Fire and the Wongan Hills:

Determining fire return intervals for vegetation and Critically Endangered flora

A State Natural Resource Management-Funded Project

B. Phillips, B. Beecham, D. Jolliffe & A. Crawford

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Cover photo

View of Mt Rupert from Speaker's Chair in Wongan Hills Nature Reserve (L. Canackle).

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1. Executive Summary

A three year project was undertaken by the Department of Parks and Wildlife from 2011-2015 with funding from State NRM. The project focused on determining tolerable fire return intervals for seven species of Critically Endangered (CR) flora and for the vegetation types of the biodiverse Wongan Hills Ecoscape,[1] with the aim of reconciling the requirements of the CR species with those of the associated vegetation.

The ecological attributes pertaining to each species and vegetation community were used in conjunction with data collected from prescribed burns and senescence monitoring during the project to determine the minimum and maximum fire return intervals for the species and vegetation types.

The results suggest that the seven CR species tolerate broader fire return intervals than their associated vegetation. Therefore the burn planning process should prioritise the requirements of the vegetation communities, thus ensuring the requirements are met for both the CR species and the vegetation communities of the Wongan Hills.

The project resulted in increased plant numbers and population area for at least two Critically Endangered species, in addition to regeneration of senescent habitat for three CR species through the use of prescribed fire.

[1] The boundaries of the Wongan Hills Ecoscape are defined in the Wongan Hills Ecoscape Interim Conservation Plan (2008).

2. Introduction

Many vegetation communities in the Western Australian Wheatbelt contain plant species that could be classified as fire-dependent, particularly in kwongan heaths and shrublands. Parsons & Gosper (2011) highlighted that, on average, fire-return intervals are increasing on smaller wheatbelt reserves, and over the last 30-40 years exceed 100-300 years compared with larger reserves and uncleared landscapes. However, there is insufficient information available to conservation managers in the Wheatbelt about the effects of increasing fire return intervals, or fire exclusion, on the senescence and loss of plant species richness, particularly on populations of serotinous obligate seeders and threatened flora.

The Wongan Hills supports a rich diversity of plant communities, including kwongan heaths and shrublands, and many populations of threatened and priority flora. This remaining vegetation is scattered across a network of conservation reserves, other crown lands and privately owned remnants. Whilst the fire history is not well documented, it appears that many areas of vegetation have not been burnt for at least 60 years. There is also some evidence that populations of common species of banksias and hakeas, as well as some threatened flora species, have failed to regenerate in the absence of fire.

In 2011 the Department of Parks and Wildlife implemented a three year State NRM funded Threatened flora conservation project entitled *'Ecological fire management guidelines to protect and recover critically endangered flora and their associated habitat of the Wongan Hills'*. The project brief below outlines the broad objectives, while table 1 outlines the specific project outcomes.

> "As part of a broader program to develop a fire management plan for the Wongan Hills, this project will develop ecologically-based fire management guidelines to protect and maintain populations of critically endangered flora, and their associated critical habitat, whilst considering the requirements of other threatened flora and the significant vegetation communities of the Wongan Hills.
> The project will focus on identifying the fire responses of seven Critically Endangered flora species (*Acacia pharangites, A. vassalli, Daviesia euphorbioides, Gastrolobium glaucum, G. hamulosum, Lysiosepalum abollatum, Verticordia staminosa* subsp. *staminosa*), and use the vital attributes approach to determine appropriate fire intervals for these species and their associated critical habitat. Suitable fire intervals will also be calculated for other Threatened and Priority flora and the vegetation communities of the "Plant Assemblages of the Wongan Hills System" Priority Ecological Community. This will ensure that the requirements of all key species and communities are considered, and that fire regimes do not favour some species at the expense of others. This information will be used to define suitable fire regimes across the Wongan Hills that maintain the diversity of species and vegetation communities. The project will spatially identify areas with similar fire requirements and group these into logical units for fire management purposes (Beecham and Jolliffe 2012)."

Table 1. Project outcomes from Wongan Hills State NRM grant application.

OUTCOME NUMBER	OUTCOMES	MILESTONE NUMBER
1.	Develop an Ecological Fire Management Guideline for Wongan Hills that defines appropriate fire regimes to maintain and enhance the area's unique biodiversity, including the requirements	1, 6

	of the seven Critically Endangered flora and their critical habitat (*Acacia pharangites, A. vassalli, Daviesia euphorbioides, Gastrolobium glaucum, G. hamulosum, Lysiosepalum abollatum, Verticordia staminosa* subsp. *staminosa*)	
2.	Develop an understanding of the fire regime requirements of seven Critically Endangered flora species and their critical habitat to improve their conservation status (*Acacia pharangites, A. vassalli, Daviesia euphorbioides, Gastrolobium glaucum, G. hamulosum, Lysiosepalum abollatum, Verticordia staminosa* subsp. *staminosa*)	2, 3, 4, 5

This report seeks to define the likely minimum (MinFRI) and maximum fire return intervals (MaxFRI) required to maintain or enhance biodiversity in fire-dependent vegetation communities of Wongan Hills, taking in to account the specific requirements of the seven Critically Endangered species of Threatened flora (Table 1, Outcome 1). The conservation outcomes for the CR species have also been documented following the application of prescribed fire in CR habitat to promote recruitment. These outcomes have been used in conjunction with data from other sources to inform their optimal fire regimes (Outcome 2).

3. Materials and Methods

To determine optimal fire regimes in the Wongan Hills landscape, the MinFRI and MaxFRI were determined for the Critically Endangered species as well as the common species most at risk of local extinction in fire prone vegetation communities. The ecological attributes of these species were used to define these intervals.

For the purpose of the project, the minimum fire return interval for Critically Endangered species was defined as twice the primary juvenile period, where 'most' (>50%) plants had some flowers (Shedley 2011). The justification was based on ensuring sufficient time for either a soil seed bank to accumulate for obligate seeders or for underground storage organs to establish sufficient starch reserves in resprouters. In some cases this has been adjusted to account for short-lived species. All species in the project are obligate seeders with a soil seed bank with the exception of *Gastrolobium glaucum*, which is also a re-sprouter (Willers 2002).

The MaxFRI for any Western Australian threatened flora has rarely been determined due to inadequate knowledge of the longevity of the soil seed banks (Shedley 2011). The results of the various components of this project have been used to generate conservative estimates of the longevity of soil seed bank for the seven CR species, from which broad maximum intervals have been derived. Generally the MaxFRI has been estimated as the likely longevity of the plant plus the minimum known or estimated longevity of the soil seed bank.

The minimum fire return interval for a vegetation community has been defined previously as the time since the last fire at which either greater than 50% of the slowest maturing serotinous species are bearing fruit or when mean fruit crop size reaches 25% of the maximum for that species (Gosper et al. 2013).

In Wongan Hills, most fuel ages[2] are generally between 40-60 years or over 60 years. Due to the lack of young to medium age fuel, the minimum fire return interval could not be determined using either measure. Minimum fire intervals have therefore been set at twice the likely juvenile period for the serotinous obligate seeder species occurring in the vegetation type. Likely juvenile periods were estimated based on observations from the few recently burnt sites and knowledge of other species in the genus of the serotinous 'indicator species'.

The MaxFRI for vegetation communities were determined using a number of measures, including greater than 25% mortality of vegetation (Gosper et al. 2013), greater than 25% mortality of indicator species (Gosper et al. 2013), and a parent to seedling ratio less than or equal to four (Bond 1989). Each vegetation community was assessed by undertaking senescence transects to determine mortality levels and potential parent to seedling ratios.

To determine the MinFRI and MaxFRI, the project design included a number of components:

1. Monitoring known populations of the seven CR species to obtain accurate and current population data and to identify species requiring active fire management. Monitoring was undertaken for populations occurring within the boundaries of the Wongan Hills Ecoscape. Sixteen populations, including a number of subpopulations, were monitored. For each population the number and location of mature plants, juveniles and seedlings[3] were recorded

[2] Vegetation age has been referred to as 'fuel age' throughout the document.
[3] Evidence of flowering or fruiting indicated maturity, while seedlings had developed cotyledons only and juveniles had developed juvenile or mature foliage but had not flowered or fruited.

along with habitat details and potential threats. Some populations were assigned new population numbers (see Appendix 1) at this stage and will be referred to by the new numbers throughout the report. All data was recorded using Threatened and Priority Flora Report Forms and was entered in to the department's Threatened and Priority Flora Database.

2. A literature review, involving the collation and review of past monitoring data and species information for the seven Critically Endangered species. The aim of the review was to summarise the ecological attributes for each species and identify knowledge gaps. Similar information was also sought for each indicator species identified as part of the senescence transects outlined in point '6' below.

3. Wongan Hills fire history data were collated from a number of sources, including vegetation survey reports (Coates 1992), historic newspaper articles, Department of Parks and Wildlife corporate data, Department of Fire and Emergency Services corporate data, VegMachine™ analysis of vegetation loss[4] and oral histories from long term residents of Wongan Hills. This information was collated and presented in the form of a fire history map and used as the basis for determining MinFRIs and MaxFRIs over the course of the project.

4. Prescribed burns were undertaken at three locations in senescent habitat supporting CR species with the aim of promoting regeneration of these species and their associated habitat. Monitoring plots and/or transects were installed to assess the response of the CR species to fire and record their population dynamics over time.

   The prescribed burns included:

   Daviesia euphorbioides population 2BC: CWB_009

   Daviesia euphorbioides population 2BC was burnt through the application of prescribed fire on 29/5/2014. The burn was located in the south of Nature Reserve 51093 and was bounded by the rail line to the south, access tracks to the west and east and an open edge to the north. Scrub rolling was undertaken to a width of 30 m for a distance of 0.7 km along the southern burn boundary, to encourage the burn to carry through the standing vegetation. A flamethrower was used to introduce a continuous line of fire along the scrub rolled southern boundary. The planned burn area was a total of 28.3 ha and did not support any CR plants prior to the burn. The burn was implemented under the following conditions (Department of Parks and Wildlife 2015a):

   Time: 12:30
   Cloud cover: 1/8
   Temperature: 24.1 °C
   RH: 53.2%
   Wind direction: WSW
   Wind speed: 4 km/h, gusting to 7 km/h
   Flame height: 2.5-3 m (scrub rolled area)
   Flame length: 2-3 m (scrub rolled area)
   ROS: 200 m/h (scrub rolled area)

   Two subpopulations (4B and 4C) of *Conostylis wonganensis* (EN) were recorded within the burn area in 2000, however no plants were located during an extensive pre-burn survey

[4] Analysis of the following time intervals: 1990-2012, 1990-2000, 2000-2012, 2006-2012.

targeting this species. A post-burn survey during the flowering period for this species was also undertaken.

Three temperature loggers (DS1922T ibuttons®) were buried to a depth of 1 cm within the burn area to determine the temperature experienced by the seed bank. Six 100 m x 2 m transects were established in the burn area to monitor recruitment post-burn in spring 2014. The start and end coordinates were recorded for each transect and were marked in the field using steel fence droppers. Plants were counted and coordinates recorded for each individual. These transects were re-assessed in winter 2015 and a population boundary was also captured. The number of plants recorded within transects was extrapolated across the total area of the population to give an estimate of the total number of plants.

<u>*Gastrolobium hamulosum* populations 7 and 8: CWB_008</u>

Gastrolobium hamulosum populations 7 and 8 were planned to be burnt under prescribed conditions as part of a 51.7 ha burn (CWB_008) in autumn 2014. The burn area was located in the north of Nature Reserve 51093, bounded by an access track to the north and west, Craig Rd to the east and a saline creek system to the south. Scrub rolling was undertaken along the northern boundary of the burn to a width of 30 m, for a distance of 1.7 km. However, conditions were not suitable to undertake the burn in 2014 due to a short autumn burning season. Monitoring was undertaken at the site in spring 2014 and juvenile plants were located in populations 7 and 8. The plants were found in the track marks of the machine that performed the scrub rolling. It is assumed that soil movement by the machine's tracks scarified the seed coat of some seeds, overcoming the physical dormancy of the seed and resulting in the germination event.

In March 2015, four lines of scrub rolling were also undertaken perpendicular to the original scrub rolling. Two lines approximately 30 m apart were rolled to a width of 2 m for 150 – 200 m at population 7 and the same pattern was applied at population 8. It was hoped that this pattern of scrub rolling would increase the penetration of the burn in to the standing vegetation, increasing the potential area for *Gastrolobium hamulosum* to germinate.

In April 2015, soil seed bank sampling was undertaken at the two *Gastrolobium hamulosum* sites prior to prescribed burning. The aim of sampling was to determine if viable seed could be found in the soil seed bank. It was hoped that the presence or absence of a soil seed bank could explain germination results post-burn. At each population, ten soil samples were taken, resulting in a total of 20 soil samples for the burn area. Each sample was taken from a square 15 cm x 15 cm x 2 cm deep. Samples were all taken either adjacent to a living seedling (the result of germination post scrub rolling) or adjacent to a seedling that germinated and disappeared over the summer months.

Prior to examining the soil samples, a small sample of *Gastrolobium hamulosum* collected from the Wongan Hills area and stored at the Department of Parks and Wildlife's Threatened Flora Seed Centre was examined to determine the size of the seed. The seed was then germinated and grown on, so that seedling appearance could be compared to those obtained from soil seed bank seed. *G. hamulosum* seed were 2 - 3 mm in length and 1.5 - 2 mm in width.

Soil samples were weighed then passed through two sieves. A top sieve of 2.8 mm was used to remove gravel and large pieces of organic matter whilst a bottom sieve of 1 mm was used to remove soil particles smaller than the *Gastrolobium* seed. The remaining soil fraction was examined under a microscope, with any seed which appeared to be *Gastrolobium* counted. The viability of *Gastrolobium* seed obtained was estimated using a germination test. As *Gastrolobium* have physical dormancy the seed coats were nicked. This not only overcame the physical dormancy but allowed the seed fill to be assessed. Nicked seed were placed into 60 mm plastic Petri dishes containing 7.5 gL^{-1} agar, then germinated in a growth room at 15°C with a 12 h photoperiod. Seed were classed as germinated when radicle emergence of at least 2mm was seen. Germinants were transferred to soil and grown on in a nursery so that the identity of seedlings could be confirmed as *G. hamulosum*.

The prescribed burn was implemented on the 22nd April 2015. Immediately prior to ignition, open ended drums were positioned over each remaining juvenile and water was applied to protect them. Fire was introduced using a flamethrower in a continuous line along the northern boundary. The burn was implemented under the following conditions:

Time: 11:24
Cloud cover: 1/8
Temperature: 22.5 °C
RH: 44.7%
Wind direction: NE
Wind speed: 18 km/h
Flame height: 1 m
Flame length: 1-2 m
ROS: 50 m/h (Department of Parks and Wildlife 2015a)

The results from the soil seed bank were extrapolated across the area in which germination occurred post-burn to give an estimate of the size of the soil seed bank.

Post-burn monitoring was undertaken using stratified random sampling. The area of each population was divided in to a grid based on the location of evenly spaced steel star pickets along the kangaroo exclusion fence (installed post-burn). Each cell of the grid was numbered according to the number of pickets it was away from the NW strainer post. In the case of population 7 which is a larger fenced area, the area was divided in half and the numbering system was repeated in each half. A random number generator was used to generate two numbers that indicated the cell in which the quadrat would be located. A 1 x 1m quadrat was then randomly placed within the larger cell. The numbers of seedlings were recorded in twenty-six 1 x 1 m plots and fifteen 1 x 1 m plots in populations 7 and 8 respectively. A population boundary was then recorded for each and the results were extrapolated across the area of the population in each case.

Acacia pharangites subpopulation 1D: Burn undertaken by landholder

In autumn 2015 Duncan Holme, a local landholder, proposed to undertake a prescribed burn on his property (Lot 3, Plan 40776), commonly known as Mt O'Brien. The burn was bounded by a powerline access track and the access road to the Mt O'Brien tower and consisted of 21.7 ha. Mr Holme proposed the burn to reduce the fuel load in the area and to investigate the impact of fire on the threatened species that occur at this location. A subpopulation of CR *A. pharangites*, consisting of a single plant, occurred within the proposed burn area. A permit was issued for incidental taking of this plant and other threatened and priority species occurring in the burn area, including *Microcorys eremophiloides* T(VU) (population 4AC), *Grevillea kenneallyi* P2 (population 3) and *Acacia semicircinalis* P4 (populations 4 and 5).

