Gnangara Sustainability Strategy
An across-government initiative

Groundwater – Biodiversity – Land use

GUIDELINES FOR DEVELOPING ECOLOGICAL BURNING REGIMES FOR THE GNANGARA GROUNDWATER SYSTEM

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Department of Environment and Conservation

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Report for the Gnangara Sustainability Strategy and the Department of Environment and Conservation

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Summary

- Development of fire regimes that are optimal for biodiversity conservation is one of the major challenges in current fire management throughout Australia.
- Although the impact of inappropriate fire regimes has been identified as a major threat to biodiversity on the Swan Coastal Plain information on these impacts has been limited.
- Recent studies on the GGS (2007-2010) have increased knowledge of the impacts of fire on biodiversity, and of fire records and fuel ages.
- This document utilised this recent information to develop guidelines for ecological fire regimes on the GGS to protect biodiversity.
- The guidelines are also essential to assess the Gnangara Sustainability Strategy proposal to increase burning for recharge benefits.
- Specific ecological objectives were to:
    - ➢ develop and maintain ecologically defined temporal and spatial age-class distribution for vegetation communities,
    - ➢ increase long unburnt areas for vegetation and fauna communities,
    - ➢ maintain refugia for significant species and wetlands,
    - ➢ monitor age classes, refugia, flora and fauna,
    - ➢ adopt an adaptive management approach
- Vital attributes and juvenile periods of plant species were identified in order to determine appropriate fire intervals.
- Key fire response plant species were identified with juvenile periods of 4-6 YSLF (year since last fire) for fire sensitive species relying on seed for reproduction.
- Key fire response plant species included the two dominant Banksia species *Banksia menziesii* and *Banksia attenuata* (resprouters) with a juvenile period of 8 YSLF.
- A minimum fire interval of 8-16 years (twice juvenile period) is recommended based on the information for key flora fire response species.
- Analyses of the fuel age distribution (2009) found that the area of old fuel age (>21years) is very low, and 60% of the GGS is of young fuel age (1-7 years).

- *Banksia* woodlands and *Melaleuca/E. rudis* woodlands do not approximate the idealised distribution and are highly skewed to the 1- 6 years since fire age.
- Burning to approximate the idealised age distributions can be met over time and is likely to involve a decrease in annual area of prescribed burning.
- Key fire response fauna species were identified based on conservation status and data on the relationships to successional ages and response curves on the GGS.
- Strong evidence for post-fire seral responses and habitat requirements of reptiles and mammals was obtained from fauna studies.
- Burning regimes need to reflect the need for different types of fire so as to produce seral ages and habitats, including retention of long-unburnt *Banksia* and *Melaleuca* that are important to overall reptile abundance and species such as honey possum, quenda, rakali, *Neelaps calonotus, and Menetia greyii.*
- Burning regimes need to incorporate spatial aspects of fauna distribution and habitat (for example Honey Possums) to undertake appropriate burning around refugia and ecological linkages.
- The endangered Carnaby's Black Cockatoo is a key fire response species and *Banksia* woodlands in older fuel ages (20-30 YSLB) produced more seed to support populations compared to young fuel age (0–5 YSLB).
- It is recommended that management actions be undertaken to increase the amount of *Banksia* woodland in the 20-30 YSLF category to ensure maximal food resources (particularly with respect to the removal of pine plantations -a major food resource- up until 2027).
- Wetland biota on GGS is at high risk from fire including direct impacts on habitats, taxa and communities, and indirect impacts through declines in water quality.
- It is recommended that burning regimes ensure retention and protection of long-unburnt wetland-associated vegetation as refugia for high priority wetlands and for associated fauna species (for example Quenda, Rakali).
- There is a need to develop an adaptive management framework to monitor the impacts of ecological fire regimes and to evaluate and where necessary redefine ecological fire management objectives.

Introduction

The long-term effect of fire on a landscape varies according to sequences of fire events, rather than to a single fire event. Sequences of fires, known as fire regimes, are determined by four major factors: intensity (how severe fires are), frequency (how often fires occur), season (the time of year fires occur) and scale (the extent and patchiness of a fire). It is important to understand the fire regime in order to define risks to people and property, and to make management decisions (Bradstock *et al.* 2002). In terms of biodiversity, inappropriate fire regimes (for example long periods of fire exclusion, sustained frequent burning, large and intense wildfires and post-fire grazing (Burrows and Wardell-Johnson 2003) may lead to local extinctions of plants and animals and result in a loss of biodiversity and structural complexity over time (Burrows and Wardell-Johnson 2003). However, what may be an inappropriate fire regime for one species may be beneficial to another species (Whelan *et al.* 2006).

Fire management involves the prevention of fire, the suppression of existing fires, and the introduction of fire where it is appropriate. Fuel quantity and weather conditions are the most influential factors of fire intensity, but fuel quantity is the only factor that can be effectively controlled by fire management (Bowman 2003; Burrows *et al.* 2008). Therefore, fire regimes are commonly planned to reduce fuel loads so as to prevent or reduce the risk or intensity of wildfires (Attiwill and Wilson 2006). Prescribed burning refers to the planned use of fire to achieve these specific land management objectives to a predetermined area.

Development of fire regimes that are optimal for biodiversity conservation is one of the major challenges in fire management throughout Australia (Burrows 2008; Clarke 2008; Whelan *et al.* 2006). There are a range of evidence-based practical fire regimes that can be implemented to conserve biodiversity and protect property and life (Burrows 2008). Plant vital attributes and life histories developed initially by Noble and Slatyer (1980) have been employed to predict the responses of plant species and vegetation communities to fire and fire regimes and thus direct the development of ecologically appropriate fire regimes that will not result in local extinctions of plants and animals and structural complexity over time (Burrows and Wardell-Johnson 2003; Gill and McCarthy 1998; Tolhurst 1999;

Whelan *et al.* 2006; Woinarski 1999). Development of ecological fire regimes has commonly been based on plants as they are the first trophic level of terrestrial ecosystems. Vital attributes such as regeneration requirements, post-fire regeneration strategies, juvenile periods and the longevity of longer-lived woody species that mostly reproduce after fire are useful criteria to determine minimum and maximum intervals between lethal fires for a particular ecosystem (Burrows 2008).

The flora vital attributes model does have limitations that generally reflect knowledge gaps in our understanding of flora responses to fire (Cawson and Muir 2008). These include a lack of information on vital attributes for many flora species, deficiencies in understanding the effects of characteristics of the fire regime (fire intensity, extent and season) on flora vital attributes. For example, the regeneration response of a species may be vegetative after a surface fire or seed-based after a crown fire (Tolhurst and Friend 2001). Although the current model largely ignores these influences, monitoring could produce more knowledge about them

Determination of fire regimes for a particular area or ecosystem involves identification of the vital attributes of plant species in each community where possible and subsequently 'key fire response species' for each community (Friend *et al.* 1999). The 'key fire response species' are those that are most sensitive to fire because they are most likely to be disadvantaged by excessively short or long fire intervals. Having identified the key species it is possible to determine the time interval between fires required to conserve species, i.e. the maximum and minimum intervals between high intensity and lethal fires (Bradstock *et al.* 1996; Friend 1999; Gill and McCarthy 1998; Tolhurst 1999).

Studies of time-since fire (age of vegetation) and proportion of landscape for age intervals have been undertaken in environments subject to high fire frequency events where fire occurs randomly across the landscape. The models that are most stable are based on the Weibull probability distribution in the form of a negative exponential where there are more patches of recently burnt young vegetation and fewer of long unburnt (McCarthy *et al.* 2001; Tolhurst 1999). Although there is much support for a negative exponential distribution, there is some concern that the probability of ignition will not be the same for all communities (Clarke 2008; Gill and McCarthy 1998).

Fire mosaic patterns based on theoretically derived negative exponential distributions of vegetation/fuel age classes across an ecological unit (vegetation complex, habitat type or landscape unit) have been employed to develop ecological fire regimes (Fire Ecology Working Group 2002; 2004; McCarthy 2000; Tolhurst 1999; 2000; Wouters *et al.* 2000). The negative exponential function can be paramatised by various plant life history attributes (for example juvenile period and longevity of fire sensitive species) within the ecological unit that are used to set minimum and maximum fire intervals. The actual age distribution of a vegetation or landscape unit can be compared to the theoretical age distribution to identify age classes over or underrepresented. (Figure 1). These can then be assessed for burning if over represented, or exclusion if underrepresented.

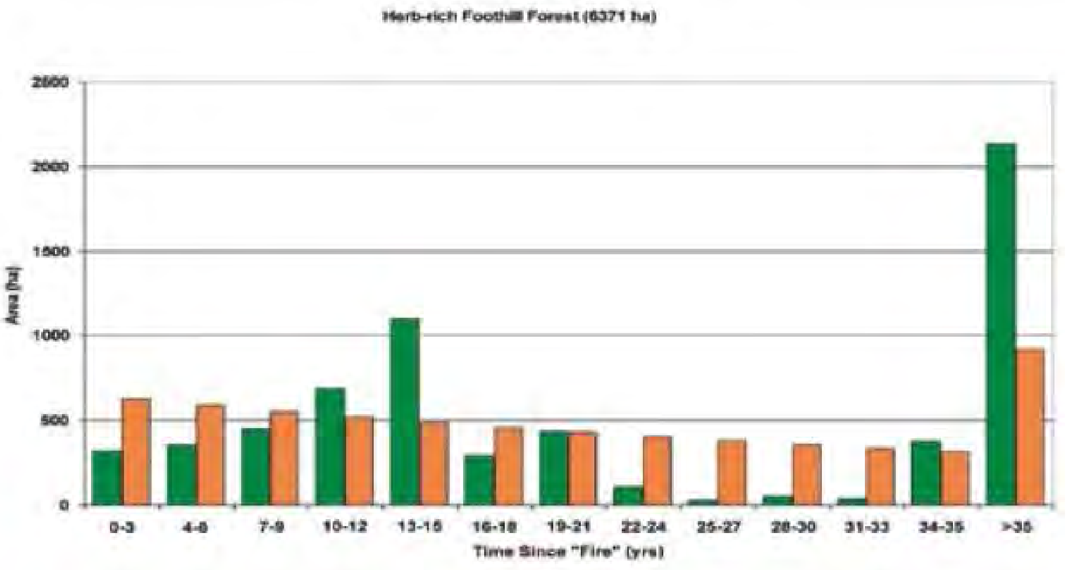


Figure 1. Idealised time since fire distribution (orange) and actual distribution (green) for herb-rich foothill forest in Victoria (Tolhurst 2000)

These ecologically-based fire regimes are not fixed rotational patterns but guide the prescribed burning regime required. They are dynamic systems requiring application of ongoing monitoring (Tolhurst 1999) which fits within an adaptive management framework (Burrows *et al.* 1999; Friend *et al.* 1999). Further it is necessary to identify areas where burning should be undertaken.

Another approach to developing ecological fire regimes is to establish detailed descriptions of the distribution of vegetation classes (post-fire seral stages or growth stages) according to functional habitat traits (for example floristic compositions, live & dead vegetation structure, surface litter coverage, biomass) all of which are a function of time since fire (Burrows 2008; Cheal 2010).

Historically ecological fire management regimes have focussed mainly on vegetation as providing habitat and successional phases for fauna (Fire Ecology Working Group 2002; Kenny *et al.* 2004). Ecological fire regimes appropriate for fauna can also be based on life histories, post fire succession patterns and habitat requirements (Friend 1993; Friend and Wayne 2003; MacHunter *et al.* 2009). Selection of key fauna fire response species has also been recommended (MacHunter *et al.* 2009). However significant differences in the response of animals to fire need to be accommodated (Bradstock *et al.* 2005; Clarke 2008). In contrast to plants, animals are mobile and the spatial components of their habitats and fire responses need to be assessed more closely. Fauna habitat requirements require more detail on spatial and landscape components that are necessary for survival post fire, dispersal and recolonisation. There is little information on the sizes, shapes, age structure or configurations of suitable habitat for fauna in relationship to fire dynamics and fire mosaics (Bradstock *et al.* 2005).

Fire regimes that provide patchiness and heterogeneity are widely considered to be a most appropriate management approach in fire-prone areas to maintain biodiversity (Burrows and Wardell-Johnson 2004; Gill *et al.* 2003). The fire- management strategies are commonly referred to as patch-mosaic burning (Parr and Andersen 2006). A major assumption is that because taxa exhibit different responses to fires, patchy burning will provide habitats over space and time that will cater for survival of biota across the landscape and within habitats (Bradstock *et al.* 1995; Burrows and Wardell-Johnson 2003). There are, however, major questions as to how much, or what patterns of mosaic burning are required, or what is the ecological significance for different taxa. These concerns have been designated as the fire-mosaic paradigm (Bradstock *et al.* 2005; Parr and Andersen 2006). For example as spatial scale is significant for fauna there is a need to identify to what extent a species may require patchy burns within its habitat. While some species require patchy burns, others may perceive these as fragmentation (Bradstock *et al.* 2005).

The development of ecological burning for GGS has involved identification of a broad ecological management objective, and more specific ecological objectives. As no single fire regime is optimal for all species and communities (Abbott and Burrows 2003;

Bradstock *et al.* 2005; Burrows 2008) our approach has been to develop diverse ecological burning regimes on the GGS where we aim to set ecological limits based on our current knowledge of impacts on biodiversity. Analyses of fire history records and age class distributions on the GGS have been undertaken recently (Sonneman and Kuehs in prep). Vital attribute information has also been obtained and key fire response species identified to enable the determination of minimum and maximum tolerable fire intervals (Wilson *et al.* 2010a). These information sets have been employed for comparison of actual and idealised age class distributions, and to determine requirements for burning to approximate ideal age class distributions of successional ages in vegetation communities.

In addition we have assessed specific post fire succession requirements for key species, threatened taxa and communities (for example wetlands, Honey possum, Quenda, Rakali, Carnaby's cockatoo Valentine 2010; Wilson *et al.* 2010a). Multivariate analyses of habitat requirements have been undertaken for some fauna species and communities in relationship to post-fire seral stages (Valentine *et al.* in prep.; Valentine *et al.* 2009b; Wilson *et al.* 2010a). These measurable attributes can be employed to assess the suitability of habitat for fauna, to assess ecological burning and fire management outcomes and for monitoring of age classes.

Based on this information on key fauna species and communities such as wetlands in this report we aim to identify possible refugia, particularly any long unburnt areas to be protected from burning frequencies that would result in the further decline of taxa and communities at risk from inappropriate fire regimes. This has entailed defining aspects of spatial and landscape identification of habitat. Further in this report mechanisms and processes for the input of the developed guidelines into the Department of Environment and Conservation (DEC) prescribed burning management plans have been identified. An outline of an adaptive management approach involving monitoring of age classes, refugia, flora, fauna and habitat has also been described.

There is information available from bore monitoring and models that increased recharge on the GGS is related to increased frequency of burns (Vogwill *et al.* 2008). Modification of fire regimes on Crown land has thus been proposed as a cost effective option to enhance water yield to the Gnangara Mound (Canci 2005; Yesertener 2007). The draft Gnangara Sustainability Strategy released in 2009 (Government of Western Australia 2009b) recommended that in order for an increase in fire frequency to become a management option, the biodiversity consequences must be understood and the water yield and biodiversity balance quantified. A number of fire projects were undertaken for the Gnangara Sustainability Strategy (GSS) between 2007 and 2010 to address these gaps by improving our knowledge of the impacts of fire on biodiversity values on the Gnangara Groundwater System (GGS). The information in this document aims to guide fire management decisions for GSS with regards to the protection of biodiversity, and is essential also to provide a basis for any decision to increase burning for recharge benefits as proposed as an option by the GSS (Government of Western Australia 2009b).

Fire regimes on the GGS are not the only threat to biodiversity. The impacts of fragmentation, rainfall and aquifer declines, the plant pathogen *Phytophthora cinnamomi* and introduced predators have all been found to be having serious impacts on biodiversity (Government of Western Australia 2000a; Mitchell *et al.* 2003; Wilson and Valentine 2009). The interactions and compounding effects of these impacts must be taken into account when developing ecological fire regimes on the GSS.

Gnangara Groundwater System

The Gnangara groundwater system is located on the Swan Coastal Plain (SWA2) IBRA sub-region, north of the Swan River, Perth, Western Australia and covers an area of approximately 220 000 hectares (Figure 2) The Gnangara groundwater system consists of an unconfined, superficial aquifer known as the Gnangara Mound that overlies the confined Leederville and Yarragadee aquifers, as well as the smaller Mirrabooka and Kings Park aquifers (Government of Western Australia 2009b). The area covered by the Gnangara groundwater system represents a distinct water catchment that extends from Perth (Swan River) in the south, to the Moore River and Gingin Brook in the north, and from the Darling Scarp in the east to the Indian Ocean in the west (Government of Western Australia 2009b). The Gnangara Mound is directly recharged by rainfall (Allen 1981; Government of Western Australia 2009b) and provides the city of Perth with ~ 60 % of its drinking water. It supports numerous significant biodiversity assets, including the largest patch of remnant vegetation south of the Moore River, a number of Bush Forever sites, threatened species and ecological communities, and ~ 600 wetlands. However, declining rainfall and runoff levels in the past 30 years have heavily impacted on water availability and the ecosystems in the region.

The impacts of a drying climate and declining groundwater levels strongly influence the water levels of the Gnangara groundwater system (Froend *et al.* 2004; Horwitz *et al.* 2008). Since the late 1960s, monthly rainfall has generally been below average (Yesertener 2007), resulting in decreased flows to public water supply dams and declining groundwater levels in the aquifers (Vogwill *et al.* 2008). Indeed, groundwater levels have decreased by up to 4 m in the centre of the Gnangara Mound and the eastern, north-eastern and coastal mound areas have experienced declines in the water table of 1 – 2 m (Yesertener 2007).

The Gnangara Sustainability Strategy

Maintaining biodiversity is fundamental to maintaining ecosystem processes and is an environmental policy and priority of both Commonwealth and State Governments in Australia. To tackle the impending water crisis, the Gnangara Sustainability Strategy (GSS) was initiated to provide a framework for balancing water, land and environmental issues; and to develop a water management regime that is socially, economically and environmentally sustainable for the Gnangara groundwater system (DOW 2008). A multi-agency taskforce was established in 2007 to undertake the GSS project, which incorporates existing land and water use policies, studies on the ecosystem assets and processes, and the development of a decision-making process to integrate values, risks and planning processes (DOW 2008).

The draft Gnangara Sustainability Strategy was released in 2009 (Government of Western Australia 2009b). The project undertook modelling of the relative impacts of climate, water abstraction and land use on the water balance of the groundwater system out until 2030. Under all but the most optimistic assumptions for climate, declines in groundwater storage and water levels are predicted. Major recommendations of the Strategy included: reduction of public and private abstraction by 20%, the development of desalination plants, increased recharge from treated wastewater, and storm water, development of local area models and risk assessment to identify wetlands and GDEs at most risk, accelerated removal of pines and establishment of strategic ecological linkages. Protection of remnant vegetation from threats (fire, dieback, fragmentation, predators) was also recommended.

Figure 2. Location and extent of the Gnangara Groundwater System and the Gnangara Sustainability Strategy (GSS) study area

The implementation of the optimum fire regime that will maximise groundwater recharge, while maintaining biodiversity values was a further major recommendation.

The GSS project modelling of the relative impacts of climate, water abstraction and land use on the water balance of the groundwater system out until 2030 was based on PRAMS (Perth Regional Aquifer Models). The GSS base scenario - burn regime of 10% total native vegetation each year on 10-year rotation i.e. 10% vegetation burnt in 2008 will be re-burnt in 2018

One of the challenges involved in developing a land and water use management plan for the GSS study area is the strong interconnectedness between land uses and hydrological balance, which in turn affects consumptive water yields and the ecological integrity of water-dependent ecosystems and other terrestrial ecosystems. Modification of fire regimes on Crown land has been proposed as a cost effective option to enhance water yield to the Gnangara Mound (Canci 2005; Yesertener 2007). Information from bore monitoring found that recharge of > 0.5-2 m occurred 3-4 yrs post fire (Canci 2005; Yesertener 2007) and models and hydrographs that increased recharge was related to increased frequency of burns (Vogwill *et al.* 2008).

In order for an increase in fire frequency to become a management option, the biodiversity consequences must be understood and the water yield and biodiversity balance quantified. The GSS seeks to address these gaps by improving our knowledge of the impacts of fire on biodiversity values on the Gnangara groundwater system. A number of fire projects were undertaken for the GSS (2007-2010). The projects include:

1. *Recharge and fire in native Banksia woodland on Gnangara Mound.* (Silberstein *et al.* 2010)

This project was undertaken by CSIRO and examined the effect of fire on ground water recharge. This project was designed to determine the changes in water recharge to the groundwater table under native vegetation following fire, and the time course of recharge accompanying recovery of the vegetation after fire.

2. *Impact of fire on biodiversity of the Gnangara Groundwater System* (Wilson *et al.* 2010a)

The second project was undertaken by DEC GSS to examine the impact of fire on biodiversity. This was addressed by a number of sub-projects carried out between 2007 and 2010. A summary of their findings are presented in the report on the impact of fire on biodiversity of the GGS (Wilson *et al.* 2010a) however more detailed information can be found in the relevant technical reports. The sub-projects included:

- *Patterns of ground-dwelling vertebrate biodiversity* (Valentine *et al.* 2009b). This fauna survey assessed the current distribution of terrestrial vertebrates across the GGS, examined biodiversity patterns, and assessed susceptibility of taxa and communities to threats such as declining groundwater and fire.
- *Impact of fire on avifaunal communities* (Davis 2009a). This project investigated the impact of prescribed burning on diversity, composition and abundance of avifauna
- *Post-fire response of terrestrial fauna* (Sonneman *et al.* 2010). This study compared the pre- and post-fire faunal assemblages of sites following a wildfire in January 2009.
- *Patterns of floristic diversity* (Mickle *et al.* 2009). This project assessed the current occurrence and distribution of plant taxa across the GSS fauna study sites, and examined species composition between landforms (Bassendean and Spearwood dunes), vegetation types, and between sites with different fire ages.
- *Post-fire juvenile period of plants* (Mickle *et al.* 2010b). The project collected secondary juvenile period (post-fire time to flowering) information for in *Banksia* woodland after a prescribed fire to assess the juvenile period of flora species for the purpose of determining the appropriate fire interval (burn regime).
- *Time to Flowering across a fire chronosequence* (Mickle *et al.* 2010a). The study obtained specific fire response (for example post-fire regeneration strategies) and secondary juvenile period (post-fire time to flowering) information for plants whose first time to flowering following fire exceeds 18 months (as examined in project above).
- *Food availability for Carnaby's Cockatoo in relationship to fire regimes on the GGS* (Valentine 2010). The study assessed food availability, in the form of fruiting cones, of populations of *B. attenuata* and *B. menziesii* at sites of different time since fire. The information was then examined in relation to the caloriphic content

of Banksias as a food item for Carnaby's black-cockatoos. The outcomes are assessed in relation to fire management recommendations to optimise food availability for this endangered bird.

3. *Spatial Fire history analysis in the GSS study area* (Sonneman and Kuehs in prep)
The aim of this project undertaken by DEC GSS were to update the AFED spatial dataset using remote sensing information and DEC databases for the GSS study area to more accurately determine fire history, current fire regime and fire frequency. Landsat imagery was employed to check and update the fire boundaries, check the accuracy of the year since last fire for areas, examine the burning frequency within the study area over the last thirty years. This information has then been used to develop an ecologically based fire regime model to direct future fire management within the study area.

4. *Fire Management Operations on the GSS Study area* (Muller 2010)
The purpose of this report was to review fire management operations on the major areas of Crown Land managed by DEC on the Gnangara groundwater system in relation to the impacts of such practices on groundwater recharge and biodiversity.

5. *Guidelines for Ecological burning regimes for the Gnangara Groundwater system* (Wilson *et al.* 2010b)
The subject of this report, the purpose was to develop ecological burning regimes and fire management guidelines on the major areas of Crown Land managed by DEC on the Gnangara groundwater system in relation to the impacts of such practices on biodiversity.

General description of flora & fauna on the GGS

The south-west of Western Australia is recognised as a global biodiversity hotspot within this region (Hopper and Gioia 2004) and the GGS constitutes an important component. The study area is located within the subregion of the Swan coastal plain (SWA2) as defined under the Interim Biogeographic Regionalisation of Australia (IBRA). Forming 30 per cent of the IBRA, the GSS study area represents a vital component of this biogeographical element. Although there have been large amounts of clearing for urbanisation and agriculture, the total remnant native woodland in the GSS study area covers more than

100,000 hectares (approx. 50% of the total GGS area), including the largest continuous area of remnant vegetation on the Swan coastal plain south of the Moore River. The remnant woodland within the GSS study area has significant state biodiversity values, containing as it does a number of Bush Forever areas, threatened species and ecological communities, and a suite of approximately 600 wetlands.

Table 1. Current (2005–06) and pre-European extent of vegetation complexes in the GSS study area (Heddle *et al.* 1980). Those in bold indicate that > 60% is located within GSS study area. (* area in DEC managed land as defined by Sonneman and Brown (2008)).

Landform	**Vegetation complex**	**Pre-European extent in the GSS**		**Current extent in the GSS**		**Current extent protected in the GSS***	
		ha	**%**	**ha**	**%**	**ha**	**%**
Quindalup Dunes	Quindalup	15 843	30	9614	61	1804	11
Spearwood Dunes	Cottesloe - central and south	21 593	48	8381	39	3575	17
	Cottesloe - north	21 399	49	15 461	72	5038	24
	Karrakatta - central and south	24 284	49	3484	14	1348	6
	Karrakatta - north	15 365	35	5868	38	778	5
	Karrakatta – north transition	**5260**	**100**	**4751**	**90**	**2102**	**40**
Marine (estuarine and lagoonal) deposits	Vasse	549	5	6	1	5	1
Wetlands	Herdsman	4144	43	996	24	770	19
	Pinjar	**4893**	**100**	**1140**	**23**	**905**	**18**
Combinations of Quindalup/Spearwood/Bassendean Dunes	Moore River	797	9	267	34	0	0
Bassendean Dunes	Bassendean - central and south	10 437	12	1923	18	1566	15
	Bassendean - central and south transition	2178	100	2176	100	2175	100
	Bassendean - north	**51 920**	**66**	**34 705**	**67**	**10 194**	**20**
	Bassendean – north transition	7789	37	6687	86	2845	37
	Caladenia	277	3	49	18	0	0
Combinations of Bassendean Dunes / Pinjarra Plain	Southern River	7490	13	1429	19	1047	14
Pinjarra Plain	Beermullah	1000	15	87	9	81	8
	Guildford	486	1	91	19	83	17
	Swan	1741	10	83	5	48	3
	Yanga	**16 321**	**62**	**3680**	**23**	**482**	**3**
Gingin Scarp	Coonambidgee	448	7	336	75	0	0
	Total	**214 214**		**101 212**		**34 846**	

The distribution of vegetation on the northern Swan coastal plain is predominantly determined by the underlying landforms and soils, depth to watertable and climatic conditions (Cresswell and Bridgewater 1985; Heddle *et al.* 1980). Heddle *et al*. (1980) defined broad vegetation complexes across the Swan coastal plain in relation to these landform–soil units (Churchward and McArthur 1980), and the varying climatic conditions. Twenty-one of these broad vegetation complexes occur in the GSS study area (Table 1; Figure 4). Three of the vegetation complexes are located entirely within the GSS study area (Bassendean Complex Central and South Transition, Karrakatta Complex North Transition and Pinjar Complex). In general, the main dune systems (Quindalup, Spearwood and Bassendean) and their associated vegetation complexes are dominated by a *Banksia* overstorey and sporadic stands of *Eucalyptus*, *Corymbia* and *Allocasuarina*, and an understorey consisting mainly of low shrubs from the *Myrtaceae*, *Fabaceae* and *Proteaceae* families. A complex mosaic of wetlands occurs on the Swan coastal plain, each fringed by *Melaleuca* spp. and *Banksia littoralis*, with variable understorey species from the *Cyperaceae*, *Juncaceae* and *Myrtaceae* families are also a significant feature (Semeniuk *et al.* 1990).

More detailed mapping of vegetation types has also been completed for existing remnant vegetation, but only over a proportion of the GSS study area (Mattiske Consulting Pty Ltd 2003). Thirty-two different vegetation types were identified and mapped, ranging from closed heath communities to *Banksia* woodlands and open eucalypt forests (Figure 4 and Table 2).

Table 2. Broad vegetation categories grouped based on Mattiske Consulting Pty Ltd (2003) vegetation mapping.

Vegetation category	**Current extent in GSS (ha)**	**Current extent protected in DEC Managed land**	
		ha	**%**
Banksia woodland	53 435	39 577	74%
Marri woodland	21 937	12 337	56%
Melaleuca and Eucalyptus rudis woodland	9 313	3 132	34%
Tuart woodland	2 382	959	40%
Heath/Shrubland	4 971	3 507	71%
Sedgeland	751	496	66%
Acacia Shrubland	398	212	53%
Casuarina woodland	10		0%

Floristic diversity

Species richness in the GSS is high – the total number of plant taxa recorded is 1901, including 1337 native taxa and 564 introduced taxa. The GSS study area contains some 17% of the floristic diversity in the South Western Australian Floristic Region (SWAFR), and nearly 50% of the native vascular plants recorded from the Swan Coastal Plain.

The highest diversity has been recorded in woodlands of the Bassendean dunes and on the eastern side of the plain (Government of Western Australia 2000b). Woody native species from the Myrtaceae and Proteaceae families tend to dominate the flora of the GSS and the Swan Coastal Plain (Barrett and Pin Tay 2005). Prominent overstorey species in the GSS include tuart (*Eucalyptus gomphocephala*), jarrah (*E. marginata*), marri (*Corymbia calophylla*), the coastal blackbutt (*E. todtiana*), *Melaleuca* spp., as well as several *Banksia* species, including the slender banksia (*B. attenuata*), firewood banksia (*B. menziesii*), holly-leaved banksia (*B. ilicifolia*) and the swamp banksia (*B. littoralis*).

Plant species richness varied among vegetation types, with *Banksia* woodlands containing most plant species, typically within the lower strata of vegetation (< 40 cm) (Kinloch *et al.* 2009a; Valentine *et al.* 2009a) and the lowest in *Melaleuca* damplands (Figure 3). *Banksia* woodlands are renowned for having high species richness (Dodd and Griffin 1989). Several of the *Melaleuca* sites in our study conformed to a seasonal wetland vegetation type that typically has low species number (Gibson *et al.* 1994).

