface salinity with an EM-38 metre showed a slight decline in salinity. Also noted in 2002 was the presence of *Armillaria*. The incidences of affected trees have increased in 2008.

In 2002, canopy loss due to WCD decline was noted as very recent but also up to approximately 10 years old (post 1990). This was generally less than 6 years old in 2008 (post 2002). Crown health within sites in 2008 was still improved by fire-regenerated dense stands of young wandoo trees up to 30 years old and by other road verge regeneration. Although some young wandoo have since declined, they did not display the decline severity or variability of mature trees (Appendix 2).

In 2002, incidences of decline increased within areas where there was increasing occurrence of wandoo. On the northern transect, increasing decline correlated with increasing rainfall moving westwards with decline more evident at about the 450 mm rainfall isohyet. Moving west along the central transect, decline became more evident west of Wickepin on the 450 mm isohyet. Crown health then generally improved at sites near or within the State forest around the 650 mm isohyet. On the southern transect, however, decline was more evident at the 400 mm isohyet but became less evident just east of the 650 mm isohyet near Frankland. Six years ago the eastern extremities of all transects were generally healthier, as was the western extremity of the southern transect. The central transect was healthier in the west to a lesser degree (Map 1). In 2008, wandoo in higher (western) and lower (eastern) rainfall areas have generally suffered a post 2002 decline (Map 2). Trees between the abovementioned isohyets were generally recovering: this being more advanced around York; less advanced around Wickepin and Narrogin; and far slower in the south (Fig. 22-25).

5.11.1. Northern transect

Out of 37 sites, 20 have improved, 7 have remained stable, and 10 show further crown decline (Fig. 23). Of the declining sites, 8 were located on the eastern extremity, east of York. Wandoo crowns from York to John Forest N.P., however, have become less transparent as leaf densities have increased. Consequently, the dead branches and branchlets evident in the crowns six years ago were being shrouded in foliage growth derived from the epicormic response to the decline event. Average leaf density values across the transect increased by approximately 10% but were still below the average crown density (Appendix 1, Table 1). With respect to the WRG crown assessment method, declines on the eastern extremity were not considerable with about half the sites retaining the C2 decline stage while others fell from C2 to C3. West of York, several sites have improved from C3 to C2 and a few from C4 to C3.

5.11.2. Central transect

Out of 41 sites, 5 have improved, 7 have remained stable, and 29 show further decline (Fig.24). Wandoo crowns have become more transparent on the eastern and western extremities as leaf densities fall. The incidences of dead branches increased on average with more small dead branches and branchlets evident in the crowns. Contribution of epicormic growth to foliage also increased. More specifically, previously healthy sites (in 2002) between Dudinin and Wickepin have suffered a post 2002 decline then generally recovered with fast-growing epicormic growth that has occupied the defoliated crown branches relatively quickly. Leaf density values have thus improved but are still below that of 2002 when decline was not evident at these sites. Other sites classed as less healthy in 2002 had a slower epicormic response to decline. With respect to the WRG crown assessment method marked declines were at sites falling from crown rating categories of C2 to C3. In the western sector, east of Collie, falls from C2 to C4 and C2 to C5 were due to wildfires in 2007-08 that scorched canopies and destroyed trees (see section 5.5). Marked declines were from the eastern extremity at Pingaring (east of Kulin) to Jitarning. From this point westwards to Pig Gully Road (just west of Williams), crown health values generally improved, and then moving west to Collie, sites generally showed increasing incidences of decline.

5.11.3. Southern transect

Out of 48 sites, 8 have improved, 6 have remained stable, and 34 show further crown decline (Fig.25). Across the transect, wandoo crowns have also become more transparent as leaf densities fall. The incidences of dead branches have increased on average with more small dead branches evident in the crowns than in 2002. Contribution of epicormic growth to foliage has also increased. Epicorms were occupying the lower part of defoliated branches within crowns. Crown ratings generally fell from C2 to C3, from the eastern extremity at Chillinup (on the Pallinup River) to just east of Chester Pass Road (in the Stirling Ranges). From this point westwards to Rock Hole Nature Reserve, crown health values slightly improved. Previously healthy sites with no epicormic growth now showed increasing WCD from Rock Hole N.R. to Noobijup Road at the western extremity (west of Rocky Gully).

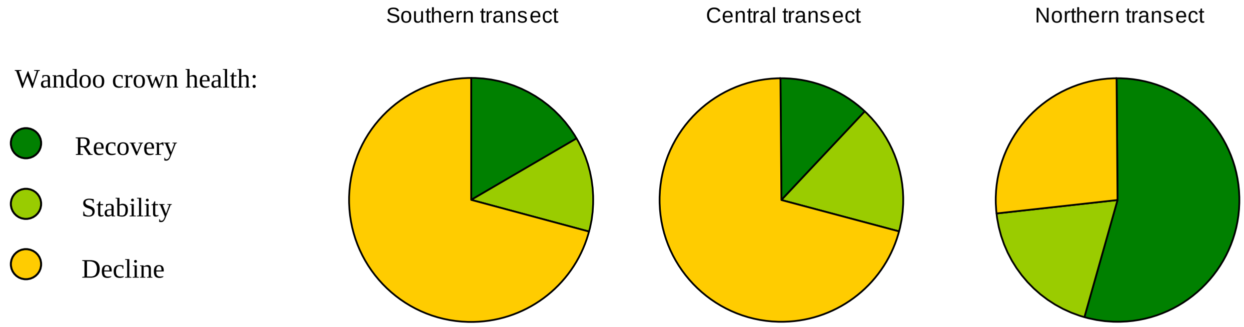


Fig. 22: Wandoo crown health in 2008 for the southern, central and northern transects. Diagrams illustrate the number of sites for each transect where crown condition has improved, remained stable and declined. There is clear evidence of recovery along the northern transect. Outcomes for the southern and central transects appear similar to each other, however, recovery on the former is slower, as displayed in Figs. 24 and 25.

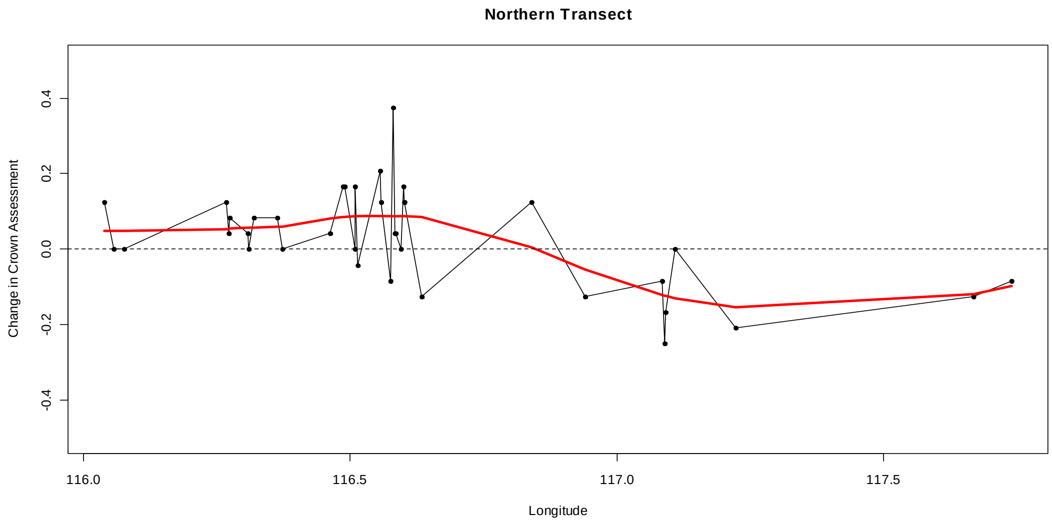


Fig. 23: Changes in crown condition for the northern transect from 2002 – 2008.