To investigate the impact of fire on *A. pharangites*, a seed burial trial was established in the burn area. Seed for the trial was sourced from the Department's Threatened Flora Seed Centre and consisted of seed from a single plant collected from the same population in 2012. The viability of the seed was not tested but a visual examination suggested the seed was likely to be viable. A rectangular area of approximately 0.7 ha surrounding the sole plant was designated as the study area, in which 12 seed plots were installed. Numbered metal fence droppers marked each site and leaf litter was removed from each plot site. A sheet of perspex drilled with 16 holes in a 4x4 grid pattern with spacings of 10 cm, was fixed in place using metal pegs at three of the four corners. In each hole, an *A. pharangites* seed was buried to a depth of 1 cm. The perspex template was then removed and the leaf litter replaced.

When undertaking senescence transects in this vegetation prior to the burn (outlined in point 7 below), the density of *Microcorys eremophiloides* was calculated using the point centre quarter method (Cottam & Curtis 1956). While not a target species in this project, documenting the fire response of this Vulnerable species is also important.

The area surrounding the single plant was raked and surrounding vegetation was hand pruned in an attempt to exclude the plant from fire. On the day of the burn, nine temperature loggers (DS1922T ibuttons®) were buried adjacent to randomly selected grids and one was buried adjacent to the mature *A. pharangites* plant. The burn was undertaken in the late afternoon on 11/5/2015 and from approx. 13:00 on 12/5/2015. Conditions were recorded during the burn on 11/5 and the morning prior to the burn on 12/5 (Table 2).

Table 2. Weather observations from Mt O'brien (Wongan Hills) prescribed burn targeting *Acacia pharangites*.

Date	Time	Wind direction	Wind speed	Temperature	RH	DP	Comments
11/05/2015	15:30	E	5.6; gusts to 14	23.3	36.7	7.6	This was taken from S side near Acacia pharangites. Duncan commenced edging N boundary - near infrastructure and along powerline shortly after this reading but wind would be stronger due to increased elevation where burning. Backburning approx. 4m /hr.
11/05/2015	17:06	E/SE	3.8	21	44		Southern boundary edged. Fire behaviour dying down.
11/05/2015	17:30	SE	4 to 7	19.7	47.8		Low fire behaviour, Duncan lights seed plots individually. Occasional mallees go up through the crowns, otherwise trickling around on the ground, approx. 10/hr with the wind. Ibuttons retrieved between 17:50 and 18:20, some plots hadn't been impacted yet.
12/05/2015	9:20	ESE	11.5; gusts to16	16.6	68.2		Burn mostly out. Duncan plans to strip out middle of burn @13:00 today, using the stronger winds and heat of day. Edging is complete and seed plots impacted so BP departs. Burn is likely to impact further Microcorys eremophiloides.

In spring 2015 each seed plot was caged with rabbit netting to prevent grazing of seedlings. Each plot was then examined for the presence of *A. pharangites* germinants. The number of plants in each plot was recorded and the survival rate calculated. A less intensive survey of the entire burn area was conducted to locate any *A. pharangites* seedlings that had emerged.

5. Seed was collected from the seven CR species with the aim of using it to conduct soil seed bank dynamics experiments. In most cases the quantities collected were not large enough to warrant use and were instead stored at the Threatened Flora Seed Centre for the purpose of conservation or future translocations.

6. Seed viability testing of species similar to the seven CR species was undertaken for old seed collections to indicate potential longevity of the soil seed bank.

A collection of seed dating back to the early 1920s was used to determine the potential longevity of seed from the Fabaceae, predominantly *Acacia,* but including *Gastrolobium* and *Daviesia*. The seed, thought to have been put together as a seed reference collection, was originally housed in the Western Australian Herbarium but was later moved into a transportable building with no temperature control in the mid to late 1990s. The temperature inside this building likely exceeded the ambient temperature during summer. In 2011 the collection was moved into the new herbarium building where it was housed in an air conditioned office in the Threatened Flora Seed Centre. These seed had been stored in glass vials with push in plastic lids. Measurement of the moisture content of seed from inside the vials upon opening indicated the vials were not moisture proof and the seed inside would have been exposed to ambient moisture levels. The collections chosen for testing were mainly species occurring in the Wongan Hills area, but included samples of the oldest Fabaceae seed in the collection. Many of the seed collections had information linking the seed to a herbarium specimen in the Western Australian Herbarium enabling the current name to be applied to the collection. Only seed with a collection date was tested, with seed age being the difference between the collection date and the date of the start of the germination test. For collections where only the month of collection was available the middle of the month (15^{th}) was used for the age calculation. Where only a year of collection was given, a mid-December date was used as an estimate of collection date.

Seed germination was used to estimate the viability of these collections. For all collections the seed coat was nicked using a scalpel to overcome physical dormancy, as well as to check seed fill. Only filled seed were used in germination tests. Samples of up to 100 seed depending upon seed availability were placed into 60 mm plastic Petri dishes containing 7.5 gL^{-1} agar, then germinated in a growth room at 15°C with a 12 h photoperiod. Seed were classed as germinated when radicle emergence of at least 2 mm was seen.

7. Transects were monitored in various vegetation communities to determine levels of senescence and inform maximum fire interval calculations for the project. Areas were targeted if they were well-represented communities in Wongan Hills, associated with a CR species and were represented in multiple fuel age classes. A description of each vegetation type included in the senescence transect monitoring can be found in Appendix 4.

Transects were situated at least 50 m from an access track, running perpendicular to the track if possible for a distance of 100 m (Brooks & Carley 2013). Serotinous, non-resprouter species were selected as indicator species while on site, to ensure they were present at sufficient densities throughout the vegetation type (Brooks & Carley 2013). Serotiny and the inability to resprout (non-resprouting, serotinous obligate seeders) are characteristics of species in the community most sensitive to long inter-fire periods (Gosper et al. 2010). Therefore indicator species were selected on this basis to enable a maximum fire interval to be determined.

A 100 m tape was extended along the length of each transect, GPS coordinates were recorded for the start and end points and a photo was taken from the start point along the length of the transect (Brooks & Carley 2013).

Rapid assessment of senescence

At 1 m intervals along the length of each transect a measure of general vegetation senescence was recorded. A 25 mm diameter PVC pole, 2 m in length was placed vertically, immediately adjacent to the metre mark on the tape and the plant senescence category was recorded (Brooks & Carley 2013). The categories were:

Bare ground (B), recorded where the pole did not contact any perennial vegetation rooted in to the ground.
A live plant (L), recorded where the pole touched any perennial, live plant.
A standing dead plant (SD), recorded when the pole touched a dead plant still rooted in the ground with no living parts (Brooks & Carley 2013).
A dead part of a living plant (L/D), recorded when the pole touched a dead branch that was greater than or equal to 30% of a living plant, or when it touched both a living plant and standing dead plant. This was a slight modification to the method used by Brooks and Carley(2013), as we were interested in the ongoing process of senescence within the community, not just the presence of live and dead plants.

Intensive assessment of senescence

We used a point-centered quarter method (Mitchell 2007) to estimate the population density of the indicator species to compare pre-and-post fire mortality and regeneration with seed crop and population density. At 25 m intervals along each transect, an imaginary line was drawn perpendicular to the transect to divide the area into four quadrants. Within each quadrant the distance from the centre to the nearest living plant of each indicator species was recorded. If no plants were present within a 12.5 m radius, a zero value was recorded. The number of clearly identifiable dead indicator plants (rooted in the quadrant) between the centre and the first living plant was also recorded. Each live plant was recorded as 'mature' or 'juvenile', and in the case of dioecious species, 'male' (Brooks & Carley 2013). For each live plant, the number of closed and open fruit or infructescences were recorded, either by counting all fruit on the plant or by counting the fruit on a branch and multiplying it by the number of equivalent fruit-bearing branches. For one or occasionally two plants for each species per transect, all fruit, or the portion counted, were removed from each plant and sent to the Threatened Flora Seed Centre for seed quantification and viability testing.

Following transportation to the Threatened Flora Seed Centre, fruit were held in a dehumidifying room (15% relative humidity at 15°C) until seed were extracted and germinated. Most *Hakea* fruit opened after collection and seed were removed by hand. For those that did not open the follicle halves were prised apart to extract the seed. *Banksia* fruit (follicles) were collected as infructescences from which the follicles were extracted by hand. Seed was extracted by cutting the edge of the follicle with secateurs so that the follicle could be opened to remove the seed without damage. *Petrophile* fruit (nuts) were collected as cones. The cones were manually pulled apart to extract the nuts. The edge of the nuts was nicked to visually determine whether they contained a seed.

Seed of *Banksia* and *Hakea* were placed into 90 mm plastic Petri dishes containing 7.5 gL^{-1} agar, whilst nicked *Petrophile* nuts were soaked in 10% Plant Preservative Mixture (PPM^{TM}) for 15 min then placed into 90 mm plastic Petri dishes containing 7.5 gL^{-1} agar plus 100 mgL^{-1} gibberellic acid. All seed was then germinated in a growth room at 15°C with a 12 h photoperiod. Seed were classed as germinated when radicle emergence of at least 2 mm was seen.

Senescence transect data analysis

The results from the rapid and intensive assessments of mortality were analysed using linear regression to determine if one measure could be used as a surrogate for the other. However,

no relationship was found and therefore determination of MaxFRI for each community was made using multiple measures of senescence.
The data from the rapid assessment of senescence was collated and any transect where more than 25% of the data points were determined to be 'D' or 'L/D' was deemed to be senescent and to have to have exceeded their MaxFRI (Gosper et al. 2013). MaxFRIs for vegetation types were also determined using indicator species mortality (part of the 'intensive' assessment of senescence) to assign each species to a category of risk of non-persistence in that vegetation type. Risk categories were based on those used by Gosper et al. (2013). Where at least one species was at either 'moderate' or 'high' risk of failing to persist in the landscape, that vegetation type was determined to have exceeded its MaxFRI.

The quantification and viability testing of the seed collected from indicator species in each transect enabled MaxFRIs to be determined by a third measure; the likelihood of persistence of the species by comparing likely parent to seedling ratios with the minimum parent to seedling ratio required for persistence of serotinous obligate seeders at a site (Bond 1989, p.2). The results of the quantification of seed from the sampled fruit and infructescences were applied to all fruit count data and the mean number of seed per plant was calculated for each indicator species in each transect. The viability for each sample was then used as a multiplier to determine the mean number of viable seed per plant. Modelling by Bond (1989) in South African fynbos for a suite of proteaceous species suggests there is a high chance of local extinction of a species if the parent to seedling ratio is less than 1:4 (Bond 1989). An assumption was made that the mean number of viable seed per plant was a reliable indicator of parent to seedling ratio. If the mean number of viable seed per plant was less than 4, that transect was considered to have exceeded its MaxFRI. However these estimates of seedling to parent ratios are based on very limited available data and are indicative only. For example, modelling by Enright *et al* (1996) showed that up to 200 viable seeds were required for self-replacement in a population of *Banksia hookeriana* on the northern sandplains if rainfall during the summer following fire was well below average. The ongoing monitoring of indicator species in the Wongan Hills will be used to help address this lack of data.

If a transect was deemed to have exceeded its MaxFRI by one or more of the measures outlined above, that vegetation type was determined to be currently requiring fire or to have required fire prior to sampling to retain all species in the community. This information was then cross referenced with the optimal fire regimes for any of the seven CR species that occur in these vegetation types to determine whether burning is recommended for each community.

These site specific results were applied to all occurrences of that vegetation community likely to have a similar fuel age. A map was then produced to delineate areas that can be targeted for prescribed burning in the near future.

Additionally, estimates of time since fire based on the known fire history of the Wongan Hills were verified by adding the Wongan Hills data to a model developed by Gosper et al. (2013), showing the relationship between the proportion of standing dead vegetation (rapid assessment) and fuel age. Brooks and Carley (2013) added to the original data with their senescence transect work in the Parks and Wildlife Great Southern District. The Wongan data were added to both datasets to determine the potential accuracy of the estimated fuel ages for the Wongan Hills, as well as the efficacy of the model itself.

Project data was stored on the Parks and Wildlife Central Wheatbelt District Northam Shared Drive, as well as on the Department's Threatened and Priority Flora and the Electronic Prescribed Fire Plan databases.

4. Results & Discussion

4.1 Fire history

The fire history of the Wongan Hills is presented in figure 1. Information is not available for the majority of the Wongan Hills and therefore all areas without a recorded fire are assumed to be unburnt for at least 69 years, as the earliest significant fire for which information is available occurred in either 1943 (Mr D Holme 2015, pers. comm., 16 March) or 1946 (Mr I Smith 2015, pers. comm., 16 January). Prior to this there is anecdotal evidence of pastoralists "firing the scrubs from time to time in the summer season so as to obtain a growth of sweet "feed" for stock after the first autumn rains - a practice much in vogue in Western Australia (Milligan 1903)." However, it is unclear how much, if any of this landscape was impacted and the frequency with which areas experienced repeated burning. Evidence of the 1943/1946 fire came from oral history from a local resident Ian Smith, who was a boy at the time. He indicated that the whole of the Wongan Hills Nature Reserve (Mt Matilda) burnt at this time (Mr I Smith 2015, pers. comm., 16 January).

Valley areas of the private property south of Mt Matilda and Fowler's Gully Nature Reserve were cleared, burnt and cropped in 1946, then allowed to regenerate a year or two later (Mr D Holme 2015, pers. comm., 16 March).

Steam engines were used in the Wongan Hills from 1911 to 1955, at which point they were replaced by diesel engines (State Heritage Council of WA – Places Database 2013). Fires and prescribed burning in the rail reserve are likely to have been common during the steam engine era, however specific details are not available and therefore potential fire history has not been included on the map. This potential history is worth noting, particularly for CR species occurring along the rail line and when making assumptions regarding fuel age in the fire prone vegetation types included in the project.

In the 1960s there was a small fire on the crest of a hill in the Mt Rupert area (vegetated private property north of Mt Matilda). This information was provided by the Flora Conservation Officer in the 1990s, through his liaison with the former landholders of this property (Mr M Fitzgerald 2015, pers. comm, 2 October).

In the 1970s a fire impacted the northern boundary of Water Reserve 16418 (Coates 1993) and another impacted farming land and possibly some freehold vegetation to the east of the water reserve (Mr I Smith 2015, pers. comm 16 January). Aerial imagery from the 1970s or 1980s showed evidence of a fire having impacted the northern boundary of Water Reserve 16418 in the 1960s or 70s (Mr M Fitzgerald 2015, pers. comm, 2 October). This is likely to be the same as that reported by Coates as the 1970s fire, however it has been added to the map due to the differences in the burn boundary mapped by Coates and that suggested by Mike Fitzgerald.

From 1950 to 1985, the landholder burnt small buffers of vegetation immediately east of Wongan Hills Nature Reserve every three years (Mr D Holme 2015, pers. comm, 16 March).

In 1994 a small fire occurred in Fowlers Gully Nature Reserve as a result of farm machinery use in the adjacent paddock (Mr I Smith 2015, pers. comm, 4 May).

Fires potentially occurred in small areas of townsite vegetation on the corner of Quinlan and Ellis St in 2002 (Collins 2007), and in 2010 at the corner of Airport and Wandoo Rds (Mr I Smith 2015, pers. comm, 16 January). A fire also occurred on the eastern side of the Northam-Pithara Rd where it intersects the Waddington-Wongan Hills Rd in 2011 (Department of Fire and Emergency Services Operational Information Systems Branch 2015, pers. comm, 2 January). A prescribed burn was attempted by the Bushfire Brigades in 2013 at the corner of Johnson and Wilding St which only burnt fringing vegetation. Many of these burns and fires are too small to see on the fire history map but are available as a GIS shapefile on the Parks and Wildlife Northam Shared drive.