A total of 47 species of rare flora occur within the GSS study area, of which 10 are declared rare flora (DRF) and 37 are priority flora (Atkins 2008) and a total of 10 Threatened Ecological Communities (TECs) have been recorded within the GSS study area (English *et al.* 1996). The Yanchep caves, tumulus mound springs, Muchea Limestone and Northern (Gingin) Ironstone communities are unique to the GSS study area and are listed as critically endangered (Gibson *et al.* 2000)

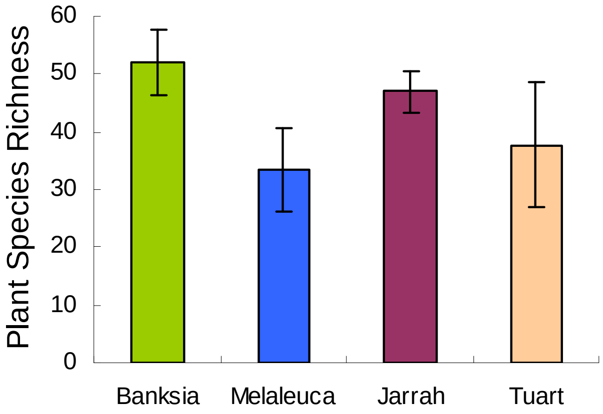


Figure 3. Average plant species richness (± 95% CI) across vegetation types, using untransformed data for ease of interpretation.

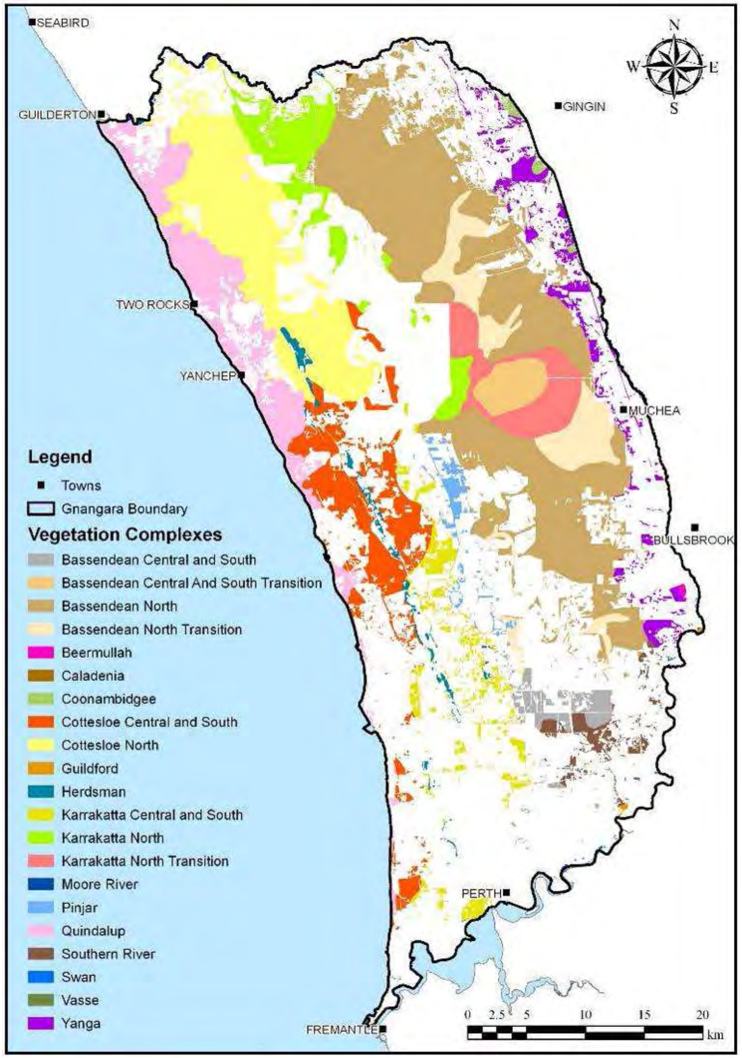


Figure 4. Heddle (1980).Vegetation complexes in the GSS study area in remnant vegetation as at 2006 (DEC 2009c)

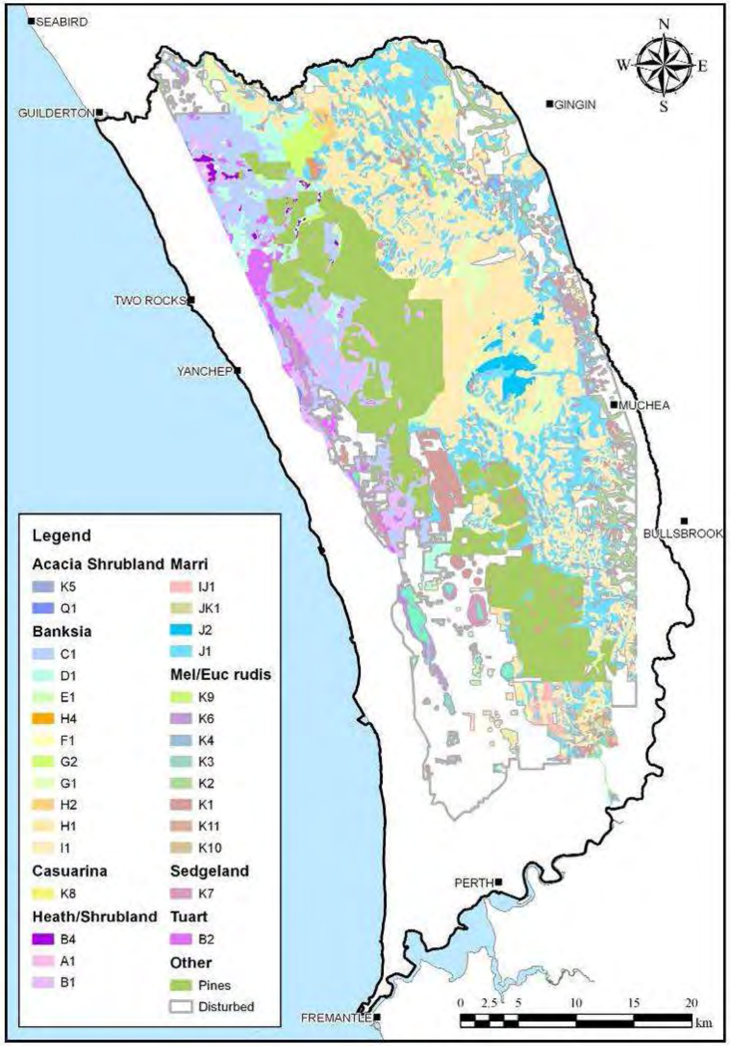


Figure 5. Site-vegetation types described within the GSS study area (mapped by Mattiske Consulting Pty Ltd (2003),).

Fauna Diversity

The GSS study area is known for the richness of its terrestrial vertebrate taxa. The reptilian fauna in particular is highly diverse, being represented by approximately 39 genera and 64 species including geckos, dragons, goannas, turtles and snakes (How and Dell 1993; 1994; 2000; Huang 2009; Storr *et al.* 1978; Valentine *et al.* 2009a). Thirteen frog species have been recorded over the study area (Bamford and Huang 2009). A total of 33 native mammal species were documented historically (1839–1907) on the northern Swan coastal plain, but by 1978 only 12 species (9 ground dwelling, 3 bat species) were recorded (Kitchener *et al.* 1978). Approximately 176 species of birds (excluding seabirds and migrants) have been recorded on the GGS. Of the extant fauna in the GSS study area, 12 frog, 27 reptile, 9 bird and 2 mammal taxa are considered regional endemics to south-west Western Australia. Of these taxa, one frog and seven reptiles are restricted to the Swan Coastal Plain.

There are currently six listed threatened fauna species, two of which are critically endangered – the western swamp tortoise *Pseudemydura umbrina* and the Crystal Cave crangonyctoid (Environment Protection and Biodiversity Conservation Act 1999). The taxa listed as priority fauna include three mammal, two bird, four invertebrate and one fish species (Government of Western Australia 2000b; Mitchell *et al.* 2003).

Reptiles are the most diverse and most abundant faunal group in the study area. Most reptile species have declined in local distribution and abundance in urban areas since European settlement and now remain in bushland remnants (How and Dell 1994; 2000). All 13 species of frogs (Bamford and Huang 2009) historically known to occur in the GSS study area still occur on the Swan Coastal Plain, with the possible exception of *Heleioporous barycragus*, which may occur only on the south eastern edge, and the burrowing frog *Neobatrachus pelobatoides*, formerly widespread but now known only from populations south of Perth (How and Dell 2000).

It is recognised that a number of bird species have become locally extinct or are declining on the Swan coastal plain (Government of Western Australia 2000b). Nine are regarded as extinct, or nearly so, and approximately 50 per cent of the passerines and 40 per cent of the non-passerines have declined in abundance since European settlement (Government of

Western Australia 2000b). Wetland birds have been particularly impacted by large-scale loss of coastal-plain wetlands (How and Dell 1993). Carnaby's black cockatoo (*Calyptorhynchus latirostris*) is listed as endangered under the Environment Protection and Biodiversity Conservation Act 1999. The birds feed on proteaceous plants including Banksia, Dryandra, Hakea and Grevillea (Shah 2006). Losses of feeding and roosting sites due to urban development have been identified as key threatening processes for this species. There are large populations in the GSS pine plantations, and the pines are considered to be a major habitat and food source. Black cockatoos roost in pines and mix pine seed and Banksia as major food sources.

The mammals of the GSS study area have experienced very high threats and impacts. More than half of the species known from the Swan coastal plain having become locally extinct by 1978 and all species exhibited declines in distribution and abundance (Kitchener *et al.* 1978). Species considered to be extinct from the northern Swan coastal plain include the woylie, tammar wallaby, numbat, brush-tailed phascogale and quokka (How and Dell 2000; Reaveley 2009; Valentine *et al.* 2009a). Species that are currently extant, such as the western grey kangaroo (*Macropus fuliginosuos*), are thought to be reasonably common, while others such as the bush rat (*Rattus fuscipes*), water rat (*Hydromys chrysogaster*), brush wallaby (*Macropus irma*), ash-grey mouse (*Pseudomys albocinereus*), honey possum (*Tarsipes rostratus*) and western pygmy possum (*Cercartetus concinnus*) occur only in restricted or isolated populations (How and Dell 2000; Kitchener *et al.* 1978; Reaveley 2009; Valentine *et al.* 2009b).

Although invertebrates are a major component of the terrestrial fauna, they have been studied little. Surveys on the Swan coastal plain have, however, uncovered a rich diversity of taxa (Harvey *et al.* 1997; How *et al.* 1996). A number of invertebrate taxa found in the Perth metropolitan area are listed as fauna likely to become extinct, four of them as priority fauna. They include the graceful sun moth (*Synemon gratiosa*) and two native bee species in the genera *Leiproctus* and *Neopasiphae* (DEC 2009a; Government of Western Australia 2000b).

Development of ecological fire regimes on GGS

These guidelines are prepared to guide fire management decisions for the GGS with regards to the protection of biodiversity, and to guide fire management of remnant vegetation and reserves. They will strengthen development of fire management plans for the Swan Region, strategic burning plans and burn prescriptions. The information is essential also to provide a basis for any decision to increase burning for recharge benefits as proposed as an option by the GSS (Government of Western Australia 2009b).

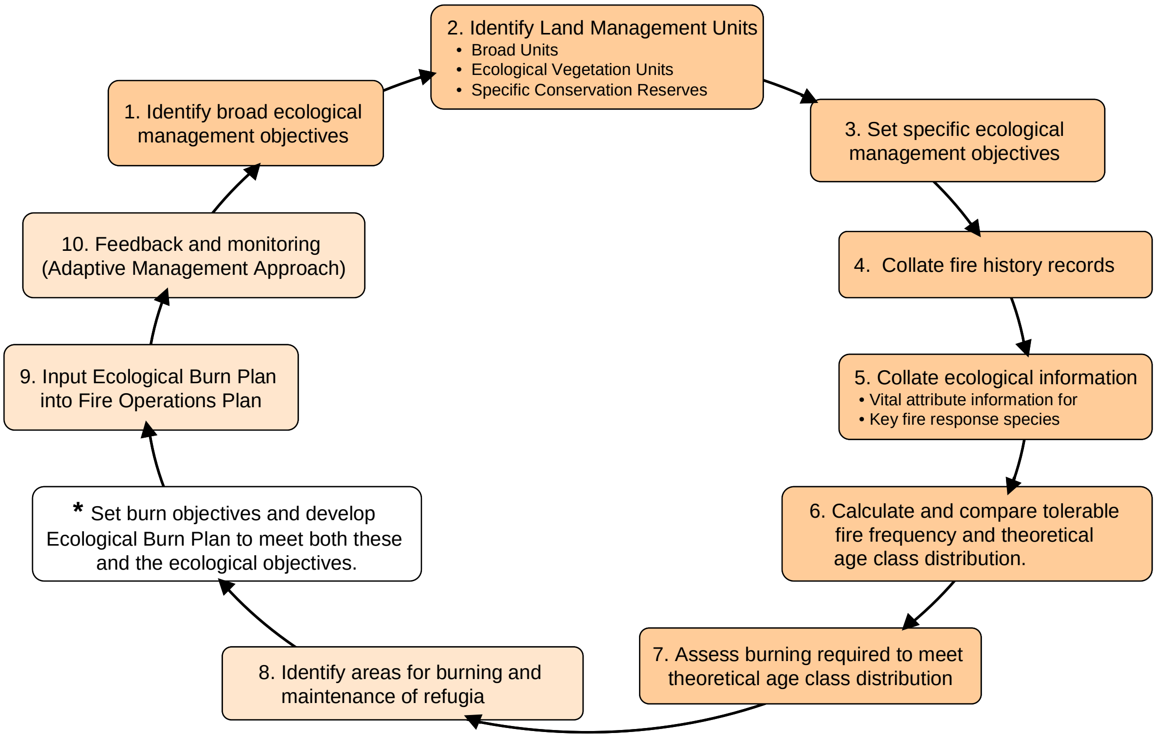


Figure 6. Process for the development of ecological burning regimes on the GGS. Pale coloured boxes indicate topics covered only partially in this report. Topic with no colour is not covered at all in this report however will be required for effective management of fire regime.

Procedures for developing an ecological burning regime have been developed previously (Fire Ecology Working Group 2004; Friend *et al.* 1999; Lindorff 2001; Shedley 2007; Tolhurst 1999). Based on these general procedures we have identified major stages appropriate for the GGS (Figure 6).

1. Scope and broad objectives for the ecological guidelines

A recent workshop identified broad ecological management objectives for fire regimes on the GGS (GSS Fire Workshop April 2010).

The broad objectives are to:

- Avoid inappropriate fire regimes for biodiversity
- Ensure long-term survival of taxa and communities
- Identify and develop appropriates ecological fire regimes

Further we have taken into account a range of general fire management principles that were developed for Western Australia based on the current scientific knowledge, to enhance biodiversity conservation and ecological management objectives (Abbott and Burrows 2003; Department of Natural Resources and Environment and Parks Victoria 1999). While the principles provide a strong framework for the development of these GGS guidelines, in some cases they may not be achievable, particularly in the fragmented remnants and reserves of the GGS.

Principle 1

The vegetation and climate of south-west WA make it highly prone to bushfire. Fire should be regarded as an environmental factor that has and will continue to influence the nature of south-west landscapes and biodiversity and is integral to conservation and land management.

Principal 2

Species and communities vary in their adaptations to, and reliance on, fire. Knowledge of the temporal and spatial scales of fires in relation to the life-histories of organisms or communities involved underpins the use of fire in natural resource management.

Principle 3

Following fire, environmental factors such as landform, topography and species' life history attributes, and random events such as climate events, often drive ecosystems towards a new transient state with respect to species composition and structure. This may preclude the identification of changes specifically attributable to fire.

Principle 4

Fire management is required for two primary reasons, which are not necessarily mutually exclusive: a) to protect and conserve the biota; b) to reduce the occurrence of large, damaging wildfires. The biological impact (killing power) of a single fire event and the rate of recovery are directly proportional to the intensity and size of the fire.

Principle 5

Fire management should be both precautionary and adaptive, considering ecological and protection objectives in order to optimise outcomes.

Principle 6

Fire diversity promotes biodiversity at both the landscape scale and the local scale. At the landscape scale, a mosaic of patches of vegetation representing a range of biologically-derived fire frequencies, intervals, seasons, intensities and scales will provide diversity of habitats for organisms that are mobile and can move through the landscape. At the local scale, appropriate fire regimes based on biological attributes are necessary to ensure the persistence of sessile organisms and structures.

Principle 7

Avoid applying the same fire regime over large areas for long periods of time and minimize seral and structural homogenization by not treating large areas with extreme regimes such as very frequent or very infrequent fire intervals.

Principle 8

The scale, or grain-size, of the mosaic should: a) enable natal dispersal; b) optimise boundary habitat (interface between two or more seral states); and c) optimise connectivity (ability of fauna to cross between seral states).

Principle 9

All available knowledge, including life histories, vital attributes of the flora and fauna and knowledge of Noongar fire regimes should be utilized to develop ecologically based fire regimes for a landscape unit or a vegetation complex.

Principle 10

Fire history, vegetation complexes and landscape units should be used to develop known and ideal fire age class distributions.

Principle 11

Wildfire can damage and destroy both conservation and societal values; hence risk management must be based on a systematic and structured approach to identifying and managing the consequences of such an event.

Principal 12

Fire management should adapt to changing community expectations and to new knowledge gained through research, monitoring and experience.

2. Landscape management units

The broadest landscape management unit for these guidelines is the GGS. Other management units that have been identified include conservation reserves that are examined in more detail as case studies to provide examples of analyses of fire history and development of ecological fire regimes including:

- Yeal Nature Reserve (11,243 hectares)
- Yanchep National Park (2,876 hectares)

Yeal Nature Reserve is the largest single DEC managed reserve in the Gnangara system and is found to the north east of the pine plantations (Figure 30). Yanchep National Park is located to the west of the GGS close to the coast, residential and rural zones (Figure 30). It has the highest number of visitors of reserves on the GGS. These reserves differ in landform, vegetation communities and management regimes. They will provide useful case studies for different aspects of developing guidelines for ecological fire regimes on the Gnangara system.

A selection of ecological vegetation units were examined in these guidelines to provide examples of the different management units to be aware of when managing the fire regime. Vegetation complexes defined by Heddle *et al*. (1980) and grouped by similar landform units (see Figure 4 and Table 1) include:

- Bassendean vegetation complex
- Cottesloe/Karrakatta vegetation complex
- Quindalup dunes vegetation complex

Vegetation types mapped by Mattiske Consulting Pty Ltd (2003) and grouped by dominant vegetation type (see Figure 4 and Table 2) include:

- Banksia woodland
- Marri woodland
- Melaleuca woodland

3. Specific ecological objectives

Specific ecological objectives identified were based on information obtained on impacts of fire on biodiversity on the GGS (Wilson *et al.* 2010a) and a recent workshop (GSS Fire Workshop April 2010).

Objectives identified included:

1. Develop and maintain an ecologically defined temporal and spatial age-class distribution for vegetation communities
2. Increase long unburnt areas for vegetation and fauna communities
3. Maintain refugia for significant species and wetlands
4. Monitor age classes, refugia, flora and fauna
5. Adopt an adaptive management approach

4. Fire history records and age class distributions

An analysis of the spatial fire history in the GSS study area was undertaken by Sonneman and Kuehs (in prep). The aims were to update the spatial annual fire event dataset using remote sensing information and DEC databases and to more accurately determine fire history, the current fire regime and fire frequency. Landsat imagery was employed to confirm and update the fire boundaries, assess the accuracy of the year since last fire for areas, and examine the burning frequency within the study area over the last thirty years.

Annual Burn Trends

Analysis of the annual area burnt by fire type (wildfire, prescribed burn) across the total GGS over a 39 year period (1970-2009) revealed that wildfires comprised from 43 to 49% of total burns for each decade with an average of 46% (Table 3, Figure 7), while on DEC managed land wildfires constituted between 28 and 47% of total burns with an average of 38% (Table 3). More than 90% of the area burnt by wildfires in fire seasons 1985/86, 2002/03 and 2008/09 was the result of a single wildfire. Of the other fire seasons where wildfires burnt greater than 1000 hectares (1971/72, 1979/80, 1990/91, and 1994/95) approximately 50% of the area resulted from a single fire. The largest wildfire occurred in 1985/86 and covered 10,179 ha.

There was a decreasing trend in the area of prescribed burning undertaken from 1970 to 2000 followed by an increase in the recent decade (Figure 7; Table 3). The area of prescribed burning was maximal in the early 1970's and minimal in the early 1990s. There was a decrease in the amount of prescribed burning undertaken following years where there was high wildfire activity (for example 1986/87 and 1994/95).

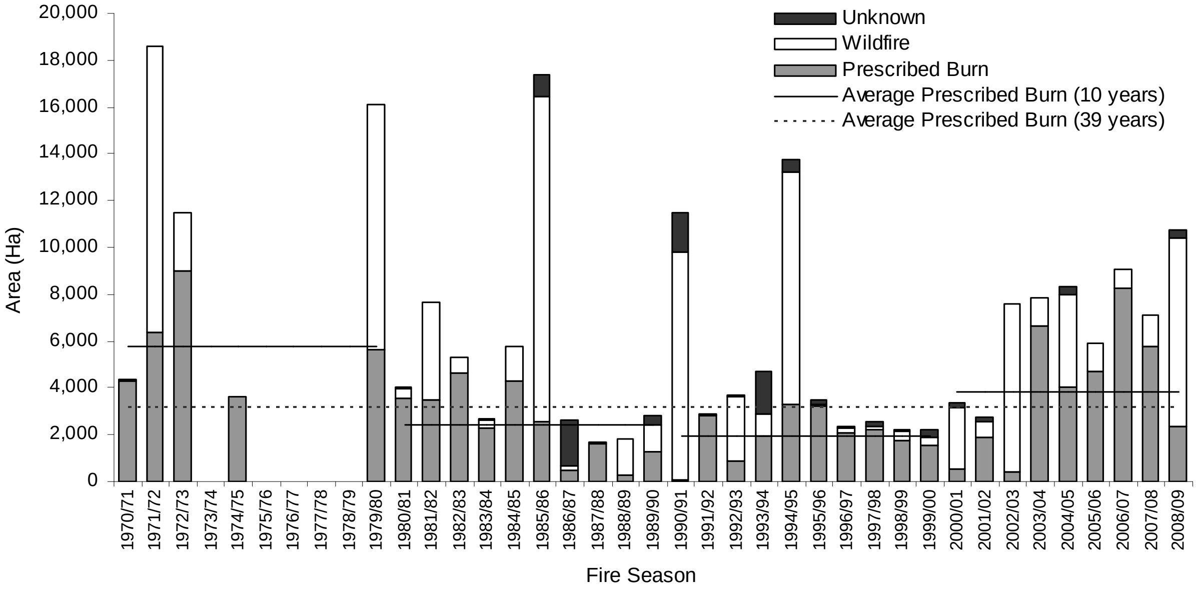


Figure 7. Annual area burnt by fire type across the Gnangara groundwater system (excluding pine plantation areas).

Table 3. Average hectares burnt in each decade by fire type for all remnant vegetation with the GSS study area as well as for DEC managed land only.

All Remnant Vegetation within GSS					
	Unknown	**Prescribed Burn**	**Wildfire**	**Number of Years of data**	**% Wildfires**
2000/01-2008/09	112	3832	3025	9	43%
1990/91-1999/00	515	1976	2438	10	49%
1980/81-1989/90	355	2437	2389	10	46%
1970/71-1979/80	0	5775	5069	5	47%
Average for 39 yrs	**286**	**3161**	**2966**	**34**	**46%**
DEC Managed Land					
	Unknown	**Prescribed Burn**	**Wildfire**	**Number of Years of data**	**% Wildfires**
2000/01-2008/09	39	3752	1464	9	28%
1990/91-1999/00	396	1914	1530	10	40%
1980/81-1989/90	254	2071	1721	10	43%
1970/71-1979/80	0	4684	4090	5	47%
Average for 39 yrs	**202**	**2854**	**1880**	**34**	**38%**

Area and numbers of prescribed burns and wildfires

Examination of the average area burnt per fire season (for fires >10ha) shows that over the last 20 years there is a trend towards larger prescribed burns particularly in the last 5 years(Figure 8a). The number of prescribed burns each year decreased from the 1970s (Figure 8b) but appears to have stabilized in the last 20 years

The average size of wild fires has decreased over time (Figure 8c). However the decline in average size of wildfires observed between the 1980's to the 1990's does not continue into the 2000's as might be expected with the increased area of prescribed burning. The number of wild fires each year shows a slight increasing trend (Figure 8d).

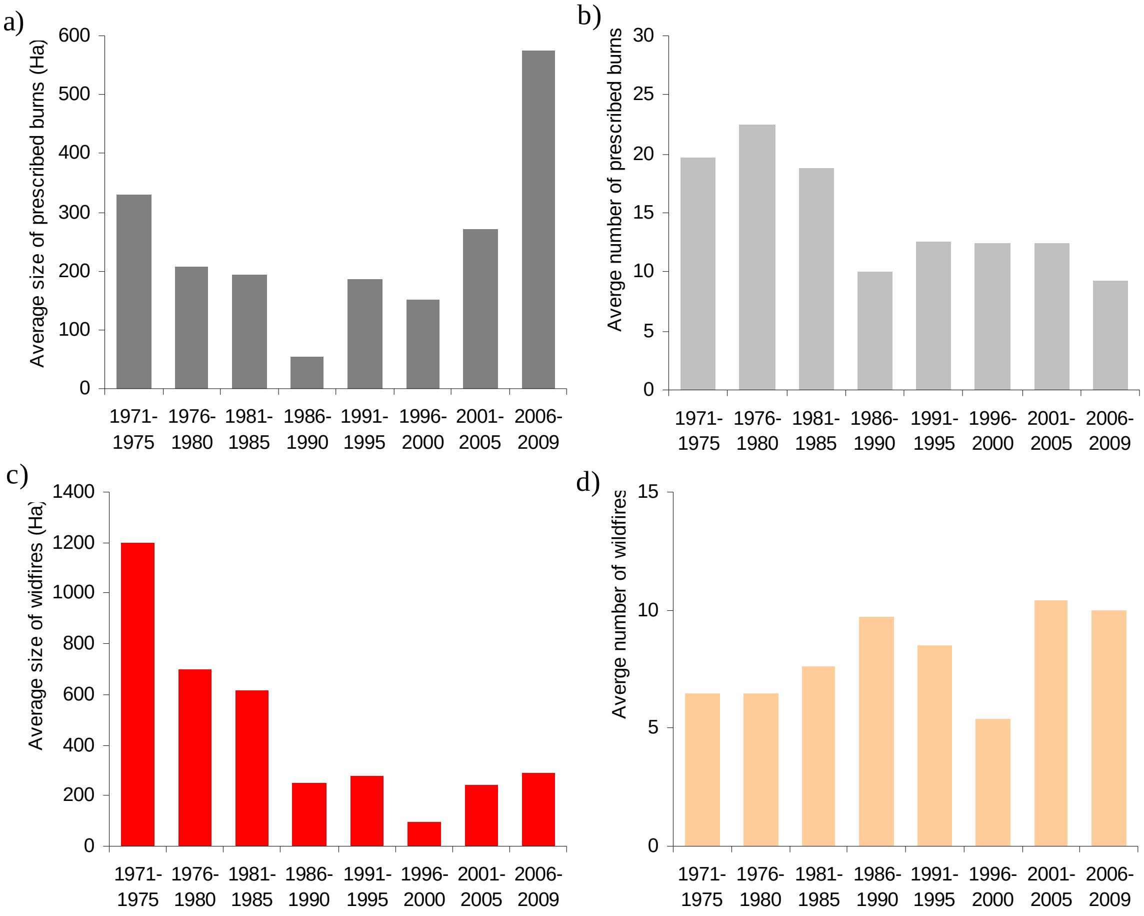


Figure 8. Average area of (a) prescribed burns and (c) wildfires and average number of (b) prescribed burns and (d) wildfires over the last few decades: 1972 to 2009. Data is limited to fires > 10 hectares as those smaller are considered predominantly to be errors in mapping. Years 1973/1974 and 1975/1976 to 19779/1980 are not included in the data due to missing data.

Fuel Age Distribution

The fuel age distribution as of 2009 for the whole Gnangara system (Figure 9) shows that the area of old fuel age (>21years) is very low. A major proportion of the area (60%) is in the 1-7 years since last burn range (Figure 9). The fuel age distribution for DEC managed land shows a similar distribution but with a somewhat higher percentage (67%) younger than 7 years.

The fire history of all remnant vegetation is unknown for 42% (59,002 hectares). Within DEC managed land, the percentage of land with unknown fire history is considerably less at 9% (6,364 hectares). Much of the area of unknown fire history outside of DEC land consists of private property located in the north east corner of the GGS (see Figure 11). Burning is thus likely to be undertaken privately and not recorded on the DEC system. Other fires attended only by non-DEC fire management services are also not recorded in the DEC system and are thus included in the unknown fire age category.

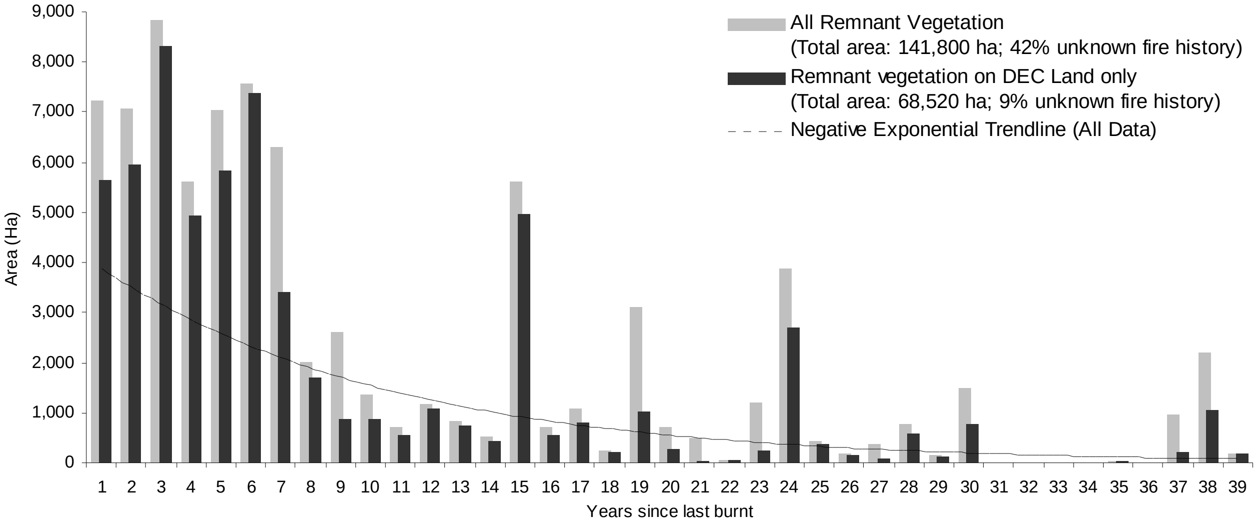


Figure 9. Fuel age distribution as at 2009 for all remnant vegetation and DEC managed land only within the Gnangara system. The dashed line shows the simplest negative exponential fit to all the data (it is no the theoretical distribution) but highlights the current trend).