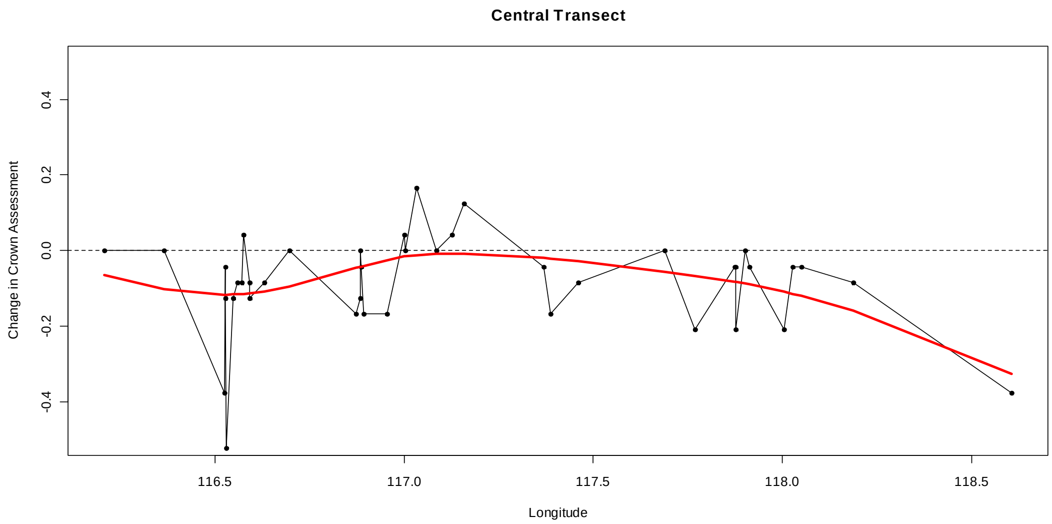


Fig. 24: Changes in crown condition for the central transect from 2002 – 2008.

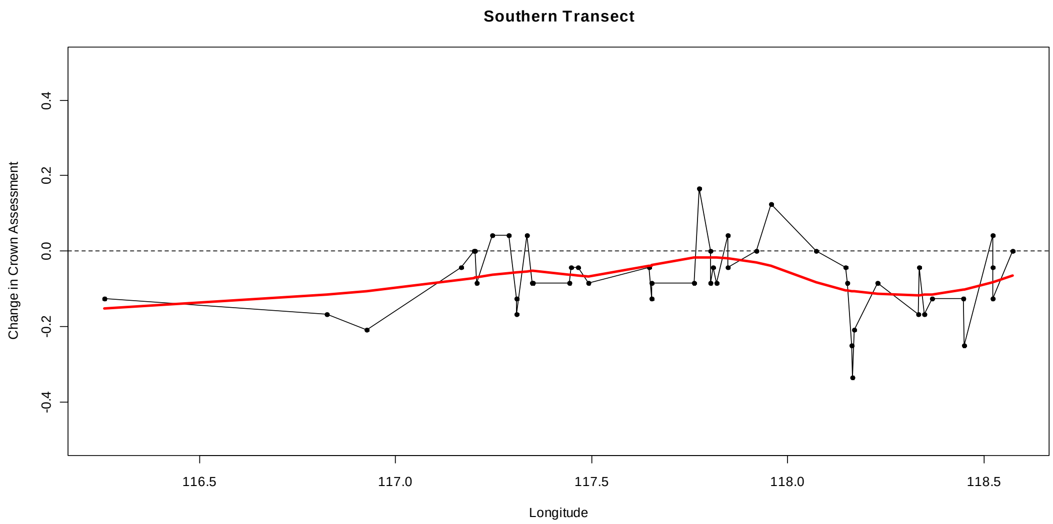
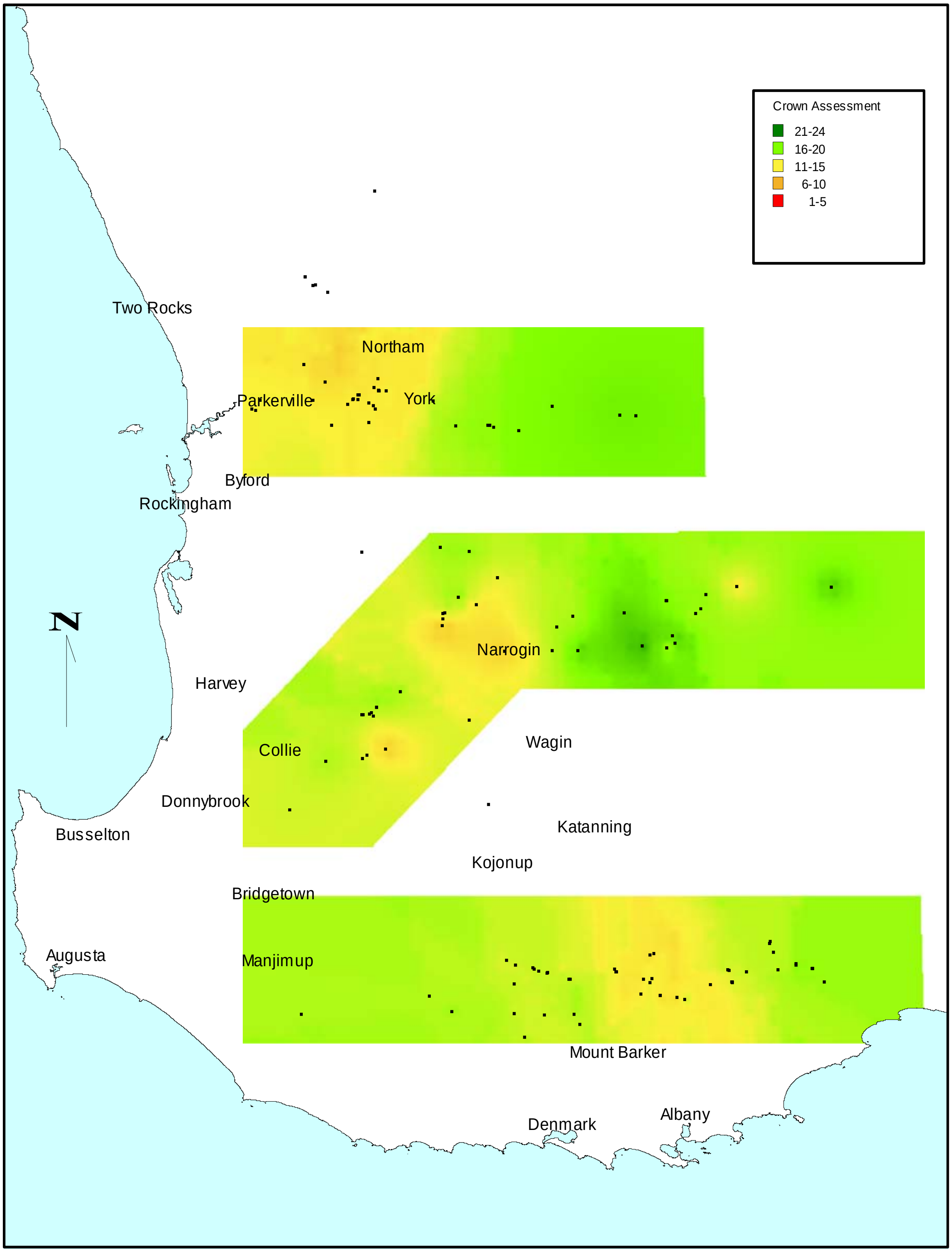
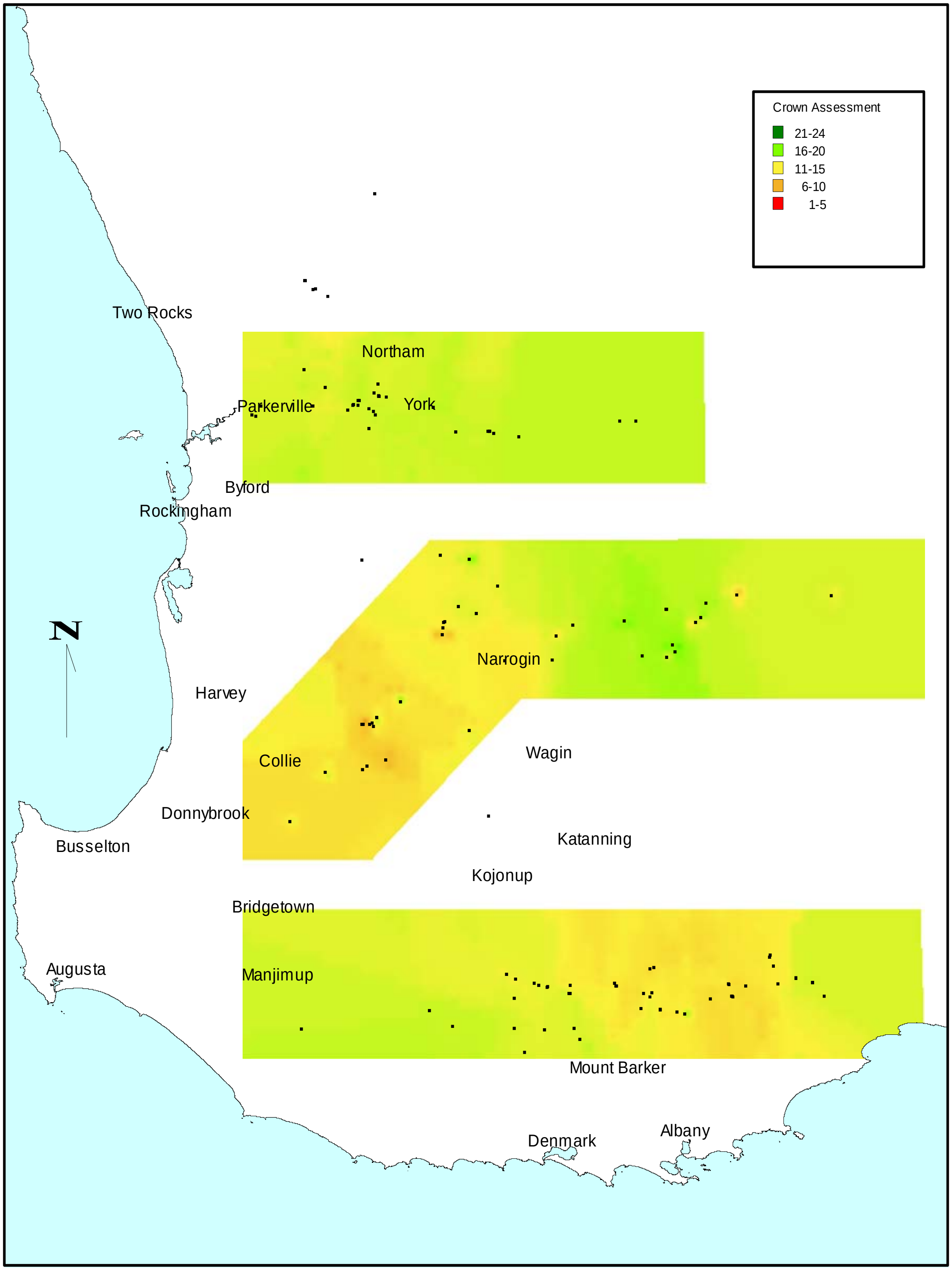