Small scale *Daviesia euphorbioides* recruitment burns were also undertaken by Parks and Wildlife in 2013 in rail reserve immediately south of Nature Reserve 51093 (Department of Parks and Wildlife 2014).

The burns in 2014 and 2015 undertaken as part of this project have also been included on the fire history map in figure 1.

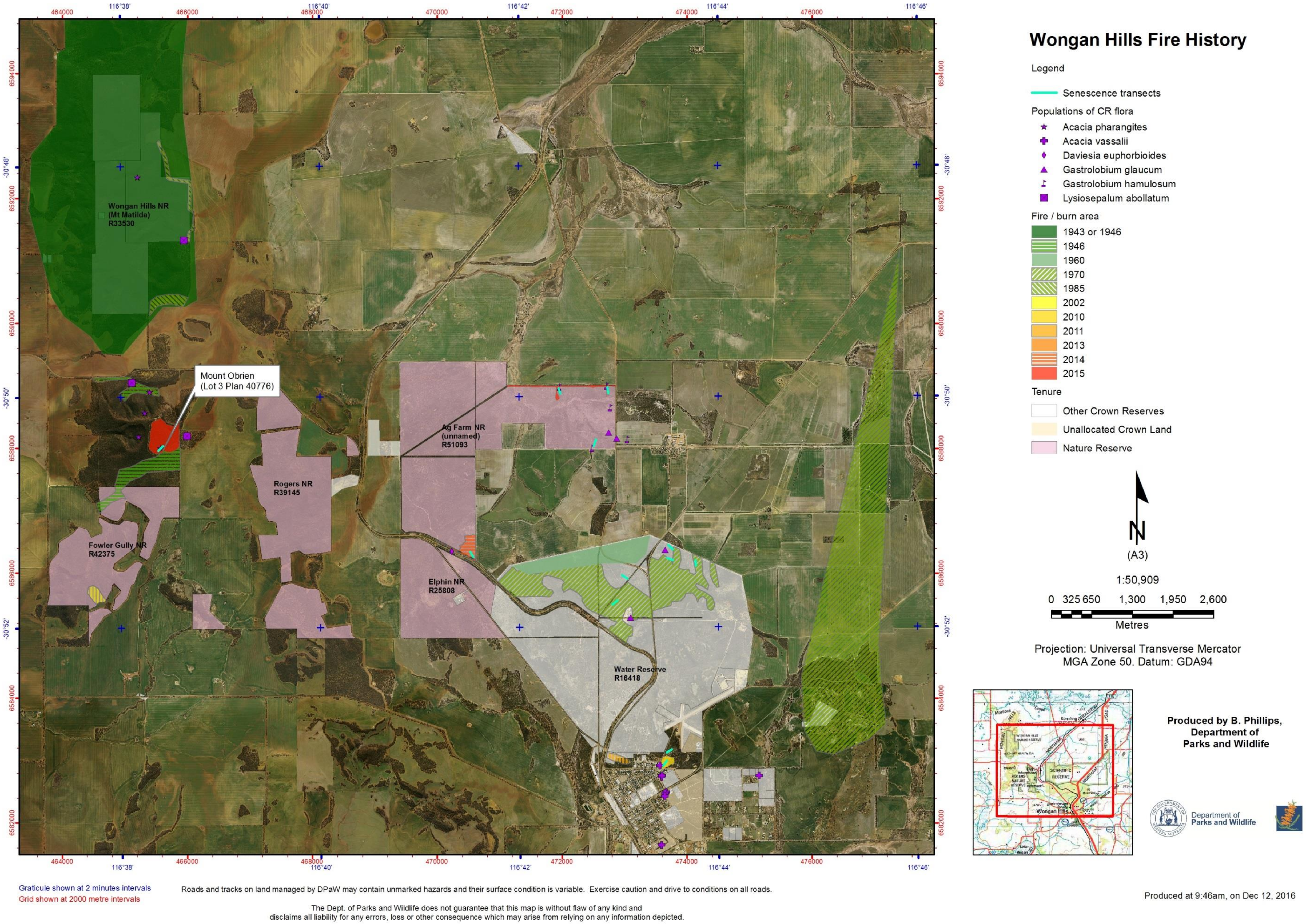

Figure 1. Fire history of the Wongan Hills.

Results from the senescence transects were used to verify the fire history in some areas. The Wongan data was fitted to a model that used the proportion of standing dead as a predictor of fuel age from Gosper et al. (2013) and Brooks and Carley (2013).

The fit of the data to the model shows the collated fire history to be largely accurate, particularly if the Ks vegetation type is excluded from the data. The fit of the model (R^2=0.37) was weaker than for Gosper's original data (R^2=0.44) and for Gosper and Brooks' combined data sets (R^2=0.38). However, exclusion of the sedgeland community (Ks) improved the fit (R^2=0.4). The proportion of standing dead vegetation best predicted fuel age in the vicinity of 20-40 years old and was less reliable in predicting particularly young or old fuels (Figure 2).

The fit of the Wongan data to the model suggests the fire history collated for this project is broadly accurate, although the breadth of the confidence intervals also suggests that the estimates of fuel age in this project should not be used in isolation to determine fire regimes.

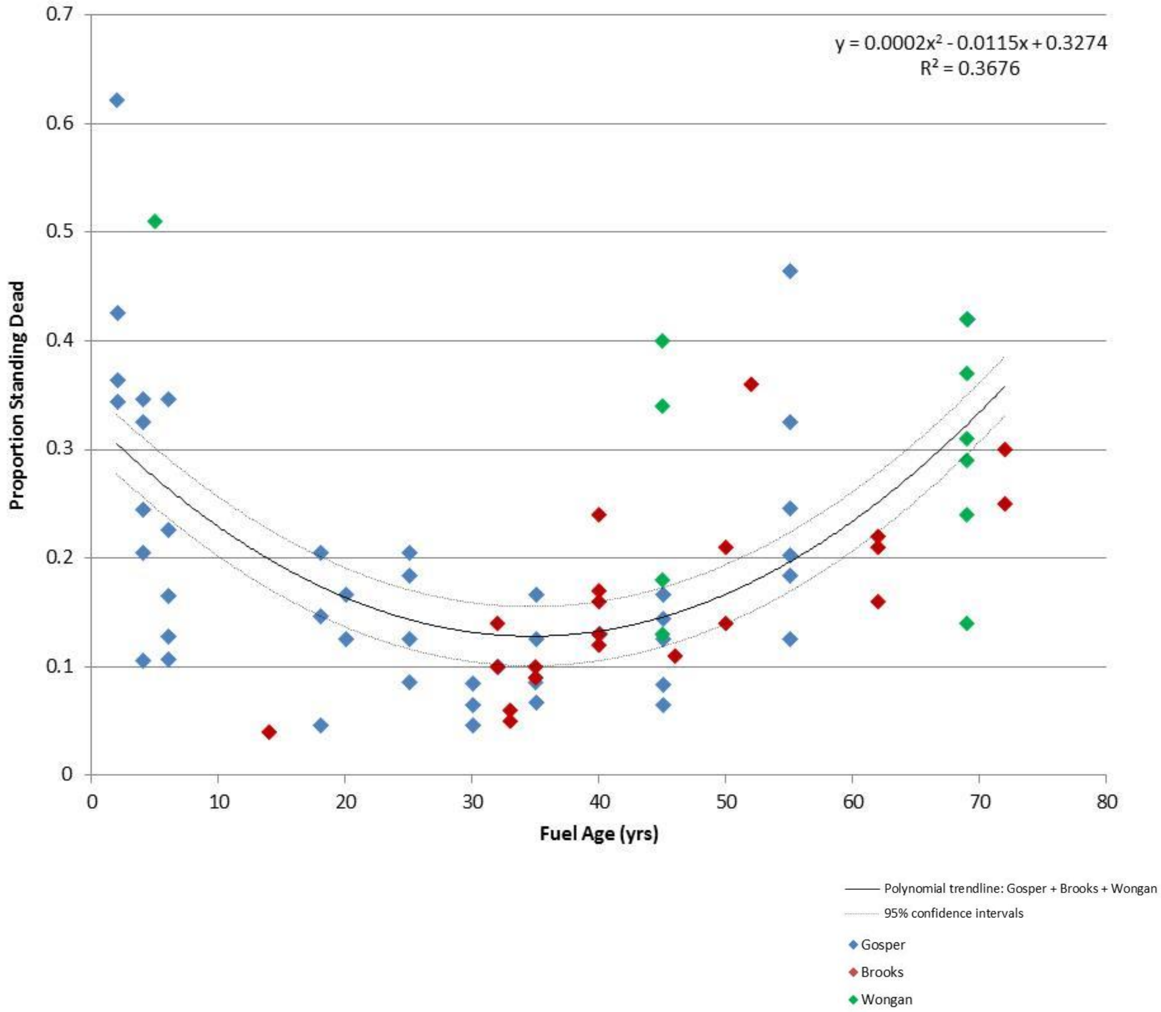

Figure 2. Relationship between the proportion of standing dead vegetation and fuel age, combining data from Gosper et al. (2013), Brooks & Carley (2013) and Wongan Hills.

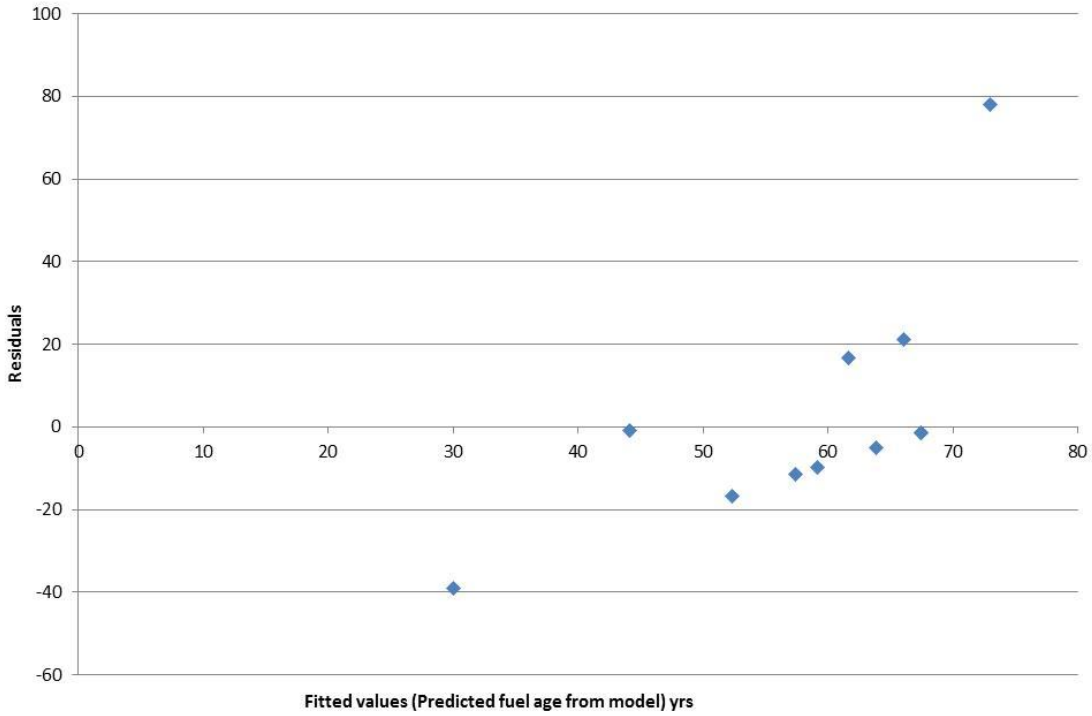

Figure 3. Residuals of the correlation between Wongan Hills standing dead vegetation data and fuel age predicted by combined data from Gosper (2011), Brooks & Carley (2013) and Wongan data.

The residuals show that the data is generally a good fit once poorly fitting outliers from Ks transects and young fuel are excluded. The positive outlier is from a site with five year old fuel (transect 'Ky2? Townsite'). The model predicted the vegetation in this transect to be 73 years old, due to the high levels of standing dead (Figure 3). This is further evidence that the model is less accurate when considering very young fuels. The negative outlier is from the transect 'Ks Ag farm', for which the fuel age is likely to be greater than 69 years, yet was predicted to be 30 years old by the model. The other sedgeland transect 'Ks Water Reserve' could not be included in this figure as the levels of standing dead were so low that they did not exist on the curve. The use of standing dead vegetation as a predictor of fuel age appears to be inappropriate for the Ks vegetation type and for particularly young fuels.

The results of the literature review for each threatened species have been summarised in Appendix 2 and have been used to justify the determination of the MinFRI and MaxFRI for each species.

4.2 Post-burn monitoring results

4.2.1 *Daviesia euphorbioides* population 2BC prescribed burn: Nature Reserve 51093

Approximately 8.8 ha (31% of the planned burn area) was impacted by the prescribed burn targeting *Daviesia euphorbioides* in autumn 2014. Conditions were not favourable to carry the burn through much of the standing vegetation beyond the scrub rolled boundary.

No plants were present in the planned burn area prior to the burn, however mature plants were present south of the southern burn boundary (within the rail corridor) and to the east of the eastern burn boundary. In 1989, the coordinates for population 3b suggest plants occurred within the burn area (approximately 30m from the SE corner of the burn) yet the accuracy of the coordinates is unknown. While four plants were recorded in this location in 1989 (Department of Parks and Wildlife 1989), no plants remained in 2000 (Department of Parks and Wildlife 2001). The plants found to the south and east of the access tracks (in rail reserve) prior to the burn were the result of small recruitment burns in 2007, 2009 (Collins 2009) and 2013 (Department of Parks and Wildlife 2014) and possibly track maintenance.

Monitoring of the burn area in spring 2014 found that *Daviesia euphorbioides* had recruited within the burn area. Six transects established within the scrub rolled and burnt area yielded 93 juveniles. In winter 2015, 82 juveniles and three mature plants were recorded in the same transects, suggesting survival of recruits after one summer was 91% (assuming no second year recruitment post-fire). The three mature plants were flowering at the time of monitoring and were later observed to be fruiting, suggesting it is possible for some individuals (3.5%) to reach reproductive maturity after only one year. Implementing the burn resulted in an increased extant population size of 2.5 ha. Extrapolation of the transect results across the 2.5 ha indicates the burn may have increased the population size by as much as 104 mature plants and 2438 juveniles.

Initial emergence was not recorded in the small enclosed areas in the adjacent rail reserve that were burnt in autumn 2013. After the first summer (March 2014) a total of 106 immature plants remained. By 2015, a total of 51 plants (22 mature and 29 immature) remained, a sharp decline over the course of the second summer of 52%. This suggests the recruits from the 2014 burn may also experience high mortality during the second summer post-germination.

Ants are known to contribute to seed dispersal in species of the Fabaceae. Whilst it is possible for ants to disperse seed of Fabaceae up to 180 m (Whitney 2002), dispersal over much shorter distances (Gomez and Espadaler 2013) is more common (4.7 m for *Daviesia triflora* and 8.1 m for *Acacia blakelyi* (He et al. 2009)). Since some of the juveniles within the burn area were up to 110m from existing plants outside the burn area, it appears unlikely that seed was introduced to the site from these plants. Since plants have not been located within the burn area since at least 1989, it is possible that the longevity of the soil seed bank is 25 years or more. The collation of fire history for the project showed no record of fire within the burn area since prior to 1946. Although it is possible that burns in the rail reserve or fires caused by steam engines escaped in to the surrounding bushland, this has not been documented and other evidence suggests the fuel was at least 68 years at the time of burning (Figure 2). It is therefore possible that the seed bank has persisted in the soil since 1946 or earlier due to the potential lack of disturbance in the burn area prior to this. This indicates the species has a MaxFRI of between 25 and 68 years or more.