Fuel age distribution was also analysed across selected vegetation groups. The fuel age distribution for selected vegetation complexes (Figure 10) and vegetation community types (Figure 11) show similar general patterns to the overall distribution. The Bassendean complex has a broad range of fuel ages covering almost every year for which there is data

(Figure 10). The distribution is however skewed with 58% being 2 to 6 years since last burnt. Only 8% of the Bassendean complex has an unknown fire history. The Cottesloe/Karrakatta complex has a similar distribution to the Bassendean complex and is skewed to 1-7 years post fire age. The Quindalup complex covers a small area (2,085 ha) and is the only vegetation complex that shows a clumped distribution where 40% is of one age (24 years). The remainder is predominantly 7 and 5 years since last burn. It is also the only complex for which the fire history is known for the entire area.

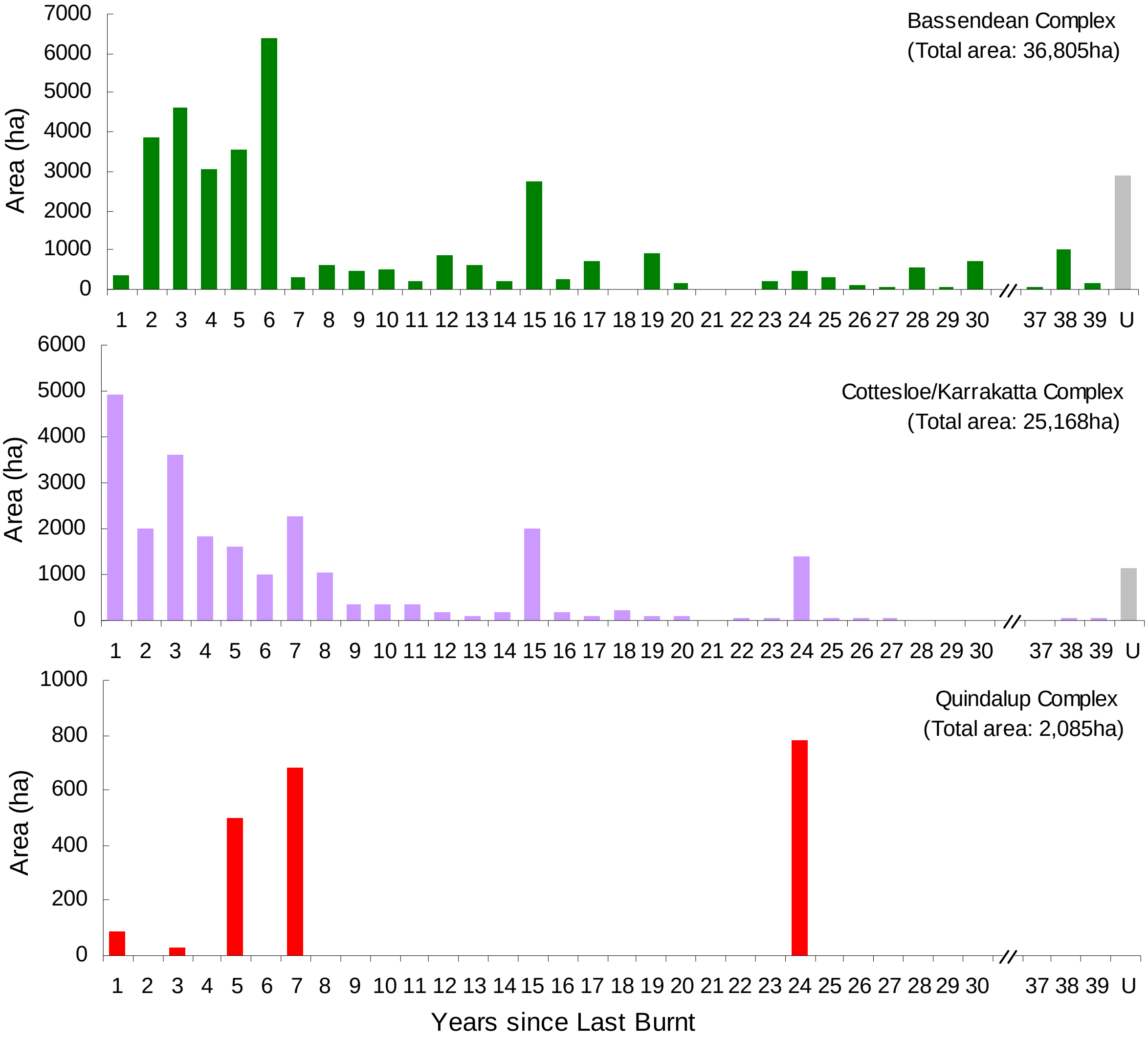


Figure 10. Fuel age distribution of Heddle (1980) vegetation complexes within DEC managed land.

The *Banksia* community has a broad range of fuel ages but is skewed to the 1 to 6 years since last burn (Figure 11). There is also a large area of 15 years since last burn. Marri has a similar distribution but has a higher area of unknown fire history (Figure 11). The *Melaleuca*/*Eucalyptus rudis* community covers a small area (2,895 ha) but has a similar distribution to the *Banksia* and Marri.

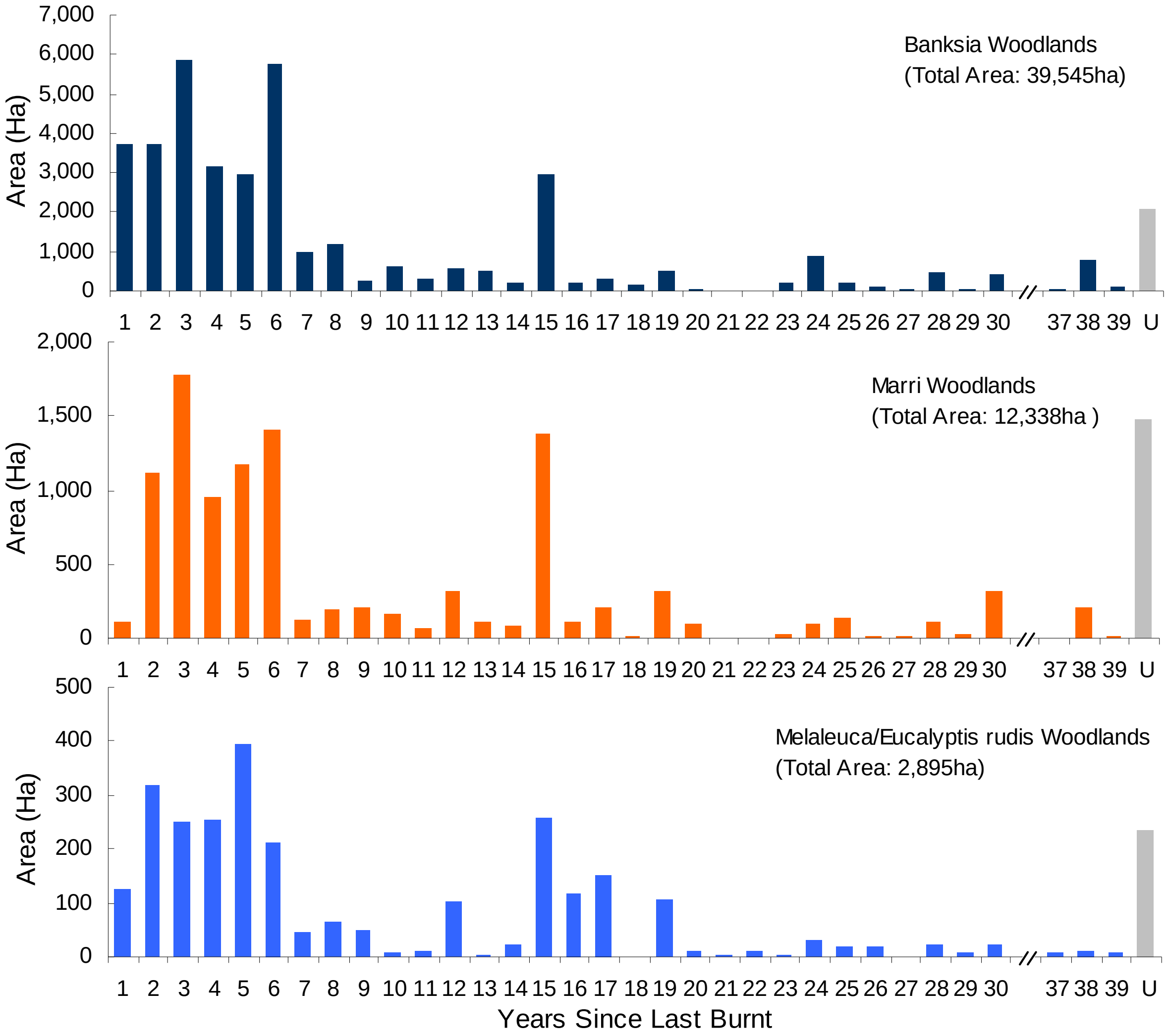


Figure 11. Fuel age distribution for vegetation categories Banksia, Marri and Melaleuca/Eucalyptus rudis (based on Mattiske Consulting Pty Ltd 2003) on DEC managed land

The spatial distribution of fuel ages shows there is a higher proportion of young fuel age (<5 years) surrounding pine plantations (Figure 14). The small areas of old fuel ages 21-39 years are predominantly limited to locations in the north east (Yeal Nature Reserve) and in the north west (Wilbinga Conservation Reserve).

Spatial autocorrelation using Moran's I evaluates whether a pattern expressed is clustered, dispersed, or random. The spatial distribution of fuel age for the whole Gnangara system (Figure 14a) is considered statistically clustered with a Moran's I of 0.1 with z = 2.65 and p = 0.01 indicating that there is a less than 1% likelihood that this clustering pattern in the result of random chance. Thus large areas of similar fuel age are highly clustered. There is no evidence of a patchy mosaic at the landscape spatial scale. For DEC managed land only

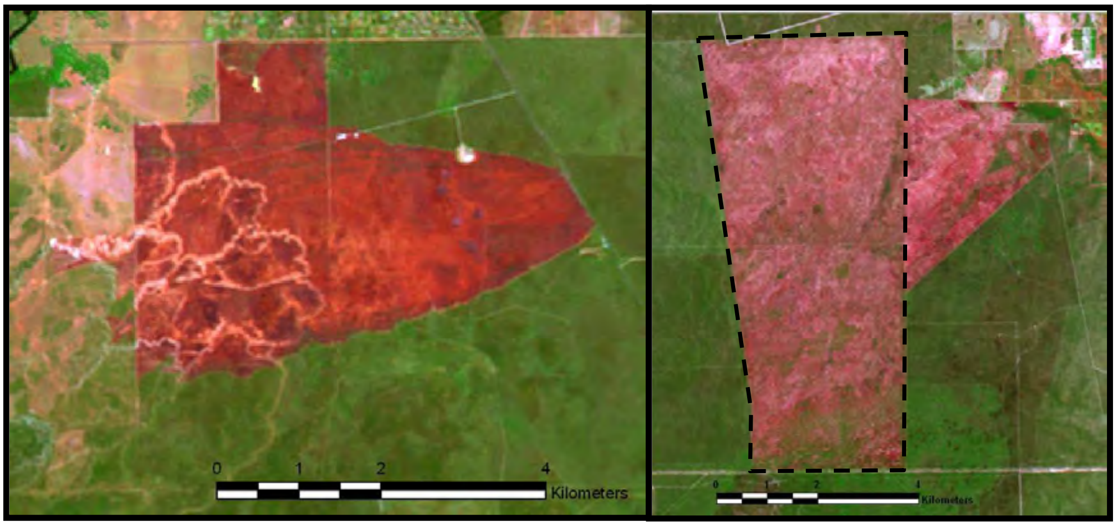
(Figure 14b), the Moran’s I is 0.09 with z = 3.06 and p = 0.01 meaning it is even more statistically clustered than all remnant vegetation.

The maximum area of the same fuel age is 5,471 hectares and is 6 years since last burnt. The second largest area of the same fuel age is 4,582 and is 1 years since last burnt. This area is predominantly due to the large wildfire occurring in January 2009 at Two Rocks and Yanchep. If fuel ages are grouped in to 5 year groups (as in Figure 14), the largest area is 7,456 hectares of 1-5 YSLB area. The maximum size of a continuous block of old fuel age 36-40 YSLB is 3,877 hectares.

Patchiness and Fire intensity

While no analysis of patchiness was performed, visual interpretation of enhanced Landsat imagery provides evidence that fires in Banksia woodland are predominantly non patchy. Figure 12 shows an example of a non-patchy wildfire and a prescribed burn within the GGS. Figure 13 shows comparative example of what patchy burns look like. Where prescribed burns were patchy, internal patches of older fuel age within prescribed burns were taken into account during the mapping process (Figure 13). Banksia woodland has a rich understorey of woody shrubs that provide an understorey that dominates the fuel complex in total quantity and continuity (Burrows and McCaw 1990). Fuel accumulation occurs rapidly in the first four years (5.5. t per ha) after fire, making the woodland predisposed to supporting intense and quick moving wildfire under extreme fire weather conditions (Burrows and McCaw 1990). Further the fuel dries rapidly and is susceptible to rapid spread by wind.

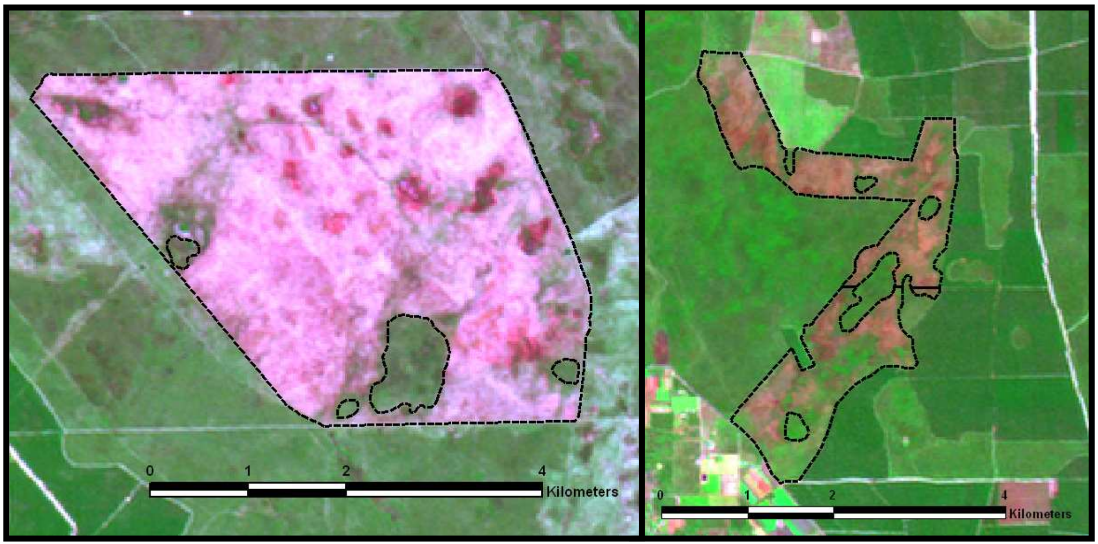
Fire intensity was also not examined during analysis of fire history for the GGS. Differences are known to exist in intensity between wildfires and prescribed burns however, due to time constraints, these have not been analysed here. There is some scope for further studies to examine patterns of intensity with respect to wild fires versus prescribed burns, seasons of fire and effects of changing climatic conditions such as decreasing rainfall of wildfire and prescribed burn intensities



Wildfire
Burn date 2/2/2005
Landsat Date 9/2/2005

Prescribed Burn
Burn date: 5/10/2003
Landsat date: 28/11/2003

Figure 12. Enhanced Landsat imagery examples of a wildfire and a prescribed burn (dashed line) within *Banksia* woodland on the Gnangara groundwater system.



Prescribed Burn
Burn date 2/11/2005
Landsat Date 5/02/2006

Prescribed Burn
Burn date: 15/10/2005,
Landsat date: 05/02/2006

Figure 13. Enhanced Landsat imagery examples of some examples of 'patchy' burns. The dashed outline marked the fire boundary showing exclusion of internal unburnt patches. Patchiness appears to depend on topography and the, presence of wetlands or patches of higher overstorey species. No patchy wildfires were observed.

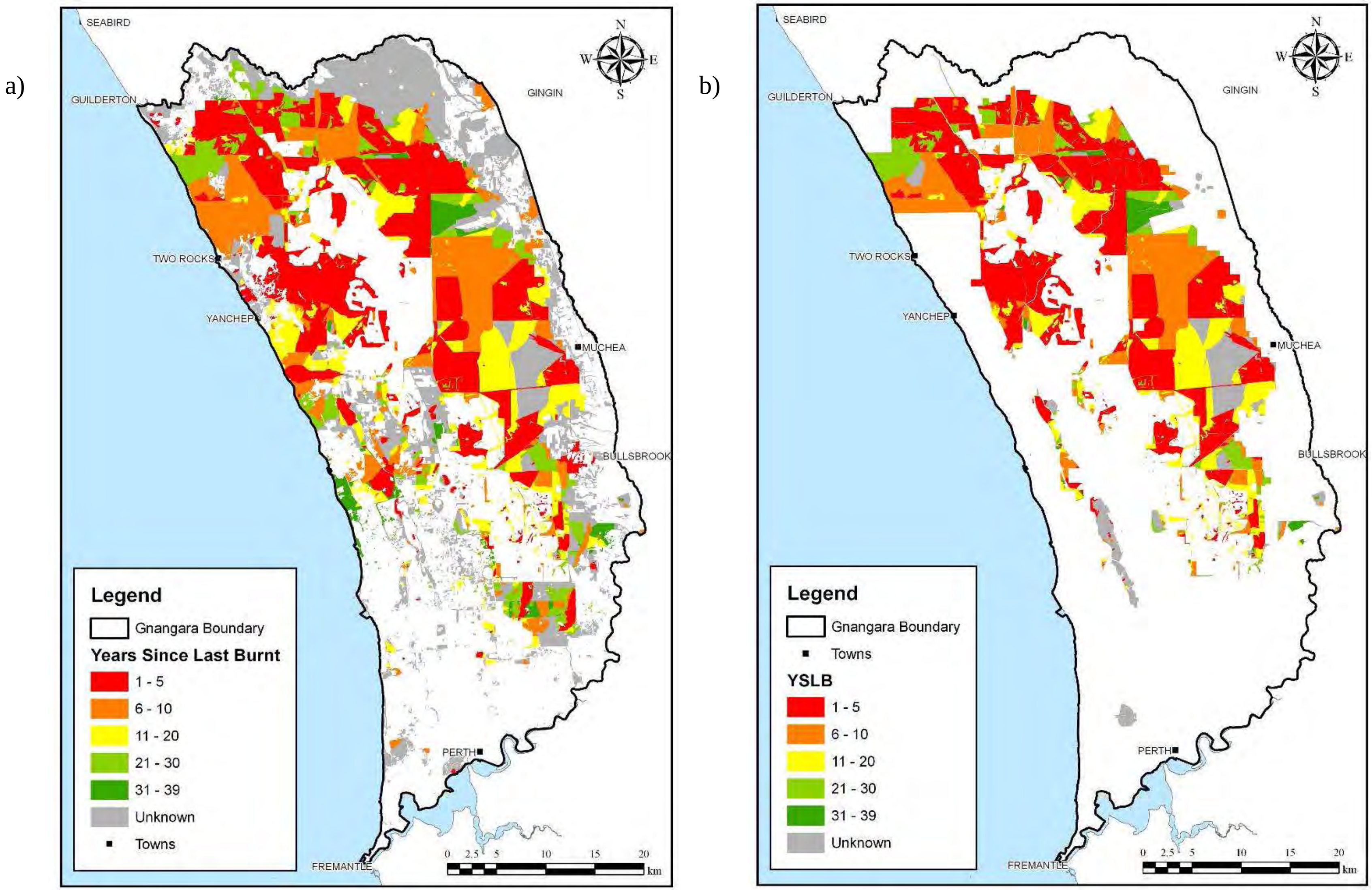


Figure 14. Fuel Age Distribution as at 2009 for remnant vegetation within a) the whole Gnangara system and b) DEC managed land only, not including pine plantation burns. Data range from 1970 to 2009 with 5 years of missing data in the early 1970's.

Fire Frequency

Over the 39 year period the largest area of all burnt remnant vegetation on the GGS was burnt 1 to 3 times (Figure 15). The area of all remnant vegetation burnt multiple times was higher than that on DEC managed land.

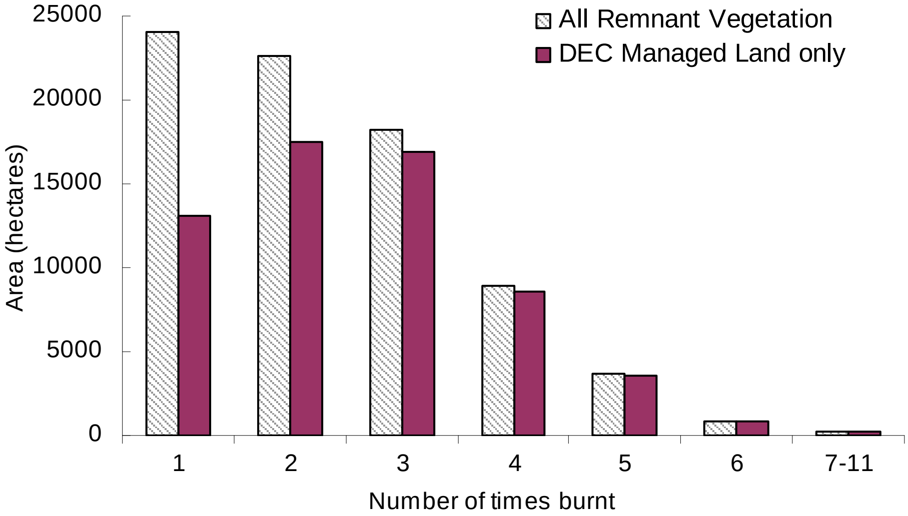


Figure 15. Total land area (in hectares) of burnt remnant vegetation for frequency classes (1970-2009) (Excludes pine plantation and missing information from the 1970's (see Sonneman and Kuehs in prep).

The average number of times an area was burnt is 2.25 for all remnant vegetation compared to 2.85 on DEC managed land. This difference could be explained by fire management and increased fuel reduction burning occurring on DEC land.

The majority (65%) of Bassendean vegetation was burnt 2 to 3 times, while for the Cottesloe/Karrakatta complex the majority (70%) was burnt 2 to 4 times. The Quindalup complex was predominantly burnt 1 to 2 times with 80% of the area falling in this category (Figure 16).

As the bar graphs in Figure 16 show, the majority of *Banksia* woodland was burnt 2 to 3 times (61%). *Melaleuca/E. rudis* woodland showed a similar pattern with 63% of the area burnt 2 to 3 times in the last 39 years. Both also reflect the pattern of the Bassendean complex. *Marri* woodland had most burnt 1 to 3 times (66%).

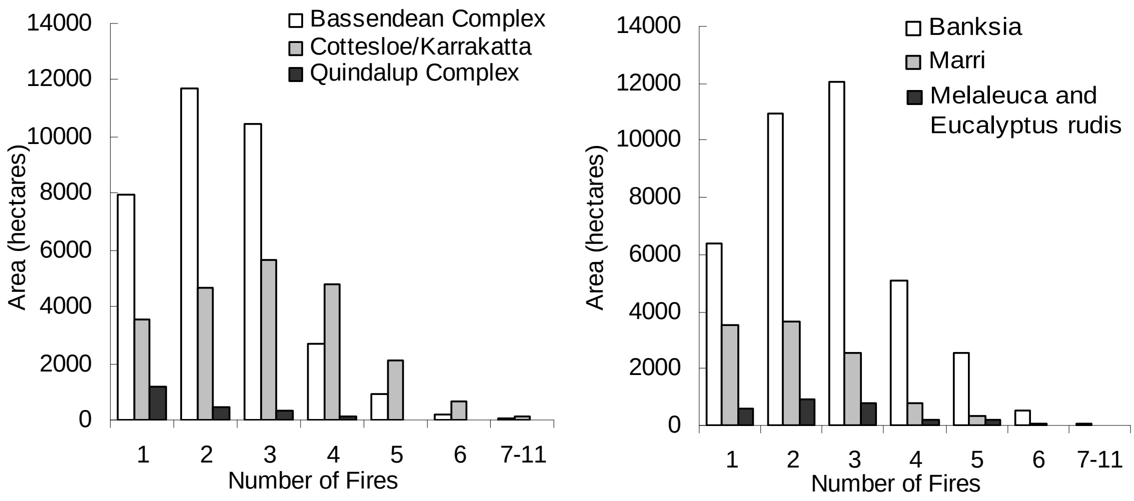


Figure 16. Number of fires over 39 years displayed for different vegetation communities: a) Heddle (1980) vegetation communities grouped by common landform, and b) vegetation types grouped by dominant vegetation as mapped by Mattiske Consulting Pty Ltd (2003).

The spatial distribution of fuel frequency shows that higher frequencies of fires occur surrounding the pine plantations (Figure 17). Most recently burnt sites have the highest number of fires occurring over the last 39 years.

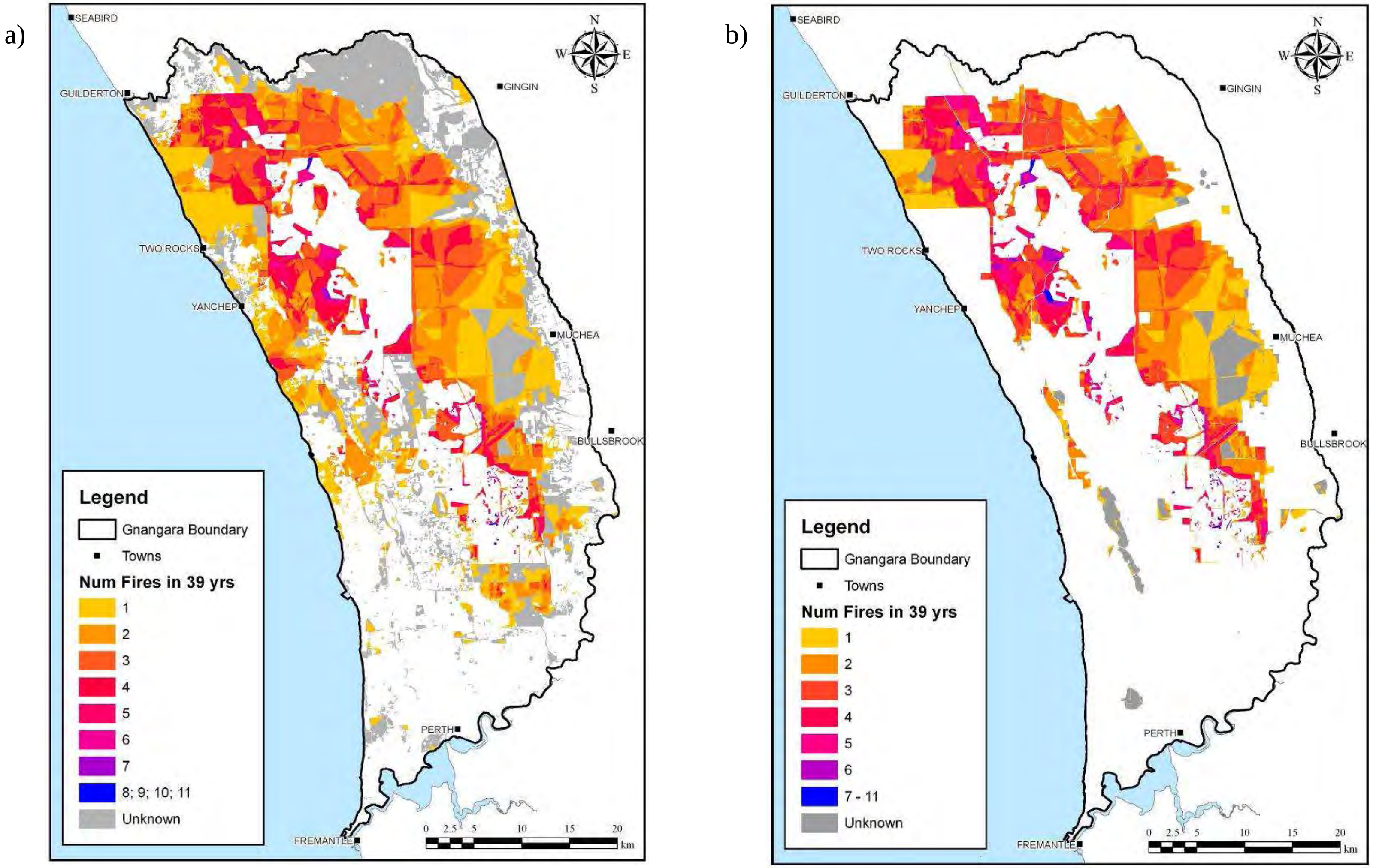


Figure 17. Graphic representation of number of fires over a 38 year period between 1970/71 and 2008/09 for a) all remnant vegetation in the Gnangara system and b) DEC managed land only (Does not include any pine plantation areas). Classes 7, 8, 9, 10 and 11 have been grouped together as they represent less than 0.1% of the total area and are likely a result of errors from spatial analysis. Unknown fire history area makes up 42% of all remnant vegetation and 9% of Dec land.

Fire interval

Fire frequency can be defined as the number of fires within a specific time period and can be assessed by a number of components including the length of the inter-fire intervals; the variability of the length of the inter-fire intervals; and the sequence of fire intervals (Cary and Morrison 1995; Morrison *et al.* 1995): The components are interrelated, for example as the number of fires within a specific time period changes so does the average length of the inter-fire intervals. Fire interval, the period of time between successive fires, is considered to play a role in regards to impacting biodiversity. In particular, consecutively short intervals between lethal fires could limit reproduction of some plants that require a minimum interval post fire to reproduce effectively (Bradstock *et al.* 1997; Cary and Morrison 1995; Fox and Fox 1987; Keith 1995; Morrison *et al.* 1995; Nieuwenhuis 1987) . At the other end of the scale, consecutively long intervals between fires would affect species that require fire for reproduction.

Recent work in Western Australia in jarrah and shrublands of the Walpole area investigated the impacts of short < 5yrs, mixed 6-9 yrs, long > 10 yrs, and very long 30 yrs on species composition of plants, ants, beetles, vertebrates and macrofungi (Wittkuhn *et al.* in press). There was weak evidence of differences between the impacts of Short-Short and Long-Long intervals on the composition of plants, ants and beetles. However it is possible that the most recent fire interval which was long (12 years) may have overshadowed any impacts of fire intervals some 14-20 yrs previously.