Fig. 25: Changes in crown condition for the southern transect from 2002 – 2008.

MAP 1: SPATIAL PATTERN OF WCD IN 2002



MAP 2: SPATIAL PATTERN OF WCD IN 2008



6. DISCUSSION

Tested in 2002 was that environmental disturbance had caused wandoo decline. More insect damage related to lower crown ratings. Rainfall deficits did not appear to incite decline higher in the landscape because wandoo crowns progressively improved from lower to higher positions. Inconclusive was whether higher stem density caused tree water deficits, with no significant relationship established. Crown condition improved with increasing time since intense fire but an optimum fire interval was not recognised. Changes in land use showed no relationship, with paddocks and road reserves displaying some of the better crown condition. Apart from obvious historical disruption to wandoo woodlands, fragmentation did not appear to be predisposing wandoo to crown decline with sites within large woodland areas showing lower crown condition. Understorey cover and litter structure had no significant relationship, although there were slight trends of decreasing understorey cover and increasing litter with improving crown condition.

Tested in 2008 was that environmental disturbance continued to cause wandoo decline. This appears to be the case with increasing incidences of post 2002 decline, although recovery is evident in the Avon. It was difficult to implicate rainfall deficits as inciting decline because the higher and lower rainfall zones, straddling the mid rainfall zones, now showed more decline. This survey showed no discernable relationship (see below), despite the general implication of rainfall deficits in the decline of wandoo and other woodland species. From west to east, however, there was evidence of a general increase in WCD, shown by this change in crown decline since 2002 (see below). This is likely related to a collective post 2002 decline on the eastern sectors of all transects and the marked improvement of crown health in the western sector of the northern transect, regardless of decline on the western parts of the southern and central transects. Higher stem density did not appear to result in water deficits with no contrast in crown ratings over variable tree densities. Associated understoreys did not have a relationship with wandoo crown condition that suggested similar or related decline patterns. Correlations relating to crown condition in 2002 have been confirmed in 2008. These are insect damage, fire history, position in the landscape, slope, land use and connectivity (Appendix 1, Table 2).

6.1. Average annual rainfall

In 2002, the most marked WCD was between the 400-450 mm and 650 mm isohyets, particularly on the southern and central transects. Since the mid-20th century, May-July winter rainfall in south-western Australia decreased sharply. In the last 25 years from 1976-2001, May-October average rainfall has been 85-90% of the preceding 50 year average from 1925-1975 (IOCI, 2002). The mapped contours, representing the range of these % changes roughly coincided with more severe decline areas (Map 1) that illustrated a zone of marked WCD in the Narrogin, Williams and Darkan Shires (Mercer, 2003). This is less clear in 2008 (Map 2) because further WCD has occurred east and west of those zones of higher rainfall deficits (see section 5.10). Also, no trend in 2008 crown decline, or recovery related to 1976-2007 average annual rainfall along transects. No trend was evident either for change in crown condition (2002-2008) and 2002-2007 rainfall. IOCI (2004) reported that south-west rainfall decline was not gradual but abrupt, in the mid-1970s. Later data from 1976-2003 May-October average rainfall showed further declines up to 30% compared to the long-term mean rainfall before that period. Data does show that there was a trend of declining rainfall east to west (Fig. 17), as would be expected, with increasing negative change in crown ratings (2002-2008). It is speculative to implicate that less rainfall is responsible without more investigation. This does not explain the decline in the west, on the central and southern transects, nor does it explain the recovery in the last six years within the mid- rainfall zone. More localized rainfall deficits could be implicated.

6.2. Insect damage

6.2.1. Foliar insect damage

For both surveys, foliar damage levels for all 3 transects (11-25%) fell within the range usually reported for Australian woodland eucalypts, that is 15-30% (Burdon and Chilvers, 1974; Springett, 1978; Fox and Morrow, 1983). In fact foliar damage remained consistent for several years (Mercer, 1991 and 2003). In 2002, lerp insect damage was considered worthy of closer attention in analysis. Its impact, however, did not relate to crown health trends. In 2008 there was little activity of lerp insects. Chewing larvae and insects were primarily responsible, contributing to 80% or more of leaf damage. On the western end of the southern transect, insect damage increased where younger epicormic growth predominated and these sites had suffered post 2002 decline. This may indicate tree stress and decline with increased insect attack as a consequence, however, it was not evident on the other transects and there was no statistical trend.

6.2.2. Damage to bark and cambium

The marked increase in borer attack on trunks and large branches of wandoo occurred across the survey area in 2008. This is of concern where smaller trees (<20cm DBHOB) have been “collared” by galleries and occasionally killed. Persistent cyclical attack from larger borer species was rarely observed in 2002, usually occurring on old fire-scarred trees that were vulnerable to attack. Observations and photograph records in Boyagin (1991, 2002 and 2008) illustrated how persistent borer attacks can be on older trees, damaged in a 1968 wildfire. If environmental stress was implicated in wandoo decline and this stress persists, the question to ask is - do trunk and large branch borers have the potential to significantly contribute to wandoo decline in future as the twig borer appears to have done? The twig borer species was reported in detail by Hooper and Sivasithamparam (2005) who have shown a strong relationship existed between increasing WCD over the last 10 or so years and infestations of this borer, associated with canker fungi. In turn this was likely causing canopy loss (ibid.). The nature of this damage was described under the umbrella of “typical” or “present” decline in this survey. A similar association has been identified for large branch and trunk borers. Brown et *al.* (1990) reported two pathogenic canker fungi (*Botryosphaeria ribis* and *Endothiella* sp.) isolated from necrotic tissue around bore holes of the longicorn beetle, *Tryphocaria punctipennis*, suggesting that their activity favoured canker establishment. Mercer (1991) reported insect damage and fungal pathogens were not impacting heavily on wandoo (in 1991) as had occurred in eastern Australian woodlands. There was no evidence that these decline agents (namely borers and aerial cankers) were active and widespread as they were now. Hussey (1999) does record borer and canker damage on a wandoo in Helena Valley in 1992.