Monitoring was also undertaken for *Conostylis wonganensis* as it was recorded within the burn area in 2000 (Department of Parks and Wildlife 2000b). Conostylis are known to germinate in response to fire cues (Downes et al. 2015) so it was considered likely that seedlings of this species may also be found. The monitoring was undertaken in 2015 when other populations of this species were flowering, however no plants were located. The site will continue to be monitored during flowering period to see if this species has recruited in response to the burn.

4.2.2 *Gastrolobium hamulosum* populations 7 & 8 prescribed burn: Nature Reserve 51093

Only 4.7ha (9%) of the planned burn area was impacted by the burn in autumn 2015, as the burn did not carry through the standing vegetation due to low wind speed. Prior to scrub rolling, no plants were present within the burn area, with the last recorded plant observed in 2006 at population 8 and the last three plants at population 7 observed in 2006.

Scrub rolling in 2014 resulted in the emergence of some *Gastrolobium hamulosum* in the depressions created by the machine tracks. In September 2014 nine juveniles were located at population 7 and 45 were found in population 8. By January 2015, plant numbers had dropped to one and seven respectively, indicating a combined survival rate of 13% after one summer. A total of ten plants were located on the day of burn and were protected with metal drums during the burn. Monitoring in July 2015 located four and three plants in populations 7 and 8 respectively. Grazing by kangaroos was high at this site, which made locating the grazed plants difficult during the January monitoring. This may account for the fluctuation in the data between monitoring periods.

Post-burn monitoring in September 2015 showed this species had recruited well at both populations. Recruits were observed in burnt areas within the original scrub rolled area and along the scrub rolled lines perpendicular to the original scrub rolling. Following the burn the area in which juvenile *G. hamulosum* was found to occur increased by 0.18 ha in population 7 and by 0.24 ha in population 8. Plant number estimates based on the quadrat counts were 1246 in population 7 and 9440 for population 8. Based on survival from post-scrub rolling recruitment, it is anticipated that there will be high mortality over summer. The populations will continue to be monitored annually.

The purpose of taking the soil samples was to determine whether viable seed could be found. To increase the chance of finding seed, samples were taken from areas immediately adjacent to where seedlings had established following scrub rolling disturbance. As the distribution of seeds within the soil is not likely to be homogenous (Csontos 2007) and the sampling regime used was not random, estimates of soil seed numbers if applied across the whole of the burn area are likely to be inflated.

Of the 10 soil seed bank samples taken from population 7, *G. hamulosum* seed was extracted from four samples, with a total of seven seed collected from the samples, with a viability of 57%. In population 8, seed was present in seven of the 10 samples. Twenty-two seed were present in the samples with a viability of 73%. Germinants resulting from the germination tests were grown on to verify the seedling identity. All surviving seedlings were found to be *G. hamulosum*.

Extrapolating these results across the known population area suggests the soil seed bank could consist of up to 56 000 seed, 32 000 of which may be viable in population 7 and 234 600 seed, 171 300 of may be viable in population 8.

As so few plants remained at either population in 2006, it is unlikely that they made a significant contribution to the soil seed bank in the intervening years until 2013 when no plants remained. Therefore germination of the species at each site suggests that the soil seed bank is likely to persist for at least nine years. Following the burn seedlings were found up to 150 m from the northern boundary of the reserve and there was no record of disturbance in this area since at least prior to the 1970s and potentially since 1946. This suggests the seed bank could potentially persist for 69 years or more, however further research is required in this area.

The low survival of recruits post scrub rolling was thought to be due to grazing by kangaroos and summer drought stress, based on observations made at the site (Department of Parks and Wildlife 2015c). In an effort to reduce grazing pressure, fencing was installed around the site of each population to exclude kangaroos. Reticulation systems were also installed in an effort to improve survival over summer.

4.2.3 *Acacia pharangites* subpopulation 1D: Nature Reserve 51093

The proposed burn area was almost entirely impacted by fire, although much of the area burnt slowly through the leaf litter rather than the canopy.

Although 11 of the seed plots were burnt, some plots had not burnt by the time the temperature sensors were removed. For the six seed plots for which data is available, the maximum temperature ranged from 31 – 88 °C, with a mean of 47 °C.

Despite raking around the plant and pruning surrounding vegetation, the single mature plant in the population was destroyed due to radiant heat from the burn.

Seedlings with bipinnate leaves were located both inside and outside the plots, which were likely to be Acacia seedlings, possibly *Acacia pharangites*, however the absence of phyllodes meant positive identification was not possible. These seedlings will continue to be monitored until their identity can be confirmed. Seedling mortality is expected to be high since only 20% of seedlings that emerged from a natural recruitment event (subpopulation 1A in 2014) survived until the following winter (Department of Parks and Wildlife 2015d). In late July 2015, 150mm of rain fell on Duncan Holme's property over two days (Duncan Holme, 2015, pers. comm, 3 August). Although the rain was steady and did not cause visible soil erosion at the site of the seed plots, it was observed that there had been movement of the humus layer downslope in some areas. If the seedlings observed are determined to be *Acacia pharangites*, it may be difficult to determine whether they resulted from the known quantity of seed buried in the seed plots or whether they are germinants from the natural seed bank.

The study has the potential to reveal to what extent fire plays a role in germination for this species, likely temperatures required to trigger germination, whether a soil seed bank exists for this species at this site and the likely size of this seed bank. It may also give some idea of seed bank longevity.

The pre-burn density of *Microcorys eremophiloides* within the study area was 66 plants per hectare. No seedlings of this species have as yet been identified post-fire. The study area will continue to be monitored for the emergence of this threatened species as well as the Priority taxa *A. semicircinalis* and *Grevillea kenneallyi*.

4.3 Viability of historic seed collections

Information on the soil seed bank longevity for threatened species from Wongan Hills is lacking, as is similar information for species from the same genera. The availability of old seed (up to 90 years old), of known identity, provided an opportunity to determine whether seed of the Fabaceae were capable of surviving for these periods.

The two main factors affecting seed longevity are storage temperature and seed moisture content (Roberts 1972). The old collections were stored in a number of locations and the exact storage conditions over time were not known. For a period of 15 years they were stored in a transportable building with no temperature control where the temperature was at best equal to ambient conditions or well in excess of ambient conditions. The vials in which the seed were stored were not airtight and seed moisture content is likely to have changed in relation to the ambient humidity.

The initial viability of the seed collections was not known. The visual appearance of many of the collections (for example shrivelled appearance) indicated the seed was likely to be of poor quality and hence low initial viability. Germination of seed shows the potential for the seed to have survived the storage conditions, however unknown initial viability means failure to germinate does not necessarily indicate a failure to have survived the storage conditions.

Germination of the *Acacia* collections was highly variable (Figure 4). Some collections had little to no viable seed after 30 years in storage (eg. *Acacia microbotrya*), whilst one collection (*Acacia restiaceae*) had 90% viability after 75 years in storage. A 90 year old collection of *Acacia bidentata* was the oldest tested with a viability of 13%. Only one collection of *Daviesia* and *Gastrolobium* were tested. The collection of *D. cordata* appeared to be of poor quality and may have been immature when collected. No viable seed were found in this collection. The *G. callistachys* was 50 years old and still had a viability of over 40%.

Whilst the conditions experienced by seeds in the soil seed bank are vastly different to those experienced by the old collections, these results indicate the potential of seed of *Acacia* to survive for at least 90 years and for seed of *Gastrolobium* to survive for at least 50 years.

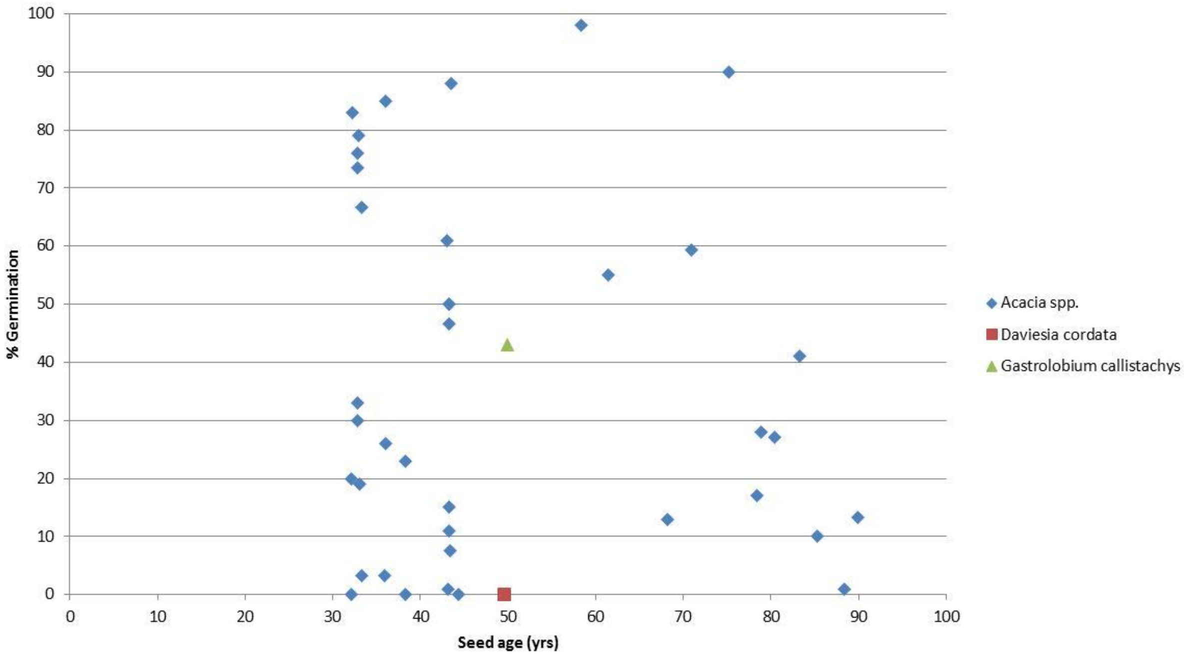

Figure 4. Germination (%) of historic seed collections.

4.4 Senescence Transect Results

Transects were located in various vegetation types in the Wongan Hills, focusing on vegetation types supporting CR species and those with multiple fuel age classes (Figure 6). Of the 12 transects assessed, eight consisted of greater than 25% standing dead vegetation (Figure 5), indicating the vegetation at the majority of sites was senescing (Gosper et al. 2013). This suggests that the absence of fire in much of the Wongan Hills for such a lengthy period may result in the ongoing loss of biodiversity, particularly serotinous species. The few cases in which transects did not meet the threshold indicating a senescent community have been explained below.

The 'Ks' community should be excluded from the senescence study as it was found that the measure of senescence was not reliable for this community. Despite the vegetation being long unburnt in one transect and 45 years old in the other, combined with an appearance of senescence amongst the indicator species, neither transect in the Ks community met the 25% threshold. It is possible that the dominance of living sedges in this community, combined with the low density of heath species resulted in low levels of standing dead, meaning the measure is inappropriate for this vegetation type.

The 'Ky1? Townsite' transect fell just short of the 25% threshold with 24% standing dead vegetation and although it did not reach the threshold indicating a senescent community, it is clearly approaching senescence. The transect was located in long unburnt vegetation and the only potential indicator species present was the apparently long lived *Hakea erecta*. It is possible that short lived serotinous species once occurred in this area that have now disappeared from this community due to the absence of fire.

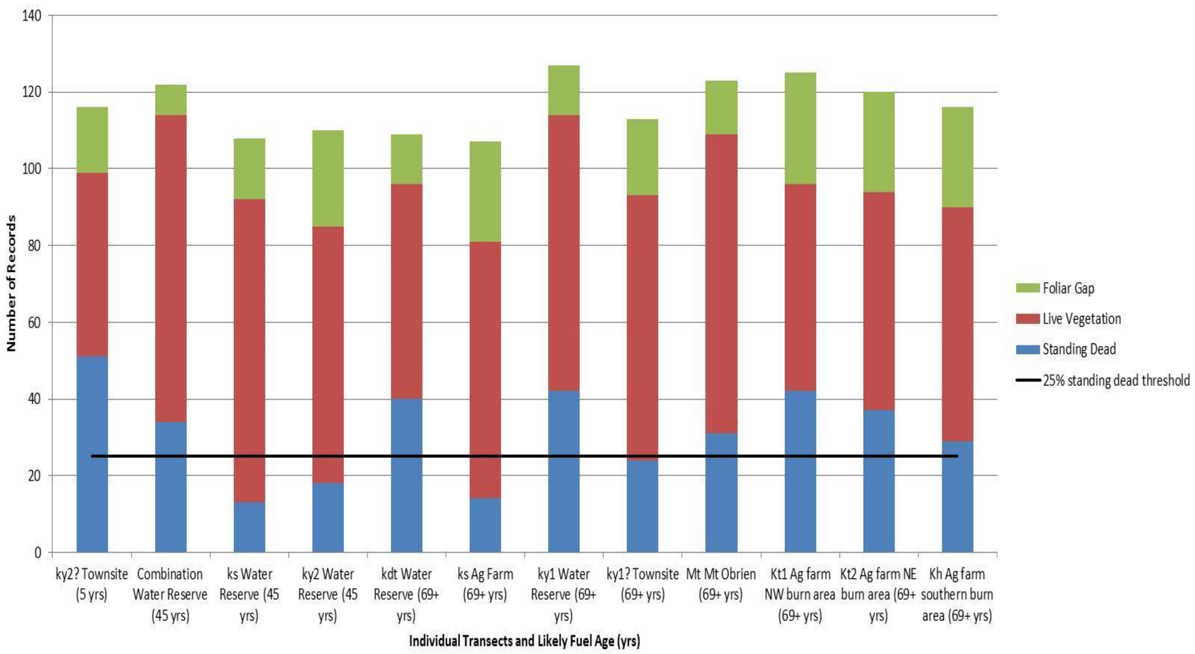

Figure 5. Results of rapid assessment of senescence by site showing number of records of each category along each transect and the 25% 'senescence' threshold. Transect labels include vegetation type (Appendix 4), location descriptor and likely fuel age.

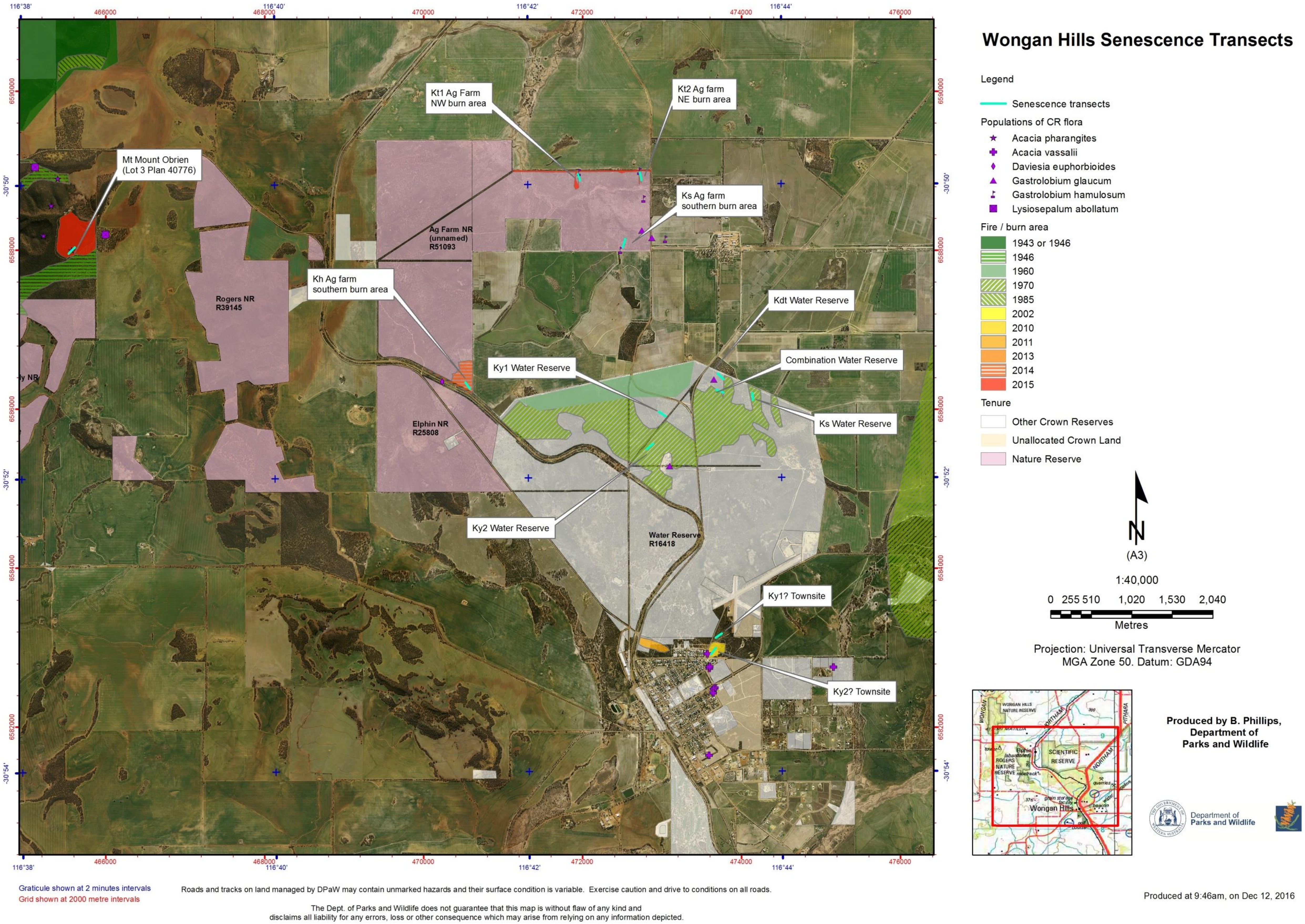

Figure 6. Senescence transect locations.