Although the impact of YSLF on flora and fauna on the GGS has been assessed the impact of fire interval sequences has not been examined. A brief examination of fire intervals indicated that the average number of years between consecutive fires is about 8 years, with a maximum time between fire of 12 years for areas burnt two or more times. Based on the results from the GSS fire studies it is predicted that repeated short fire intervals would negatively impact key plant species such as *Lysinema ciliatum*, *Darwinia foetida* (Table 5) and key fauna species such as *Menetia greyii*, *Morethia obscura*, Carnaby's Cockatoo, and Honey Possum (Table 6).

5. Vital attribute information, key fire response species and habitat variables

Flora

Key fire response plant species can be selected using a suite of characteristics including fire sensitivity, commonness or rarity, structural dominance within the community (Shedley 2007). These attributes are then used to define maximum and minimum tolerable interfire periods for the land management unit or vegetation community in question. One of the main vital attributes used to select key fire response flora species is the method of persistence (Tolhurst 1999) also known as regeneration strategy (Burrows *et al.* 2008). The regeneration strategies are generally divided into two categories: seeders and resprouters (see Table 4), Species that are killed by fire and rely entirely on seed for persistence after a fire, whether stored in the canopy, soil, or propagation through dispersion from nearby area, are the most likely to be affected by inappropriate fire patterns. A species in this category, for example, may undergo localized extinction if fires are too frequent as it does not allow time for the species to mature and produce seed.

Table 4. Regeneration strategies for seeders and resprouters based on Burrows *et al.* (2008)

Seeders	Resprouters
(1) Stem girdling or 100% scorch kills, depends on canopy stored seed	(4) Survives stem girdling or 100% scorch, soil suckers (rhizome, corm, bulb, tuber)
(2) Stem girdling or 100% scorch kills, depends on soil stored seed	(5) Survives stem girdling or 100% scorch, basal sprouts (lignotuber)
(3) Stem girdling or 100% scorch kills, no stored seed	(6) Survives100% scorch, epicormic shoots
(8) Stem girdling or 100% scorch kills, any of 1,2,3 above	(7) Survives100% scorch, large apical bud
(10) Ferns and allies (spores)	(9) Survives100% scorch, any of 4,5,6,7 above

Another important vital attribute for key fire response species is the juvenile period (or time to first flowering), as those species that have a long juvenile period may be eliminated if fire intervals are too short. Burrows *et al*. (2008) defined the juvenile period as the time for at least 50% of a population of plants to have flowered following fire. As the first seed set will not necessarily be sufficient to maintain a species' abundance it has been suggested that the minimum fire interval be twice that of the juvenile period of the longest maturing plant species killed by fire and primarily relying on stored seed for reproduction (Burrows *et al.* 2008; Friend *et al.* 1999).

Longevity (the age at which senescence and death occurs) should also be taken into account, but this information is often unknown or difficult to find out (Shedley 2007). Key fire response species were selected using the list of species known to exist in the GGS based on floristic surveys by the GSS (Mickle *et al.* 2010a; Mickle *et al.* 2009) including declared rare and priority flora (Valentine *et al.* 2009a). This list was supplemented with species vital attribute information from the Vegetation Species List and Response Database (DEC 2008b). Some values, especially for rare or priority species that could not be found in the database were inferred from information available from *FloraBase* (Western Australian Herbarium 1998-2009). The compiled flora species list with all vital known attributes can be seen in the appendix.

The key fire response species were then selected from this list based on the vital attribute criteria including regeneration strategy (species killed by fire and relying of seeds for reproduction); juvenile period (greater than 48 months), conservation status (DRF) and endemism (GSS endemic). The 39 key fire response species selected with these criteria are shown in Table 5.

The data collected on juvenile period and post-fire regeneration strategies have advanced our understanding and ability to utilise these criteria to develop an ecologically appropriate burn regime for the Banksia woodland on the Swan Coastal Plain. Burrows (2008) recommends that the minimum interval between fires lethal to fire sensitive species be approximately twice the juvenile period of the slowest maturing species. Based on this statement, the highest recorded juvenile period in species relying solely on seed for reproduction (seeders) is 4 years for species surveyed by GSS (Mickle *et al.* 2010a) including *Lysinema ciliatum* and the DRF *Darwinia foetida.* Supplemented data from the database (DEC 2008b) suggests a maximum juvenile period of 5 years for seeder species *Melaleuca viminea.* The highest juvenile period for resprouters is 8 years for *Banksia menziesii* and *Banksia attenuata* (GSS survey, Mickle *et al.* 2010a) and 4 years for database supplemented data. Inferred data for rare and GSS endemic flora suggest a potential maximum of 6- 7 years.

Based on the key species selected using the vital attribute criteria (Table 5) a minimum fire interval of 8 to 16 years is recommended (twice the juvenile period of 4 to 8 years).

The maximum interval between fires is recommended to be based on the senescence time for the longer lived woody species. Given the dominance of Banksia species, it has been estimated that the maximum age to which *Banksia* would live is 45 years (Enright *et al.* 1998). This would prevent potentially detrimental senescence of the woodland as the *Banksia* species reach the end of their lives.

Based on this information a conservative estimate of 40 years is suggested as the maximum fire cycle.

This work is not based on a complete list of fire responses to all species know for the region and will be supplemented in the future as data on more species is obtained on the GGS.

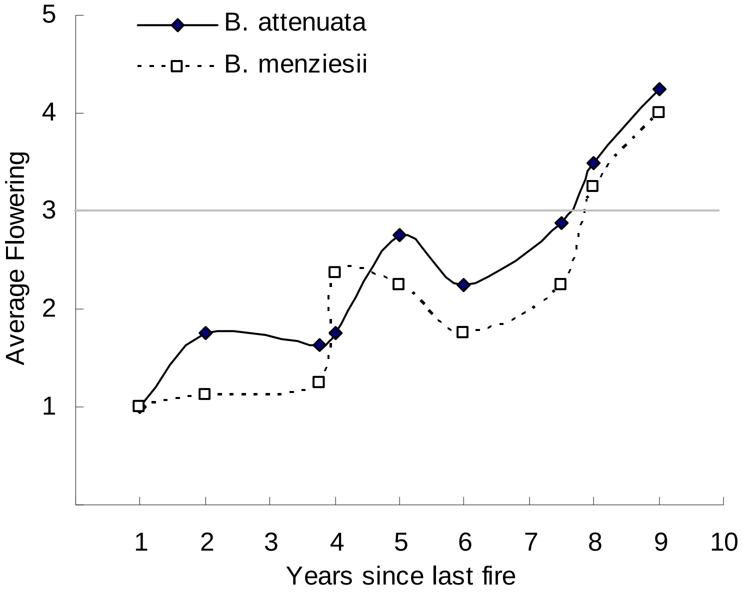


Figure 18. Average percentage flowering for *B. attenuata* and *B. menzesei*. Percentages are according to Burrows *et al*. (2008) based on data from chronosequence report supplemented by April 2010 resurveying of the same sites plus one new site.

Table 5. Key fire response flora species as selected using their vital attributes criteria including regeneration strategy (any species 100% killed by fire relying on seed for reproduction), juvenile period (greater than 45 months), conservation status (DRF), and endemism (GSS endemic). A more comprehensive list can be found in the Appendix.

Family	Species	Conservation Status[1]	Endemism[2]	Regeneration Strategy[3]	Juvenile Period[4]			DB reference locality	Banksia (16)[7]	Melaleuca (12)[7]	Chrono (9)[8]
					Years GSS (DB)	GSS[5] (mnths)	DB[6] (mnths)				
Epacridaceae	*Leucopogon conostephioides*			Seeders	4 (5)	<45	60	Northern Sandplain	6	2	6
Epacridaceae	*Andersonia lehmanniana*			Seeders	4 (3)	<45	36	Dandaragan			4
Epacridaceae	*Lysinema ciliatum*			Seeders	4 (2)	<48	24	Nannup	1		6
Myrtaceae	*Beaufortia elegans*			Seeders	4 (2)	<45	24	Cataby	5	2	7
Mimosaceae	*Acacia pulchella*			Seeders	4 (2)	<45	22	Mt Cooke			7
Papilionaceae	*Gompholobium tomentosum*			Seeders	4 (2)	<45	20	Nannup	9	3	6
Myrtaceae	*Darwinia foetida*	DRF	LE	Seeders	4*	*>48**					
Rutaceae	*Boronia purdieana*			Seeders	4	<45					8
Papilionaceae	*Gastrolobium capitatum*			Seeders	4	<45			5	1	7
Epacridaceae	*Leucopogon squarrosus*			Seeders	4	<45					6
Asteraceae	*Podotheca chrysantha*			Seeders	4	<45			1		6
Hydatellaceae	*Trithuria occidentalis*	DRF	GSS	Seeders	1*	*<12**					
Proteaceae	*Banksia menziesii*			Resprouters	8 (2)	96	24	Perth	12	1	9
Proteaceae	*Banksia attenuata*			Resprouters	8 (2)	90	24	Perth	16	2	9
Myrtaceae	*Calytrix sapphirina*			Resprouters	5	<60		Eneabba			3
Orchidaceae	*Elythranthera brunonis*			Resprouters	5 (2)	<60	24	Stirling Range	2	1	5
Stylidiaceae	*Stylidium bicolour*			Resprouters	4	<48					2
Myrtaceae	*Eucalyptus argutifolia*	DRF	LE	Resprouters	4	48*					
Myrtaceae	*Eucalyptus x mundijongensis*	P1	GSS	Resprouters	4	48*					
Cyperaceae	*Schoenus curvifolius*			Resprouters	4 (2)	48	24	Stirling Range	8	1	8
Orchidaceae	*Caladenia flava*			Resprouters	4 (1)	<48	9	Mt Cooke		1	7
Myrtaceae	*Eremaea pauciflora*			Resprouters	2 (4)	24	48	Jurien Bay	1	1	3

Family	Species	Conservation Status[1]	Endemism[2]	Regeneration Strategy[3]	Juvenile Period[4]			DB reference locality	Banksia (16)[7]	Melaleuca (12)[7]	Chrono (9)[8]
					Years GSS (DB)	GSS[5] (mnths)	DB[6] (mnths)				
Epacridaceae	*Conostephium pendulum*			Resprouters	1 (5)	12	60	Northern Sandplain	8	3	8
Orchidaceae	*Epiblema grandiflorum var. cyaneum*	DRF	GSS	Resprouters	1*	12*					
Cyperaceae	*Eleocharis keigheryi*	DRF	RE	Resprouters	1 – 6*	4 to 72*					
Dasypogonaceae	*Calectasia sp. Pinjar (C. Tauss 557)*	P1	GSS	Resprouters	2*	24*					
Proteaceae	*Grevillea curviloba subsp. curviloba*	DRF	GSS	?	1 – 6*	6 to 72*					
Proteaceae	*Grevillea curviloba subsp. incurva*	DRF	RE	?	1 – 6*	6 to 72*					
Pittosperaceae	*Marianthus paralius*	DRF	LE	?	2*	24*					
Myrtaceae	*Melaleuca systena*	TEC		?	1 – 7*	? 18-84*					
Aizoaceae	*Sarcozona bicarinata*	P3	GSS	?	?	?					
Myrtaceae	*Melaleuca viminea*			Seeders	(5)	-	60	Perup			
Epacridaceae	*Astroloma xerophyllum*			Seeders	(4)	-	48	Badgingarra Nat. Park			
Papilionaceae	*Templetonia retusa*			Seeders	(4)	-	48	Swan Coastal Plain		3	
Orchidaceae	*Corymbia calophylla*			Resprouters	(4)	-	48	Walpole			
Myrtaceae	*Eucalyptus gomphocephala*			Resprouters	(4)	-	48	Swan Coastal Plain			
Myrtaceae	*Eucalyptus marginata*			Resprouters	(4)	-	48	Nannup			
Orchidaceae	*Drakaea elastica*	DRF	LE	Resprouters	(1)	-	12				
Orchidaceae	*Caladenia huegelii*	DRF	RE	Resprouters	(1)	-	9				

1.DRF (Declared Rare Flora), P3 (Priority flora) (Valentine *et al.* 2009a) and TEC (Species vital to Threatened Ecological Community),

2. GSS: unique to GSS study area; LE: locally endemic to Swan Coastal Plain; RE: regionally endemic to South Western Australian Floristic Region; (Valentine *et al.* 2009a).

3. Seeders = 1,2,3, 8 and 10; Resprouters = 4,5,6,7 and 9; ? = uncertainty or multiple strategies – see Appendix 1 for actual codes. Based on (Burrows *et al.* 2008).

4. Juvenile period based on Burrow (pers comm. 2009) (see Mickle *et al.* 2010a)

5. Juvenile periods (in months) determine during Gnangara Sustainability Strategy (GSS) flora studies (see Mickle *et al.* 2010a; Mickle *et al.* 2009)

6. Juvenile period (in months) obtained from Vegetation Species List and Response Database (DEC 2008b)

7. Number of Floristics survey site species occurs in Banksia-dominant or Melaleuca-dominant sites. Total number of sites surveyed in brackets. (Mickle *et al.* 2009)

8. Number of Chronosequence survey sites species occurs at (all sites are Banksia-dominant). Total number of sites surveyed in brackets. (Mickle *et al.* 2010a)

* indicates inferred information based predominantly on *FloraBase* (Western Australian Herbarium 1998-2009)

Fauna

Historically ecological fire management regimes have focussed mainly on vegetation as providing habitat and successionally phases for fauna (Fire Ecology Working Group 2002; Kenny *et al.* 2004). Fire regimes can also be based on the vital attributes of vertebrate fauna (Burrows 2008). However, determining fire regimes based on the vital attributes of fauna is less clear due to factors such as mobility, predation and habitat availability which all affect the distribution of fauna species (Burrows 2008). There is a need to gain more information on fauna life histories and habitat requirements, their timed fire responses, and habitat factors linked to post-fire habitat changes (for example litter, understorey cover, food resources) and the spatial habitat distribution of species.

One useful approach is to categorise species responses in relation to the changes in their abundance over time following fire (Fox 1982; MacHunter *et al.* 2009; Whelan 2002). Species that peak in abundance at different fuel ages have been broadly categorised as early, mid or late successional species. Fire response curves can be assigned for species where information is available, and in some instances estimated relative abundances will be possible. Successional responses of a number of reptile species were assessed based on GSS field studies (Valentine *et al.* 2009b) and categorised into early, mid and late (Figure 19).

Another approach involves identification of habitat parameters associated with the different post fire stages-fuel ages of different vegetation types that are important for individual species (MacHunter *et al.* 2009; McElhinny *et al.* 2006). Habitat parameters could include percentage cover of understorey, canopy, litter, open ground, coarse woody debris, tree diameter and various others, shrub composition. These parameters can be linked with post fire stages and estimated fauna fire response curves or relative abundance in post fire stages. The parameters can also be employed to monitor outcomes of burns and ecological fire regimes.

Based on this fauna and habitat information it is possible to identify key fire response species i.e. species most likely to be affected by long or short intervals between fires. It would be beneficial to select species whose habitat requirements can clearly or logically be linked to habitat changes with post-fire vegetation succession (Burrows 2008; MacHunter *et al.* 2009). Spatial components of fauna habitats and seral ages should be incorporated into ecological fire regimes where possible. This is particularly important with regards to factors such as patch size, connectivity between patches and the home ranges and dispersal capabilities of taxa.

Key Fire Response fauna species identified for the GGS are shown in Table 6. They were based on conservation status, endemism, preferred fire age and data on the relationships to successional ages and response curves obtained from GSS field studies (Swinburn *et al.* 2009; Valentine *et al.* 2009b). The sites surveyed covered a range of fuel ages including 3, 4, 6, 7, 10, 17, 22, 26, and 36 YSLB and patterns with fuel age were examined based on fuel age grouped into Young (<11 YSLB) and Old (>16 YSLB).

Overall reptile abundance and abundance of reptile species *Menetia greyii*, and *Morethia obscura* were significantly higher in old (>16YSLB) fuel age (Table 7. Valentine *et al.* 2009b). *Rankinia adelaidensis* is one of a few reptile species that showed a strong preference for young (<11 YSLB) (Valentine *et al.* 2009b). The locally endemic *Crinia insignifera* (the sign-bearing froglet) also showed preference for older fuel ages (>16YSLB) (Valentine *et al.* 2009b).

Recent work found that the differences between fuel ages were particularly pronounced in *Melaleuca* sites (Valentine *et al.* 2009b). Young fuel age sites in *Melaleuca* habitat tended to contain fewer reptiles, and had few species associated with them. Although some differences were also detected between fuel ages in *Banksia* sites, they were less pronounced, with young and old fuel age *Banksia* sites having more species in common (for example *Morethia obscura*).

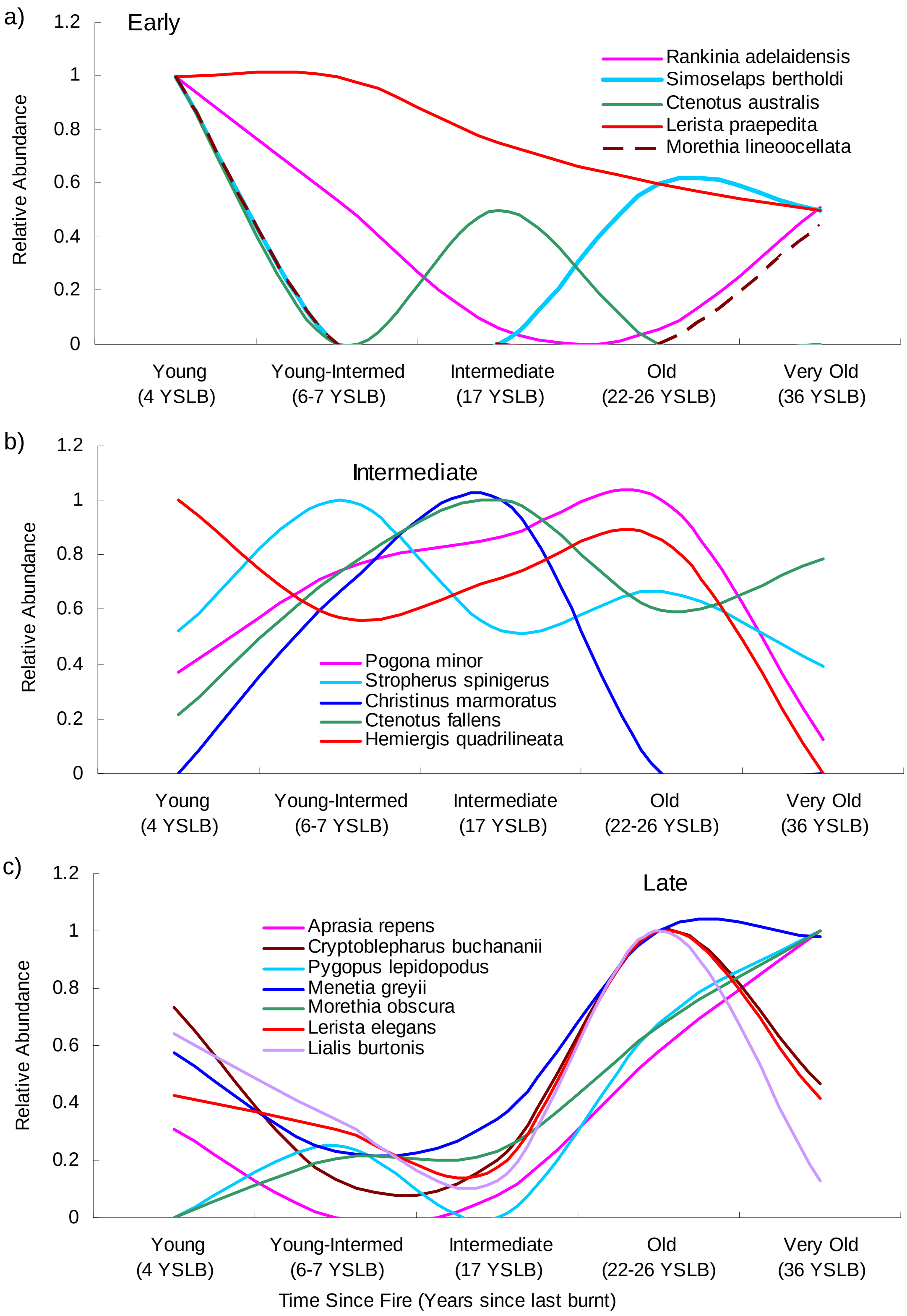


Figure 19. Successional responses of reptiles in *Banksia* woodland (using relative abundance estimates) to time since fire. Responses are separated into a) early, b) intermediate, and c) late.

Information on avifauna responses to fire is poorly researched however surveys by Davis (2009a; b) offer suggestions of a few species showing a preference for older fuel age such as Splendid fairy wrens and Yellow rumped thornbills. Recent research by Valentine (2010) examined food availability for the endangered Carnaby's Black Cockatoo in relation to fire regimes. Banksia woodlands in older fuel ages (with a peak between 20 and 30 YSLB) produced more seed suitable to support sufficient numbers of Carnaby's Cockatoos (Figure 20). Woodlands 0 – 5 YSLB would support much lower numbers of Carnaby's.

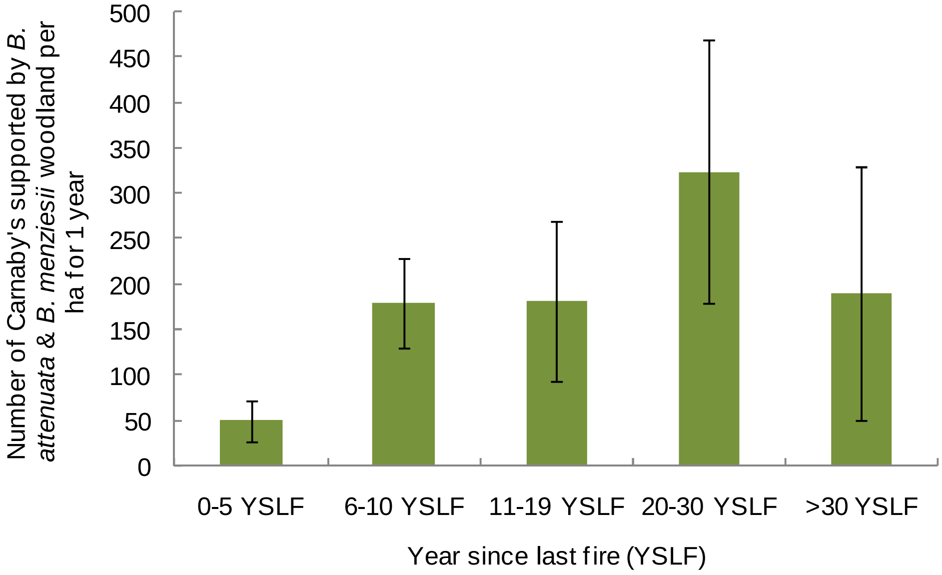


Figure 20. Total number of Carnaby's 1 hectare of Banksia woodland could support for one year.

Information of the fire responses of key mammal fauna in the GGS is also limited. Fauna surveys in the GSS over the period 2007 – 2010 provided more information on the fire responses of *Tarsipes rostratus* (honey possum) and *Mus musculus* (house mouse) both of which were captured in significant numbers during surveys to show patterns (Valentine *et al.* 2009b). While not statistically significant, the honey possum showed preference for old fuel ages, peaking in abundance at sites between 20 and 26 years since last burnt. The introduced house mouse showed statistically significant preference for sites with young fuel age (<7 YSLB). The relative abundances of these mammal species in relation to YSLB (Figure 21) shows the difference in their successional patterns with *Mus musculus* preferring young fuel age woodland and *Tarsipes rostratus* preferring

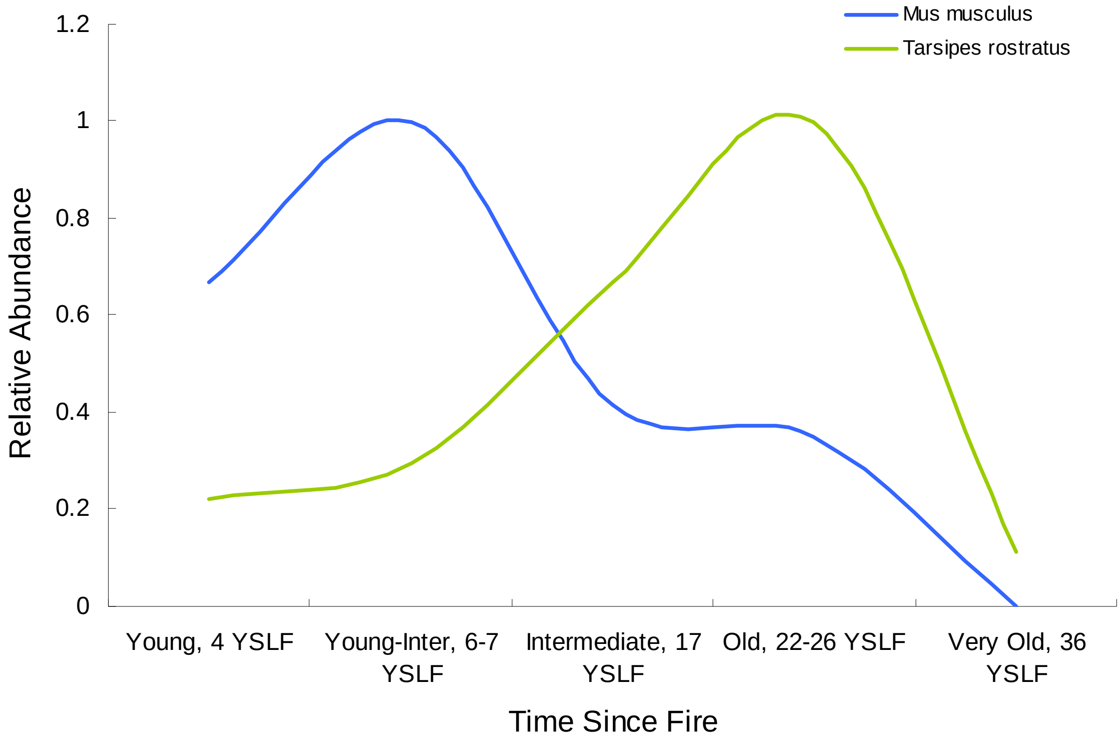


Figure 21. Successional responses of *Mus musculus* and *Tarsipes rostratus* in *Banksia* woodland (using relative abundance estimates) to time since fire.

Other key fauna species identified include the mammal species Quenda (*Isoodon obesulus*) and Water rat (*Hydromys chrysogaster*), the critically endangered Western Swamp Tortoise and the endangered Graceful Sun Moth (Table 6, Wilson *et al.* 2010a). While preferred fire age for these species has not been researched we have information on the preference of Quenda for dense habitat in areas (possibly linked to predator pressure), the strong link of Water rat rakali to persisting wetlands and dense riparian vegetation (Valentine *et al.* 2009b; Wilson *et al.* 2010a). There is information linking local extinction of the Sun moth after fire due to loss of food sources.

Table 6. Key Fire Response Fauna Species and some of the vital attributes used to select them including endemism, conservation status, and preferred fire age.

	Species	**Common Name**	**Endem.**‡	**Cons status**†	**Preferred Fire Age**∞	**Meth.**◊	**Comments**
Invertebrates	*Synemon gratiosa*	Graceful sun moth	LE	E	unknown		Preference for *Lomandra* species; breed on grasses, sedges and rushes. Limited dispersal ability therefore lose food source after fire and become locally extinct. (DEWHA 2008)
Amphibians	*Crinia insignifera*	sign-bearing froglet	LE		>16 years	2	Driven primarily by proximity to water - but require population recovery time of about 5-7 years (Conroy 2001; Driscoll and Roberts 1997)
Reptiles	*Pseudemydura umbrina*	Western swamp tortoise	GSS	CE, SI	unknown		Populations restricted to Ellen Brook Nature Reserve and Twin Swamps Nature Reserve on the eastern boundary of the GSS (Burbidge and Kuchling 2004)
	Rankinia adelaidensis adelaidensis	western heath dragon	LE		<11 YSLB	1,3	Significant preference for Banksia woodland
	Aprasia repens	sandplain worm lizard	RE		>16 YSLB	3	
	Delma concinna concinna	west coast javelin lizard	LE		<11 YSLB	2	
	Demansia psammophis reticulata	yellow-faced whip snake	RE		>16 YSLB	2	
	Lerista elegans	west coast four-toed lerista	WA		>16 YSLB	1, 3	
	Menetia greyii	common dwarf skink	AUS		>16 YSLB	1*, 3	
	Morethia obscura	southern pale-flecked morethia	AUS		>16 YSLB	1**	
	Neelaps calonotos	black-striped snake	LE	P3	>16 YSLB	2	
	Pletholax gracilis gracilis	keeled legless lizard	LE		unknown		
	Tiliqua occipitalis	western bluetongue	AUS		>16 YSLB	4	
	Tiliqua rugosa	bobtail	AUS		>16 YSLB	4	
Overall Reptile abundance					>16 YSLB	1**	

	Species	**Common Name**	**Endem.**[‡]	**Cons status**[†]	**Preferred Fire Age**[∞]	**Meth.**[◊]	**Comments**
Birds	*Calyptorhynchus latirostris*	Carnaby's Black Cockatoo	RE	E, S1	Long unburnt (20-30 YSLB)	5 (6)	Rely on Banksia for food - so effects of fire on banksia woodland will effect them (Valentine 2010)
	Acanthiza chrysorrhoa	Yellow-rumped Thornbills	AUS		Recently burnt	7	Species declining (Bleby *et al.* 2009b)
	Malurus splendens	Splendid Fairy-wrens	AUS		Long unburnt	7	Nest placement in favoured plant, *Xanthorrhoea preissii*, increases with time since fire (Bleby *et al.* 2009a), Species declining (Bleby *et al.* 2009b)
Mammals	*Tarsipes rostratus*	Honey Possum	RE		20-26 yrs	1	Known to return to burnt areas 2-4 years after fire (Everaardt 2003).
	Isoodon obesulus	Quenda or Bandicoot	WA	P5	unknown		dense mid-storey level heath associated with wetlands. Increase in numbers where foxes are baited
	Hydromys chrysogaster	Rakali or Water rat	AUS	P4	unknown		Reliant of permanent wetlands.
	Rattus fuscipes	Bush rat	AUS		unknown		
	Mus musculus	House mouse	I		<7years	1**	

‡ Endemism within Australia: GSS (unique to GSS study area), LE (locally endemic to the Swan Coastal Plain), RE (regionally endemic to south-west Western Australia), WA (restricted to Western Australia), AUS (occurring within and outside Western Australia, and I (Introduced).

† Conservation Status**:** CE – Critically Endangered on EPBC Act; E – Endangered on EPBC Act; V – Vulnerable on EPBC Act; S1 – Schedule 1 of WA Wildlife Conservation Act; P3 – Priority 3 fauna on DEC Priority List; P4 – Priority 4 fauna on DEC Priority List; P5 – Priority 5 fauna on DEC Priority List.