There is no explanation for large longitudinal lesions occasionally observed on the trunks of smaller wandoo or branches of larger trees in 2008 (section 5.4.2). They could possibly be healing after the formation of drought cracks, or else related to borer activity. Further investigation is warranted to identify this damage type.

6.3 Fire history

Findings in 2002 suggested that exclusion of high intensity fire was probably not a contributor to environmental stress in decline of wandoo because longer periods without intense fire related to higher crown ratings. Defoliating wildfires have aggravated the symptoms of crown decline in other parts of Australia (Jurskis 2004). Damaging fire may have brought disturbance that allowed WCD to develop. Visual crown assessment, however, may distort the data in relation to (intense) fire history.

Healthy wandoo may actually be observed in the field as refoliating after scorching from intense fire and not afflicted by WCD (Mercer 2003). Research continues to accumulate regarding long periods without fire inciting declining health in Australian eucalypt communities (Withers and Ashton 1977; Ellis et *al.* 1980; Jurskis 2005; Archibald et *al.* 2006; Underwood 2006). This research implicates a lack of frequent low intensity fires; increasing nitrogen loads; and insect damage as a catalyst for eucalypt crown decline. Understorey succession in the absence of fire and increasing litter has also been implicated in eucalypt declines. There is insufficient research at this stage to implicate such a decline mechanism with wandoo health (see section 6.5). In fact, intense fire was very destructive to all age classes of wandoo at Collie Road on the central transect (section 5.5) with up to 30% of trees fire-killed (Fig 26). There also appeared to be inadequate ashbed regeneration, which suggested scorching may have destroyed seed capsules in the canopy before seed fall. This was uncharacteristic of wandoo where high density clumped regeneration was normal after hot fire (Hatch 1960; Burrows et *al.* (1990). 2002 records showed moderate to light distribution of fruit, buds and new leaves at the Collie Road sites. Whether this was the case just before the 2007 fire is not known. Understorey regeneration (germination and sprouting) was uniform over the burnt areas. Jurskis and Turner (2002) reported that vigorous understorey regeneration after wildfire can dominate a burnt site. It is too early to tell whether the recent fire will cause long term decline at Collie Road but recovery is likely to be slow as was observed on the southern transect (see section 5.5). Before changes in fire management that have resulted in less frequent burning there was a 5-7 year period between autumn fires (Campbell 1956), or 6-8 years according to Underwood (unpubl.). Less frequent burning as occurs today does encourage hotter fires if dense understorey is present (Penny Hussey, Land for Wildlife, DEC, pers. comm.).

There are indications that the combination of WCD and an intense fire represents a severe stress for woodlands from which they recover with difficulty. Keaginine N.R., on the northern transect, for example, experienced an intense fire in 1991. Recovery at this site was slow and was followed by the typical decline pattern or possibly a water deficit. The fire destroyed canopies and probably standing trees as well and inflicted damage similar to that recorded on the central transect after a 2007 fire and the southern transect after 1997 and 2000 wildfires. Post-fire recovery appeared to have suffered a further decline event as the age of epicorms were judged to be another growth flush about 2 years old in 2008. The health of the Keaginine site may have been compromised to a point where the rate of recovery was poor. Similarly, the southern transect sites in the Stirling Range N.P. showed slow recovery (Fig. 27 and 28). The rate of recovery appeared to be inhibited by successive or concurrent decline events, implicating disturbances from fire, water deficits and the present “typical” decline.

Wills (et *al.* 2000) observed the present crown decline pattern in both dense regrowth and old open stands, subject to regular fuel reduction burning, and in open stands of mature trees probably unburnt for several decades. Furthermore and not necessarily involving fire, the 2002 and 2008 surveys showed variable impacts of this decline in sites in open paddocks, parkland cleared areas, private remnants, road reserves and State bushlands. There were few cases where ascendance of lower strata was evident and certainly more cases of low level understorey decline (see section 5.7). This trend may reverse over time due to the vigorous growth and recruitment by species such as *Allocasuarina huegeliana* that do not wholly rely on fire for seed set and germination. There was nothing definitive or common enough on the transects to implicate this phenomenon in general WCD with only 5 sites recorded with this as a dominant species.


Fig. 26: Comparative images at Collie Road site in 2002 (left) and 2008 (right). After wildfire in the autumn of 2007**,** recovery of post-fire epicormics appears to be limited. On the southern transect, soil moisture deficit was implicated in causing epicormic growth to die back. This may not be the case at the above sites. An extremely hot fire was possibly the cause of low seed fall and germination, as well as destruction of standing trees. Note the fire-killed *Allocasuarina huegeliana* in the foreground which were post 2002 recruits.


Fig. 27: Comparative images at Salt River Road site in 2002 (left) and 2008 (right). After wildfire in 1997, recovery of post-fire epicormic growth quickly died back. Previous low rainfall years before the fire may have created a soil moisture deficit and this growth could not be sustained. Note the slow epicormic growth typical of recovery on the southern transect.


Fig. 28: Comparative images at Red Gum Pass site in 2002 (left) and 2008 (right). After wildfire in the summer of 2000, recovery of post-fire epicormic growth also quickly died back. Again, preceding low rainfall years were implicated. Note the wandoo and understorey regeneration in 2008 and a 2nd epicormic response.

6.4. Position in the landscape, slope of gradient, land use and connectivity

Similar crown condition six years later with respect to position in the landscape, land use, connectivity and slope gradient may suggest that the present decline is not as dynamic as expected (see section 5.6). Position in the landscape was of most interest. As was suggested in 2002, healthier wandoo higher in the landscape may be attributed to: less exposure to agricultural impact; sub-soil conditions acting as micro-catchments; and well established deep tap roots. Excavations of wandoo root systems, on the crest of a hill in granitic/doleritic profiles, have shown wandoo roots penetrating up to 23 metres down into the profile (John Bartle, DEC, pers. comm.). Burgess (2006), however, supports Lamont (1985) in that mature wandoo have a well developed lateral root system concentrated between 20-40cm soil depth. There was still an intact tap root that, along with sinker roots, penetrated the laterite layer into deeper clay (Lamont, 1985). Dry and exposed ridgetop forests were reported as been generally unaffected by declines (Hopkins 1974; Podger 1981). White (1969) argues that large outcrops have shallow soils over granite and high clay content, prone to desiccation in hot weather. Trees would be susceptible to decline when weather extremes created a water deficit. This does not appear to be the case for wandoo where outcrops had the highest crown rating and little negative change in crown rating from 2002 to 2008 (section 5.2.5). The wandoo root system described above may have the ability to adapt to a more hostile terrain that characterizes many higher landscapes. Regarding valley floors (with the lowest crown ratings), recent research by Jurskis (2005) and others supported the concept that trees were more susceptible to decline in the lower landscape. The function of roots may be impaired by changes in valley soils characterised by poorer drainage and aeration. Jurskis (2004) suggested that agricultural practices in valleys were the causes of tree decline.

On a regional scale, variability in WCD was evident as previously healthy trees have declined in some districts but have displayed recovery in others. On a local landscape scale, these changes have not been reflected with some results (described above) for 2002 persisting in 2008. Using crown assessment by Abbott (1992), changes in crown condition fluctuated mainly due to decreasing/increasing values for leaf density and epicormic growth. Incidence of larger dead branches remained relatively constant over six years with less variability than the other assessment components. That is, C4 and C5 ratings were relatively uncommon. Such decline severity is often found for wandoo in saline conditions, for example, where trees may exist with large dead branches protruding from a contracted canopy (see Appendix 2). Batini (2005) recorded in a survey that 70% of trees were classified as C1 and C2 where crowns retained more than 60% of their leaf. Only 7% had ratings of C4 and C5. Despite the visual impact of decline, the death rate remained low, if 5-10% (Wills 2004) can be considered low.