The transect in ‘Ky2 Water Reserve’ was the only other site where less than 25% standing dead vegetation was recorded. This vegetation is younger than most of the vegetation that was monitored, being approximately 45 years since the last fire. The level of standing dead was still reasonably high, at 18%. For this vegetation, a fuel age of 45 years is not yet senescent according to the threshold. A transect that crosses vegetation types (Combination Water Reserve) also has a fuel age of 45 years, yet it is senescent according to the measure. This suggests that different vegetation types have variable fire frequency requirements.

‘Ky2 Townsite’ had a high percentage of standing dead vegetation (Figure 5), yet high levels of standing dead is indicative of both long unburnt and recently burnt fuels. In this case, a fire impacted this area only five years prior, accounting for the high level of standing dead vegetation. Recently burnt fuel can easily be determined by a visual examination of the site, as in this case.

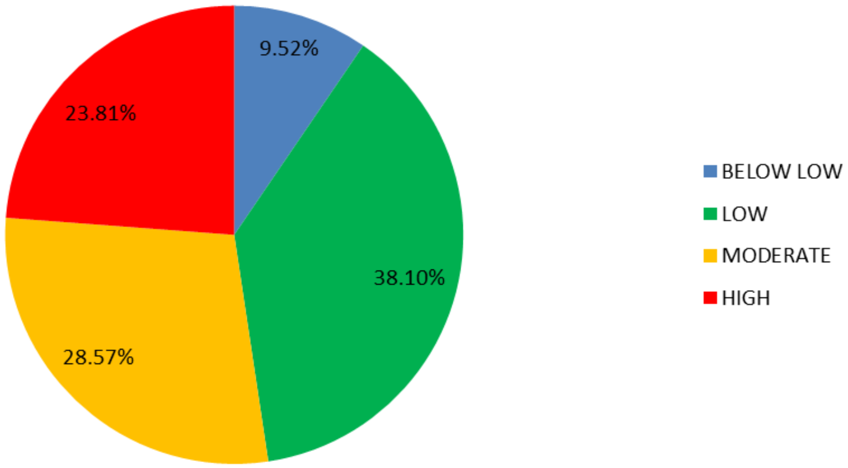

Figure 7. Pooled results showing percentage of indicator species reaching risk thresholds (Below low= <10%; Low=10-24%; Moderate=25-49%; High=>50%) for persistence.

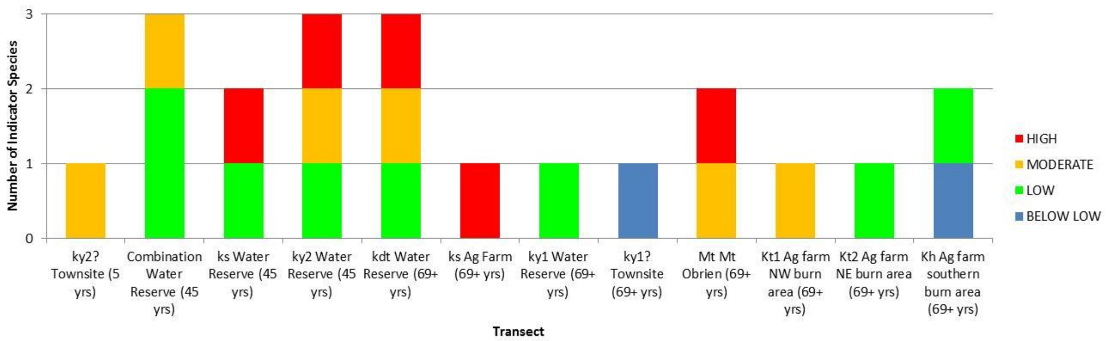

Figure 8. Number of indicator species reaching Gosper et al. (2013) assigned risk thresholds (Below low= <10%; Low=10-24%; Moderate=25-49%; High=>50%) for persistence by transect.

The intensive assessment of indicator species mortality resulted in more than 50% of indicator species being at ‘high’ or ‘moderate’ risk of failing to persist in that vegetation community, according to Gosper et al.’s (2013) risk thresholds (Figure 7). This indicates that using this measure, much of the vegetation in Wongan Hills is approaching or has surpassed its maximum fire return interval.

Eight out of 12 transects had at least one indicator species at moderate or high risk of failing to persist long term (Figure 8), indicating these communities are likely to have exceeded their MaxFRIs (Gosper et al. 2013). The only transects without at least one species in the moderate or high risk categories were ‘Ky1 Water Reserve’, ‘Ky1? Townsite’, ‘Kt2 Ag Farm’ and ‘Kh Ag Farm’ (Figure 8). The vegetation at these locations is likely to be long unburnt (greater than 69 years since fire). A potential explanation for the apparent low risk to indicator species at these sites is that the absence of fire may have lead to the loss of some indicator species long before the transects were undertaken. The remaining species are likely to be longer-lived, giving the appearance that disturbance is not yet required, yet biodiversity may already have been lost from the system. This appears to be the case for ‘Ky1 Water Reserve’, ‘Ky1? Townsite’ and ‘Kt2 Ag Farm NE burn area’, where only one potential indicator species could be found at each site (*Hakea erecta* in the case of the former two transects and *Hakea scoparia* in the latter). Coates (1992) recorded *Hakea platysperma*, *Hakea circumalata* and *Petrophile ericifolia* as commonly occurring species in the Ky1 vegetation type, however there were no living representatives of these species in 2015.

The results suggest that the majority of sites may have already exceeded their MaxFRI and that in the few cases where the results indicate otherwise, there are possible explanations to account for the unexpected results.

Table 3. Summary of the likelihood of the indicator species persistence at each site if burnt were imminently based on fruit collections and seed viability for each species.

Transect	Species	Mean # viable seed per plant	Likely to persist long term (mean # viable seed per plant >4)	Comments
Combination Water Reserve	Banksia purdieana	43	Y	
	Hakea gilbertii	5	Y	Borderline
	Petrophile shuttleworthiana	14	Y	
kdt Water Reserve	Banksia purdieana	130	Y	
	Hakea gilbertii	14	Y	
	Petrophile shuttleworthiana	21	Y	
Kh Ag farm southern burn area	Banksia purdieana			No fruit collection made for this transect.
	Hakea incrassata			No fruit collection made for this transect.
ks Ag Farm	Hakea scoparia subsp. scoparia	125	Y	
ks Water Reserve	Hakea multilineata	15	Y	
	Hakea platysperma	1	N	
Kt2 Ag farm NE burn area	Hakea scoparia subsp. scoparia			No fruit collection made for this transect.
ky1 Water Reserve	Hakea erecta	32	Y	
ky1? Townsite	Hakea erecta	66	Y	
ky2 Water Reserve	Hakea circumalata	11	Y	
	Hakea erecta	239	Y	
	Hakea platysperma	1	N	
ky2? Townsite	Hakea erecta			No fruit due to recent fire.
Mt Mt Obrien	Banksia wonganensis	430	Y	
	Hakea scoparia subsp. scoparia	40	Y	
Kt1 Ag farm NW burn area	Hakea scoparia subsp. scoparia	251	Y	

A parent to seedling ratio of less than 1:4 is likely to result in local extinction of serotinous obligate seeders (Bond 1989). Any species where the mean number of viable seed per plant is four or more is considered capable of long term persistence, while any species with less than four viable seed per plant is considered at risk of local extinction. These vegetation communities are therefore likely to be beyond their MaxFRIs.

Hakea platysperma is unlikely to persist in either ‘Ks Water Reserve’ or ‘Ky2 Water Reserve’ (Table 3), both of which were impacted by fire approximately 45 years ago. This species was known to occur in Ky1, Ks and Kh vegetation communities from vegetation surveys undertaken in the 1980s and 1990s (Coates 1988, 1992). Evidence of this species was found in many transects in the form of clusters of the distinctive fruit on the ground. This indicates *Hakea platysperma* is one of the most sensitive species in the vegetation communities examined and therefore its requirements should determine the fire regime where it is represented in the community. The MaxFRIs for these vegetation communities should therefore be less than 45 years. Based on the parent to seedling ratios in ‘Ks Water Reserve’ and ‘Ky2 Water Reserve’, even if burning was undertaken immediately, this species would be lost from most communities (Table 3).

Table 4. Summary of results of multiple measures of senescence for each transect with a recommendation for fire management.

Transect	Likely fuel age (yrs) at time of survey (NO SCORE)	Predicted fuel age (yrs) from Gosper/Brooks model (NO SCORE)	At least one indicator sp at 'moderate' risk of recruitment failure based on Gosper et al. (>25% dead) (SCORES: X=1; BLANK=0)	At least one indicator species not likely to persist long-term based on Bond parent to seedling ratio (X=1; BLANK=0)?	Veg senescent (>25% recorded as 'dead' or 'dead/alive' in rapid assessment) (SCORES: X=1; BLANK=0)	Overall Senescence (N=not senescent by any measure; Y=senescent by 1 or more measures)	Recommendation
kdt Water Reserve	69+	66.06	X		X	Y	BURN
Combination Water Reserve	45	61.62	X		X	Y	BURN
ks Ag Farm	69+	30	X			Y	BURN IF POSSIBLE
ks Water Reserve	45	Does not fit model	X	X		Y	BURN IF POSSIBLE
ky1 Water Reserve	69+	67.42			X	Y	BURN
ky2 Water Reserve	45	44.14	X	X		Y	BURN
ky1? Townsite	69+	52.36				N	BURN
ky2? Townsite	5	73.01	X		X	Y	NO BURN
Mt Mt Obrien	69+	59.16	X		X	Y	BURN (BURNT 2015)
Kt1 Ag farm NW burn area	69+	67.42	X		X	Y	BURN (BURNT 2015)
Kt2 Ag farm NE burn area	69+	63.91			X	Y	BURN (BURNT 2015)
Kh Ag farm southern burn area	69+	57.39			X	Y	BURN (BURNT 2014)

The vegetation in transects were assessed as senescent if they met the senescence threshold for at least one criterion. The results show that 11 of the 12 sites have exceeded their MaxFRIs and should be burnt (Table 4). It is possible that species have already been lost from many communities and therefore should have been burnt earlier. Having exceeded their MaxFRIs, these communities should be burnt, but may no longer be a priority to burn immediately if there are no species at imminent risk. For example, 'Ky1? Townsite' did not meet any of the criteria for senescence as it is possible that serotinous obligate seeder species (such as *Hakea platysperma*) once existed in this vegetation type, but are now locally extinct. If this is the case, this vegetation type should be burnt at shorter intervals yet burning at the site now will not return the lost species to the system. However, it is available to burn and the impact will not be detrimental to any species currently in the community, hence burning is recommended.

As outlined earlier, 'Ky2? Townsite' meets two criteria for senescence, however this vegetation was burnt only 5 years previously, accounting for high levels of standing dead vegetation. Since the fuel in this area is only five years old and the *Hakea erecta* have not begun to set fruit, this area has not yet reached its minimum fire return interval and should be excluded from burning.

Table 5. Minimum and maximum fire return intervals for vegetation types for which senescence data were collected.

Vegetation type	Minimum fire return interval MinFRI (years)	Maximum fire return interval MaxFRI (years)
Kdt/Kdh	15-20	35-40
Ks	15-20	35-40
Ky1/Ky2	15-20	35-40
Mt	15-20	40-50
Kt	15-20	40-50
Kh	15-20	40-50

MinFRIs have been set at 15-20 years for all vegetation types and MaxFRIs have been set at 35-40 years or 40-50 years based on available information (Table 5). Vegetation type Kdt/Kdh is thought to be the same vegetation type with a different fuel age (Coates 1992). The older fuel (Kdt) was represented in 'kdt Water Reserve' and the younger fuel (Kdh) was represented in 'Combination Water Reserve' with fuel ages of greater than 69 years and 45 years respectively (Table 4). The 45 year old vegetation in the transect 'Combination Water Reserve' was already senescent, leading to the MaxFRI being estimated as 35-40 years for the vegetation type Kdt/Kdh (Table 5).

MaxFRI was estimated as 35-40 years for the Ks vegetation type as it was senescent by multiple measures at both 69 and 45 years post-fire. Serotinous species diversity was higher in the younger vegetation, suggesting species may have been lost at the older site. *Hakea platysperma* is also unlikely to persist long term in the younger fuel, suggesting this vegetation type should have a MaxFRI of 35-40 years or possibly less. The same rationale was used to estimate the MaxFRI as 35-40 years in the Ky1/Ky2 vegetation type.

The vegetation types Mt, Kt and Kh were all senescent by at least one measure at 69 years post-fire, yet there was no evidence of *Hakea platysperma* or other species sensitive to long inter-fire periods occurring currently or historically in these locations. Therefore the MaxFRI was set at 40-50 years for these vegetation types.

The MinFRI has been set at 15-20 years for all vegetation types. Burrows et al. (2008) determined that in the high rainfall forests of the south west of Western Australia, canopy-stored seeder species had a juvenile period of three years on average. Twice the juvenile period equates to a six year MinFRI. On account of very low rainfall in the Wongan Hills, this figure has been doubled again to give a MinFRI of 12 years. Burrows et al. (2008) also states that in less flammable areas where plants with longer juvenile periods occur, the minimum fire return interval should be at least 10-12 years. Since Burrows et al. (2008) was referring to areas within the forest region in this statement, an extra buffer has been added. Therefore an estimation of 15-20 years was assigned as a MinFRI for vegetation communities of the Wongan Hills supporting serotinous obligate seeder species. Studies of several banksia species on the northern sandplains, summarised in Lamont et al (2007), suggest optimal fire intervals of 10-20 years for population growth.

The estimated fire return intervals for vegetation types were used in conjunction with the collated fire history of the Wongan Hills to generate burn planning maps (Figure 9). The maps indicate areas where particular vegetation types have exceeded their MaxFRI and are available to burn. Woodlands and granite outcrops have been mapped as unavailable to burn, as have areas that were burnt as part of this project or areas impacted by fire in the last 15-20 years. Although steep terrain has not been specifically excluded in the maps, these areas should also be considered for exclusion during the burn planning process to reduce the risk of erosion. Senescence transects were not undertaken in mallee or Melaleuca-dominated vegetation types and therefore have been mapped as 'likely available to burn'. These communities can be included in burn areas when planning a burn targeting 'available to burn' vegetation. The map has been designed as an initial indication of areas that can be targeted for prescribed burning. Threatened and Priority species still need to be considered on a case by case basis in the planning process. The allocation of vegetation into management cells and prioritisation of these cells for burning over time is still required and will be undertaken using the Fire Regime Optimisation Planning System (FiReOPS) developed by Parks and Wildlife Wheatbelt Region staff (Beecham & Lacey 2015).