∞ Fuel age in Years Since Last Burnt
(Data for Valentine (2009b) sites cover fuel ages 3, 4, 6, 7, 10, 17, 22, 26, and 36YSLB grouped into Young (<11YSLB) and Old (>16YSLB) fuel ages)

◊ Methodology:

1. Preferred fire age derived from species abundance analyses (Valentine *et al.* 2009b). Significants indicated by ** ($p < 0.01$) and * ($p < 0.05$)
2. Insufficient data for analysis however multiple captures in only one fire age (at least 2) (Valentine *et al.* 2009b)
3. Preferred fire age derived from NMDS ordinations of reptile assemblages (Valentine *et al.* 2009b)
4. Implied trend only from Cage and Elliot trap data (Valentine *et al.* 2009b)
5. Information only (Davis 2009b)
6. Preferable fuel age suggested through analysis of number of Carnaby's Cockatoos that Banksia woodlands could support (Valentine 2010)
7. Implied trend only from Davis (2009b) - data covers 26 years evenly

Habitat variables

Habitat variables associated with the different post fire stages-fuel ages of different vegetation types that are important for fauna communities and species on the GGS have been examined (Valentine 2010; Valentine *et al.* 2009b). Differences between vegetation type and fuel age were assessed using a two-factor ANOVA. Habitat and response variables at each site, including dominant species of reptiles were correlated using Pearson's correlation coefficient. In addition, fuel age was correlated with habitat and response variables, with combined vegetation types, and with vegetation types separately.

A number of microhabitat and vegetation structural attributes were associated with fuel age (Valentine *et al.* in prep.). In *Melaleuca* sites, litter depth and canopy cover were positively associated with fuel age (Figure 22). In contrast touch pole counts in the 20 – 40 cm, 40 – 60 cm and 60 – 80 cm height categories were negatively associated with fuel age indicating a decrease in low to midstorey cover as the vegetation ages. In *Banksia* woodland sites litter depth was positively associated with fuel age (Figure 22). However, when examining the relationship between litter depth and fuel age, a second order polynomial (quadratic) equation explained more variation in the *Banksia* woodland sites (Figure 22). The relationship indicates that mid-range fuel age categories (between 15 – 25 years since last burn) have higher amounts of litter than either young or very old fuel age sites. In *Banksia* woodland sites vegetation cover (touch pole counts) was significantly correlated with fuel age (Valentine *et al.* in prep.).

The differences in vegetation structure between fuel ages were more pronounced in *Melaleuca* sites. For example, litter depth was greater in old fuel age sites for both *Banksia* and *Melaleuca*, but the differences between old and young fuel age site in *Melaleuca* sites was more than double the differences between *Banksia* sites. In *Banksia* sites, the old fuel ages contained higher amounts of understorey structure, whereas in *Melaleuca* sites, the young fuel ages contained greatest understorey structure.

Recent approaches to determine ecological fire regimes aim to determine the proportion of the land system as functional habitat or growth or developmental stages (Burrows 2008; Cheal 2010). The categories combine fuel age into groups that reflect more closely the state of the vegetation as habitat (structure, biomass, cover) rather than a specific age. The detailed habitat variables obtained from the GSS studies can provide an excellent source of data for the development of growth stages for tolerable fire intervals similar to these approaches (Cheal 2010).

The abundance of selected species was also associated with habitat variables in fuel ages. For example *Rankinia a. adelaidensis* also indicated a significant 2nd order polynomial relationship (quadratic) with fuel age in the *Banksia* woodland sites indicating higher abundance in early and late succession (Figure 23). The abundance of this dragon was correlated with soil cover which also showed a significant 2nd order polynomial relationship (quadratic) with fuel age in *Banksia* woodland sites (Figure 23).

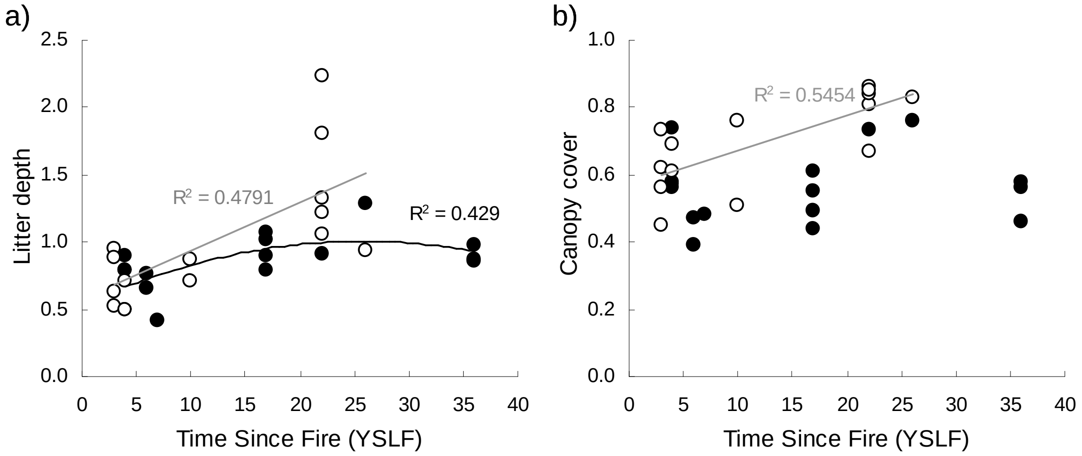


Figure 22. Associations of a) litter depth and b) canopy cover with fuel age. Linear trend lines and r^2 values are provided for *Melaleuca* sites on each graph, while a 2nd order polynomial trend line and r^2 is provided for the *Banksia* woodland sites for the variable litter depth. Black circles = Banksia; Clear circles = Melaleuca.

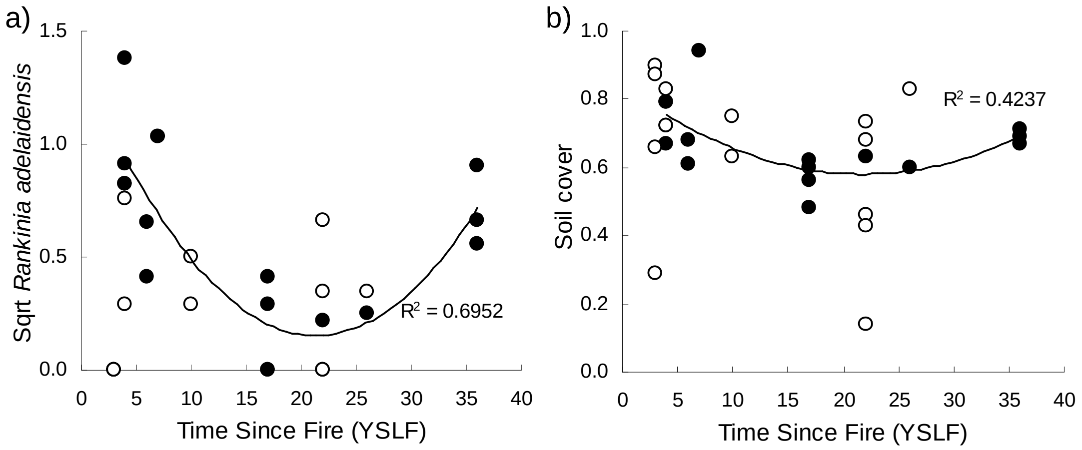


Figure 23. Associations of a) the abundance of *Rankinia a. adelaidensis* and b) soil cover with fuel age. 2nd order polynomial trend lines and r^2 values are plotted for *Banksia* woodland sites. Black circles = Banksia; Clear circles = Melaleuca.

6. Calculating idealised fire regime

An ideal fuel age distribution is not likely to occur however if fires are permitted to occur naturally and run their course then it is to be expected that the mosaic of fire ages will follow an approximate negative exponential curve (Appendix 1 in Tolhurst 2000). An ideal fire age distribution can be used as a guide for fire management. For this project the ideal fuel age distribution was calculated based on Tolhurst (2000). This model uses minimum and maximum tolerable interfire periods to maintain all species within different vegetation communities to estimate an appropriate fire interval. The equation used by Tolhurst (2000) is summarised below.

The variables to be defined for this calculation include:

Total area of community: ***(a)***

Maximum tolerable interfire period: ***(m)***

Planning period (group size for age class distribution histogram): ***(p)***

Duration of ideal fire cycle: ***(c)****

* For the purposes of this calculation the "Ideal' fire cycle is equal to the mid point between the Minimum and Maximum tolerable interfere periods.

From these variables parameters for an exponential equation can be calculated.

Area to be burnt in **first** planning period

$$f = p \times \frac{a}{c}$$

Area to be burnt in **final** planning period

$$l = p\left(\frac{c}{m} \times \frac{a}{m}\right)$$

The decay constant (k) and coefficient (b) for an exponential equation ($a_t = b\ exp^{(kt)}$) can then be calculated using:

$$k = {\ln(l/b)} \big/ {m}$$

$$b = \left(f / l^{0.025}\right)^{1/0.975}$$

These parameters are then entered into the exponential equation and the ideal distribution can be calculated for each t = time interval. The age class distribution should be truncated at the maximum tolerable fire interval. The sum of the area for each age class should equal the total area of the vegetation community.

Minimum and maximum tolerable fire intervals frequencies

For the purposes of calculating an ideal fire regime, the minimum interval is commonly estimated as two times the longest juvenile period for species killed by fire and relying on seed stores for reproduction so that species are provided with sufficient time to produce seed (Burrows *et al.* 2008). In some cases patchy and low intensity burns that result in sufficient scorch free plants could result in reduced fire intervals (Burrows *et al.* 2008).

Based on the key species selected using the vital attribute criteria (Table 5) a minimum fire interval of 8 to 16 years is recommended (twice the maximum juvenile period of fire sensitive species). A conservative maximum fire cycle 40 years is suggested based on expected age of senescence of Banksia woodland. Values for minimum and maximum tolerable interfere period, and the 'Ideal' fire cycle are shown in Table 7

The recommended minimum fire interval is also supported by other information on the rate of increase of *B. attenuata.* The species method of persistence is a combination of resprouting after fire from soil-protected buds in swollen stem tissue (lignotubers) and seeds stored on persistence cones (Enright and Lamont 1989). Seed release and seeding recruitment are cued to fire and recruitment is most likely where summer fire is followed by a wet winter in the following year (Enright and Lamont 1992). It is estimated that *B. attenuata* on northern sandplains has the greatest rate of increase for a fire frequency of 7-20 years, with maximum at 13 years (Enright *et al.* 1998).

Food availability for the endangered Carnaby's Black Cockatoo in relation to fire regimes in *Banksia* woodlands should also be considered when proposing a recommended minimum fire interval. Food availability was found to be maximal in *Banksia* woodlands in older fuel ages (20 - 30 YSLB) (Valentine 2010). Further, the highest number of Carnaby's black-cockatoos that could be supported was in the 20-30 YSLB category, while the lowest number was supported in the 0-5 YSLB category. These results indicate that fire management actions to conserve food resources for Carnaby's black-cockatoos should involve maintaining or increasing long-unburnt Banksia woodland habitat within the 20 - 30 YSLF category. In addition, to conserve future food resources for Carnaby's black-cockatoos, fire management options should consider adequate protection of the current 11-

19 YSLF Banksia habitat. This is particularly important in light of the removal of pine plantations (the other significant food source) over the next 18 years under the GSS (Government of Western Australia 2009b).

Protection of threatened species, threatened ecological communities that are covered by State and Commonwealth legislation and significant habitats require specific fire regimes. This is may involve implementation of particular regimes to ensure their persistence, or to protect from inappropriate fire regimes, such as frequent lethal or infrequent intense fires, which are likely to cause their decline. In some cases this may involve identification of suitable locations for refugia (for examplefor quenda, rakali, wetlands). Further for species such as honey possums that have preferences for old fuel ages and a restricted distribution it is important to maintain connectivity for populations over time. Thus ecological burning must include spatial components (patch size and location of burns) to ensure suitable habitat connectivity. An example is provided in section 8.

Comparison of actual and idealised age class distributions

An ideal fuel age distribution was calculated for all of DEC managed land within the GGS area and then specifically for Banksia woodlands and Melaleuca woodlands within DEC managed land. The total area for each land management unit as well as the maximum and minimum tolerable interfere periods and 'Ideal' fire cycle is shown in Table 7.

Table 7. Land management units and parameters used to calculate the ideal fire age distribution

	Land Management Unit: DEC land		
	All Remnant Vegetation	**Ecological Vegetation Community**	
		***Banksia* Woodland**	***Melaleuca/Eucalyptus rudis* Woodland**
Total area (Hectares)	62,154	39,558	2,913
Minimum Tolerable Fire Frequency	8 – 16	8 – 16	8 – 16
Maximum Tolerable Fire Frequency	40	40	40
'Ideal' Fire Cycle (years)	**24 – 28**	**24 – 28**	**24 – 28**

It is evident that at across the GGS *Banksia* woodlands do not approximate the idealised distribution and are highly skewed to 1- 6 years since fire age (Figure 24). There is also a high proportion of woodlands at the 15 years since last burn age.

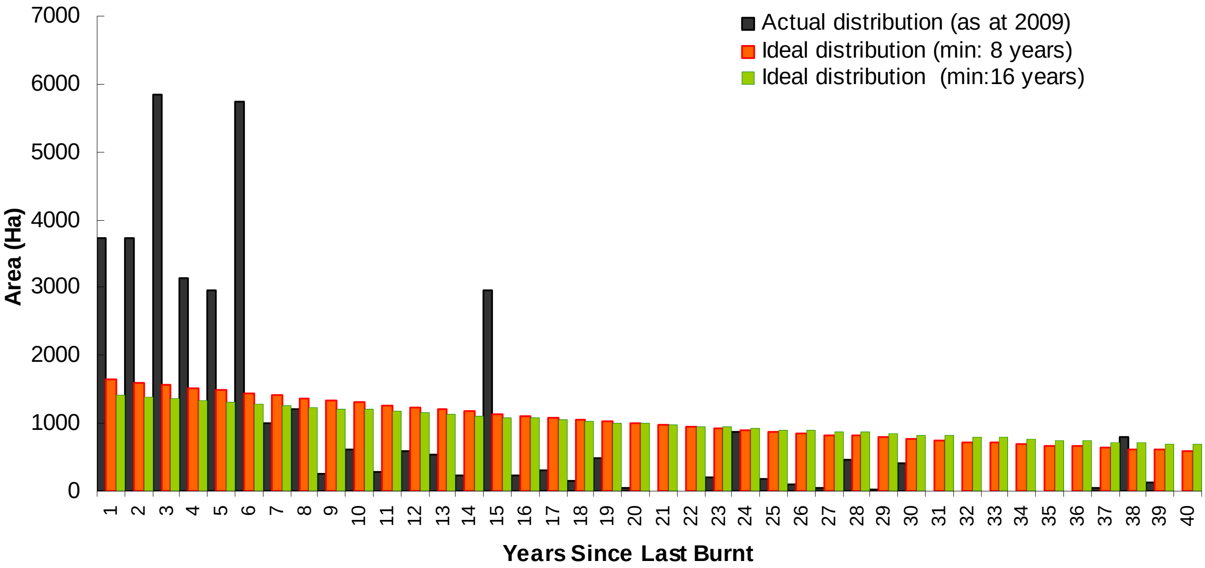


Figure 24. Calculated ideal fuel age for *Banksia* Woodland vegetation community using a fire cycle based on minimum tolerable fire interval of 8 and 16 years with a maximum tolerable fire interval of 40 years, and a total area of 39,559 hectares

The *Melaleuca/E. rudis* also does not approximate the idealised distribution and is highly skewed to the 1- 6 years since fire age (Figure 25). There is however a higher proportion of 15-19 YSLB than for *Banksia* woodlands.

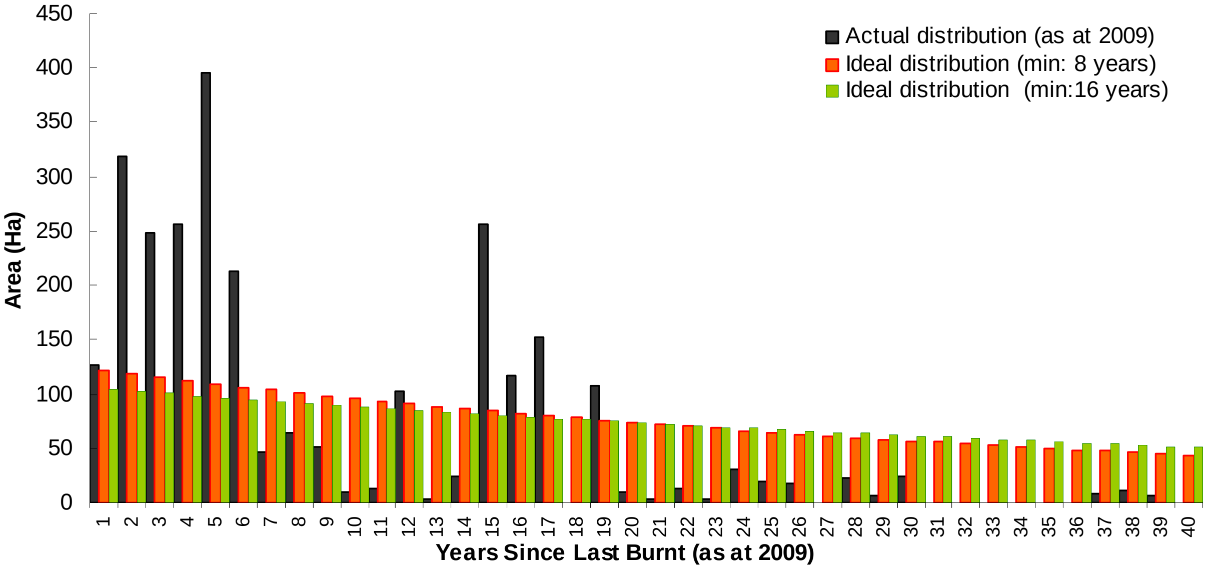


Figure 25. Calculated ideal fuel age for *Melaleuca/Eucalyptus rudis* Woodland vegetation community using a fire cycle based on minimum tolerable fire interval of 8 and 16 years with a maximum tolerable fire interval of 40 years, and a total area of 2,913 hectares

7. Burning requirements

Burning to meet ideal fuel age distribution

The burning requirements to approximate the idealised age distributions can be met through wildfires or prescribed burning. To determine the requirements for prescribed burning it is necessary to estimate the probability and area of wildfire likely on the GGS.

The area likely to be burnt by wildfire would ideally be calculated based on fires started naturally and allowed to run their course. Many fires in the GGS are started by deliberately or accidently and every fire is managed and controlled by DEC and other fire fighting authorities, nevertheless calculations can be undertaken to estimate areas likely to be burnt by wildfire and the effective fire cycle (Table 8). The effective fire cycle is the number of years an area equivalent to the total area of land management unit or ecological vegetation community would be burnt by naturally started wildfires alone and is based on a calculation from Lindorf (2001).

$$\text{Effective fire cycles} = \frac{\text{Total area of LMU} \times \text{Recorded fire history period (years)}}{\text{Average Area burnt} \times \text{Number of periods burnt}}$$

The ‘Effective’ fire cycle can be compared to the ‘Ideal’ fire cycle as calculated from Key Fire response species vital attribute information (see Table 7).

The area to be burnt each year should be approximately equal to the total area divided by the fire cycle. This area can be burnt either by wildfire or prescribed burning. For example, for all DEC managed land, the total area is 62,154 hectares with an ‘Ideal’ fire cycle of 24-28 years and an ‘Effective’ fire cycle of 39 years. Therefore between 2220 and 2590 hectares, (or 1591 hectares if calculated under ‘Effective’ fire cycle) would need to be burnt each year (by either wildfire or prescribed burn) to approach the ‘Ideal’ fire regime distribution (Table 8). The current average annual area burnt is 4970 hectares indicating a need for a reduction in area of annual prescribed burning to try and approach the ideal distribution.

For Banksia on DEC managed land, the total area is 39,558 hectares with an ideal fire cycle of 24-28 years. Therefore from 1413 to 1648 hectares would need to be burnt each year (either by wildfire or prescribed burn) to approach the 'Ideal' fire regime distribution. Currently the annual burn rate is 3040 hectares of prescribed burns and wildfires (Table 8).

For Melaleuca on DEC managed land, the total area is 2913 hectares with an ideal fire cycle of 24-28 years. Therefore between 104-121 hectares would need to be burnt each year (either by wildfire or prescribed burn) to approach the 'Ideal' fire regime distribution. Currently the annual burn rate is 213 hectares of prescribed burns and wildfires (Table 8).

Table 8. Calculations of the probability of wildfire, the average burnt area and the effective fire cycle

Fire Season	**Age Class**	**Area (ha) burnt by Wildfire in DEC managed land**		
		All Remnant Vegetation	*Banksia* Woodland	*Melaleuca*/ *Eucalyptus rudis* Woodland
Total area (ha)		62,154.8	39,558.7	2,913.2
Number of periods burnt		32	32	31
Annual chance of wildfire		100%	100%	97%
Average area burnt annually by wildfires		1,939	1,110	101
Average % burnt annually by wildfires		3.1%	2.8%	3.5%
Effective Fire Cycle (years)		**39**	**43**	**36**
Ideal Fire Cycle (years)		**24-28**	**24-28**	**24-28**
Annual area (ha) to be burnt under **'Effective' Fire Cycle**		1591	911	80
Annual area (ha) to be burnt under **'Ideal' Fire Cycle**		2220-2590	1413-1648	104-121
Current average area burnt each year - Total and (% prescribed burn)		4,970 (57%)	3,040 (63%)	213 (42%)

* No fire history information available for the GSS area for these years

Functional habitat and Growth stages

Another approach that has been developed recently to determine ecological fire regimes is to determine the proportion of the land system as functional habitat or growth or developmental stages (Burrows 2008; Cheal 2010). These categories combine fuel age classes into categories that reflect more closely the state of the vegetation as habitat (structure, biomass, cover) rather than a specific age. Here we have assigned classes based on the developmental stages of the *Banksia* woodlands in relationship to functional habitats and fauna requirements (for exampleHoney possum, Carnabys Cockatoo, reptile communities, reptile species). The class boundaries may be somewhat arbitrary, but for the GGS we have based our stages on our fauna classes, 0-5, 6-10, 11-19, 20-30, >30 (Figure 26). Figure 27 gives a comparison of the same data in five year groups.

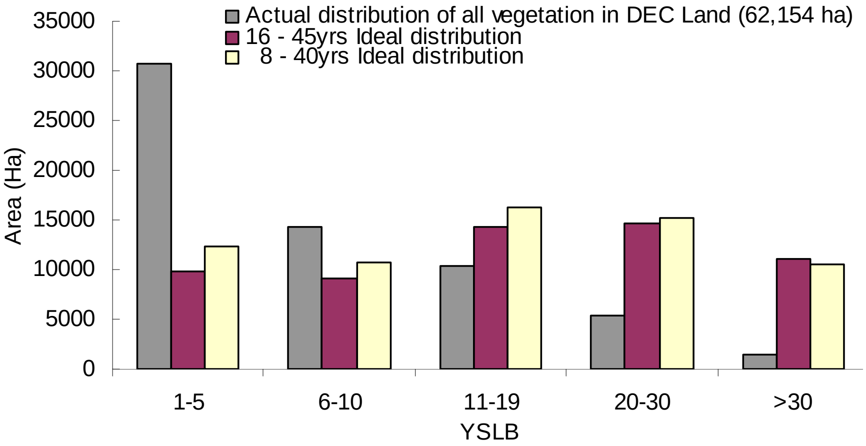


Figure 26. Actual and ideal fire information for the all vegetation in DEC managed land grouped the same as those used for Carnaby's cockatoo food recourse analysis (see Figure 20)

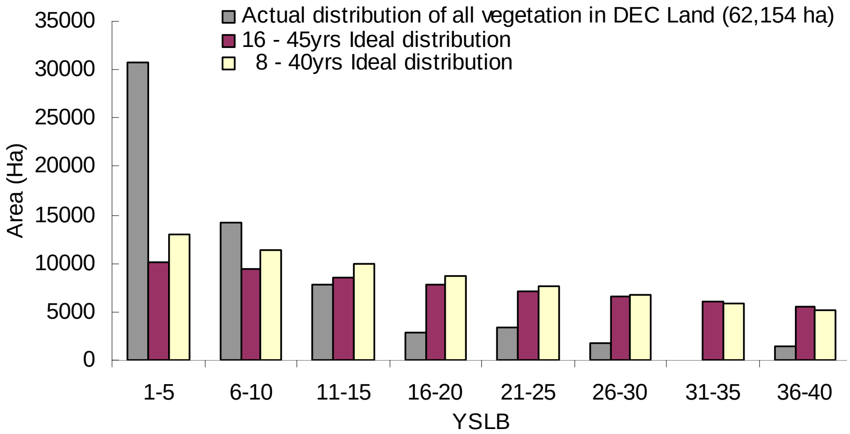


Figure 27. Actual and ideal fire information fro all vegetation in DEC managed land grouped in 5 year blocks.

Burning for spatial scale arrangements of seral stages

While evidence-based rationale for minimum and maximum fire return intervals, and estimates of the proportion of landscape in various fuel age classes / seral stages have been provided there are other considerations for appropriate fire regimes. One of these involves determining how these age classes or seral stages are arranged across the landscape, while another is to determine the scale of the burn patches. Both of these are particularly important for fauna. In contrast to plants, animals are mobile and the spatial components of their habitats and fire responses need to be assessed more closely (Bradstock *et al.* 2005; Clarke 2008). The maintenance of the metapopulation dynamics of fauna species in fire impacted landscapes is important. This involves the provision of structural and functional connectivity in seral habitat networks that preserve dispersal for metapopulations. These are complex issue, about which we have little information. Recommendations for the GGS should thus be implemented in an adaptive management framework.

The GSS studies have identified that the dependence of fauna species on fire mediated habitat hetereogeneity is variable and dependent on species life-history traits, dispersal and territory sizes. There is however little information on these factors or the sizes, shapes, age structure or configurations of suitable habitat for fauna in relationship to fire dynamics and fire mosaics. However based on the current knowledge of fire impacts on fauna in the GGS some general recommendations on spatial aspects of ecological fire regimes can be made.

Fire regimes on the GGS need to ensure the retention of long-unburnt *Banksia* woodland important to species such as honey possum, some reptiles and birds, due to habitat features including litter and food sources. They should ensure the retention and protection of long-unburnt wetland-associated vegetation known to be important for fauna species (for exampleRakali, Bush rats, Quenda) as designated as refugia. Regimes need to incorporate spatial aspects of fauna distribution, habitat and home ranges for example for Honey Possum to identify appropriate scale of burning around refugia and for provision of linkages. There is thus a need for further work be undertaken to incorporate spatial aspects of fire sensitive fauna distribution, habitat and home ranges in fire regimes.

Until we have evidence to the contrary, it may be wise to assume little or no *in situ* capacity for post-fire recolonisation by key fire response fauna, although this is probably not the case. That is to say, assume recolonisation is from adjacent ‘unburnt’ populations. Therefore, spatial arrangement should aim to maximize the connectedness of functional seral stages to facilitate recolonisation and to increase landscape permeability (Figure 28). The schematic diagrams in Figure 28 show an example of burn used to facilitate connectivity between the different fuel ages to maximise fauna access. Figure 28a shows a long narrow burn which would better facilitate movement and recolonisation between the old and young fuel age patches than the burn in Figure 28b which burns out the entire old patch. Further exploration is required to examine various scenarios to determine the best possible arrangements for different situation such as burns around wetlands, burning to protect or enhance linkage corridors, or for TEC’s.

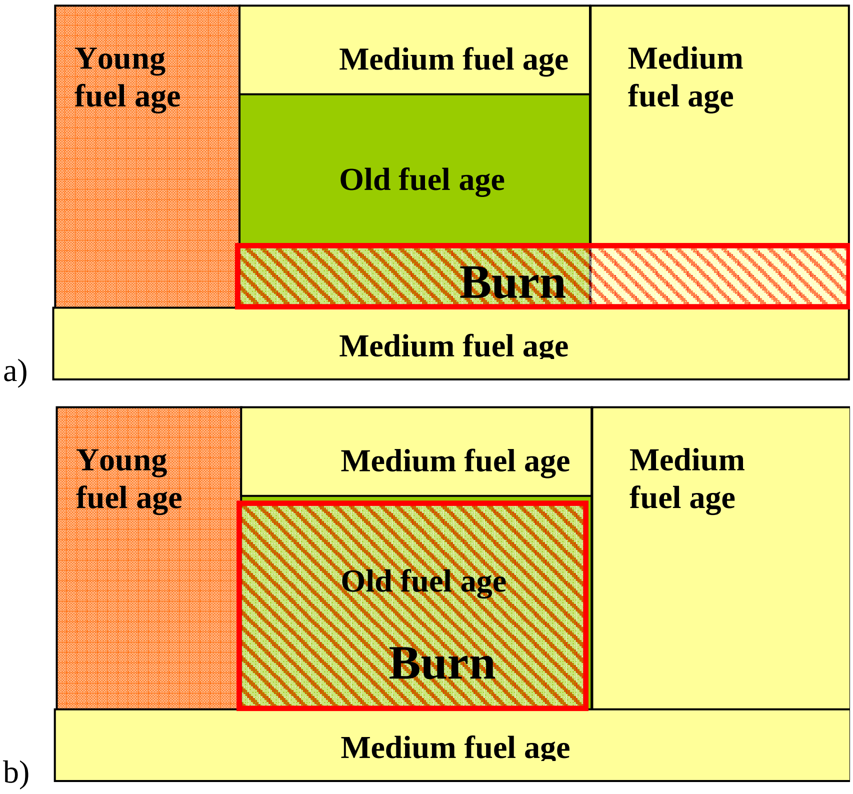


Figure 28. Schematic example of a burn to facilitate connectivity between the different fuel ages to maximise fauna movement and recolonisation. Narrower burns (a) are better for fauna access and connectivity than broader burns (b).

Very little is known about patch size and home range preferences for the fauna that inhabit the GSS. Home range calculations based on radio tracking and trapping data were completed for Quenda at Jandakot and Canning (Gardner 2004). The home range of males was estimated as 10.6 hectares with a range from 4.1 to 27.6 hectares while for females the average was 12.7 hectares and ranged from 0.01 to 27.5 hectares. Further study is required to determine the home range of this species on the GGS and any variations that may be related to particular habitats, or rates of predation.

Based on the lack of spatial information, we propose that burnt patch sizes of less than 200 hectares may be appropriate, and complies with the area of prescribed burns undertaken between 1976 and 2000 (Figure 8a). Consistent with adaptive management a variety of size classes out to 200 hectares could be trialled. To a large extent, the size of burnt patches will be dictated by the logical burn units, or the existing layout of roads and tracks that will be prescribed burn boundaries.

Burning and interactions with other threats

Climate change and fire regimes

Overall, it is expected that global fire activity will continue to increase as a consequence of climate change (Flannigan *et al.* 2009). In Australia the frequency of very high and extreme fire danger days will increase by 4-25% by 2020 and by 15-70% by 2050 (Hennessy *et al.* 2007). Many flora and fauna species will be vulnerable to extensive and frequent fires, especially fauna that have small home ranges and are relatively immobile and longer-lived obligate seeder flora species (Yates *et al.* 2008). Ideal conditions/seasons for prescribed burning may also become restricted due to weather conditions that pose higher wildfire risk in spring and autumn (Hennessy *et al.* 2007).