6.5. Understorey and litter

There appeared to be no relationship between crown ratings and understorey decline. There was, however, a general but insignificant trend of less understorey cover and more litter cover under wandoo with higher crown ratings. Despite the use of more discrete categories in estimates, the understorey component across the survey area showed to be generally stable. Nearly 80% of recordings were between 0% and 10% decline levels. The decline of *Desmocladus* may be related to the autumn season that would distort results. With regard to collective understorey cover, there was a general but insignificant trend of less understorey cover mostly evident on the central transect. In fact understorey ascendance was observed at Borden (southern transect) and Boolading (central transect) where average crown ratings have fallen to C4 and C5 stages. Also observed at these sites and others, was occasional wandoo regeneration <6 years old that was not a consequence of fire, which is uncommon. Shearer et *al* (1997) observed regenerating wandoo under mature trees that had died from *Amilllaria luteobubalina* infection. Mature (competitive) wandoo do exclude understorey and inhibit germination in the absence of fire, probably due to their efficient lateral root system (Lamont, 1985) and possibly due to their allelopathic tannins and phenols accumulating in the soil. The ascendance of understorey at the expense of eucalypt canopy species has been cited by several authors (see section 6.3). It was likely that germination and seedling growth were occurring because chronically declining wandoo trees were no longer competitive. Jurskis (2004) suggested that understorey may eventually replace chronically declining eucalypt stands due to an upset in the competitive balance by environmental change. Shrubs have tended to replace native grasses in some areas and species such as rock oak (*Allocasuarina huegeliana*) have been able to move away from rock outcrops to form dense thickets in previously open woodland. Less frequent fires were implicated (Underwood, pers. comm. cited in Batini 2005). The ascendance of woody understorey over native grasses was observed by Underwood (2006) from about 40 years ago in forest management areas. There were, however, few cases in the 2008 survey of vigorous understorey growth under declining wandoo. No single fast-growing species (such as *Allocasuarina huegeliana*) was uniformly dominating the lower strata. This may change in the future.

Around 40 years ago, healthy dense wandoo crowns were also observed by Underwood (2006) and Campbell (1956). Harris (1955) observed similarly healthy crowns and noted that……"Under a virgin Wandoo stand the undergrowth vegetation is not plentiful and under some large trees there is no undergrowth at all. This lack of undergrowth could be caused by repeated fires, or it may be that Wandoo has taken complete possession of the site, and has suppressed the undergrowth….." The last observation supports Lamont (1985) that wandoo suppresses undergrowth by depriving it of adequate soil moisture. Results of the 2008 survey lend support to healthier wandoo having less associated understorey. Litter cover progressively increased under healthier wandoo crowns but generally decreased across the survey area since 2002.

6.6. Age of epicorms

The age of epicormic growth was a good indicator for assessing what stages of decline or recovery were being displayed for wandoo. All transects displayed significantly more older epicorms six years after the 2002 survey. This indicated that recovery was under way, as these epicorms occupy the crowns. There is a north to south trend evident where recovery was more advanced in the Avon, intermediate in the central wheat belt and less advanced on the south coast. On the southern transect, the general display of slow-growing epicorms, sometimes >5 years old, suggests that a transition to recovery was a long process on this latitude. On the central and northern transects, epicorms of similar age indicated a recovery phase was under way. Changes in crown rating (2002 to 2008) against age of epicorms (2008) showed that average negative change decreased towards zero as the age of epicormic growth increased. The positive change for sites with epicorms >5 years (section 5.2.5, Fig. 18), was an indicator that crown health was improving.

6.7. Phenology

Phenology assesses the presence and distribution of new leaves, buds, fruit and flowers in the crown. These components can vary from none in the canopy through to a very dense, even distribution. Increased presence of these components related to improving crown health in both surveys. Despite slower recovery on the southern transect, phenology activity and vigour (particularly increased growth of leaves and buds compared to 2002) suggested that recovery may have started.

Alternatively, this may contradict the above result and indicate there is no strong relationship with phenology and WCD. The presence and vigour of new leaves may indicate improving crown health on the central and northern transects, but there is less bud growth than in 2002. Variability in phenology of wandoo was evident along all transects. This variability was reported earlier by Campbell (1956), Hewett and Underwood (1963) and Mercer (1991). With respect to flowering, Manning (2001) reported that January to February was considered to be the flowering window for wandoo south of Wandering. However, the general status of bud growth on the southern transect suggested flowering was due some months after this time frame. The central transect straddled the summer flowering (January to February) and spring flowering (September to December) windows for wandoo. The northern transect straddled the winter flowering (March to June) and spring flowering (September to December) windows for wandoo. Buds were of similar age across the survey area that may indicate a period of mask flowering for wandoo was approaching but this is speculative. Good flowering was extremely difficult to predict in forest reserves and private remnants (ibid.).

6.8. Comparison of 1991, 2002 and 2008 data at Boyagin, Noombling and Popanyinning

The hypothesis that healthier sites were more resilient to decline has not been supported by 2008 observations showing that Boyagin, classed as healthy in 2002, declined over the past six years. The intermediate and degraded sites, Noombling and Popanyinning, have marginally improved (Figs 29, 30, 31). It was difficult to judge whether the decline would continue or recovery would begin. It may be pertinent to consider that resilience was also indicated by a rapid recovery response. This appeared to be the case, (see below) on the central transect where a previously healthy site recovered quickly from a post 2002 decline event. Alternatively, less healthy sites showed slow recovery from both post 1990 and post 2002 decline events. It remains to be seen what rate of recovery will occur at Boyagin. At Boyagin and Popanyinning, veteran wandoo showed further marginal decline, displaying long term dieback symptoms possibly over 30 years old. One veteran at Popanyinning had further declined with loss of epicorms observed in 1991 but replaced with 3-5 year old epicorms by 2002. In 2008, the crown has not improved and epicorms have appeared on the bole (Fig. 32). Veteran wandoo at Boyagin impacted by a 1968 fire and bark-borers generally showed less leaf density to 2002 but marginal improvement on some trees to 2008.

6.9. General trends along transects and decline patterns

Decline trends identified in 2002 were still apparent in 2008 but less clear as previously healthier wandoo now show decline (see section 5.11). There were still, however, unaffected trees amongst even the severely affected. This was noted by Batini and Manning (2004) and demonstrated the variability noted by Wills et al. (2000), discussed below. This 2008 survey found that average crown ratings (accounting for several trees within quadrats) were also variable with poor sites been recorded in areas of recovery and vise versa. These results appear to reflect those of Whitford et *al*. (2008) where crown assessment over the wandoo geographic range was based on within-site transects. As a comparison, this study and the 2002 and 2008 surveys included a coincidental location at Yilliminning Rock, east of Narrogin. Whitford recorded this site as C3 that has improved (stabilised) from 2006 to 2007. The 2008 survey recorded this site marginally declining from 15 to 14 (Abbott 1992) over six years, but remaining at the C3 stage. Conspicuous trends on the northern, central and southern transects were, respectively: general recovery of most sites (Fig. 33); decline and rapid recovery of previously healthy trees (Fig. 34); and recent decline of previously healthy trees (Fig. 35). The 2008 survey has identified the shift of decline to higher and lower rainfall zones while recovery was occurring within the mid-range isohyets. Also, recovery was most advanced in the north and least advanced in the south (see Maps 1 and 2; section 6.6). Post 2002 WCD has appeared amongst previously healthy trees in some districts and some post 1990 declines have worsened. Alternatively, in other districts, there was general recovery from post 1990 and post 2002 decline events. The 2002 and 2008 surveys supported Wills et *al.* (2000) similarly describing the present decline to be both recent and long term, to be variable and not continuous across the landscape. Although recovery was often evident after a decline event and considered by some authors to be part of a survival mechanism, the cumulative impact on the remaining wandoo population was likely to be more decline across its range with low recruitment taking place (see section 6.5). The incidences of wandoo germination under older declining trees was nowhere near the rates that occurred on ashbeds after fire. Mercer (2003) reported that wandoo regeneration stands less than 30 years old generally remained healthy. Although more young trees were observed with decline in 2008, the symptoms were limited to exposure of branchlets and they still showed resilience when compared to older trees. In other parts of Australia, regrowth stands appear not to suffer from crown decline until they reach at least 30 years of age (Jurskis 2004). Batini (2005) also showed that younger wandoo (DBHOB <30cm) were much healthier than older trees (DBHOB >30cm). With respect to crown defoliations due to heat stress, the 2007 event has shown to be similar to the 1991 event in time of occurrence and symptoms displayed. Terminal foliage generally returned within weeks, there were few incidences of epicormic response, and all wandoo observed have recovered (Peter White, DEC, pers. comm.).

6.9.1. Northern transect

There has been a transition to recovery on the northern transect where the improvement of wandoo health was the most advanced and a more convincing display than recorded elsewhere. West of York, epicormic growth has now occupied the crowns as wandoo seek a stable equilibrium. Similar to the other transects, there was a post 2002 decline event on the eastern extremity of the northern transect, where decreasing crown ratings and younger epicorms were evident.