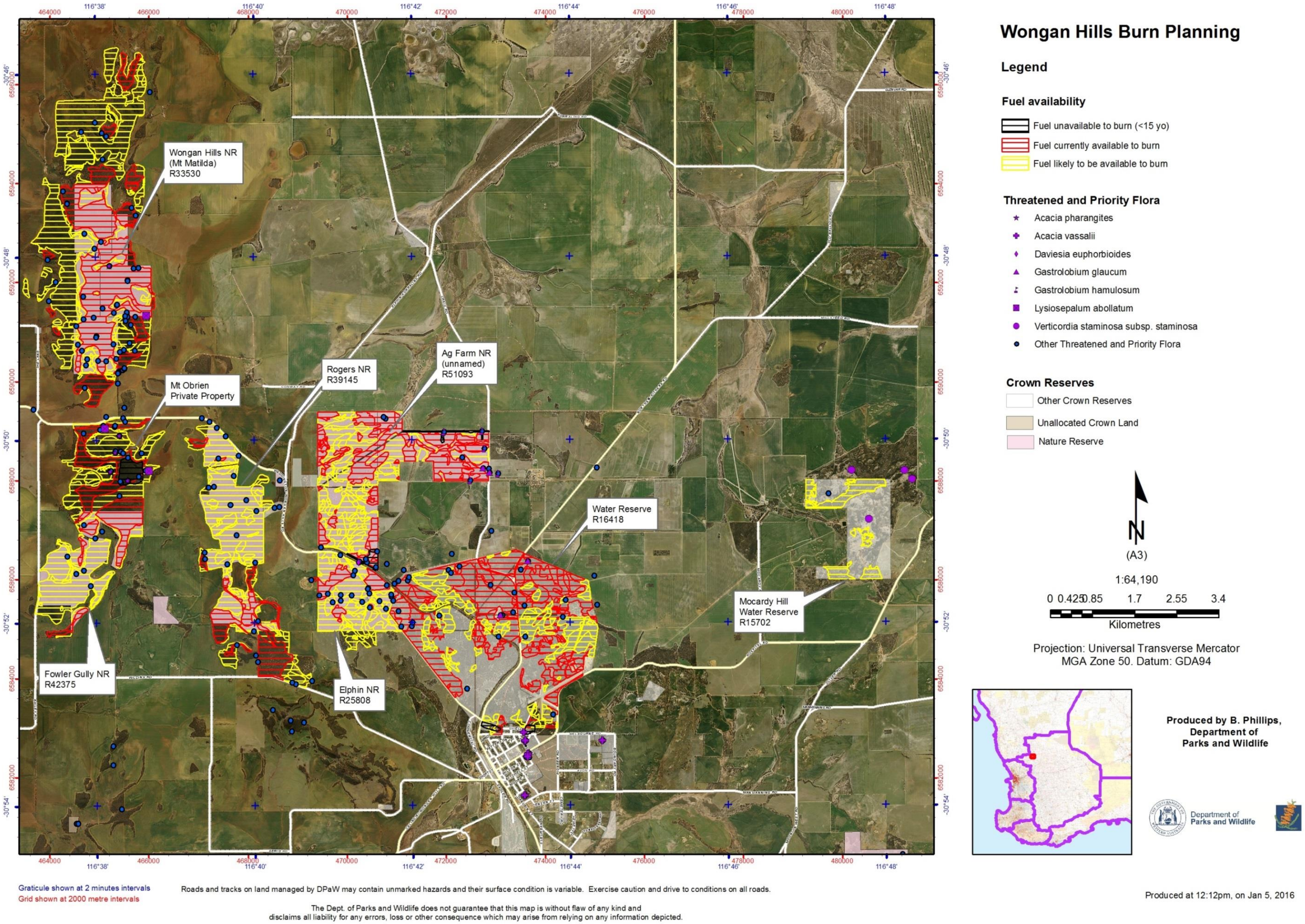

Figure 9. Overview map showing availability of fuel to burn based on the results from the Wongan Hills project.

Table 6. Summary of the MinFRI and MaxFRI for the seven CR species in addition to the MinFRI and MaxFRI for the vegetation types associated with these species.

Species	Vegetation type	Minimum Fire Return Interval (=2x juvenile period)	Maximum Fire Return Interval (=longevity of plants + seed bank)	Min Fire Return Interval for Associated Vegetation Community	Max Fire Return Interval for Associated Vegetation Community
Acacia pharangites	Mt	10	99	15-20	40-50
Acacia vassalii	Ky1/2	10	>51	15-20	35-40
Daviesia euphorbioides	Kh	6	25-68	15-20	40-50
Gastrolobium glaucum	Ks, Kdt/Kdh	<20	35-69	15-20	35-40
Gastrolobium hamulosum	Kt, Ks	10	45 – 69	15-20	35-40
Lysiosepalum abollatum	N/A	6	15 – 69	N/A: vegetation unlikely to carry fire	N/A: vegetation unlikely to carry fire
Verticordia staminosa subsp. staminosa	N/A	N/A: species should be excluded from fire	N/A: species should be excluded from fire	N/A: vegetation unlikely to carry fire	N/A: vegetation unlikely to carry fire

The juvenile period for *Acacia pharangites* is unknown, however recruits from a natural recent germination event are at least two years old and have not yet flowered or fruited. Annual monitoring of the recruits will enable the juvenile period to be determined. Acacias generally have a juvenile period of 1-4 years (Doran et al. 1983). For this species a slight buffer was applied and the MinFRI was set as 10 years. Aside from the recent recruitment event that occurred at subpopulation 1A, there has been no record of inter-fire recruitment. Subpopulation 1A was cleared and burnt in 1946, cropped for one or two years, then allowed to regenerate. Assuming the mature plants in this subpopulation are the same plants that recruited in the 1940s, they could be up to 69 years old. The longevity of the soil seed bank for this species is unknown, yet viability testing of historical collections during this project found Acacia species to be viable for between 30 and 90 years (Figure 4). Based on the assumption that the seed remains viable for a minimum of 30 years, the MaxFRI was estimated as 99 years. The MaxFRI for the associated vegetation is 40-50 years and therefore the requirements of the vegetation would dictate the fire regime in this instance.

Acacia vassalii has a juvenile period of five years (Shedley 2011). Recruitment was observed in population 2 following fire 21 years ago and there is no evidence of fire at population 1AB for at least 69 years. Assuming no inter-fire recruitment, indications are that the longevity of this species is at least 21 years. Using the soil seed bank data from other Acacia species, the MaxFRI has been estimated as greater than 51 years for this species, while the associated vegetation should ideally be burnt at intervals of less than 35-40 years.

Daviesia euphorbioides has a short juvenile period of two or three years and a short lifespan, being approximately 10 years (Department of Parks and Wildlife 2005). The results from the prescribed burn at subpopulations 2b and 2c suggest seed can persist in the soil for at least 25 years and potentially up to 68 years. It is a fitting life history strategy for a short-lived disturbance opportunist to have a long-lived seedbank, particularly in low rainfall areas where fire intervals are lengthy due to slow growth rates and accumulation of biomass (Burrows 2008). The MaxFRI for this species is 25-68 years whereas it is 40-50 years for the associated vegetation. This suggests that in this case the requirements of the threatened species should dictate the MaxFRI (ie. more frequent fire than required by the vegetation type), until more conclusive evidence of soil seed bank longevity becomes available.

The MinFRI of *Gastrolobium glaucum* has been estimated as less than 20 years and the MaxFRI as 35-69 years, however both require further investigation and refinement. *Gastrolobium glaucum* was originally thought to be an obligate seeder killed by fire or disturbance, however it was discovered that it often reshoots from underground stolons following disturbance (Willers 2002). The species can also recruit from seed and whilst seed set appears to be low, the seed set has a high viability (Department of Parks and Wildlife 2015b). The period between disturbance and flowering could not be found in the literature, however a report for population 2 in 1989 indicates plants were flowering after clearing of the powerline easement 5-10 years prior to that date. This enables the secondary juvenile period (ie. time to reproductive maturity following resprouting) to be estimated as less than 10 years. The Min FRI has been based on this estimated secondary juvenile period. Primary juvenile period could not be determined from past reports due to difficulties discerning seedlings from resprouting plants.

Mature plants have been recorded in subpopulation 1B since 1970 and the area has not burnt since at least prior to the 1970s (Harris & Yates 2003) and potentially for up to 69 years. Resprouters are often long lived with low seed set (Bond & Midgley 2001) and this species appears to fit this profile. It is difficult to determine the MaxFRI for this species since the plants are not killed by disturbance and hence plant and seedbank longevity are unknown. The MaxFRI has been estimated as 35-69 years, however the MaxFRI for the vegetation type is 35-40 years, suggesting the vegetation community should drive the fire regime in this case. This species requires more intensive investigation of its ecological attributes to refine the fire return intervals.

Gastrolobium hamulosum has a juvenile period of four or five years (Harris & Yates 2003), setting the MinFRI at 10 years. The longevity of *Gastrolobium hamulosum* is unknown, however subpopulations 1B and 1C have not burnt since before the 1970s (Harris & Yates 2003) and potentially since before 1946. Therefore MaxFRI was estimated as 45-69 years. The MaxFRI may increase once further information becomes available regarding plant longevity and soil seed bank longevity. This is supported by viability testing of a single collection of *Gastrolobium callistachys,* where a 50 year old collection had a viability of 43% (Figure 4). The Ks and Kt vegetation types associated with this species have a MaxFRI of 35-40 years, due to the presence of *Hakea platysperma* in the Ks vegetation type. The MinFRIs of these vegetation types are 15-20 years, meaning that the requirements of the vegetation should drive the burning regime.

As a hard-seeded species, *Lysiosepalum abollatum* is likely to respond to fire and is known to have recruited following clearing and burning in 1946. However, the only known natural population of this species occurs in this previously cleared, sparse creekline which is unlikely to burn naturally. It is therefore difficult to determine if fire is the main germination cue for this species. A recruitment event was observed in 2001 following flooding and inundation (Roy-Chowdbury & Smith 2003), suggesting these conditions also trigger germination. Given the sparse creekline habitat of the species, flooding is likely to occur more frequently than fire and therefore is a more likely trigger for germination. Since the vegetation is unlikely to be fire-prone and does not appear to support serotinous obligate seeder species, calculations have not been made for minimum and maximum FRIs for the vegetation type. The MaxFRI for *Lysiosepalum abollatum* was presented as a range based on a minimum longevity of 15 years, since some plants were likely to have survived since recruitment in 2001 and potentially since the initial recruitment event following clearing and burning in 1946. The seedbank longevity for this species is unknown so has not been included in the MaxFRI calculation, yet it is likely to be persistent as it is a hard-seeded species. The MinFRI was set at six years based on a juvenile period of three years as determined from the translocation data from population two (Department of Parks and Wildlife 2011).

Minimum and maximum FRIs have not been calculated for *Verticordia staminosa subsp. staminosa* or its associated vegetation since neither the species nor habitat would benefit from fire and it would be highly detrimental to *Verticordia staminosa subsp. staminosa* (Yates et al. 2007). This area should be excluded from bushfire and prescribed fire.

The results reconciling the fire regime requirements of the CR species with those of the associated vegetation for each species demonstrate that the requirements of the vegetation should be used to drive the fire regime in the Wongan Hills in most cases. The CR species are generally less sensitive to extremely short or long inter-fire periods than the vegetation types in which they occur. The exception is *Daviesia euphorbioides*, for which the MaxFRI could be as low as 25 years; which is a departure from the MaxFRI for the vegetation type of 40-50 years.

5. Future Management & Recommendations

Ongoing monitoring of Threatened flora is required within the areas burnt as part of this project. Monitoring will be consistent with the initial post-burn monitoring of each species and will be undertaken on an annual or biennial basis. Juvenile periods will be documented and all species will be targeted for seed collection once mature. A subset of plants in each population will be permanently tagged to enable longevity to eventually be determined for long-lived species.

If there is recruitment from a natural soil seed bank within the *Acacia pharangites* burn area, quadrats will be installed to record the number of individuals and a population boundary will be captured, from which the number of plants will be estimated. The quadrats will be monitored annually to determine survival rates. The seed plots will also be monitored annually or biennially to determine juvenile period and plant longevity.

Indicator species in recently burnt areas will be opportunistically monitored for fruit set to determine juvenile periods and refine MinFRIs for the vegetation types supporting these species.

The data generated from this project will be used in conjunction with the Wheatbelt Region Fire Regime Optimisaton Planning System (Beecham & Lacey 2015) to develop an ongoing master burn plan for the vegetation of the Wongan Hills. This project has focused largely on the requirements of the Critically Endangered species of the Wongan Hills. Therefore the requirements of other Threatened and Priority flora will also be carefully considered in the development of the master burn plan, in addition to other environmental sensitivities.

Many of the burns for this project were undertaken under low wind speed, which resulted in smaller burn areas than were anticipated. Small burn areas are likely to be heavily grazed by kangaroos, impacting greatly on vegetation quality and diversity as well as Threatened species. It is therefore recommended that future burns in the Wongan Hills are undertaken under higher wind speeds to achieve planned burn results.

Although the absence of fire in the Wongan Hills has resulted in reduced biodiversity in some vegetation types, it is also important to consider the impact of a drying climate and the potential ramifications if burning is undertaken during periods of below average rainfall. This is of particular concern for the serotinous obligate seeder species, which may be lost from the system if poor summer rainfall results in high seedling mortality following a fire.

Soil seed bank longevity of Threatened species is an area in which very little research has been undertaken and yet it is critical for determining MaxFRIs for appropriate fire management of these species. Further research should be undertaken in this area for all CR species occurring in the Wongan Hills and in the Wheatbelt more broadly.

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Appendix 1. Monitoring results for populations of CR flora during Wongan Hills project.