More frequent, high intensity, large scale fires, as a result of climate change, will have implications for the biodiversity of the GSS study area. Although the *Banksia* woodland of the GSS study area are generally adapted to fire (Enright *et al.* 1998) species such as *Banksia prionotes* where adults are killed by fire, but fire stimulates seeds to germinate is thought to be particularly vulnerable to frequent, widespread fire events. Resprouters (for example *B. attenuata*, *B. grandis*, *B. menziesii)* where adult trees can survive low to medium intensity fire and regenerate from lignotubers may also be subject to local extinction but at a much slower rate than species where adults are killed by fire Enright *et al.* (1998). A number of studies also indicate that frequent, widespread, and/or severe fires will impact on priority fauna in the GSS study area. For example, following a major summer fire followed by a series of minor fires, the population size of a number of bird species including the splendid fairy wren (*Malurus splendens*) and western thornbill (*Acanthiza inornata*) declined for eight years (Brooker 1998). Capture rates of the honey possum (*Tarsipes rostratus*) also decline markedly after fire, typically remaining low for more than five years post fire, with maximum abundances recorded 20-30 years post-fire (Everaardt 2003).

Fire and Predators

Predation of native mammals by foxes is considered to be a major factor contributing to the decline and local extinction of mammal species on the Swan Coastal Plain (Kitchener *et al.* 1978; Reaveley 2009). Although foxes have been recorded regularly in fauna surveys on the northern Swan Coastal Plain (Kitchener *et al.* 1978; Valentine *et al.* 2009b) and observed by DEC Swan Coastal District staff (Reaveley 2009) there is no coordinated baiting program within the GSS study area except for Whiteman Park where a fox control program has been carried out since 1990.

Introduced predators affect species through direct predation, which can keep prey in a ‘predator pit’ of low abundance (Pech *et al.* 1992), in which either the predation alone may cause extinction (over-harvesting), or other causes and interactions exacerbate the predation effect. Direct predation may also lead to changes in the habitat use of prey species, so that species become confined to refugia where the availability of dense vegetation and food provide some degree of protection and resilience (Kinnear *et al.* 1988). These areas are not necessarily typical of a species’ habitat requirements but provide protection from predators. For example, in the GSS study area *Isoodon obesulus* (quenda) is restricted to dense wetland-associated vegetation, although it occupies upland or less dense habitat in areas where predators have been suppressed (Bamford and Bamford 1994; Valentine *et al.* 2009b). Populations of quenda and *Macropus irma* (brush wallaby) within Whiteman Park have both increased in number since fox baiting commenced (C Rafferty pers.com. 2009).

Inappropriate fire regimes are likely to increase the impacts of fox predation on the GGS as a result of the removal of dense wetland-associated vegetation which currently provides some degree of protection and resilience to species where fox baiting is currently not in place.

Weeds and fire

The interaction of pest plants with fire and their effect on fire regimes, particularly fire intensity and frequency, has been the subject of considerable study (Brooks *et al.* 2004; D'Antonio 2000; D'Antonio and Vitousek 1992). Pest plants affect fire regimes by invading an area and substantially modifying vegetation structure and composition, which can affect the intensity and/or frequency of a fire (Levine *et al.* 2003). For example, the grass–fire cycle occurs when an introduced grass species invades a shrubby habitat, alters the vegetation structure and creates a continuous fuel bed that can lead to an increase in fire frequency, and subsequently result in the conversion of shrublands to grasslands (D'Antonio and Vitousek 1992). In addition, introduced grass species may increase fuel loads and may contain more combustible elements than native species. These two factors subsequently alter fire intensity (Grice 2004; Levine *et al.* 2003).

Invasion of post-fire vegetation by herbaceous pest plants has been identified as a threat to the conservation of south-west Western Australian Proteaceae species (Lamont *et al.* 1995). Intense fire can open areas of vegetation and create a rich ash bed, allowing invasive pest plants with competitive advantages to rapidly establish with, or instead of, native vegetation. Fragmented and remnant areas of native vegetation are particularly susceptible to pest plant invasion following fire, often leading to a loss in native vegetation (Milberg and Lamont 1995).

On the GGS the invasion of weeds is a major concern following the removal of pine plantations and the implementation of 9000 hectares of ecological linkages, as recommended under the GSS (Government of Western Australia 2009a). Thirty species have been identified as high priorities for management (Keighery and Bettink 2008) and these have been prioritised for their invasiveness, actual and potential distribution, trends, classification or rating and ecological impacts. All of the species satisfy one or more ecological impact attribute criteria, based on Platt *et al.* (2005). These criteria range from altered fire regimes, altered nutrient conditions and altered hydrological patterns, to loss of biodiversity and allelopathic effects. Taxa such as veldt grass *Ehrharta calycina* are already present in major sites of infestation in post- pine areas. These weeds may have major implications for the implementation of ecological fire regimes in the future.

Interaction of fire and impact of Phytophthora cinnamomi on flora and fauna

Phytophthora cinnamomi is listed as one of the world's 100 most devastating invading species by the IUCN Species Survival Commission (Cahill *et al.* 2008). The plant pathogen has been shown to alter plant species abundance and richness, as well as the structure of vegetation in sclerophyllous vegetation throughout Australia (McDougall *et al.* 2002; Podger and Brown 1989; Shearer *et al.* 2007a; Weste 1974; Weste *et al.* 2002). The lethal epidemic of *Phytophthora* 'dieback' has been identified as a 'key threatening process' in the Australian environment (Environment Australia 2009; O'Gara *et al.* 2005). *P. cinnamomi* is widely distributed in *Banksia* woodlands of the Swan Coastal Plain (Podger 1968; Shearer 1994). Common species such as *Banksia attenuata* and *B. grandis* reach 50% mortality in 7 to 12 years, whereas mortality rates for declared rare flora were much more rapid, with local extinction of most of the assessed declared rare flora occurring in < 3 years (Shearer *et al.* 2007). *P. cinnamomi* infestation also caused significant changes in ground and canopy cover in woodlands where the ground cover (40%) in old infested areas was reduced compared with adjoining healthy vegetation (68%) and canopy cover was reduced from 48% in healthy to 25% in old diseased areas (Shearer *et al.* 2007).

Analyses of the occurrence and distribution of the pathogen on the study area in 2009 established that 20,747 hectares (10 %) of the area is infested with *P. cinnamomi* and that the pathogen occurs across all land uses, ranging from small urban remnants to large areas in the conservation estate (Wilson *et al.* 2009).

Information on the susceptibility of plant species to *P. cinnamomi* was available for only 240 of the 1337 species that are known to occur in the GSS study area, and 53% of these species have been recorded as displaying a level of susceptibility to the pathogen, or to the indirect effects it has on plant communities (Wilson and Valentine 2009). Eight of the ten threatened ecological communities located in the GSS study area were identified as having species susceptible to *P. cinnamomi.* Four were ranked as high risk, one at moderate risk, and five as low risk of *P. cinnamomi* impacts. Results of field assessments of the impacts of *P. cinnamomi* on flora and fauna found that plant species richness and canopy cover are lower in infested sites compared to uninfested habitats, and that bird species richness is lower in infested habitats (Davis 2009a; b; Swinburn *et al.* 2009).

Severe alterations to understorey species composition, overstorey, canopy structure and fauna are likely to significantly impact on the vegetation community's capacity to recover or undergo secondary succession. The implications for fire regime impacts on these damaged communities on the GGS are unclear. Fire has been shown to influence survival and dispersal of *P. cinnamomi* on the south coast of Western Australia (Moore 2005). The occurrence of fire also compounded the pressure on post-fire establishment of some species (Moore 2005).

8. Identification of areas for burning and maintenance of refugia for significant taxa and communities (case studies)

A number of factors need to be considered when identifying areas for ecological burning and the identification and maintenance of refugia. Firstly in order to achieve an approximation to the theoretical fuel age distribution it is necessary to provide the current fuel age distribution and spatial location of both fuel age and fire frequency. A second important factor is to include spatial components to maintain connectivity for fauna over time (for example linkages) and third a process to identify suitable locations for refugia. Below we provide several examples of this approach at the spatial scale of the reserve (Yanchep National Park, Yeal Reserve) and at the GGS spatial scale (linkages for fauna).

Yanchep National Park

Yanchep National Park (2,876 ha) is located to the north west of the GGS close to the coast, residential and rural zones. It has the highest number of visitors of reserves on the GGS. The park is an important conservation area set within the urban environment, and contains unique cave and karst systems, freshwater wetlands, diverse remnant vegetation and a rich diversity of native fauna. Yanchep National Park features a wetland of national importance, Threatened Ecological Communities such as the root mat communities within the caves which support endemic fauna species (DEC 2010). The park thus provides a valuable case study for developing guidelines for ecological fire regimes on the Gnangara system.

There have been several large and damaging wildfires in Yanchep National Park (1977 - 500 ha, 1983 - 800 ha, 2005 - 1,500 ha, 2009 - 1,493 ha). The 2005 wildfire significantly affected wetland vegetation and soils. Fire management guidelines are currently provided in the Yanchep National Park Management Plan (1989-1999). The guidelines have three fire frequencies (Fuel Reduction (51.6% of the park) with 6-8 years burn rotations; Vegetation Management Regime (26.1%) - 10-20 year rotation, No Fire Regime (22.3%). The management plan is due to be replaced by *"The Parks and Reserves of Yanchep and Neerabup Management Plan 2010"* and a draft has been released for public comment (DEC 2010). The draft plan proposes to manage biodiversity with fire by adopting an adaptive approach to fire management. It recommends that in the long-term it will develop, implement and monitor a range of fire regimes based on; the vital attributes of threatened species and ecological communities; vital attributes of key fire response species; developing diverse post-fire (seral) stages, or functional habitat types; managing fire to protect ecologically sensitive areas and niches (DEC 2010). The plan recommends one fire exclusion reference area and protection of wetland areas from fire.

The plan recognises that as there are gaps in current knowledge and management for biodiversity conservation it will initially focus on the protection of threatened species, threatened ecological communities that are protected by State and Commonwealth legislation and significant habitats that require specific atypical fire regimes. The plan considers it is appropriate to implement fire regimes specific to such taxa to ensure their persistence, or to protect from inappropriate fire regimes, such as frequent lethal fires, which are likely to cause the decline of these species and communities.

No data is available in the plan on vital attributes, key fire response species, the current fuel age and theoretical fuel age distributions, the spatial location of both fuel age and fire frequency, or the spatial characteristics or location of wetland areas to be protected from fire. However the plan proposes to incorporate information on the vital attributes of species into the prescribed burning program as it becomes available. As the result of the GSS fire studies (2007-2010) it is possible to supplement the recommendations of the plan in these guidelines and provide information on vital attributes, key fire response species, the current fuel age and theoretical fuel age distributions, the spatial location of both fuel age and fire frequency, and the spatial characteristics or location of wetland areas to be protected from fire.

Biodiversity at high risk from fire impacts

Approximately 75% of the wetlands of the Swan Coastal Plain have been filled or drained (Commonwealth of Australia 1997) and therefore the wetlands of the park have high conservation value. These include both permanently and seasonally inundated wetlands (i.e. lakes and sumplands) which provide protection of a range of wetland types and habitat important to native fauna (for example fish, wetland invertebrates, frogs, turtles and waterbirds).

The Loch McNess wetland system is particularly significant and is identified as being of national importance in the Directory of Important Wetlands in Australia. Other key wetlands include Lake Yonderup (permanently inundated), Lake Wilgarup (seasonal wetland sumpland), Pipidinny Swamp (sumpland, or permanently inundated wetland, Lake Nowergup (Neerabup Nature Reserve) is a permanent, deep lake (see Figure 29).

A range of wetland vegetation in Yanchep National Park is likely to be significantly impacted by inappropriate fire regimes including major complexes such as *Typha-Baumea, Melaleuca rhaphiophylla,. Melaleuca preissiana, Melaleuca viminea, Eucalyptus rudis, Juncus kraussi, Lepidosperma longitudinale, Casuarina obesa* (Horwitz *et al.* 2009b). The three Threatened ecological communities are likely to be significantly impacted by inappropriate fire regimes: Aquatic root mat community of Yanchep Caves, communities of tumulus springs (organic mound springs); Woodlands over sedgelands in Holocene dune swales of the Swan Coastal Plain – SCP19b; *Melaleuca huegelii - Melaleuca acerosa* (currently *M. systena*) shrublands on limestone ridges – SCP26a. Aquatic invertebrates are also at high risk from fire impacts including rare and endemic invertebrate taxa associated with rare wetland types such as cave streams and mound springs with stygofaunal assemblages distinguishable from the unconfined aquifer (Horwitz *et al.* 2009a; Sommer *et al.* 2008).

Three Schedule 1 (fauna that is rare or likely to become extinct) species occur in the area the ‘critically endangered’ Crystal Cave *Crangonyctoid (Hurleya sp.),* the ‘endangered’ Carnaby’s cockatoo, and the ‘vulnerable’ chuditch (these three species are also protected under the Commonwealth’s EPBC Act). Two Schedule 4 (other specially protected fauna) species that occur are the peregrine falcon (*Falco peregrinus*) and the carpet python (*Morelia spilota imbricata*).

A substantial population of *Hydromys chrysogaster* Rakali, a Priority 4 species, was found at Loch McNess within Yanchep National Park. The survival of rakali is critically linked to the persistence of wetland eco-systems and loss or reduction in size and quality of wetland areas would affect the availability of terrestrial habitat and food resource such as large aquatic insects, fishes, crustaceans, mussels, frogs, lizards, water birds and tortoises (Olsen 2008; Woollard *et al.* 1978). Loch McNess has a high frequency of fires (Sonneman and Kuehs in prep). The lake also has low numbers of islands that could provide fire free habitat for water rats. The mootit or bush rat were only located in wetland habitat in the GGS fauna studies including Loch McNess where they occurred in habitat with dense understorey and ground cover. Southern brown bandicoot or quenda (*Isoodon obesulus*) is identified as a Priority species and were typically found in moist low-lying areas with dense mid-storey vegetation in the GSS fauna studies (Valentine *et al.* 2009b). The species was only observed in high densities at Twin Swamps Nature Reserves which is both fenced and baited for protection of the critically endangered Western Swamp Tortoise. This information indicates that suppression of quenda populations is likely from fox predation in unbaited habitat. Hence, the persistence of quenda in unbaited areas on the GGS is strongly reliant on dense wetland-associated vegetation that is likely to decrease with increased fire frequency. Fire frequency should thus be low. Wetland birds are also at risk from fire regimes. Approximately 172 bird species have been recorded on the Gnangara groundwater system Bamford and Bamford (2003).

It is recommended that sites known to be important for these species and communities (high priority wetlands) are designated as refugia and protected from further loss, modification and frequent fire, particularly along lake edges and the banks where buffers need to be implemented (Figure 29).

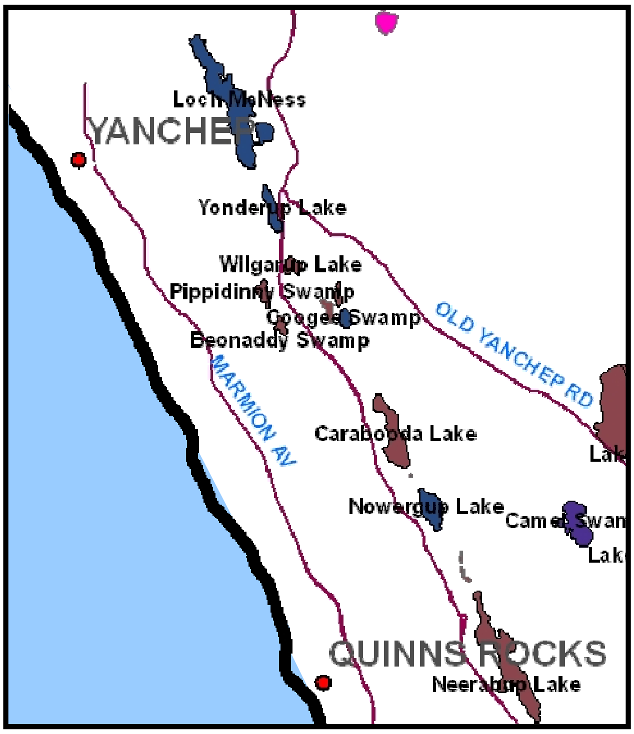


Figure 29. Key wetlands around Yanchep in the Gnangara groundwater system.

The current fuel age distribution (grouped in 5 year planning periods) for Yanchep National Park (Figure 30) shows that it is highly skewed to the 1-5 years with little in the 6-10 and 16-20 YSLB and none in the 21-35 range. It is recommended that burning be decreased in order to increase the older age vegetation and to endeavour to approach the ideal distribution. An analysis of the Banksia woodlands and Tuart woodlands is also recommended.

The management plan recognises that the remnant vegetation of the YNP, contributes important areas suitable for corridors for fauna movement for species such as the ‘endangered’ Carnaby’s cockatoo and the Honey possum on the largely cleared swan coastal plain (*The Parks and Reserves of Yanchep and Neerabup Management Plan 2010).* A major recommendation of the GSS (Government of Western Australia 2009a) is to establish ecological linkages across the GGS including significant connections with Yanchep National Park (Figure 32, Figure 33 and Figure 34). Some of these linkages will be rehabilitated after the removal of the pine plantations (Figure 33). It is vital that these linkages be managed to support the fauna species that they are designed for. In this case, to provide food resources for Carnaby’s and the Honey possum, and suitable aged vegetation structure for the Honey possum. The Honey possum was recorded both within the park and within small vegetation remnants in the pine plantations during GSS surveys (Figure 33). It is recommended that native remnant vegetation within the ecological linkages be left unburnt and of preferred post fire age for these species (20-30 YSLB). This is likely to require maintenance of more frequent burning in areas adjacent to the corridors to protect from wildfires.

An important TEC community (shrublands on limestone ridges – SCP26a) and locations of this community (Figure 32) could also be recognised as refugia and appropriate fire regime implemented.

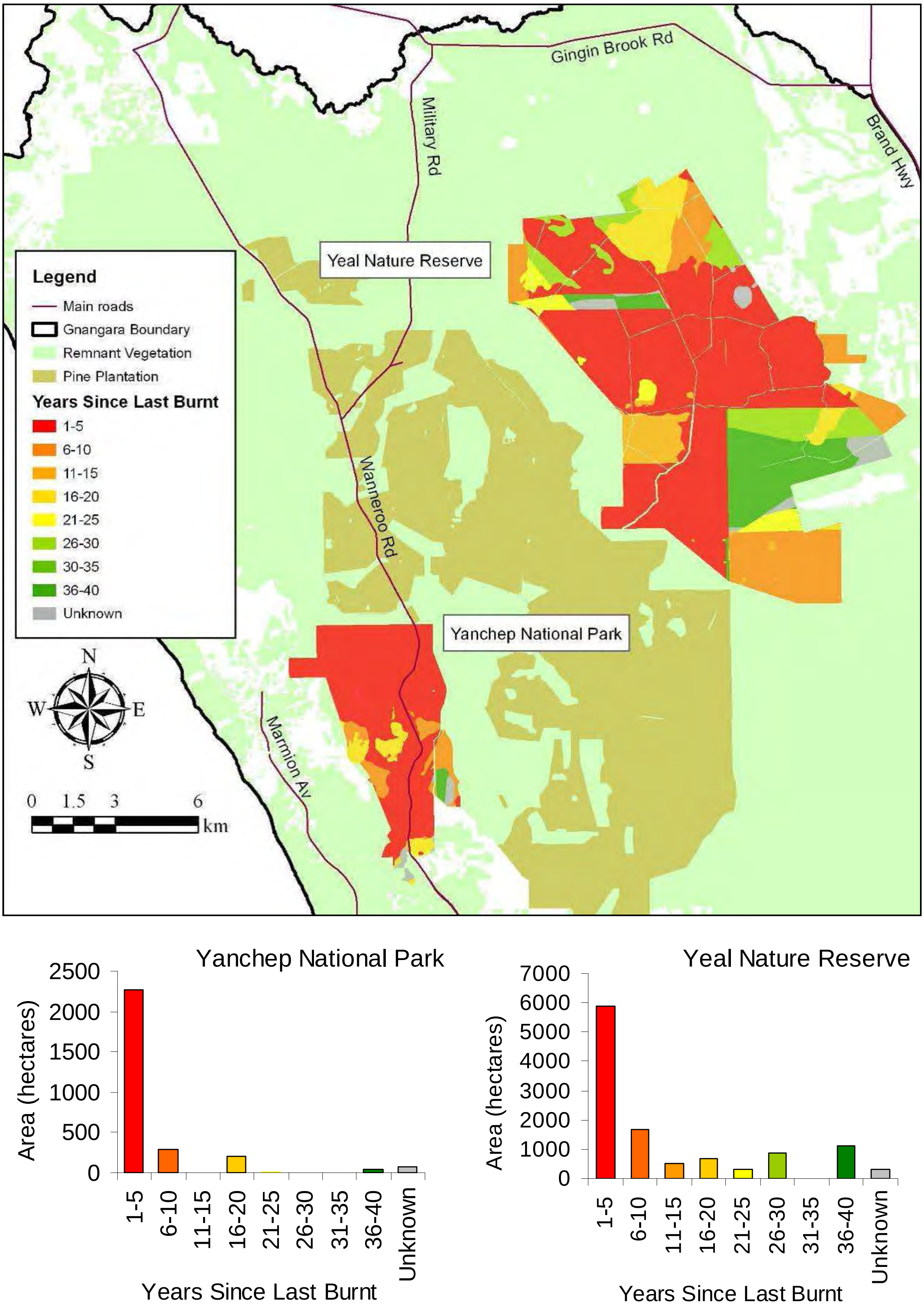


Figure 30. Fuel age distribution for Yanchep National Park and Yeal Nature Reserve

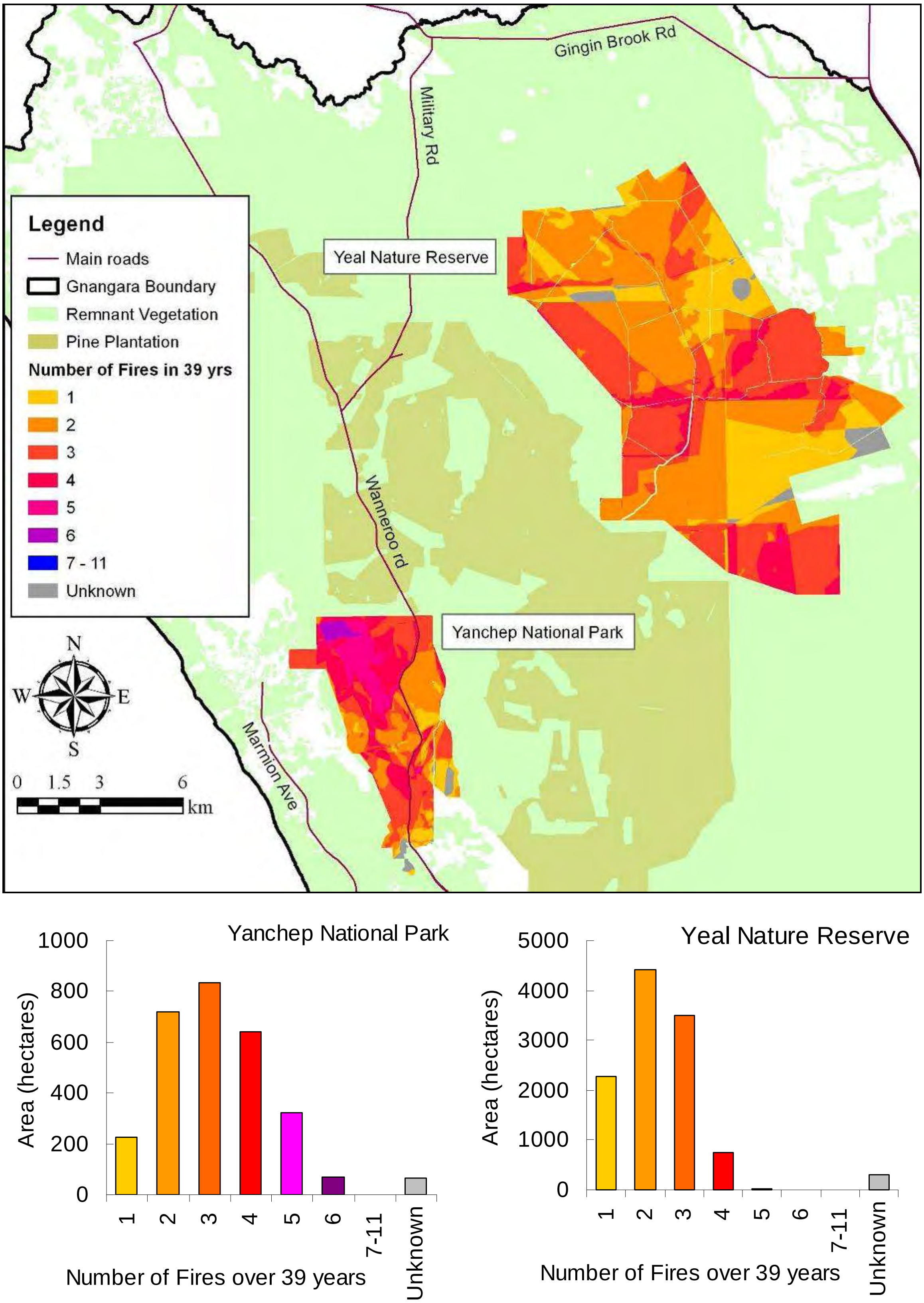


Figure 31. Fire number over 39 years for Yanchep National Park and Yeal Nature Reserve

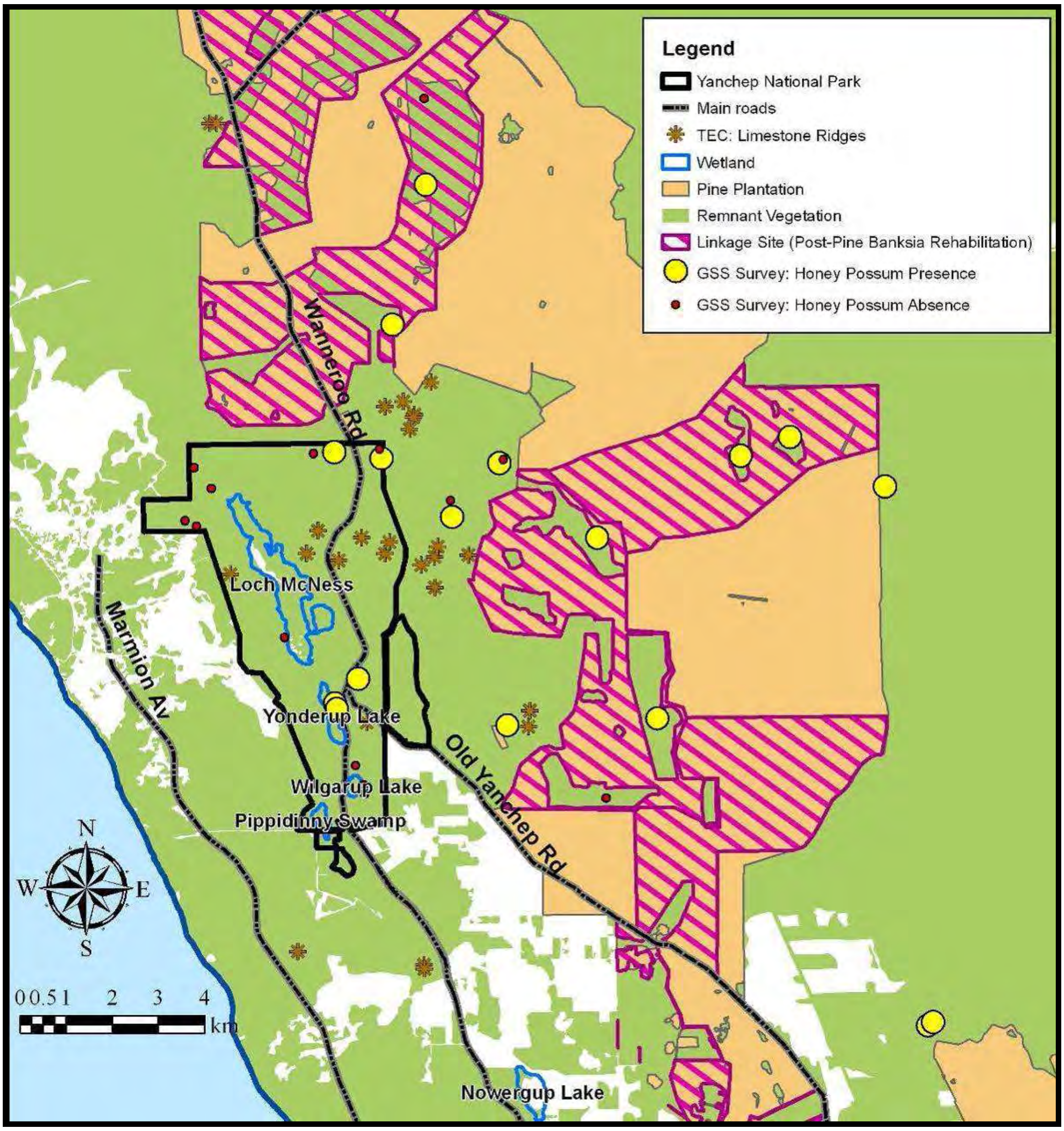


Figure 32. Location of ecological linkages, Limestone ridges communities and Honey possum records in and surrounding Yanchep National Park.

Yeal Nature Reserve

Yeal Nature Reserve (11,243 hectares) is the largest single DEC managed reserve in the Gnangara system and is found to the north east of the pine plantations, close to rural farmlands south west of GinGin. The park is an important conservation area as it contains a variety of freshwater wetlands, diverse remnant vegetation and a rich diversity of native fauna (DEC 2010). This reserve is also a valuable case study for developing guidelines for ecological fire regimes on the Gnangara system.

The current fuel age distribution for Yeal Nature Reserve shows that it has a broad distribution of fire ages with large areas of older post fire age vegetation (21-30 and 36-40 YSLB; see Figure 30). This is extremely important to GGS as it represent most of the older age vegetation still remaining on the system. It is recommended that burning be decreased in order to maintain older fuel age vegetation within Yeal Nature Reserve and to endeavour to approach the ideal distribution Figure 30). It is important to protect some of the intermediate fuel age vegetation (for example 10-20 YSLB) so it can age and replace the older fuel age vegetation.

The area is particularly important for Honey Possums habitat and it is recommended that pockets of Honey Possum preferred fuel age vegetation within the Yeal Nature Reserve be set aside as refugia (20-30 YSLB). It is also recommended that the older age habitat not be completely surrounded by recently burnt vegetation as this will restrict migration of fauna species. Linkages must be established and maintained with other suitable old vegetation.