6.9.2. Central transect

General decline in wandoo crown health occurred shortly after 2002 along this transect. Recovery has occurred, however, at sites between Wickepin and Harrismith previously classed as healthy in 2002. Of interest was the Harrismith Road site among others that showed recovery over less than 6 years. This time frame seems relatively short, when compared to that documented by Wills (2005, 2006) at Wundabiniring from 1999 to 2006, and other recoveries recorded on the northern transect. Whether the previous healthy status (crown rating of 22) was a precursor to a rapid recovery is not known. Ongoing decline and recovery was evident where sites displayed epicorms of similar age to that recorded in 2002, suggesting there had been at least a second flush of growth. Slower epicormic growth at sites, classed as less healthy in 2002, was similar to that occurring on the southern transect (see below). It is noted that destructive fire at the western end (Collie Road) has accentuated the downward trend of crown health in this section.

6.9.3. Southern transect

There was further general decline in wandoo crown health along the southern transect since 2002, although, slow-growing epicorms were beginning to occupy the lower branches of defoliated crowns, indicating at least a phase of stability. If another decline event does not occur in the short term, it is likely that this growth will rebuild the canopy, at a slow rate. The slow recovery may relate to successive disturbances (such as fire and more frequent dry winters) that gradually deplete regenerative bud resources and thus the ability of trees to recover, as illustrated in Croft et al. (2007).

Fig. 29: Boyagin site in 1991 (top), 2002 (centre) and 2008 (bottom). Wandoo canopies remained stable over 11 years at this relatively inaccessible site with no sign of the present decline. 6 years later, decline is evident.

Fig. 30: Noombling site in 1991 (top), 2002 (centre) and 2008 (bottom). Loss of canopy leaf density and defoliation of mainly small branchlets was marginal over 11 years. 6 years later, crown condition has improved.

Fig. 31: Popanyinning site in 1991 (top), 2002 (centre) and 2008 (bottom). There was little structural change over 11 years but active flagging had begun. Legacy of that decline is evident with a recovery phase under way.

Fig. 32: Wandoo veterans at Popanyinning 1991 (top) and 2008 (bottom) displaying gradual decline over 17 years, likely initiated by fire. Note the retention of branches and branchlets in the canopies over this time.

Fig. 33: Decline and recovery over 6 years on Wambyn Road, on the northern transect. The unhealthy crowns (average rating 10, C4) in 2002 (left) displayed few fruit, buds and new leaves and 2-3 year old epicorms. There was a rapid recovery by 2008 (right) with epicorms >6 years old; moderate, even loads of new leaves and buds and; the average crown rating increased to 19 (C2).

Fig. 34: Decline and recovery over 6 years on Harrismith Road, on the eastern central transect. Healthy crowns (average rating 22) in 2002 (left) displayed fruit, buds and new leaves, with old epicorms. Despite the marked increase in exposed branches, the average crown rating in 2008 (right) was 17. There was a rapid recovery with epicorms assuming the canopy within <5 years, underpinning the resilience of this site to a recent decline.

Fig. 35: Decline over 6 years at Noobijup Road, on the western extremity of the southern transect. The crowns in 2002 (left) displayed dense fruit and buds and no epicorms with an average crown rating of 20. This had decreased to 16 with 4-5 year old epicorms present in 2008 (right).

7. CONCLUSION

It appeared that environmental disturbance continued to cause wandoo decline in the south-west but some consistent recovery was evident west of York. High stem density did not appear to relate to water deficits as crown health was uniformly similar over variable density classes. Associated understorey did not have similar or related decline patterns that were significant. Understorey cover marginally decreased as crown ratings increased. Wandoo decline was not related to rainfall deficits in the south-west when comparing 2008 crown health and 2002 to 2008 change in crown health against post 1975 rainfall. Further investigations are warranted that are beyond the scope of this survey.

Several parameters showed similar outcomes for both surveys. As in 2002, foliar insect damage increased as crown health decreased, remained low to moderate but less variable and chewers were predominant. Wandoo crown condition still improved the longer a site was without high intensity fire, possibly implicating intense fire as a disturbance mechanism that may initiate tree decline. Intense fire on the central transect was implicated where a disproportionate number of trees were killed and ashbed regeneration was low. This may be either due to low seed counts or destruction of seed capsules in canopies. Revisiting the southern transect sites, burnt before 2002, showed that recovery was slow after the event and other decline agents may have been active. Similar to 2002, statistical results showed that crown health still improved: from lower to higher position in the landscape; in remnants on road reserves, with National Parks and Nature Reserves less healthy; in sites adjoining bushland with less healthy wandoo inside bushland; and on gradients of 4-6 degrees. Indicators for healthier wandoo were: the presence of epicorms >5 years old, or no epicorms at all; increasing presence of fruit, buds and new leaves; and trees showing minimal or no impact. Trunk and large branch damage from borers increased since 2002 and may pose a greater threat to wandoo if environmental stress continues.

Comparison of data from 3 sites assessed in 1991 and 2002 showed that previous site condition may have predisposed trees to greater impacts from the present WCD. In 2008, the healthy site showed WCD while the intermediate and degraded sites have marginally improved. The trend for native woody species and native grasses and sedges was to display less cover as wandoo crown rating increased, although litter cover increased. Understorey decline was low and showed no correlation with increasing or decreasing wandoo decline. Some cases showing understorey ascendance and some limited wandoo recruitment may be related to where severe WCD has weakened the competition from large trees.

In 2008, the profile of WCD has changed along the transects, displaying east to west and north to south trends. Previously healthy sites showed decline at the extremities of the transects while increasing recovery was evident from south to north. In the 2002 survey, temporal and spatial trends in decline across the survey area were evident and the decline pattern was broadscale, variable and not continuous across the landscape. Canopy loss was both recent and long term. In 2008 this was still evident but with more wandoo affected by a predominantly post 2002 decline in some districts while other districts were recovering. Some areas of post 1990 decline had deteriorated. In 2008 on the southern and central transects, the 400-450 mm and 600-650 mm rainfall zones showed recovery where there was marked crown decline in 2002. However, the eastern and western extremities now exhibited post 2002 decline as did the eastern section on the northern transect. Because there was a shift in the decline pattern, zones of marked crown decline no longer loosely coincided with marked rainfall deficit areas. Apart from new decline recorded in the second survey, recovery was generally good, intermediate and limited on the northern, central and southern transects respectively.

8. REFERENCES

Abbott, I. (1992). Ecological implications of insect pests in jarrah and karri forests. In: Research on the impact of forest management in South-west Western Australia. CALM Occasional Paper No. 2/92, July, 1992. Conservation and Land Management, Como, W.A.

Agriculture Western Australia (2002). Salinity levels for vegetation. Website Agricultural Note.

Archibald R., Bowen B., Hardy G. and McCaw L. (2006). The role of fire in tuart decline at Yalgorup? Tuart decline research findings, Tuart Bulletin No.6. A series outlining key research findings associated with tuart health in south-west Western Australia.

Batini F.E. and Manning E. (2004) Evaluation of crown condition in wandoo, Talbot block, Helena catchment. Report to Wandoo Recovery Group.

Batini, F (2005). A review of possible causes with recommendations for survey, research and management. A Report to the Wandoo Recovery Group.

Beard, I.S. (1990). Plant life in Western Australia, Kangaroo Press, Kenthurst, NSW.

Brooker, M.I.H. and Kleinig, D.A. (1990). Field guide to eucalypts - South-western and Southern Australia. Inkata Press, Melbourne and Sydney.

Brooker, M.I.H and Hopper, S.D. (1991). A taxonomic revision of *Eucalyptus wandoo*, *E. redunca* and allied species (Eucalyptus series Levispermae Maide – Myratceae) in Western Australia. Nuytsia 8 (1): 1 – 189.

Brooker, M.I.H., Slee, A.V., Connors, J.R. and Duffy, S.M. (2002). Euclid – Eucalypts of South-western and Southern Australia (Compact disc user guide). Centre for Plant Biodiversity Research. CSIRO Publishing, Collingwood, Victoria.

Brown, P.H., Albone, P.D. and McDonald, D. (1990 unpubl.). The role of biotic agents in rural tree decline of *Eucalyptus wandoo* Blakely in South-western Australia. Conservation and Land Management, Como, W.A.