Species	TPFL Population / subpopulation	Revised population number if applicable	Date monitored	Plant number / Population structure	Area of population (ha)	Reproductive state	Threats	Comments
Acacia pharangites	1A		4/12/2014 24/6/2015	8x mature; 53x juveniles 11x juveniles (mature plants not counted)	0.003	Vegetative / some fruiting	Drying climate – juvenile attrition over summer.	
Acacia pharangites	1B		4/12/2014	3x mature; 1x juvenile	0.6	Vegetative / some fruiting	Absence of disturbance and inadequate rainfall.	
Acacia pharangites	1C		4/12/2014	0x plants				
Acacia pharangites	1D		4/12/2014	1x mature	0.0001	Vegetative	Absence of disturbance.	Prescribed burn implemented in 2015 at subpopulation 1D. The single plant was destroyed by radiant heat. Seed was buried in trial plots prior to the burn. Preliminary results suggest

								there are Acacia seedlings in the burn area, however they need to be continually monitored to ensure positive identification.
TOTAL 2014 = 12x mature; 54x juveniles								
Acacia pharangites	2		6/8/2015	5x mature	0.04	Flowering	Successive low rainfall years, lack of disturbance.	
Acacia vassalii	1A		2/7/2013	0x plants			Inappropriate land use – rubbish dumping, access.	
Acacia vassalii	1B		2/7/2013	3x plants	0.04	Flowerbud	Road maintenance, rubbish dumping and weed invasion.	Brigades attempted a burn in this area in autumn 2013 which only impacted a small strip of vegetation. No *Acacia vassalii* were taken. No

								evidence of recruitment following the burn.
Acacia vassalii	1C		10/10/2014 19/5/2015	Plants not located 4x mature	 0.004	 Flowerbud	 Soil disturbance and rubbish in immediate vicinity.	 Habitat impacted by bushfire in 2010 yet only 4x plants have germinated post-fire.
TOTAL 2015 = 7x mature								
Acacia vassalii	4		10/10/2014 24/6/2015	0x plants 1x plant	 0.0001	 Flowerbud	Absence of disturbance Grassy weed infestation.	
Acacia vassalii	6A		2/7/2013	213x plants	0.06	Flowering	Rubbish, inappropriate access, soil disturbance, potential for weed invasion.	Burnt 2002 or earlier.
Acacia vassalii	6B		2/7/2013	65x plants	0.04	Flowering	Rubbish, inappropriate access, soil disturbance, potential for weed invasion, road maintenance.	Burnt 2002 or earlier.
Acacia vassalii	6C - EXTINCT							

Acacia vassalii	6D - EXTINCT							
Acacia vassalii	6E - EXTINCT							
TOTAL 2013 = 278x mature								
Acacia vassalii	7		19/5/2015	3x mature plants	0.01	Flowerbud	Track maintenance, lack of fire.	
Daviesia euphorbioides	1A		4/3/2014	1x mature plant	0.0001	Vegetative, dehisced fruit.	Too infrequent fire, rabbit grazing.	
Daviesia euphorbioides	1B		4/3/2014	49x mature plants	0.3	Vegetative, dehisced fruit.	Too infrequent fire, rabbit grazing.	Resulted from recruitment burn 2011.
TOTAL 2014/15 = 53x mature								
Daviesia euphorbioides	Historic pops 2 and 3b	2A	4/3/2013 23/6/2015	5x mature; 10x juvenile; 96x seedlings 22x mature; 29x juvenile	 0.9	Flowering and vegetative.	Most plants are juveniles and are threatened by inadequate summer rainfall.	Resulted from recruitment burns 2013.
Daviesia euphorbioides	Historic pops 2 and 3b	2B	24/9/2014 23/6/2015	93x juveniles (count from transects only) 3x mature; 82x juvenile (count from transects only) Extrapolation of up to 104x mature and 2438x juveniles	1.1	Vegetative Flowering and vegetative.	Most plants are juveniles and are threatened by inadequate summer rainfall.	Resulted from prescribed burn 2014.

				over 2.5 ha of the burnt area (2B + 2C combined).				
Daviesia euphorbioides	Historic pops 2 and 3b	2C	23/6/2015	2x mature; 35x juvenile (population boundary plants counted only). Extrapolation of up to 104x mature and 2438x juveniles over 2.5 ha of the burnt area (2B + 2C combined).	1.4	Flowering and vegetative.	Most plants are juveniles and are threatened by inadequate summer rainfall.	Resulted from prescribed burn 2014.
TOTAL = 27x mature; 146x juvenile Or up to 126x mature; 2467x juvenile by extrapolation								
Daviesia euphorbioides	9		6//9/2012	0x plants			Heavy weed infestation, lack of habitat due to roadside location.	
Gastrolobium glaucum	1A		5/11/2013	80x mature, 1x seedling	8.4	Immature fruit	Altered fire regime, lack of recruitment.	
Gastrolobium glaucum	1B		5/11/2013	1x mature	0.0001	Immature fruit	Altered fire regime, lack of recruitment,	1x plant occurs on road reserve according to the

							roadside maintenance.	GPS coordinates for this population, which is why the subpopulation 1B has been retained.
TOTAL 2013 = 81x mature; 1x seedling								
Gastrolobium glaucum	2		1/9/2015	2x clumps, consisting of approx. 25x stems.	0.005	Vegetative and flowering.	Lack of appropriate disturbance, inappropriate management due to lack of understanding of ecology of this species (clonal).	Track was mulched 2015 by Western Power contractors. All plants were avoided.
Gastrolobium glaucum	4		1/9/2015	1x clump consisting of approx. 50x stems.	0.005	Flowerbud, flowering and vegetative.	Lack of appropriate disturbance, inappropriate management due to lack of understanding of ecology of this species (clonal).	
Gastrolobium hamulosum	1A	Coordinates incorrect, part of subpop now	4/11/2013	1x mature, 1x juvenile	0.1	Immature fruit	Road maintenance, lack of successful	

		known as 1B (roadside).					recruitment.	
Gastrolobium hamulosum	1B	Pop 8	4/11/2013 25/9/2014 22/1/2015 23/7/2015 3/9/2015	0x plants 45x juveniles 7x juveniles 3x juveniles 59x juveniles (total for 15 1x1m plots) – extrapolate to 9440x juveniles	0.24	Vegetative	All plants juvenile – inadequate rainfall, kangaroo grazing.	Population scrub rolled in 2014 and burnt in 2015 as part of this project. Population now reticulated and fenced.
Gastrolobium hamulosum	1C	Pop 7	4/11/2013 25/9/2014 22/1/2015 23/7/2015 3/9/2015	0x plants 9x juveniles 1x juvenile (others could not be located due to grazing pressure) 4x juveniles 18x juveniles (total for 26x 1x1m plots) – extrapolate to 1246x juveniles	0.18	Vegetative	All plants juvenile – inadequate rainfall, kangaroo grazing.	Population scrub rolled in 2014 and burnt in 2015 as part of this project. Population now reticulated and fenced.
Gastrolobium hamulosum	1D	Part of the subpop now known as 1A (reserve).	4/11/2013	6x mature, 1x juvenile	1.1	Immature fruit	Altered fire regime, lack of recruitment.	
Gastrolobium hamulosum	1E	Actually further south						

		than coordinates – part of the subpop now known as 1A (reserve).						
TOTAL 2013 for new population 1AB = 7x mature, 2x juvenile								
Lysiosepalum abollatum	1A		12/11/2013	77x mature, 10x juvenile	2.2	Fruiting	No threats recorded.	Many plants senescent.
Lysiosepalum abollatum	1B		1/9/2015	0x plants				
TOTAL 2013 = 77x mature, 10x juvenile								
Lysiosepalum abollatum	2T		14/1/2013	17x mature	0.05	Dehisced fruit	Weed competition, herbicide drift.	
Verticordia staminosa subsp. staminosa	1A		31/10/2014	607x mature	44	Fruiting	Lack of successful recruitment, drying climate.	
Verticordia staminosa subsp. staminosa	1B		31/10/2014	7x mature	0.2	Fruiting	Lack of successful recruitment, drying climate.	
Verticordia staminosa subsp. staminosa	1C		31/10/2014	2x mature	0.4	Fruiting	Lack of successful recruitment, drying climate.	
Verticordia staminosa subsp. staminosa	1D		31/10/2014	17x mature	0.7	Fruiting	Lack of successful recruitment, drying climate.	
TOTAL 2014 = 633x mature								

Appendix 2. Compilation of ecological attributes of CR species in Wongan Hills resulting from literature review.

Species	*Acacia pharangites*	*Acacia vassalii*	*Daviesia euphorbioides*	*Gastrolobium glaucum*	*Gastrolobium hamulosum*	*Lysiosepalum abollatum*	*Verticordia staminosa subsp. staminosa*
Juvenile period	• Unknown . • Monitoring will be undertaken annually of the natural recruits at subpopulation 1A (see appendix 1) to determine juvenile period. • *Acacia spp.* start setting seed between 1-4 years (Doran et al. 1983) so potentially 4 years.	• 5 years (Shedley 2011). • Subpopulation 1C was heavily in bud, having burnt 5 years ago (see appendix 1).	• >50% of plants were flowering in the Hindmarsh translocation 2-3 years after propagation (Department of Parks and Wildlife 2005) • Therefore 3 year juvenile period.	• Unknown. • Difficult to determine due to stoloniferous nature of the species. Plants previously believed to be seedlings were more likely aerial stems arising following disturbance (Willers 2002)	• 4 years – 30% flowering; 3 years – 20% reproductive (Harris & Yates 2003)	• Translocation data shows after 3 years almost 50% plants flowering (Department of Parks and Wildlife 2011)	• At least 4 years (Yates et al. 2007).
Time to peak seed production	• Unknown • Longevity is also unknown but could be 60-70 years (see 'plant longevity'). • Estimate peak seed production as half way through life ~ 30 years.	• Unknown. • Subpopulation 1C in heavy bud, having burnt 5 years ago (see appendix 1), so peak seed production may be reached not long after maturity.	• Crown of most *Daviesia spp.* die back after 6 years resulting in reduced seed production (Schwarten 1995). • Assume then that peak seed production is between 3-5 years of age.	• Unknown due to difficulty in discerning seedlings from aerial stems (Willers 2002).	• Unknown	• Unknown	• Unknown
Quantity of seed produced per plant over course of life	• Produce 'abundant' fruit – 6 seeds per pod (Department of Environment and Conservation 2008a). • A lot of seed 'observed' in soil seed bank (Department of Environment and Conservation 2008a). • Essentially quantity unknown but can assume they are highly productive.	• Unknown • Assume fairly prolific due to the number of seed collected in 1997 (Department of Environment and Conservation 2011).	• Higher producer than other *Daviesia spp*. – 25% of the time will produce 2 ovules instead of 1 (Schwarten 1995).	• Total quantity of seed in Threatened Flora Seed Centre = 401 seed from 5 collections • Unknown low – moderate producer.	• Moderate number flowers, low seed set per plant, 2x seeds per flower (Stack & English 2002).	• Unknown.	• Low seed set relative to number of flowers produced – 1/3 of flowers produce a seed (Simpson 2011). At peak flowering, a plant can have up to 5000 flowers (Yates & Ladd 2004). • Median seed produced per

							plant in 1999 = 360, ranging from 56 to 2186 (Yates et al. 2007). • Highly productive.
Seed viability	• 1998 collection: 1/3 of collection empty when nicked, the rest shrivelled cotyledons: 2% germination (Crawford 2015) • Two subsequent collections were 97% and 100% viable (Crawford 2015).	• 1996 collection: 1159 seeds from populations 1 and 2 – 10% viability (Department of Environment and Conservation 2011). • 1997 collection: 3080 seeds collected from populations 1 and 2 – 90% viability (Department of Environment and Conservation 2011). • Seedlings sent to KP but none survived (Department of Environment and Conservation 2008).	• 80-100% germination for all *Daviesia spp.* in the study, including *Daviesia euphorbioides* (Schwarten 1995).	• One collection from Threatened Flora Seed Centre had 90% viability (Crawford 2015).	• 91-97% germination initially, one sample only 5% (Stack & English 2002).	• Germination of fresh seed collections varied from 36-96% (Monks et al. 2009).	• 1995 collection – 2250 seed with 65% viability; 1 yr later in storage, viability dropped to 32% (Evans & Brown 2001). • 1996 collection – 700 seed collected with 73% viability, then 100% after 1 year storage (Evans & Brown 2001). • Viability high, but variable.
Seed predation levels	• Variable levels of predation (Department of Environment and Conservation 2008a).	• Unknown. • Assume ants eat part, leaving seed intact but sometimes burying at depth. • Significant galling of seed pods observed 1998 (Department of Environment and Conservation 2011).	• Ants predate seed and fruit is also predated by something while on the plant (Schwarten 1995). • Unknown levels.	• Evidence of weevil predation as a common occurrence (Harris & Yates 2003).	• Unknown, assume ants predate.	• Unknown	• Unknown
Soil-stored seed bank size	• Unknown. • Monitoring of seed plots and area adjacent within Mt Obrien burn area may give some indication.	• Unknown. • Only 3x plants have survived to maturity following fire at subpopulation 1C, while plants	• Unknown • Results from burn trials in 2011 and 2013, as well as prescribed burn in 2015 (see appendix 1)	• Unknown	• Germination following 2015 prescribed burn suggest a very large soil seed bank existed at this site of up to 234	• Unknown. • Germination at subpopulation 1A so there is a seed bank but not quantified (Department of	• Unknown • Assume decent size in available niches as germination occurs following good rainfall

		recruited en masse at population 6AB after the fire in 2002/4 (see appendix 1).	suggest a large soil seed bank is present in areas with reasonable sized habitat.		600 seed.	Parks and Wildlife 2003).	(Simpson 2011).
Soil seed bank longevity	• Unknown. • Hard-seededness suggests longevity as impervious to water (Doran et al. 1983). • Viability tests of old seed collections will give some indication.	• Unknown. • Hard-seededness suggests longevity as impervious to water (Doran et al. 1983). • Viability tests of old seed collections will give some indication.	• Seed burial trial found viability declined by 50% over 12 months, which is a significant and rapid decline (Schwarten 1995). • Hard seed coat suggests longevity (Phillimore & Brown 2000).	• Unknown	• 91-97% viability initially, 87-100% after 1 year in storage (IRP). • 49 year old collection of *Gastrolobium callistachys* had 5% viability from old seed collection viability testing. • Seed bank at populations 7 and 8 remained for at least 9 years in the absence of mature plants. Burning resulted in germination en masse.	• Seed longevity of other species in the Malvaceae is 'long' (Merritt et al. 2014).	• Potentially greater than 10 years due to physical and physiological dormancy (Simpson 2011).
Seedling attrition rate	• Unknown • Monitoring of natural recruits in subpopulation 1A will give some indication.	• Unknown.	• Recruits from 2014 prescribed burn - 91% survival after one summer. • Recruits from 2013 recruitment burn – 2013 germination results unknown, survival rate of plants present after the first summer until after the second summer = 48%	• Unknown	• 13% survival of scrub rolling recruits after one summer at populations 7 and 8.	• Unknown • At translocation site population 2T, 17 out of 34 planted in 2009 were still alive 2014. This may or may not be representative of seedling attrition in a natural population (Department of Parks and Wildlife 2011).	• In 1999 39% of germinants in cracks survived their first year, 40% survival in second year. • In shallow soil, 3% survival first year, 14% second year. • In 2000 -4% survival of germinants in cracks, 0% survival in soil (Yates & Ladd 2004).
Plant longevity	• Subpopulation 1A cleared and burnt 1946, then allowed to regenerate 2? years later (Duncan Holme 2015 pers. comm., 16 March). Plants from this event were senescent (although no dead) in 2014 (see appendix 1).	• Plants in population 2 (Moora District) have lasted at least 21 years assuming there has no inter-disturbance recruitment (Patrick & Brown	• *Daviesia spp.* often die after 8-10 years (Schwarten 1995). • Lives only 'a few years' (Phillimore & Brown 2000). • Assuming 10	• Difficult to estimate longevity due to inaccuracy of past reproductive condition data. Unable to say whether those	• Subpopulation 1A – seedlings resulted from grading in 2000. Some plants remain in this pop, indicating longevity of at least 15 years (Department of	• Unknown • Subpopulation 1A– in 2000 there were100x mature plants and 77x in 2013, still present (unknown number) in 2015. Recruitment	• In excess of 50 years (Yates et al. 2007). • Longevity may be limited by size of the fissure (Yates & Ladd 2004).