It is further recommended that the sites know to be important (for example high priority wetlands) are designated as refugia and protected from further loss, modification or frequent fires.

Fire management for ecological linkages for fauna at GGS level

A major recommendation of the GSS (Government of Western Australia 2009b) is to establish ecological linkages across the GGS that promote landscape-level connectivity at a sub-regional level, by improving connectivity of remnant vegetation across the landscape, whilst focusing on key biodiversity assets. The ecological linkages proposed for the pine plantations, post-harvest, have been included. A number of factors were considered when plotting new ecological linkages. These included maximising the number of viable remnants (conservation reserves, Bush Forever sites and other bushland patches) so as to minimise the need for re-vegetation. Vegetated waterways and drainage lines were identified as linkages because they are unique ecosystems in the GSS, which form natural linkage corridors. Remnants of a vegetation complex which has low levels of retention and protection across the Gnangara groundwater system and Swan Coastal Plain were also given priority for inclusion within an ecological linkage. Linkage sites within pine plantations were chosen to include the larger high ecological value remnant vegetation patches within them. Final ecological linkages for the GSS area incorporating Bush Forever sites and highlighting 60% remnant vegetation core areas are shown in Figure 34. In total, 19 ecological linkages are proposed (Figure 34), covering 15 500 ha. Of this, 60% requires complete rehabilitation after the removal of the pine plantations.

The 500 m wide ‘conceptual linkages’ (blue lines in Figure 34) are the components of the proposed ecological linkages that are not currently protected (in reserves or Bush Forever sites). Therefore they will require acquisition, covenants with land owners and often, rehabilitation. These conceptual linkages will need to be assessed individually to determine the exact on-ground boundaries, based on remnant vegetation, land use and availability for purchase. Where possible any remnant vegetation or local natural areas should be retained in their entirety, rather than just the portion of these areas which fall within the mapped 500 m wide linkage.

These linkages need to be managed to provide food resources for Carnaby’s and the Honey possum, and suitable aged vegetation structure for the Honey possum. The Honey possum was recorded both within the Yanchep National Park, within small vegetation remnants in the pine plantations and in Yeal during GSS surveys (Figure 33). It is recommended that native remnant vegetation within the ecological linkages be managed to mature the vegetation to the preferred post fire age for these species (20-30 YSLB). This is likely to require maintenance of more frequent burning in areas adjacent to the corridors to protect from wildfires.

Post pine areas not to be restored are likely to be infested by veldt grass and other introduced species that have a high chance of fire incidence and intensity. Management in that region will have to be appropriate so fires from veldt grass don’t extend into linkages.

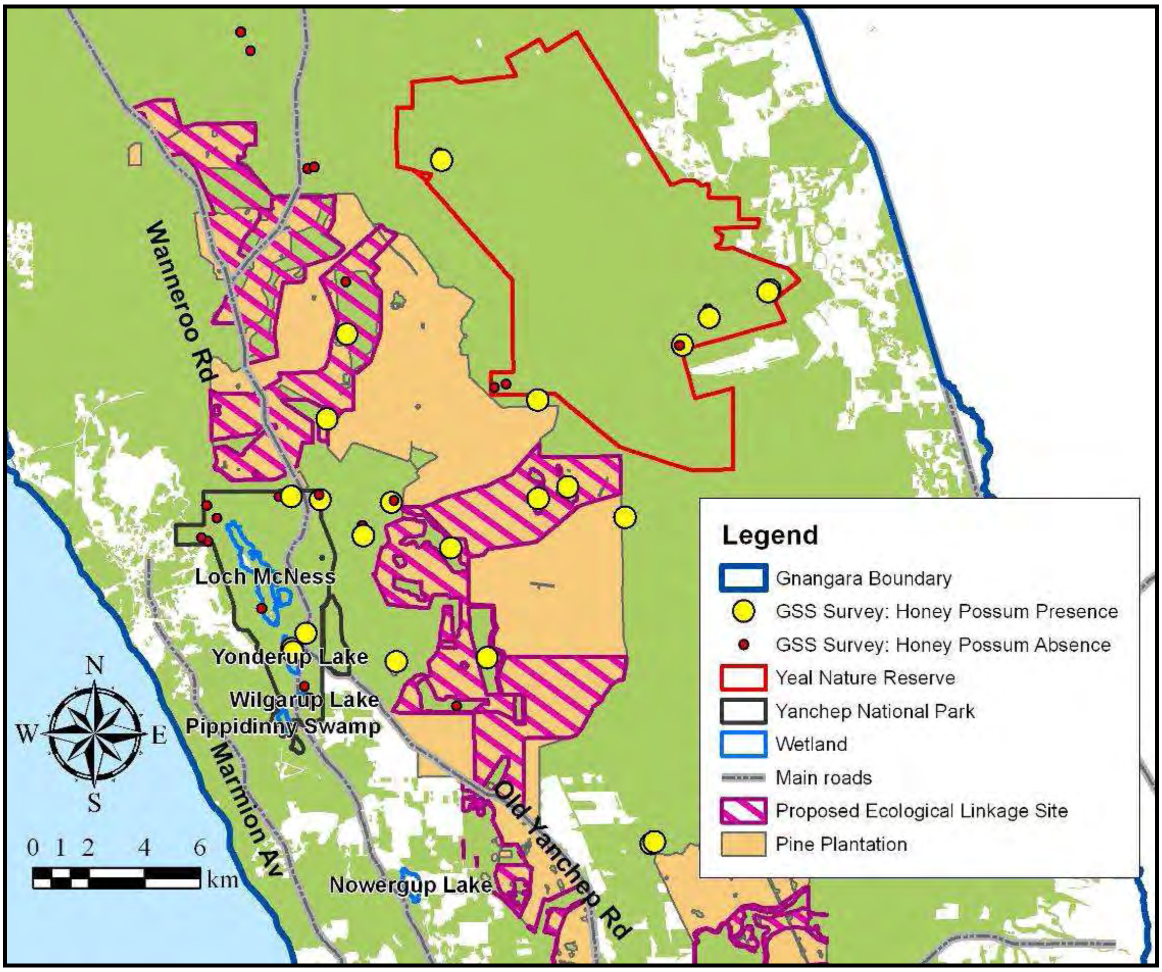


Figure 33. Proposed ecological linkages through rehabilitation of ex-pine plantation showing known locations of honey possums.

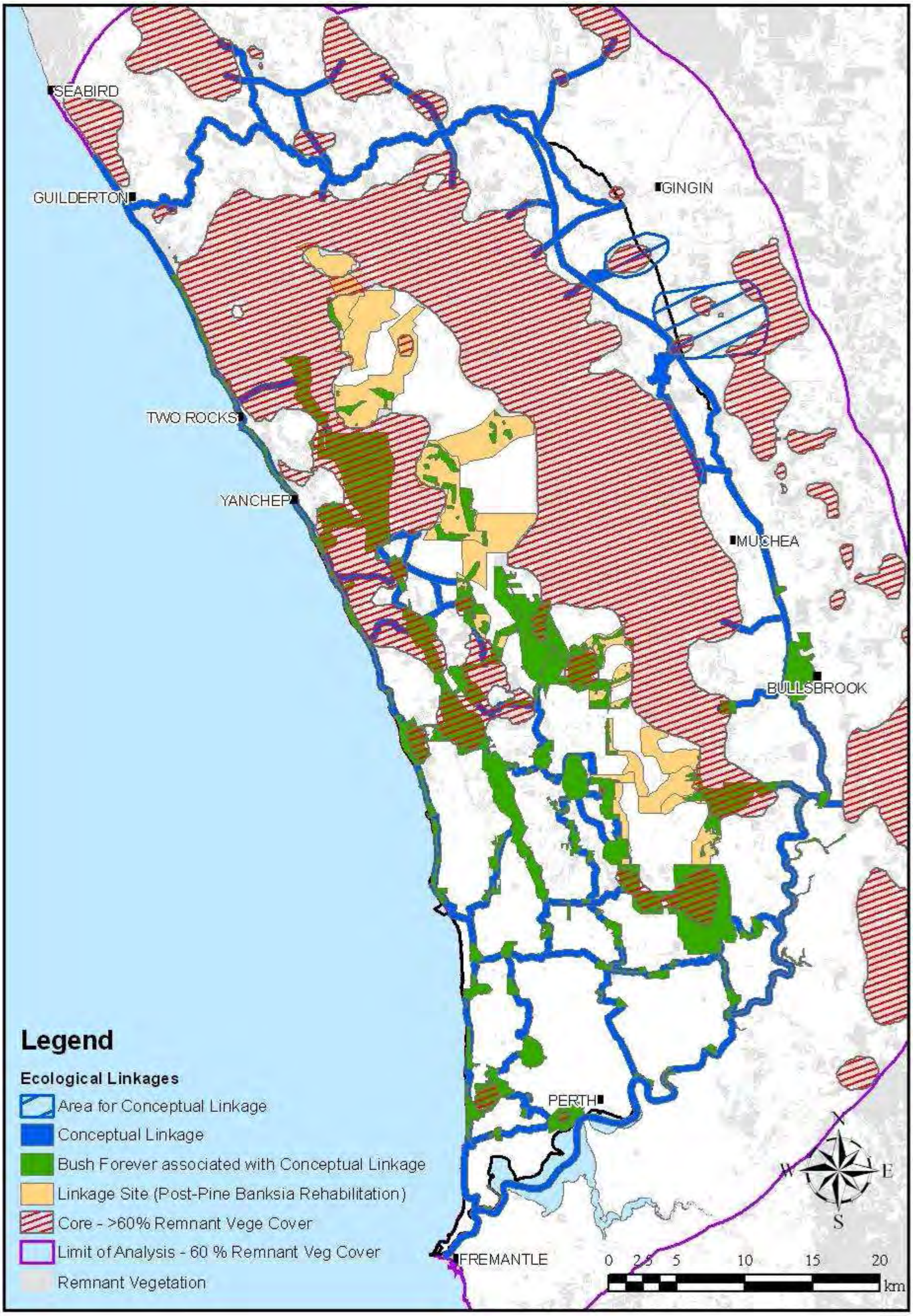


Figure 34. Final ecological linkages for the GSS area incorporating Bush Forever sites and highlighting 60% remnant vegetation core areas.

9. Input into DEC Prescribed Burning Management Plans

Management of fire including the use of fire, fire suppression and wildfire prevention by the Department of Environment and Conservation is regulated by legislation (for example *Bush Fires Act 1954*, CALM Act and precedents established under Common Law). It is also guided by the Department's *Policy Statement No. 19 – Fire Management Policy*, which includes a number of scientific principles (Abbott and Burrows 2003). Planning for prescribed burning thus involves a hierarchy of plans and links with other aspects of DEC operations (Muller 2010).

The key components in the planning process are:

- Statutory plans (Management Plans and necessary/compatible Operations guidelines)
- Strategic burning plans (Regional and Master Burn Plans)
- Burn Prescriptions

Statutory plans

The *Conservation and Land Management Act* 1984 requires land be managed in accord with approved management plans, or in the absence of such plans as "necessary operations" (in Nature Reserves) or "compatible operations" (National and Conservation Parks). Interim Management Guidelines (IMGs) for operations are normally prepared for areas that are not covered by a management plan. The following plans apply to the GGS study area.

Forest Management Plan 2004-2013

More than half the crown land in the GSS study area is State Forest subject to the Forest Management Plan 2004-2013 (FMP). The State Forest consists of approximately 50%, pine plantations and native vegetation. The FMP proposes actions at the landscape scale to use and respond to fire in a manner that: optimises the maintenance of forest ecosystem health; promotes the conservation of biodiversity; controls adverse impacts on social, cultural and economic values (DEC managed and adjoining land); and minimises the risk of smoke on people and sensitive areas. The major action that the Department undertakes is an annual prescribed burning program that: is in accordance with the fire management plan and smoke management guidelines; has regard to the goals for understorey structural diversity; and considers any special vulnerability of fauna and flora known to exist in a particular area.

In Pine Plantations the Forest Products Commission is required to: undertake an analysis of the risk from fire to its timber resources and from fire emanating from its plantations into surrounding land. FPC also cooperates with the Department and other organisations in seeking to control the risks to acceptable levels.

Park and Reserve Management Plans and Interim Management Guidelines

Approximately 25% of the total area is covered by Parks and reserves including Yeal Nature Reserve (11,243 ha), Yanchep National Park (2,876 ha) and a number of other smaller reserves.

Fire management guidelines in the Yanchep National Park Management Plan (1989-1999) contain three fire frequency definitions:

- Fuel Reduction Regime, with burn rotations of 6-8 years (51.6% of the park)
- Vegetation Management Regime- burn rotations 10-20 years (26.1% of the park)
- No Fire Regime (22.3% of the park).

This plan is due to be replaced by “The Parks and Reserves of Yanchep and Neerabup Management Plan 2010” (DEC 2010) and a draft has been released for public comment. The draft plan proposes a range of fire regimes based on the vital attributes of key species and one fire exclusion reference area. It proposes that wetland areas be protected from fire and that an adaptive approach is employed using the best available knowledge to modify the master burn plan and to meet the management objectives. It recommends that the results of monitoring and research be incorporated into the master burn plan review as it becomes available.

There is no approved management plan for Yeal Nature Reserve. Burning can be undertaken as a “necessary operation” which is defined under S33A as *“those that are necessary for the preservation or protection of persons, property, land, waters, flora or* *fauna, or for the preparation of a management plan."* The Yellagonga Regional Park management plan allows for the use of fire if required for vegetation management. There are no other management plans for Parks and Reserves in the GGS area. Many of the smaller reserves have IMGs or draft IMGs. These reserves are generally small, and most IMGs exclude prescribed burning.

Master Burn Plans and Annual Burn Plans

Regional Fire Management Plans integrate land use, nature conservation, strategic fire protection and community engagement issues and form the basis for Master Burn Planning. They establish a five year planning scope with landscape scale objectives, strategies and success criteria that are reviewed through adaptive management. The Swan Region Fire Management Plan is currently in preparation (Muller 2010).

The District Master Burn Plan is a rolling 3 year plan covering 6 burning periods (three Spring and Autumn periods). Planning involves the identification of biodiversity requirements and any obligatory burns required for land management, such as silviculture or rehabilitation. Additional burning required for protection against wildfire is then considered.

Prescribed Fire Plan

The prescribed fire plan includes all aspects relating to the conduct of a prescribed burn from the initial preparation to the final assessment of the result. It contains an overview of the approved burn plan, with a description of the burn, burn objectives, success criteria, monitoring requirements. As a burn will often serve many purposes (for example for biodiversity, community protection, water production) separate objectives and success criteria are defined for each purpose.

Operational information provided for the 'day of burn' includes checklists, action plan documents and maps and a Burn Implementation Plan prescribes the conditions under which and how the burn will be carried out, and observations to be recorded during the burn.

Post burn assessments and records are outlined and are necessary to assist the process of adaptive management. Records form part of the monitoring process, confirm compliance with the prescription, and allow for analysis to improve future results. Records outlined in the plan include: burn checklists, evaluation summary, maps of burn after each ignition, aerial plot burnt:unburnt and intensity, satellite imagery burnt:unburnt and intensity, post burn monitoring.

Pre planning information on which the prescribed fire plan is based includes: fuel assessments, operations in the area (for example harvesting or silvicultural), recreation sites and trails, specific issues/sensitive areas, any special flora, fauna and habitat requirements, burn preparation requirements, land use and neighbour issues. Stakeholder notification information that is required includes: notification to radio stations, landholders, affecting Apiary sites, public contacts.

The guidelines developed in this document can input at a number of levels of the fire management hierarchy including the Forest Management Plan 2004-2013, fire management guidelines in management plans (for example Yanchep National Park DEC 2010), Regional Fire Management Plans (Swan Region Fire Management Plan DEC in prep.), Master Burn Planning and prescribed fire planning Figure 35. An adaptive approach (see section 10) can be employed using the best available knowledge to modify these plans and to meet the management objectives. It is recommended that the results of monitoring and research be incorporated into the plans as it becomes available. Further, the guidelines would provide a strong basis for the development of Operational guidelines for burning in Banksia woodlands on the Swan Coastal Plain. An example of how ecological burning for biodiversity can be incorporated into fire management objectives is outlined in Appendix 2.

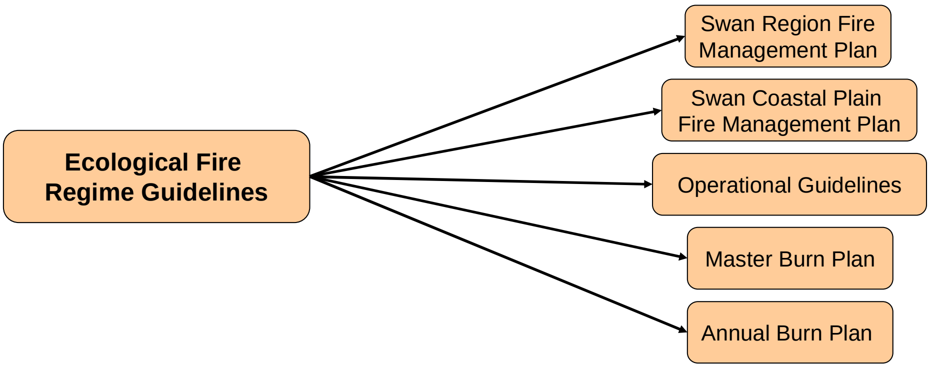


Figure 35. Ecological fire regime guidelines will feed in at a number of levels

10. Adoption of an adaptive management approach - monitoring of age classes, refugia, flora, fauna and habitat

It is important to quantify conservation achievements and to assess management effectiveness in achieving desirable outcomes (DEC 2008a). The World Conservation Union has developed a *Management Effectiveness Framework* (Hockings *et al.* 2006) that has been used for the evaluation of management in many countries including Australia where New South Wales Parks and Wildlife Service (Stathis 2006) and Parks Victoria (Parks Victoria 2007) have implemented conservation targets based on management effectiveness frameworks. The frameworks aim to measure management progress towards specific biodiversity conservation goals, and validate management strategies and actions in order to determine if management actions are indeed delivering the desired outcomes (DEC 2008a).

The DEC Nature Conservation Service has in recent years, moved towards an outcome-based or value driven management approach, where actions are linked to expected biodiversity conservation-related outcomes (DEC 2009b). This has also been linked with work to better define priorities and targets for the Service, and adoption of an active adaptive management framework for projects and programs Figure 36.

Adaptive management and the more intensive “active” adaptive management have been defined by the British Columbia Ministry of Forests (2004) as follows:

> “*Adaptive management* is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form, *active adaptive management*, employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed”.

Adaptive management thus provides a framework for managing natural resources where gaps in knowledge are recognised and dealt with in a cycle that helps managers learn from past experiences and use this new knowledge to improve future management practices.

An important aspect of *active adaptive management* approach is the recognition of factors that need to be addressed when developing projects and programs of activities, and managed to reach the target desired state or condition of biodiversity when implemented (Figure 36). This approach promotes the integration of research and management, by addressing issues at the appropriate spatial and temporal scales (DEC 2008a). It is important that the overall project goal and the specific objectives are understood and developed jointly. There should be hypotheses that are testable for each management objective.

Appropriate monitoring to assess objectives should be developed that is specific, measurable, achievable, relevant and timely (DEC 2008a). In addition monitoring should be based on clearly defined and verifiable data that is sensitive to change to show trends, both negative and positive. It is essential to ensure appropriate sampling design is developed to minimise biases in data collection (Cawson and Muir 2008; DEC 2008a)

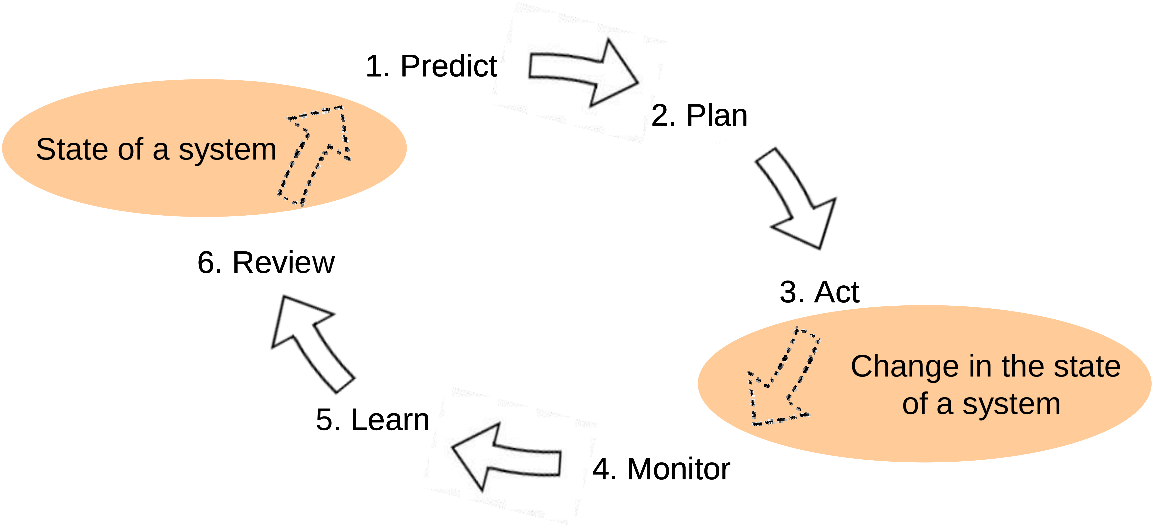


Figure 36. Adaptive management cycle from DSE (2008)

Monitoring is employed to examine and review land management actions and therefore the relationship between the monitoring objectives and land management should be close. Monitoring of flora and fauna species responses to any implemented fire regime should be undertaken to ensure species are responding as predicted and to feed into an adaptive management framework. Some key ecological outcomes need to be assessed to determine the success of achieving the specific objectives for burning. On the GGS the focus is likely to include assessment and monitoring of factors such as; vegetation age class variables; status of key fire response flora species, vital attributes of flora species, status of key fire response fauna species, fauna habitat variables, all of which have been assessed under the GSS (2007-2010) thus providing excellent baseline data and study sites.

A broad management objective for ecological burning is to ensure that flora and fauna are protected from the deleterious effects of fires and inappropriate fire regimes. It is predicted that certain species will become locally extinct if fire is too frequent or too infrequent. Ecological burning endeavours to meet this management objective by creating a mosaic of age-classes across the landscape, with the majority of the vegetation being burnt within the tolerable fire intervals defined by the flora vital attributes. This approach assumes that if the fire frequency fits within the 'tolerable fire interval' defined by the key fire response species then all species of vascular flora within the area should survive. In the GGS this assumption is largely untested. Field monitoring should be undertaken to assess the prediction (Tolhurst and Friend 2001).

The information on vital attributes for many flora species on the GGS is currently not available thus monitoring objectives could also aim to obtain information on flora vital attributes for those species that lack such data. Predicting relative dominance of flora species and the size of change in species composition following fire is also important because of the relationship to community composition, and also fauna habitat structure (Figure 22). Monitoring objectives could also aim to obtain information on species composition and dominance.

There is a lack of knowledge about the effects of attributes of the fire regime (fire intensity, extent and season) on flora vital attributes. Objectives to monitor information about the flora species' response to different fire severities, seasons and fire frequency may also be appropriate. Other factors that may affect plant responses to fire such as climate or grazing are unclear. Objectives to obtain this information may lead to a better understanding of how vital attributes change as these other factors change.

There are limitations of monitoring that need to be acknowledged when making conclusions about the effects of burning. Monitoring can demonstrate the size of a change and these changes can be correlated with a potential cause. However, a correlation between a change and a fire does not mean that the burn caused that change. Because monitoring data provides limited capability to determine a cause, so conclusions should be cautious.

Monitoring needs to be done at different scales ranging from the regional or landscape scale (for example GGS), to the community level (for example TECs, wetlands), to population and species level (threatened flora and fauna, key fire response taxa) (DSE 2008; Shedley 2007). Because the monitoring occurs at the different scales different techniques are appropriate.

Further because monitoring of fire and burning impacts and regimes requires a long term commitment there is a need to determine the availability of resources (personnel, skills, financial), and to prioritise the monitoring effort and commitment. A number of levels recommended for monitoring on the GGS are described in Table 9. Information on appropriate methods and questions are provided, together with references to baseline data and study sites that have been assessed under the GSS (2007-2010) fire studies.

Table 9. Recommendations for monitoring to further assess ecological burning regimes on GGS

Scale	Monitoring	Objectives and questions	Methods and frequency of survey	GSS reports and study sites
Landscape (GGS)				
	Fuel Age class distributions	To see if approximates ideal	GIS, remote sensing annually	(Sonneman and Kuehs in prep)
	Fire intensity/ seasonality, etc	To determine impacts on vital attributes Long-term monitoring to detect impacts of changes in rainfall level and climate change	GIS, remote sensing annually, on ground capture of weather patterns, intensity of fires, litter depth (particularly for PB)	Some of this is already being done by fire crews (especially for wildfires)
	Fire Patchiness	To determine ratio between burnt area and unburnt patches to find most suitable ratio for Banksia woodland	GIS, remote sensing, Spatial modelling and possible trial burns. Monitoring annual fire updates	
	Maintenance of linkages	To keep fires out and maintain appropriate fire age	GIS, remote sensing and surveying annually	
Community				
Vegetation	Condition/health	Monitor tree health in relation to fire	Quadrats in vegetation communities	(Kinloch *et al.* 2009a; Kinloch *et al.* 2009b)
	Sp richness and composition	Measure changes over time and in relation to fire	Quadrats in vegetation communities (10x10m), monitor every 2-3 years	Baseline GSS surveys (Mickle *et al.* 2009)

Scale	Monitoring	Objectives and questions	Methods and frequency of survey	GSS reports and study sites
	Juvenile period and post fire regeneration	Measure changes over time and in relation to fire	Quadrats in vegetation communities (10x10m), monitor every 2-3 years	Baseline GSS surveys (Mickle *et al.* 2010a; Mickle *et al.* 2010b)
	Dominant vegetation and abundance	Measure changes over time and in relation to fire	Quadrats in vegetation communities (10x10m), monitor every 2-3 years	Baseline data exists for Banksia density. eg food resources for Carnaby's (Valentine 2010)
TEC	Monitoring guidelines already exist	Measure effects over time and in relation to fire		Reference TEC recovery plans
Reptiles	Species richness and abundance	Measure changes over time and in relation to fire	Survey every 1-2 years	General ground dwelling vertebrate diversity (Valentine *et al.* 2009b); Post fire recolonisation (Sonneman *et al.* 2010) Mammals of GSS (Reaveley 2009);
Mammals	Species richness and abundance	Measure changes over time and in relation to fire	Survey every 1-2 years	
Birds	Species richness and abundance	Measure changes over time and in relation to fire	Survey every 1-2 years	Base line surveys by Davis (2009b)
Frogs	Species richness and abundance	Measure of wetland health and wetland changes over time – climate change impacts Fire patterns are unknown	Annual surveys currently being done by Bamford Consulting Ecologists	Baseline and continued surveys by Bamford and Huang (2009)

Scale	Monitoring	Objectives and questions	Methods and frequency of survey	GSS reports and study sites
Key flora species				
	Banksia attenuata	To improve data on effects of fire (eg juvenile period, post fire response)	Targeted surveys	(Mickle *et al.* 2010a; Mickle *et al.* 2010b)
	Banksia menziesii			
Key fauna species				
Amphibians	*Crinia insignifera*	To improve data on effects of fire	Targeted surveys	
Reptiles	Western Swamp Tortoise	To obtain data on effects of fire	Targeted surveys	Dr Gerald Kuchling's studies
	Rankinia adelaidensis	To improve data on effects of fire	Targeted surveys	
Birds	Carnaby's Black Cockatoo	To increase understanding of fire impacts on Banksia food availability (eg intensity)	Targeted surveys	(Valentine 2010)
Mammals	Honey Possum	To improve data on effects of fire	Targeted surveys	General ground dwelling vertebrate diversity (Valentine *et al.* 2009b); Post fire recolonisation (Sonneman *et al.* 2010) Mammals of GSS (Reaveley 2009);
	Quenda	To obtain data on effects of fire	Targeted surveys	
	Rakali	To obtain data on effects of fire	Targeted surveys	
	Bush rat	To obtain data on effects of fire	Targeted surveys	

Discussion

One major recommendation of the GSS was the implementation of the optimum fire regime that will maximise groundwater recharge, while maintaining biodiversity values. In order for any increase in fire frequency to become a management option, the impact of inappropriate fire regimes on biodiversity must be understood. It is also necessary to have a clear understanding of the current fire history and age class distributions.

Vital attribute information has been obtained and key fire response species identified to enable the determination of minimum and maximum tolerable fire intervals (Wilson *et al.* 2010a). As no single fire regime is optimal for all species and communities (Abbott and Burrows 2003; Bradstock *et al.* 2005; Burrows 2008)the approach has been to develop diverse ecological burning regimes on the GGS that aim to set ecological limits based on our current knowledge of impacts on biodiversity.

The plant vital attributes of flora species in the GSS where identified and used to select key fire response species. The key plant species included the dominant *Banksia menziesii* and *Banksia attenuata* whose post-fire juvenile period on the GGS was estimated at 8 YSLF. A minimum fire interval of 8 to 16 years is thus proposed based on twice the juvenile period (as recommended by Burrows *et al.* 2008) for fire sensitive flora species that rely on seed stores for reproduction following a fire and the dominant *Banksia* species which have the highest Juvenile period of all flora species. A maximum fire cycle of 40 years is proposed as a conservative 5 years younger that the maximum age to which *Banksia* would live (Enright *et al.* 1998). The recommended minimum fire interval is also supported by other information on the rate of increase of *B. attenuata.* It is estimated that *B. attenuata* on northern sandplains has the greatest rate of increase for a fire frequency of 7-20 years, with maximum at 13 years (Enright *et al.* 1998).

GSS field studies have advanced our understanding of the impacts of fire on the vertebrates and provided strong evidence for post-fire seral responses of reptiles and mammals and variations in food productivity. The endangered Carnaby's Black Cockatoo has been identified as a key fire response species as research on seed food availability found that on the GGS *Banksia* woodlands would support higher numbers in older fuel ages (20-30

YSLB) and much lower numbers in young fuel age 0–5 YSLB (Valentine 2010). The data provides strong support for fire regimes that maintain or increase long-unburnt habitat within the 20-30 YSLF category and increase the amount of habitat in the 11-19 YSLB. This is particularly important in view of the removal of pine plantations (the other significant food source) over the next 18 years under the GSS (Government of Western Australia 2009b).