Burdon, T.J. and Chilvers, G.A. (1974). Leaf parasites on altitudinal populations of *E. pauciffora*. Aust. J. Bot. 22: 265-69.

Burgess, S.S.O. (2006). Measuring transpiration responses to summer precipitation in a Mediterranean climate: a simple screening tool for identifying plant water-use strategies. Physiologia Plantarum 127: pp 404–412.

Burrows, N., Gardner, G., and Ward, B. (1990). Regeneration of *Eucalyptus wandoo* following fire. Aust. For. 53(4): 248-258.

Campbell, J.B. (1956 unpubl.). A silvicultural note on wandoo. Department of Conservation and Land Management, Western Australia.

Capill, L. G. (I984). Wandoo Woodland Conservation. A proposal for a system of ecological reserves. Campaign to Save Native Forests (W.A.).

Croft P., Hunter, J.T. and Reid, N. (2007). Depletion of regenerative bud resources during cyclic drought: What are the implications for fire management? Journal compilation. Ecological Management and Restoration. Vol. 8. No. 3. pp 187-192.

Curry, S.J. (1981). The association of insects with eucalypt dieback in South-western Australia. In: Eucalypt Dieback in Forests and Woodlands (ed. Old, K.M., Kile, G.A. and Ohmart, C.P.) pp 130-133.

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. Aust. For., 43: 29-35.

Fox, L.R. and Morrow, P.A. (1983). Estimates of damage by herbivorous insects of *Eucalyptus* trees. Aust. J. Ecol. 8: 139-147.

Grimes, R.F. (1978). Crown assessment of natural spotted gum *(E. maculata*) ironbark (E. *fibrosa*, *E. drepanophylla)* forest. Dept. For., Queensland, Technical Paper No. 7.

Harris, A. C. (1955). Regeneration of jarrah (Eucalyptus marginata) : a paper delivered to section K. Australian and New Zealand Association for the Advancement of Science, 31st meeting, Melbourne, 17th- 24th August 1955.

Hatch, A.B. (1960). Ashbed effects in Western Australian forest soils. W.A. For. Dept. Bull. no. 4, pp 2-20.

Hewett, P.N. and Underwood, R.J. (1963 unpubl.). The Wandoo formation. Department of Conservation and Land Management, Woodvale, Western Australia.

Hooper, Ryan J. and Sivasithamparam, K. (2005). Characterization of damage and biotic factors associated with the decline of *Eucalyptus wandoo* in southwest Western Australia. Can. J. For. Res. 35: 2589–2602.

Hopkins, E.R., 1974. Crown dieback in eucalypt forests. In: Marks, G.C., Idczak, R.M. (Eds.), Eucalypt Dieback in Australia. Proceedings of the Lakes Entrance Seminar, 1973, Forests Commission Victoria, pp. 1–16.

Hosmer and Lemeshow (1989). Applied logistic regression. Wiley and Sons, New York.

Hussey, B.M.J. (1999). How to manage your wandoo woodlands. Land for Wildlife, Department of Conservation and Land Management. Optima Press, Western Australia.

Indian Ocean Climate Initiative (2002). Climate variability and change in south west Western Australia. Indian Ocean Climate Initiative Panel, Dept. of Environment, Water and Catchment Protection, East Perth, WA.

Indian Ocean Climate Initiative (2004). How has rainfall changed? The South West. Notes on climate change in Western Australia – No. 2.

Jurskis, V. (2005). Decline of eucalypt forests as a consequence of unnatural fire regimes. *Australian Forestry* Vol. 68 No. 4 pp. 257–262.

Jurskis, V., 2004b. Observations of eucalypt decline in temperate Australian forests and woodlands. 2004 Gottstein Fellowship Report. Gottstein Trust, Melbourne.

Jurskis, V., Turner, J., 2002. Eucalypt dieback in eastern Australia: a simple model. Aust. For. 65 (2), 81–92.

Kimber, P.C. (1981). Eucalypt diebacks in the South-west of Western Australia. In: Eucalypt Dieback in Forests and Woodlands (ed. Old, K.M., Kile, G.A. and Ohmart, C.P.) pp 37-43. CSIRO, Melbourne.

Lamont, B. (1985). Gradient and zonal analysis of understorey suppression by *Eucalyptus wandoo*. Vegetatio, 63: 49-66.

Manning, Rob (2001). Pollen analysis of Eucalypts in Western Australia. A report for the Rural Industries Research and Development Corporation. RIRDC Publ. No. 01/53.

Mercer, J.W. (1991). Decline of *Eucalyptus wandoo* Blakely in the Western Australian wheatbelt area. Honours Thesis. Biological and Environmental Sciences, Murdoch University, Western Australia.

Mercer, J. (2003). Survey of *Eucalyptus wandoo* decline. A report on wandoo decline in the Western Australian wheatbelt on behalf of the Department of Conservation and Land Management. CALM, Western Australia.

Podger, F.D. (1981). Some difficulties in the diagnosis of drought as the cause of dieback in: Eucalypt Dieback in Forests and Woodlands (ed. Old, K.M., Yile, G.A. and Ohmart, C.P.) pp 163-173. CSIRO, Melbourne.

Podger, F.D. (Undated). An unexplained disorder in Wandoo. Conservation and Land Management, Western Australia.

Shearer, BL, Byrne, A, Dillon, M and Buehig, R (1997). Distribution of *Armillaria luteobubalina* and its impact on community diversity and structure in Eucalyptus wandoo woodland in southern Western Australia. Aust. Journ. Bot. Vol. 45, pp 151-165.

Springett, B.P. (1978). On the ecological role of insects in Australian eucalypt forests. Aust. J. Ecol. 3: 129-139.

Underwood, R. (2006). Wandoo Decline: A Forest Manager's Perspective. A paper presented to the Woodland Decline Symposium, Mandurah, Western Australia. November 9th 2006.

Weaver, D. (1997). Average annual rainfall isohyets from data collected from the Bureau of Meteorology Western Australia, and processed from data collected from 1177 rainfall stations from 1877 to 1993. Bureau of Meteorology Western Australia.

White, T.C.R. (1969). An index to measure weather-induced stress of trees associated with outbreaks Of psyllids in Australia. Ecology, 50: 905-909.

Wills, A., Toy, F., Steely, M. and Bur bridge, T. (2000). Crown decline in Wandoo, 1999-2000. Conservation and Land Management, Western Australia.

Wills, A., Steely, M., Toy, F. and Bur bridge, T. (2001). Crown decline in Wandoo, Supplement 2001. Conservation and Land Management, Western Australia.

Wills, A. (2005). Crown decline in Wandoo Observations from Wundabiniring Brook 1999-2005. Unpubl. report. Department of Conservation and Land Management.

Wills, A. (2006). Crown decline in Wandoo Observations from Wundabiniring Brook 1999-2006. Unpubl. report. Department of Conservation and Land Management.

Whitford K.R., Manning E.J., and Wills A.J. (2008). Wandoo Crown Condition 2007. Report of wandoo crown decline surveys.

Withers, J. and Ashton, D.H. (1977). Studies on the status of unburnt *Eucalyptus* woodland. Ocean grove, Victoria. Aust. J. Bot. 25: 623-637.

Wandoo Recovery Group (2005). Surveying wandoo crown decline - A guide for assessors. Wandoo Recovery Group and Department of Conservation and Land management, Kensington, Western Australia.

APPENDIX 1. TABLES

Table 1: Crown assessment method (Abbott, 1992) used for the 2002 and 2008 surveys.

Leaf density (exclude epicormics on bole)	
9	very dense
7	dense
5	average (refers to ideal, not the stand)
3	sparse
1	very sparse
0.5	all leaves dead
0	leaves absent
If much fruit is present, increase the score by 1.	
Incidence of dead branches	
9	none present
8	< 50% of branchlets dead
7	> 50% of branchlets dead
6	< 50% of small branches dead
5	≥ 50% of small branches dead
4	< 50% of large branches dead
3	≥ 50% of large branches dead
2	< 50% of primary branches dead (epicormics present)
1	≥ 50% of primary branches dead (no epicormics)
	all branches dead
Contribution of epicormic branches to foliage	
6	no epicormics present (foliage concentrated at extremities of branch)
5	on crown or bole < 25%
4	on crown or bole > 25-50%
3	on crown or bole > 50%
2	on crown and bole < 50%
1	on crown and bole ≥ 50%
0.5	on crown and bole 100%
0	tree is dead

Table 2: The set of potential predictor variables for crown decline for 2002 and 2008. Variables with a non-ordinal pattern (such as “Land use”) or where it was judged that the response may not be linear such as “Fire history”) were reduced to a set of dummy variables (hence LUSE1-LUSE6, FIRE0-FIRE5 as indicated).