	• Assuming no inter-fire recruitment, longevity could be 60-70 years.	2001). Plants were not senescent 2013 (Mr N Sheehy 2015, pers. comm., 8 May). • No record of plants in population 1AB burning, apart from attempted burn in 2013 impacting the edges only and not taking any plants. The few plants that occur in this population could therefore be up to 70 years old. • Population 6AB burnt 2002 or earlier (Department of Parks and Wildlife 2007), so plants are at least 13 years old. • Subpopulation 1C burnt 5 years ago. • Longevity is at least 21 years and potentially up to 70 years old.	years based on the above and collation of TPRF records for this species.	plants recorded as seedlings in the past were seedlings or just shoots from stolons. • Significant decline in numbers in subpopulation 1B (found 1970) from 1980s to 1990s presumed to be due to a lack of disturbance and resulting senescence of individuals (Department of Environment and Conservation 2008b). Individuals in these pops still present, which indicates a minimum longevity of 45 years. This is supported by area not having been burnt since prior to the 1970s (Harris & Yates 2003).	Parks and Wildlife 2000a). • Subpopulations 1BCD have not been burnt since at least 1976 (Harris & Yates 2003), probably not since the 1940s. Subpopulations 1BC (now populations 8 and 7) still had plants present in 2006, then senesced sometime after (Department of Parks and Wildlife 2006). • So longevity could be 30+ years, likely up to 69 years. • Burn undertaken at *Acacia cochlocarpa subsp. cochlocarpa* site in 2000. *Gastrolobium hamulosum* germinated and still present 2015 – plants are at least 15 years old and not senescent (Ms L Monks 2015, pers. comm., 25 May).	recorded 3 times at a maximum of 10 or so seedlings so some of these plants would have to be mature (Parks and Wildlife 2003). • Therefore at least 15 years, possibly up to 69 years (germination following clearing and burning at this site).	
Fire response (Shedley 2011 codes)	• S (observations Mt Obrien burn 2015).	• S (Shedley 2011)	• Sr (Shedley 2011) – seeder with some capacity to resprout.	• R or RS (Willers 2002).	• S (Shedley 2011)	• Unknown • Area was cleared, cropped and burnt 1940s and it has recruited so it must be capable of recruiting following fire (Duncan Holme, 2015, pers. comm 16 March). • Scarification produces good	• Smoke water was not shown to enhance germination (Simpson 2011). • Fire kills plants (Yates et al. 2007). • This supports idea that fire is not required / is absent from the ecology of this

						germination under lab conditions (Monks et al. 2009).	species.
Seeder type (Shedley 2011 codes)	• Unknown	• Sm, Sd (Shedley)	• Sp – periodic recruitment spread over several years post fire (Shedley 2011).	• Likely to be seeder and resprouter due to high viability of seed. Seeder type unknown as recruitment from seed has not yet been observed in situ.	• Sm, Sd (Shedley 2011)	• Unknown	• Recruitment in absence of fire – usually in very wet years (Yates & Ladd 2004).
Resprouter type (Shedley 2011 codes	• N/A	• N/A	• Rb – regenerated from basal buds or lignotuber (Shedley 2011).	• Likely Rr / Rd (Willers 2002).	• N/A	• N/A	• N/A – yet can occasionally reproduce vegetatively (never in response to fire).

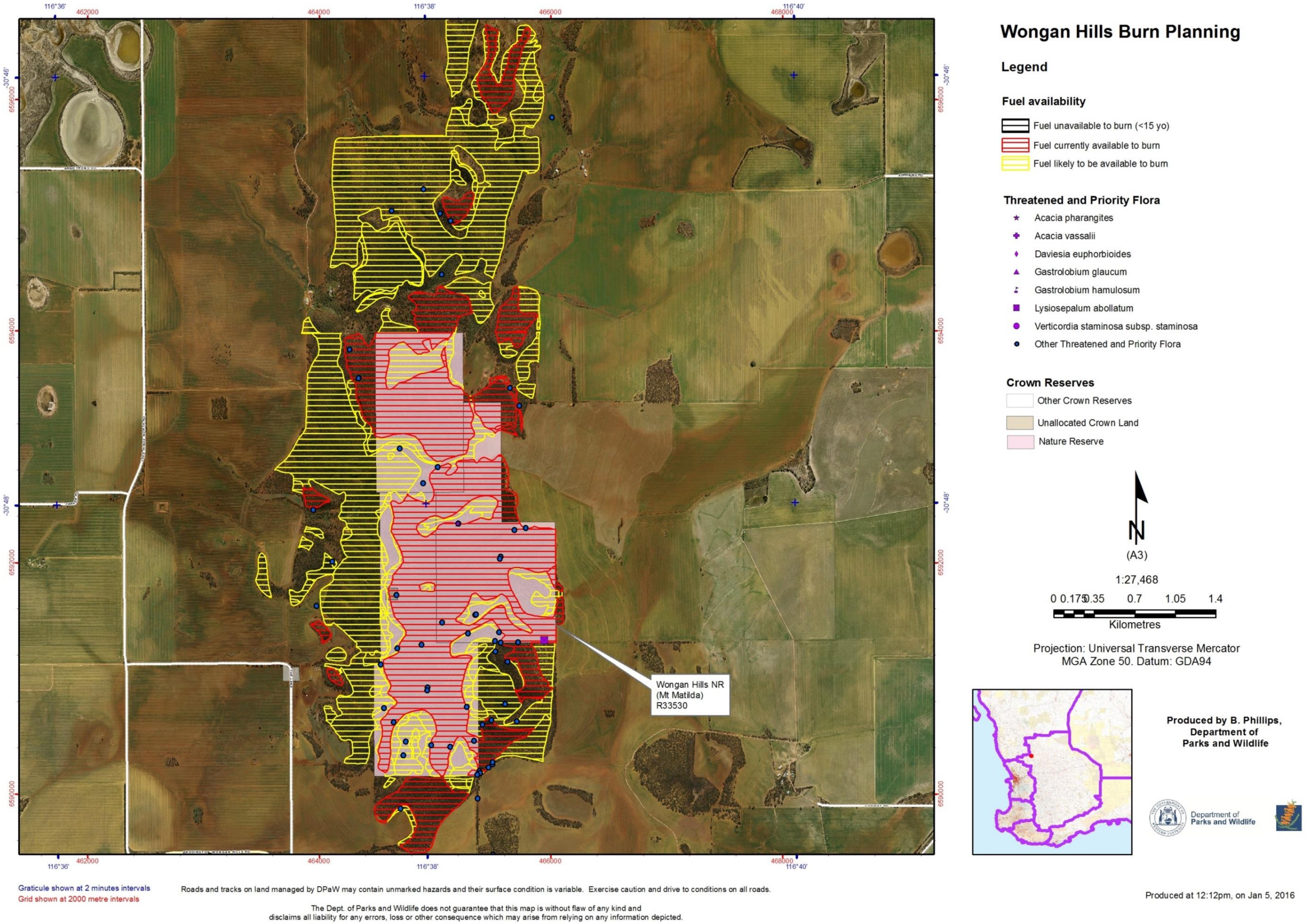
Appendix 3. Seed collections for Threatened Flora Seed Centre 2014-15 during Wongan Hills project.

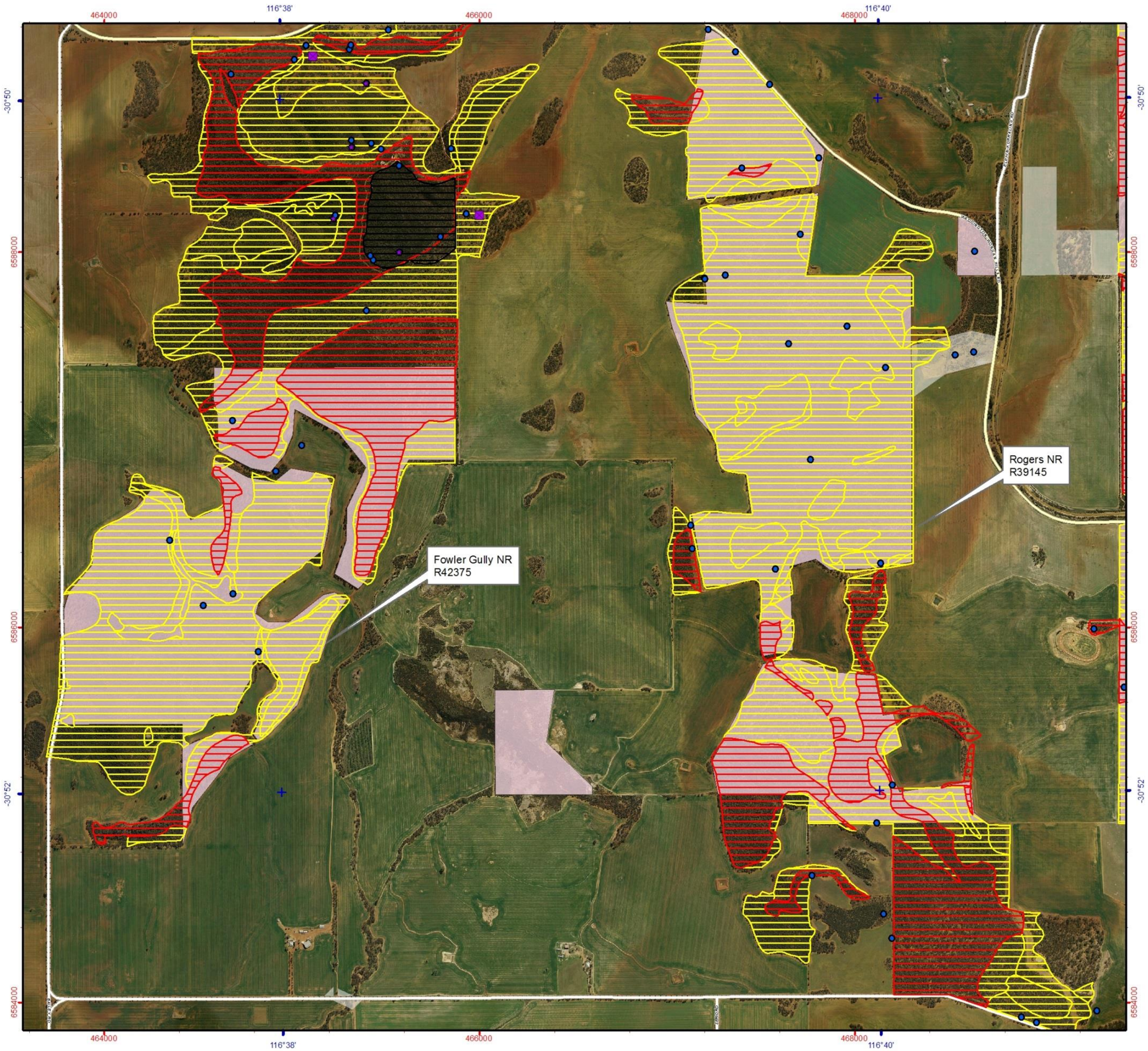
Species	Location
Verticordia staminosa subsp. staminosa	Mocardy Hill
Acacia filifolia	Craig Rd, Wongan Hills
Daviesia euphorbioides	Elphin NR railway
Daviesia euphorbioides	Elphin NR
Daviesia euphorbioides	Hudson Rd
Daviesia euphorbioides	Hindmarsh NR
Acacia vassalii	Wongan Hills. Pop 6A
Acacia vassalii	Wongan Hills
Acacia vassalii	Wongan Hills. Pop 7
Gastrolobium hamulosum	Craig Rd, Wongan Hills
Gastrolobium glaucum	Wilkins Rd
Acacia pharangites	Mt O'Brien
Acacia pygmaea	Mt Matilda NR. Pop 2
Acacia pharangites	Mt Matilda NR
Acacia denticulosa	Mt Matilda NR
Acacia pygmaea	Mt Matilda NR. Pop 1
Lysiosepalum abollatum	Mt O'Brien

Appendix 4. Vegetation type descriptions referred to in the Wongan Hills project from Coates (1988) and Coates (1992).

Vegetation type (code)	Description of vegetation type
Mt	Mallee over *Petrophile shuttleworthiana* / *Allocasuarina campestris* thicket
Kh	Mixed dense heath
Kt	*Allocasuarina campestris* thicket
Ks	Sedges / heath
Kdt	*Dryandra* / *Petrophila shuttleworthiana* thicket
Kdh	*Dryandra* low heath (likely to be the burnt equivalent of 'Kdt')
Ky1	*Allocasuarina campestris* / *Hakea erecta* heath (unburnt)
Ky2	*Allocasuarina campestris* / *Hakea erecta* heath

Appendix 5. **Detailed maps showing fuel availability of Wongan Hills vegetation based on project results and for the purpose of future burn planning.**





Wongan Hills Burn Planning

Legend

Fuel availability

- Fuel unavailable to burn (<15 yo)
- Fuel currently available to burn
- Fuel likely to be available to burn

Threatened and Priority Flora

- Acacia pharangites
- Acacia vassalii
- Daviesia euphorbioides
- Gastrolobium glaucum
- Gastrolobium hamulosum
- Lysiosepalum abollatum
- Verticordia staminosa subsp. staminosa
- Other Threatened and Priority Flora

Crown Reserves

- Other Crown Reserves
- Unallocated Crown Land
- Nature Reserve

N

(A3)

1:20,438

0 0.125 0.25 0.5 0.75 1

Kilometres

Projection: Universal Transverse Mercator
MGA Zone 50. Datum: GDA94

Produced by B. Phillips,
Department of
Parks and Wildlife

Department of Parks and Wildlife

Graticule shown at 2 minutes intervals
Grid shown at 2000 metre intervals

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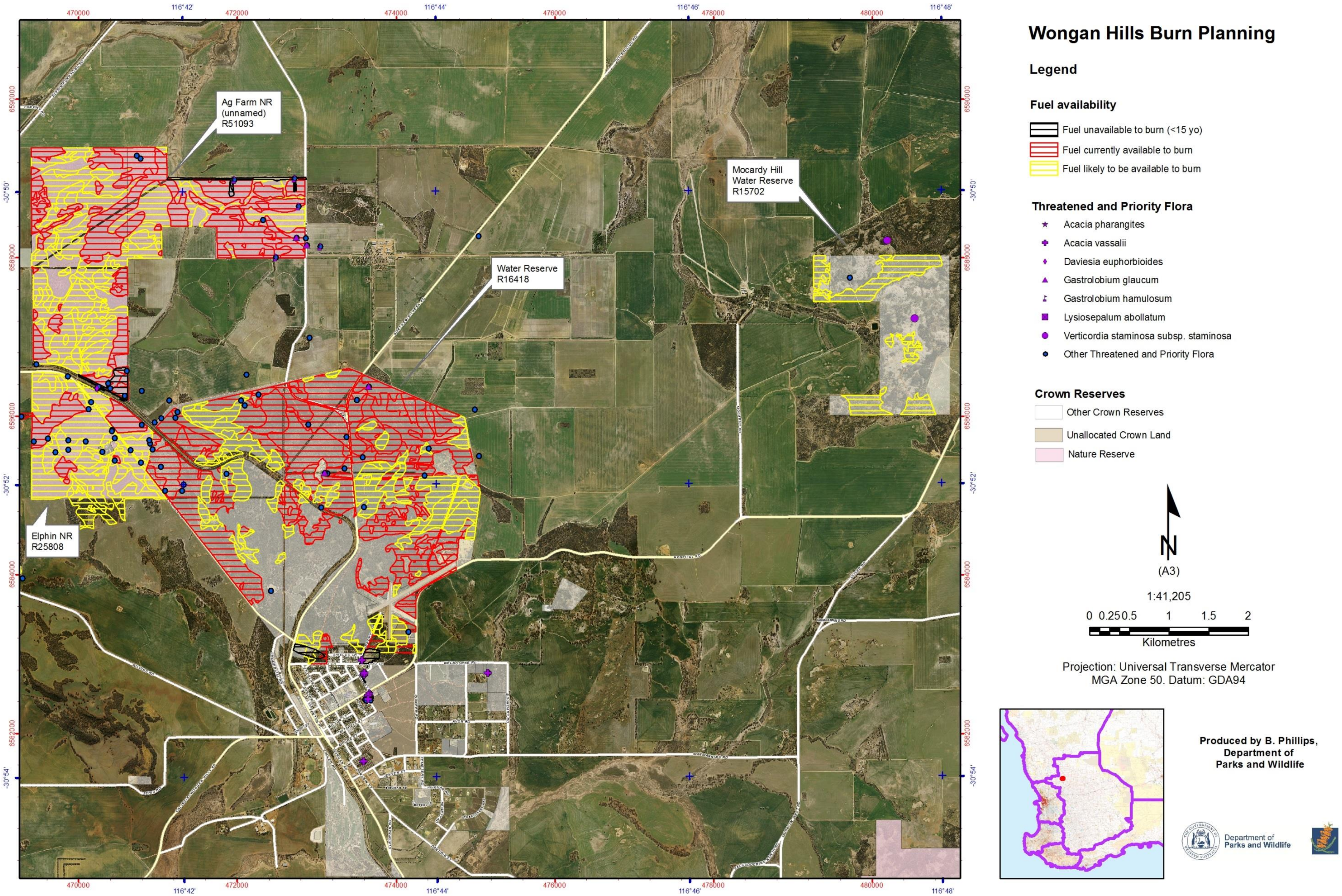
Produced at 12:12pm, on Jan 5, 2016



Graticule shown at 2 minutes intervals
Grid shown at 2000 metre intervals

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