Overall reptile abundance and abundance of some species (for example*Menetia greyii*, *Morethia obscur, Neelaps calonotos)* were significantly higher in old (>16YSLB) fuel age while others, for example Rankinia *adelaidensis*, showed a strong preference for young fuel age (<11 YSLB). The evidence of post-fire seral responses for reptiles provides strong support for maintenance of a diverse range of post-fire aged habitat including retention of long-unburnt *Banksia* and *Melaleuca* that are important to species such as *Neelaps calonotus* and *Menetia greyii.*

A key fire response mammal species *Tarsipes rostratus* (honey possums) had low abundance in recently burnt sites (<7YSLB), with a peak in relative abundance at sites 20-26 YSLB. Based on this information burning regimes need to ensure retention of long-unburnt vegetation for this species. Other key fauna species identified include the mammal species Quenda (*Isoodon obesulus*) and Water rat (*Hydromys chrysogaster*), the critically endangered Western Swamp Tortoise. While data on the preferred fire age for these species has not been obtained there is information on the preference of Quenda for dense habitat in areas, and the strong link of Water rat rakali to persisting wetlands and dense riparian vegetation. It is also recommended that that fire management planning should ensure retention and protection of long-unburnt wetland-associated vegetation as refugia for high priority wetlands and for associated fauna species such Quenda and Water rat. In the case of the Honey possum we have recommended procedures to incorporate spatial aspects of its distribution to identify refugia and ecological linkages across the GGS. It is recommended that native remnant vegetation within the ecological linkages be left unburnt and of preferred post fire age for these species (20-30 YSLB). This is likely to require maintenance of more frequent burning in areas adjacent to the corridors to protect from wildfires.

Analysis of the annual area burnt over a 39 year period (1970-2009) revealed that 43 to 49% of total burns are wildfires across the total GGS compared to 28 and 47% on DEC managed land. The fuel age distribution as of 2009 for the whole Gnangara system found that the area of old fuel age (>21years) is very low, and 60% of the area is young fuel age (1-7 years). The distribution for DEC managed land shows a similar distribution but with a somewhat higher percentage (67%) younger than 7 years. The spatial distribution of fuel ages shows there is a higher proportion of young fuel age (<5 years) surrounding pine plantations. The small areas of old fuel ages 21-39 years are predominantly limited to locations in the north east (Yeal Nature Reserve) and in the north west (Wilbinga Conservation Reserve). Statistical analysis of the spatial distribution of fuel age shows a high level of clustering, thus large areas of similar fuel age are highly associated. There is no evidence of a patchy mosaic at the landscape spatial scale

There was evidence that across the GGS *Banksia* woodlands and *Melaleuca/E. rudis* do not approximate the idealised distribution and are highly skewed to the 1-6 years since fire age. The burning requirements to approximate the idealised age distributions can be met over time through wildfire or prescribed burning. On the GGS approximately 2072 hectares would need to be burnt each year (either by wildfire or prescribed burn) to approach the 'Ideal' fire regime distribution. Currently the annual burn rate is 4970 ha. Any changes to burning such as a decrease in area will need to be assessed within the fire management planning process. Such changes would require assessment of factors such as targeted burning around areas of highest wildfire incidence, and strategic burning of limited patches/strips at a high frequency. Determining the optimal patch sizes, patchiness, frequency and locations is complex and is likely to benefit from computer simulation modelling (King *et al.* 2006; King *et al.* 2008). Further work should be undertaken for the GGS.

The guidelines developed in this document can input at a number of levels of the fire management hierarchy including the Forest Management Plan 2004-2013, fire management guidelines in management plans (for exampleYanchep National Park), Regional Fire Management Plans (Swan Region Fire Management Plan), Master Burn Planning and prescribed fire planning. There is now a need to plan to incorporate them where appropriate.

Other impacts that threaten to further increase the impact of inappropriate fire regimes on biodiversity on the GGS such as predators, weeds and the plant pathogen of *P. cinnamomi* need to be assessed. The impacts of fox predation on the GGS are likely to compound the impacts of inappropriate fire regimes as a result of the removal of dense wetland-associated vegetation which currently provides some degree of protection and resilience to species such as Quenda and Rakali where fox baiting is currently not in place. The invasion of weeds is a major concern following the removal of pine plantations and the implementation of 9000 hectares of ecological linkages, as recommended under the GSS (Government of Western Australia 2009a). Thirty species have been identified as high priorities for management (Keighery and Bettink 2008). Taxa such as veldt grass *Ehrharta calycina* are already present in major sites of infestation in post- pine areas. These weeds have major implications for the implementation of ecological fire regimes in the future as they can increase fire intensity. Approximately 20,747 hectares (10 %) of the GGS area is infested with *P. cinnamomi* casing severe alterations to understorey species composition, overstorey canopy structure and fauna that are likely to significantly impact the vegetation community's capacity to recover or undergo secondary succession. The implications for fire regime impacts on these damaged communities on the GGS are unclear, but likely to compound the pressure on post-fire establishment of species and communities.

In Australia climate change may lead to complications of future fire management and prescribed burning (Hennessy *et al.* 2007). Many flora and fauna species in these ecosystems will be vulnerable to extensive and frequent fires, especially fauna that have small home ranges and are relatively immobile and longer-lived obligate seeder flora species (Yates *et al.* 2008). Ideal conditions/seasons for prescribed burning may also become restricted due to weather conditions that pose higher wildfire risk in spring and autumn (Hennessy *et al.* 2007). More frequent, high intensity, large scale fires, as a result of climate change, will have implications for the biodiversity of the GSS study area. There is a need to assess possible changes to patterns of wildfire. Further changes in the post pine situation might change this pattern. It is recommended that modelling of the probabilities of wildfires including spatial incidence and predicting high probability locations be undertaken.

An adaptive approach needs to be employed using the best available knowledge to modify the plans and to meet the management objectives. It is recommended that the results of monitoring and research be incorporated into the plans as it becomes available. It is recommended that appropriate monitoring methods are developed, and where appropriate be based on baseline data and study sites that have been assessed under the GSS (2007-2010) fire studies.

This report on guidelines for ecological burning on the GGS provides a case study that could provide the basis for developing guidelines in south west Western Australia.

Recommendations

In order to develop ecologically appropriate fire regimes in the GSS study area, it is recommended ecological burning regimes are developed that:

- incorporate the impacts and data presented in this report and the other GSS studies and reports
- are based on a minimum fire interval of 16 years (twice juvenile period) and a maximum interval of 45 years for *Banksia* woodlands and *Melaleuca*
- are based on the productivity of *Banksia* species for food availability for Carnaby's Cockatoo and maintain the amount of habitat in the 20-30 YSLB and increase the amount of habitat in the 11-19 YSLB, particularly in light of the removal of pine plantations over the next 18 years
- decrease burning to ensure that there will be different fire ages and a fuel age frequency distribution that approaches the theoretical distribution over time for *Banksia*, *Melaleuca*
- are based on habitat requirements for flora and fauna
- ensure retention of long-unburnt *Banksia* woodland important to species such as honey possum, some reptiles and birds
- ensure retention and protection of long-unburnt wetland-associated vegetation as refugia for high priority wetlands and for associated fauna species for example Loch McNess wetland system

- incorporate spatial aspects of fauna distribution, habitat and home ranges (for example Honey possum) to identify appropriate burning around refugia and for provision of linkages.
- develop an extensive and suitable adaptive management framework to monitor the impacts of ecological fire regimes across the landscape that can be used to evaluate any changes in condition and progress towards ecological fire management objectives
- develop appropriate monitoring methods and questions, where appropriate based on baseline data and study sites already assessed under the GSS (2007-2010) fire studies.
- assess options for targeted burning, optimal patch sizes, frequency and locations based on computer simulation modelling

In order to develop and incorporate ecologically appropriate fire regimes in the DEC fire management processes, it is recommended that:

- further work be undertaken to input at a number of levels of the fire management hierarchy involving an adaptive approach which uses the best available knowledge to modify plans and to meet management objectives

In order to improve our knowledge of the impacts of fire and ecological burn regimes further work is recommended to:

- develop spatial analyses and modelling of factors such as patchiness, intensity

Assessment of recommendation regarding increased fire frequency for groundwater recharge on GGS

Our analyses and recommendations lead us to recommend that based on ecological implications for biodiversity there is no increase in fire frequency for recharge on GGS

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Appendix 1. Flora Key Fire Response Species

List of 184 flora species selected from a list of known GSS species (Mickle *et al.* 2010a; Mickle *et al.* 2009) supplemented with data from the Vegetation Species List and Response Database(DEC 2008b). The list includes all species with sufficient information on one or more vital attributes used to select the key fire response species. The vital attributes used in selecting potential key fire response species included juvenile period, regeneration strategy (from Table 4), conservation status, endemism, lifeform (a range of structural components from grasses to tall trees), and longevity (where known).

1 GSS data from florsitic survey (Mickle *et al.* 2009) and chronosequence study (Mickle *et al.* 2010a)
2 Vegetation Species List and Response Database (DEC 2008b)
3 Conservation status: Declared Rare Flora, Priority flora (Valentine *et al.* 2009a) and TEC species,
4 Endemism codes: GSS – unique to the GSS study area; LE – Locally endemic to Swan Coastal Plain; RE – regionally endemic to South Western Australian Floristic Region; and NE – Not endemic, found elsewhere in Western Australia (Valentine *et al.* 2009a).
5 Regeneration strategies based on (Burrows *et al.* 2008)
6 Indication of number of Floristic survey sites (Mickle *et al.* 2009) a species occurs in Banksia-dominant or Melaleuca-dominant sites. Total number of sites surveyed in brackets.
7 Indication of number of Chronosequence survey sites (Mickle *et al.* 2010a) species occurs at. All Chronosequence sites are Banksia-dominant. Total number of sites surveyed in brackets.
* inferred values based on flora base information (Western Australian Herbarium 1998-2009) or inferred from similar species in (DEC 2008b)

				GSS[1]					Burrows[2]				
Family	**Species**	**Conservation Status[3]**	**Endemism[4]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Banksia (16)[6]**	**Melaleuca (12)[6]**	**Chrono (9)[7]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Locality**	**Lifeform**	**Longevity**
Mimosaceae	*Acacia alata*								20	2	Mt Cooke	Medium shrub	
Mimosaceae	*Acacia benthamii*	P2	LE										
Mimosaceae	*Acacia cyclops*						1		24	2	Perth coastal	Medium shrub	Perennial
Mimosaceae	*Acacia pulchella*			<45	2			7	22	2	Mt Cooke	Medium shrub	
Mimosaceae	*Acacia stenoptera*						1		36	2	Brookton	Small shrub	Perennial
Protaecea	*Adenanthos cygnorum subsp. chamaephyton*	P3	RE										
Poaceae	*Aira cupaniana*					6	6		9	2	Mt Cooke	Annual grass	Annual
Casuarinaceae	*Allocasuarina fraseriana*								36	6	Walpole	Understorey tree	Perennial
Poaceae	*Amphipogon turbinatus*			24	4	3		5	12	4	Manjimup	Perennial grass	Perennial
Epacridaceae	*Andersonia lehmanniana*			<45	?2			4	36	4	Dandaragan	Small shrub	Perennial
	Angianthus micropodioides	P3	RE										
Haemodoraceae	*Anigozanthos humilis*			12	4			9	24	4	Mogumber	Perennial herb	Perennial
Haemodoraceae	*Anigozanthos humilis subsp. Badgingarra (S.D. Hopper 7114)*	P2	RE										
Goodeniaceae	*Anthotium junciforme*	P4	RE										
Papilionaceae	*Aotus cordifolia*	P3	RE	18	2								
Asteraceae	*Arctotheca calendula*						1		9	2	Mt Cooke	Annual herb	Annual
Epacridaceae	*Astroloma xerophyllum*								48	2	Badgingarra National Park	Small shrub	Perennial
Poaceae	*Austrostipa compressa*			<24	2	4		5	6	2	Walpole	Annual herb	Annual
Poaceae	*Austrostipa macalpinei*					1	1		12	2	Stirling Range	Perennial grass	Perennial
Proteaceae	*Banksia attenuata*			90	5	16	2	9	24	6	Perth	Understorey tree	Perennial
Proteaceae	*Banksia grandis*					1			24	6	Nannup	Understorey tree	Perennial
Proteaceae	*Banksia ilicifolia*					5	2		24	6	Nannup	Overstorey tree	Perennial
Proteaceae	*Banksia littoralis*						4		24	6	Pemberton	Understorey tree	Perennial

				GSS[1]					**Burrows[2]**				
Family	**Species**	**Conservation Status[3]**	**Endemism[4]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Banksia (16)[6]**	**Melaleuca (12)[6]**	**Chrono (9)[7]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Locality**	**Lifeform**	**Longevity**
Proteaceae	*Banksia menziesii*			96	5	12	1	9	24	6	Perth	Tall shrub	Perennial
Scrophulariaceae	*Bartsia trixago*								9	2	Mt Cooke	Annual herb	Annual
Myrtaceae	*Beaufortia elegans*			<45	2	5	2	7	24	1	Cataby	Small shrub	Perennial
Euphorbiaceae	*Beyeria cinerea subsp. cinerea*	P3	NE										
Asteraceae	*Blennospora doliiformis*	P3	RE										
Rutaceae	*Boronia purdieana*			<45	2			8					
Rutaceae	*Boronia ramosa*			<24	2			4					
Papilionaceae	*Bossiaea eriocarpa*			12	5	1	2	9	12	5	Walpole	Small shrub	Perennial
Asteraceae	*Brachyscome iberidifolia*						2		12	3	Manjimup	Annual herb	Perennial
Poaceae	*Briza maxima*					7	2		6	8	Walpole	Annual herb	Annual
Poaceae	*Briza minor*						2		6	8	Walpole	Annual herb	Annual
Colchicaceae	*Burchardia congesta*			12	4	12	2	9	24	11	Cataby	Perennial herb	Perennial
Orchidaceae	*Caladenia flava*			<48	4		1	7	9	11	Mt Cooke	Geophyte	Perennial
Orchidaceae	*Caladenia huegelii*	DRF	RE						9	11			
Dasypogonaceae	*Calectasia sp. Pinjar (C. Tauss 557)*	P1	GSS	24*	4*								
Myrtaceae	*Calytrix flavescens*			24	5	9	1	9	30	2	Stirling Range	Small shrub	Perennial
Myrtaceae	*Calytrix sapphirina*			<60	5			3		5	Eneabba	Small shrub	Perennial
Cyperaceae	*Carex tereticaulis*	P1	RE										
Lauraceae	*Cassytha racemosa*								24	2	Walpole	Climber	Perennial
Centrolepidaceae	*Centrolepis drummondiana*			12	2	5	1	3					
Asteracea	*Cirsium vulgare*						1		12	3	Walpole	Annual herb	Perennial
Proteaceae	*Conospermum stoechadis subsp. stoechadis*			12	5			5					
Epacridaceae	*Conostephium minus*			<45	?5	3		6					
Epacridaceae	*Conostephium pendulum*			12	5	8	3	8	60	5	Northern Sandplain		Perennial
Haemodoraceae	*Conostylis bracteata*	P3	LE										

				GSS[1]					Burrows[2]				
Family	**Species**	**Conservation Status[3]**	**Endemism[4]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Banksia (16)[6]**	**Melaleuca (12)[6]**	**Chrono (9)[7]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Locality**	**Lifeform**	**Longevity**
Haemodoraceae	*Conostylis juncea*			<45	4	8		8					
Haemodoraceae	*Conostylis pauciflora subsp. euryrhipis*	P4	LE										
Haemodoraceae	*Conostylis pauciflora subsp. pauciflora*	P4	LE										
Asteracea	*Conyza bonariensis*						2		12	3	Walpole	Annual herb	Annual
Orchidaceae	*Corymbia calophylla*								48	6	Walpole		Perennial
Crassulaceae	*Crassula colorata*			12	2			3					
Cyperaceae	*Cyathochaeta teretifolia*	P3	RE										
Goodeniaceae	*Dampiera linearis*			12	5	4	3	5	10	4	Mt Cooke	Small shrub	Perennial
Myrtaceae	*Darwinia foetida*	DRF	LE	*>48**	*2**								
Dasypogonaceae	*Dasypogon bromeliifolius*			<45	4	5	2	3	6	7	Nannup		Perennial
Restionaceae	*Desmocladus flexuosus*			<45	4	5	3	7					
Papilionaceae	*Dillwynia dillwynioides*	P3	LE										
Sapindaceae	*Dodonaea hackettiana*	P4	RE										
Orchidaceae	*Drakaea elastica*	DRF	LE						12	11			
Droseraceae	*Drosera menz*			12	4	1		9	8	11	Perup		Perennial
Droseraceae	*Drosera occidentalis subsp. occidentalis*	P4	RE										
Droseraceae	*Drosera pallida*			24	4	1		2	12	11	Manjimup		Perennial
Poaceae	*Ehrharta longiflora*						1		12	3	Walpole		Annual
Cyperaceae	*Eleocharis keigheryi*	DRF	RE	*4 to 72**	*9**								
Orchidaceae	*Elythranthera brunonis*			<60	4	2	1	5	24	11	Stirling Range		Perennial
Orchidaceae	*Epiblema grandiflorum var. cyaneum*	DRF	GSS	*12*	*11*								
Myrtaceae	*Eremaea beaufortioides*			<45	5	2		6	36	5	Jurien Bay		Perennial
Myrtaceae	*Eremaea pauciflora*			24	5	1	1	3	48	2	Jurien Bay		Perennial
Myrtaceae	*Eucalyptus argutifolia*	DRF	LE	48*	*5 or 6**								
Myrtaceae	*Eucalyptus gomphocephala*								48	6	Swan Coastal Plain		Perennial

				GSS[1]					Burrows[2]				
Family	**Species**	**Conservation Status[3]**	**Endemism[4]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Banksia (16)[6]**	**Melaleuca (12)[6]**	**Chrono (9)[7]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Locality**	**Lifeform**	**Longevity**
Myrtaceae	*Eucalyptus marginata*								48	6	Nannup	Overstorey tree	Perennial
Myrtaceae	*Eucalyptus rudis*					1	5		48	6	Perup		Perennial
Myrtaceae	*Eucalyptus todtiana*					4			48	6	Northern Sandplains		Perennial
Myrtaceae	*Eucalyptus x mundijongensis*	P1	GSS	48*	*5 or 6**								
Santalaceae	*Exocarpos sparteus*						1		18	2	Walpole		Perennial
Fabroniaceae	*Fabronia hampeana*	P2	RE										
Rubiaceae	*Galium murale*						1		12	2	Manjimup		Annual
Papilionaceae	*Gastrolobium capitatum*			<45	2	5	1	7					
Papilionaceae	*Gompholobium aristatum*					1			24	2	Nannup		Perennial
Papilionaceae	*Gompholobium confertum*						1		22	2	Nannup		Perennial
Papilionaceae	*Gompholobium scabrum*					1			30	2	Stirling Ranges	Medium shrub	Perennial
Papilionaceae	*Gompholobium tomentosum*			<45	2	9	3	6	20	2	Nannup		Perennial
Haloragaceae	*Gonocarpus pithyoides*			<24	5	1	2	4					
Proteaceae	*Grevillea curviloba subsp. curviloba*	DRF	GSS	*6 to 72**	*2 or 5**								
Proteaceae	*Grevillea curviloba subsp. incurva*	DRF	RE	*6 to 72**	*2 or 5**								
Proteaceae	*Grevillea evanescens*	P1	LE										
Proteaceae	*Grevillea thelemanniana*	P4	RE										
Haemodoraceae	*Haemodorum loratum*	P3	RE										
Haemodoraceae	*Haemodorum spicatum*			24	4	4	1	5	12	11	Stirling Range		Perennial
Proteaceae	*Hakea costata*					2			72	1	Northern Sandplain		Perennial
Proteaceae	*Hakea varia*									1	Stirling Range		Perennial
Lamiaceae	*Hemiandra pungens*					2			33	2	Mt Cooke	Medium shrub	
Dilleniaceae	*Hibbertia huegelii*			12	5	4		2	24	5	Northern Sandplain		Perennial
Dilleniaceae	*Hibbertia hypericoides*			12	5	7		4	9	5	Mt Cooke		Perennial
Dilleniaceae	*Hibbertia spicata subsp. leptotheca*	P3	LE										

				GSS[1]					Burrows[2]				
Family	**Species**	**Conservation Status[3]**	**Endemism[4]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Banksia (16)[6]**	**Melaleuca (12)[6]**	**Chrono (9)[7]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Locality**	**Lifeform**	**Longevity**
Dilleniaceae	*Hibbertia subvaginata*			24	5	1	2	9					
Apiaceae	*Homalosciadium homalocarpum*					5	1		9	2	Mt Cooke	Annual herb	Annual
Papilionaceae	*Hovea trisperma*					2			42	2	Perup		Perennial
Asteraceae	*Hyalosperma cotula*						2		9	2	Mt Cooke	Annual herb	Annual
Apiaceae	*Hydrocotyle callicarpa*					1	1		22	2	Mt Cooke	Annual herb	
Myrtaceae	*Hypocalymma angustifolium*					2	3		48	5	Avon Wheatbelt		Perennial
Cyperaceae	*Isolepis marginata*			12	2	5	1	6	6	8	Walpole		Perennial
Papilionaceae	*Isotropis cuneifolia subsp. glabra*	P2	LE										
Papilionaceae	*Jacksonia floribunda*					5			24	2	Northern Sandplain		Perennial
Papilionaceae	*Jacksonia sericea*	P4	LE										
Papilionaceae	*Jacksonia sternbergiana*					1				1	Geraldton Sandplain		Perennial
Papilionaceae	*Kennedia prostrata*						1		19	2	Mt Cooke	Prostrate shrub	
Sterculiaceae	*Lasiopetalum membranaceum*	P3	RE										
Asparagaceae	*Laxmannia sessiliflora*					1				2	Northern Sandplain		Perennial
Asparagaceae	*Laxmannia squarrosa*			<24	2	1		5					
Goodeniaceae	*Lechenaultia floribunda*					2	2			2	Northern Sandplain		Perennial
Goodeniaceae	*Lechenaultia magnifica*	P1	RE										
Epacridaceae	*Leucopogon conostephioides*			<45	2	6	2	6	60	2	Northern Sandplain		Perennial
Epacridaceae	*Leucopogon squarrosus*			<45	2			6					
Stylidiaceae	*Levenhookia pusilla*						2		10	8	Perup		Annual
Lobeliaceae	*Lobelia tenuior*					1	1		6	8	Walpole		Annual
Dasypogonaceae	*Lomandra caespitosa*			<45	4	2	1	2	33	4	Walpole		Perennial
Dasypogonaceae	*Lomandra hermaphrodita*			<36*	4 or 5*								
Dasypogonaceae	*Lomandra maritima*			<36*	4 or 5*								
Restionaceae	*Lyginia barbata*			24	4			9	21	5	Walpole		Perennial

				GSS[1]					Burrows[2]				
Family	**Species**	**Conservation Status[3]**	**Endemism[4]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Banksia (16)[6]**	**Melaleuca (12)[6]**	**Chrono (9)[7]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Locality**	**Lifeform**	**Longevity**
Epacridaceae	*Lysinema ciliatum*			<48	2	1		6	24	8	Nannup		Perennial
Pittosperaceae	*Marianthus paralius*	DRF	LE	*24**	*2 or 5**								
Haloragaceae	*Meionectes tenuifolia*	P3	RE										
Myrtaceae	*Melaleuca preissiana*					1	7		24	6	Mt Cooke	Understorey tree	
Myrtaceae	*Melaleuca systena*	TEC		? 18-84*	? 1,4,5,6,9*								
Myrtaceae	*Melaleuca trichophylla*			24	5	6	1	9	36	5	Geraldton Sandplain		Perennial
Myrtaceae	*Melaleuca viminea*								60	1	Perup		Perennial
Asteracea	*Millotia myosotidifolia*					2	1		12	8	Walpole		Annual
Haloragaceae	*Myriophyllum echinatum*	P3	RE										
Rubiaceae	*Opercularia vaginata*					3	1		24	2	Stirling Range		Perennial
Iridaceae	*Patersonia occidentalis*			12	4	9		9	36	2	Stirling Range		Perennial
Proteaceae	*Persoonia saccata*					1			13	5	Nannup	Understorey tree	Ephemeral
Proteaceae	*Petrophile linearis*			24	5	13	2	9	25	5	Nannup		Perennial
Proteaceae	*Petrophile macrostachya*					3			48	5	Northern Sandplain		Perennial
Proteaceae	*Petrophile serruriae*					1			32	1	Perup		Perennial
Rutaceae	*Philotheca spicata*			12	5	6		8	21	4	Mt Cooke	Medium shrub	
Haemodoraceae	*Phlebocarya ciliata*			<45	4	8	1	6	18	5	Walpole		Perennial
Loganiaceae	*Phyllangium paradoxum*			12	2	11	5	9	12	2	Walpole		Annual
Thymelaeaceae	*Pimelea sulphurea*			12	2			2	24	5	Northern Sandplain		Perennial
Asteraceae	*Podotheca chrysantha*			<45	2	1		6					
Asteraceae	*Podotheca gnaphalioides*			12	2	7	5	4		2	Northern Sandplain		Perennial
Euphorbiaceae	*Poranthera microphylla*					3	5		9	2	Mt Cooke	Annual herb	Perennial
Asteraceae	*Quinetia urvillei*					2	1		9	2	Mt Cooke	Annual herb	Annual
Myrtaceae	*Regelia ciliata*					3	1		60	5	Swan Coastal Plain		Perennial
Asteracea	*Rhodanthe pyrethrum*	P3	RE										

Family	Species	Conservation Status[3]	Endemism[4]	GSS[1]					Burrows[2]				
				Juvenile Period (mnths)	Regen[5] Strategy	Banksia (16)[6]	Melaleuca (12)[6]	Chrono (9)[7]	Juvenile Period (mnths)	Regen[5] Strategy	Locality	Lifeform	Longevity
Primulaceae	*Samolus junceus*								33	2	Walpole		Perennial
Aizoaceae	*Sarcozona bicarinata*	P3	GSS										
Cyperaceae	*Schoenus caespititius*			24	4	4		8					
Cyperaceae	*Schoenus curvifolius*			48	4	8	1	8	24	11	Stirling Range		Perennial
Cyperaceae	*Schoenus natans*	P4	RE										
Solanaceae	*Solanum nigrum*									8	Walpole		Perennial
Asteracea	*Sonchus asper*						1			3	Walpole		Biennial
Asteracea	*Sonchus oleraceus*						3			3	Walpole		Annual
Rhamnaceae	*Spyridium globulosum*						4		6	2	Walpole		Perennial
Euphorbiaceae	*Stachystemon axillaris*	P4	RE										
Proteaceae	*Stirlingia latifolia*			12	5	5		9	24	5	Northern Sandplain		Perennial
Stylidaceae	*Stylidium adpressum*					3				2	Northern Sandplain		Perennial
Stylidiaceae	*Stylidium araeophyllum*			<45	?4	7	1	5					
Stylidiaceae	*Stylidium bicolor*			<48	?4			2					
Stylidiaceae	*Stylidium brunonianum*						3		9	2	Manjimup	Perennial herb	Perennial
Stylidiaceae	*Stylidium calcaratum*					2			7	2	Perup	Annual herb	Ephemeral
Stylidiaceae	*Stylidium crossacephalum*			<45	?4	3		7					
Stylidiaceae	*Stylidium diuroides*			<24	?4			7					
Stylidiaceae	*Stylidium longitubum*	P3	RE										
Stylidiaceae	*Stylidium maritimum*	P3	RE										
Stylidiaceae	*Stylidium repens*					1	4		24	2	Northern Sandplain		Perennial
Stylidiaceae	*Stylidium repens*					1			24	2	Northern Sandplain		Perennial
Stylidiaceae	*Stylidium rigidulum*			<24	?2	5	3	5					
Stylidiaceae	*Stylidium schoenoides*					2			7	2	Perup	Perennial herb	Perennial
Papilionaceae	*Templetonia retusa*						3		48	2	Swan Coastal Plain		Perennial

				GSS[1]					**Burrows[2]**				
Family	**Species**	**Conservation Status[3]**	**Endemism[4]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Banksia (16)[6]**	**Melaleuca (12)[6]**	**Chrono (9)[7]**	**Juvenile Period (mnths)**	**Regen[5] Strategy**	**Locality**	**Lifeform**	**Longevity**
Anthericaceae	*Thysanotus thyrsoideus*					2	1			2	Avon Wheatbelt		Perennial
Apiaceae	*Trachymene pilosa*			12	2	12	9	8	12	2	Perup		Annual
Stackhousiaceae	*Tripterococcus paniculatus*	P1	RE										
Hydatellaceae	*Trithuria occidentalis*	DRF	GSS	_<12*_	_2*_								
Asteracea	*Ursinia anthemoides*					12	5		12	2	Northern Sandplain		Annual
Lentibulariaceae	*Utricularia multifida*								6	2	Walpole		Annual
Myrtaceae	*Verticordia lindleyi subsp. lindleyi*	P4	RE										
Myrtaceae	*Verticordia nitens*					4			0	2	Avon Wheatbelt		Perennial
Papilionaceae	*Viminaria juncea*						3		0	2	Walpole		Perennial
Asteracea	*Waitzia suaveolens*					2			12	2	Perup		Annual
Apiaceae	*Xanthosia huegelii*			24	5	7		9	32	5	Perup		Perennial

Appendix 2. Fire Management Objective: Ecological burning for biodiversity conservation

The conservation of biodiversity is a key management goal for the GGS. Along with other management activities, ecologically appropriate fire management is essential to achieving this goal. The specific, quantifiable fire management objectives to support the biodiversity conservation goal are as follows:

1) To create and maintain diverse seral stages with the following characteristics:

- Fire intervals between
    - minimum 8-16 years and
    - maximum 40 years
- Burnt patch size:
    - mean ~100 – 200 hectares
    - median ~10 hectares
- Contain wildfires to less than 1,000 hectares
- Proportions of seral stages (see Figure 26):
    - Very early (1-5 years) ~ 15% (currently 49 %)
    - Early (6-10 years) ~ 15%
    - Intermediate (11-19 years) ~ 25%
    - Late (20-30 years) ~ 25%
    - Very late (>30 years) ~ 20% (currently 2 %)
- Landscape distribution of seral stages:
    - each ecological fire management unit (such as those in Figure 10 and Figure 11) to contain at least three of the five seral stages and optimal habitat boundaries

2) Implementation of refugia for fauna (such as Honey Possums, Rakali, and Quenda):

- Set aside pockets of preferred fuel age vegetation (such as that within the Yeal Nature Reserve; 20-30 YSLB).
- Designate high biodiversity value sites (for example high priority wetlands) as refugia and protect from further loss, modification or frequent fires.

- Fuel management (buffer / edge) burns when appropriate

3) Ecological linkages

- Avoid completely surrounding older age habitat with recently burnt vegetation as this will restrict migration of fauna species. Linkages must be established and maintained with other suitable old vegetation
- Manage native remnant vegetation within the ecological linkages to mature to the preferred post fire age for these species requiring linkages (for example Honey possums; 20-30 YSLB). This is likely to require maintenance of more frequent burning in areas adjacent to the corridors to protect from wildfires.