Variable Name	**Description**
Dead	Proportion of trees dead due to present decline (%)
Insect	Insect damage group 0 = None or very little (0 – 5 %) 1 = Low (6 – 10 %) 2 = Moderate (11 – 25 %) 3 = High (26 – 50 %) 4 = Very high (> 50 %)
Chew	Leaf area chewed or missing (%) 0 = None 1 = Low 2 = Moderate 3 = High 4 = Very high
Mine (as above)	Leaf area browned, mined or scarred (%).
Lerp (as above)	Leaf area with lerp builders attached (%)
Woody (as above)	Cover of native woody vegetation (%)
Grass (as above)	Cover of native grass and sedges (%)
Weeds (as above)	Cover of exotic weeds (%)
Litter (as above)	Cover of litter layer (%)
Salt	Soil salinity (mSm^{-1})
Luse 1 – 6	Land use 1 = paddock 2 = parkland cleared 3 = private remnant 4 = road verge 5 = State Forest 6 = National Park or Nature Reserve
Soil 1 – 5	Soil type 1 = Sandy loam or loamy sand 2 = Duplex soil (< 50 cm over clay) 3 = Duplex soil (> 50 cm over clay) 4 = Stony duplex 5 = Shallow over laterite or granite
Position 1 – 5	Position in landscape 1 = Valley floor 2 = Low to mid slope 3 = Mid to higher slope 4 = Ridge 5 = Outcrop
Connect 1 – 4	Connectivity to reserve or remnant, 1 = Isolated 2 = Adjacent or close by 3 = Adjoining 4 = Inside
Density	Tree density /quadrat: (<10, 11-20, 21-30, 31-40, 41-50, >50)
DBHOB	Average tree diameter over bark at breast height (5-10, 11-20, 21-30, 31-40, >40)cm

Variable Name	**Description**
Fire 0 – 5	Fire history 0 = Unknown 1 = < 5 years 2 = 5 – 10 years 3 = 10 – 20 years 4 = 20 – 30 years 5 = > 30 years
Gradient	Slope gradient (degrees)
Slope 1 – 3	Slope type 1 = Uniform Slope type 2 = Convex Slope type 3 = Concave
Aspect 1 - 4	Slope aspect 1 = 0 – 90 degrees Slope aspect 2 = 90 – 180 degrees Slope aspect 3 = 180 – 270 degrees Slope aspect 4 = 270 – 360 degrees
Borer 1 – 3 (2008 only)	Trunk and large branch borers 0 = None 2 = <5 3 = > 5
Understorey decline (2008 only)	0 = 0-5% 1 = 5-10% 2 = 11-25% 3 = 26-50% 4 = >50%

Table 3: Results of separate ANOVAs of crown condition for different categories of the variables listed. Descriptions of variables are in Table 2.

Variable	Significant in 2002	Significant in 2008	Significance regarding change in crown condition
Longitude	0.05		0.001
Latitude		0.1	0.001
Altitude			
Transect location			0.001
Rainfall	0.15		0.05
% dead trees		0.001	0.1
Trees with no/minimal impact	0.05	0.001	
All foliar insect damage	0.05		
Leaves chewed			
Leaves mined			
Leaves skeletonised			
Lerps per leaf	0.05		
Galls per leaf		0.05	
Borers per tree average			
Native woody vegetation cover		0.01	
Native monocot cover			
Weeds cover			
Litter cover			
Understorey decline	n.a.		
Salinity			
Epicorm age	0.05		0.001
Land use	0.05	0.1	
Soils			
Position in the landscape	0.15		
Connectivity to bushland	0.05		0.1
Density of trees/site			0.05
Average DBHOB			
Fire history	0.05		0.05
Gradient	0.05	0.1	
Slope type			

Variable	Significant in 2002	Significant in 2008	Significance regarding change in crown condition
Aspect			
Fruit	0.05		
Buds	0.15	0.01	
New leaves		0.05	
Flowers			

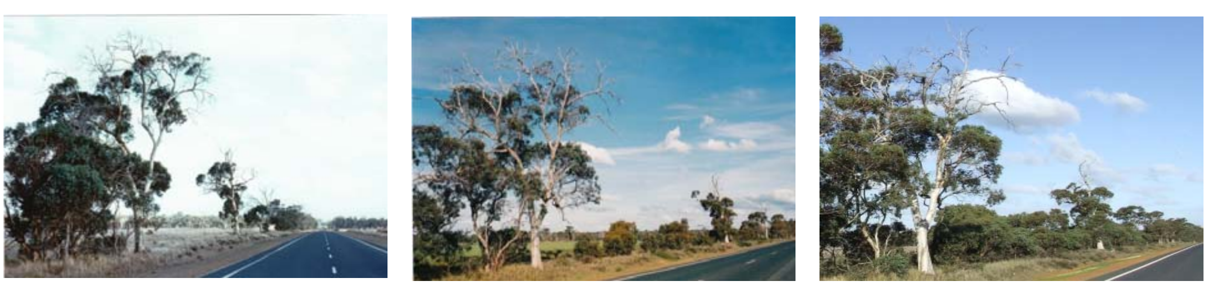
APPENDIX 2: Photographs of wandoo canopy changes over 17 years.


1. Roadside volunteer regeneration, likely from road works about 25 years previous in 2006 (left) and 2008 (right). The new decline is evident in 2008 with some branchlets losing terminal foliage.


2. One of the few cases of noticeable understorey ascendancy over six years from 2002 (left) to 2008 (right), namely of *Allocasuarina huegeliana*, in Trongkup NR on the southern transect.

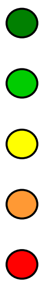

3. Valley floor wandoo affected by salinity and seasonal waterlogging in 2002 (left) and 2008 (right). The dynamics of this site over six years was thinning wandoo crowns and ascending *Melaleuca cuticularis* (Salt water paperbark) thicket.

4. Changes in paddock wandoo over a period 1991 (top), 2002 (centre) and 2008 (bottom) north of Cranbrook. The present decline was not evident in 1991 and probably appeared about 1993-95 in this district.



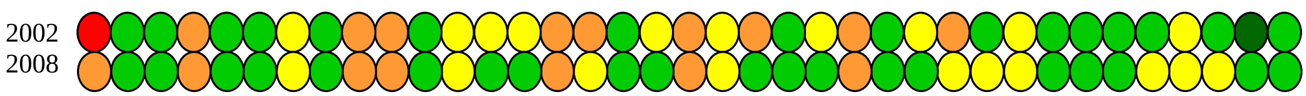
5. Changes in roadside wandoo over a period 1991 (left), 2002 (centre) and 2008 (right) south of Tenderton. In 1991, salinity and/or waterlogging were evident on this flat low landscape and the present decline was not implicated. Contracted canopies have remained relatively stable.

APPENDIX 3: Changes in wandoo crown condition between 2002 and 2008, west to east on the northern, central and southern transects with 37, 41 and 48 sites respectively.

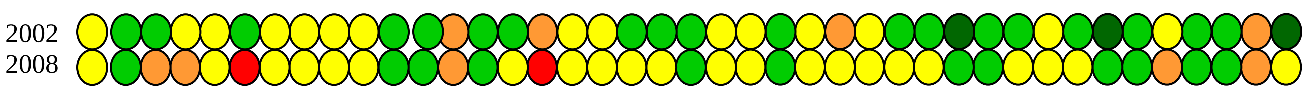


Legend:	Abbott (1992)	WRG (2005)	
	21-24	C1	Healthy crown with terminal foliage intact.
	16-20	C2	Some terminal foliage lost, branchlets exposed.
	11-15	C3	Most terminal foliage lost, small branches exposed, epicormics beginning.
	6-10	C4	All terminal foliage lost, large branches exposed, advanced epicormics.
	1-5	C5	Primary branches exposed, dead crown epicormics, new bole epicormics.
	0	C6	Dead tree

Northern transect– west to east



Central transect– west to east



Southern transect – west to east