

# IMPACT OF FIRE ON BIODIVERSITY OF THE GNANGARA GROUNDWATER SYSTEM



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



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This document has been commissioned/produced as part of the Gnamagara Sustainability Strategy (GSS). The GSS is a State Government initiative which aims to provide a framework for a whole of government approach to address land use and water planning issues associated with the Gnamagara groundwater system. For more information go to [www.gnamagara.water.wa.gov.au](http://www.gnamagara.water.wa.gov.au)

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Photo clockwise from top: Burnt *Banksia* woodland, Burning *Banksia* woodland, Flowering *Banksia sessilis* (photo courtesy of Leonie Valentine), Recovering *Banksia* woodland, *Rankinia adelaidensis* (photo courtesy of Kristen Bleby).

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## Impact of Fire on Biodiversity of the Gnangara Groundwater System

### Summary

- Fire has been an integral part of the Australian environment for millions of years
- Species and communities are adapted to specific fire regimes, determined by fire intensity, frequency, season and scale.
- Inappropriate fire regimes may have undesirable consequences including declines or local extinctions of biota.
- Although the impact of inappropriate fire regimes has been identified as a major threat to biodiversity on the Swan Coastal Plain (DEC 2007, 2009 SNCA Plan) information on these impacts is limited.
- Vital attributes and juvenile periods of a range of plant species on the GGS have been 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,
- The two dominant *Banksia* species *Banksia menziesii* and *Banksia attenuata* (resprouters) have 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
- Food availability for the Critically Endangered Carnaby's Cockatoo was found to vary in relation to time since fire for *B. menziesii* and *B. attenuata* where food was highest in 20-30 YSLF years and lowest in < 6 YSLF
- It is recommended that burning regimes maximise the amount of *Banksia* woodland in the 11-30 YSLF to ensure food sources for Carnaby's cockatoo (particularly in light of the removal of current pine plantation resources between 2002 and 2027)
- Strong evidence for post-fire seral responses and habitat requirements of reptile and mammal species was obtained from fauna studies (e.g. Honey possum, Quenda, rakali, *Neelaps calonotus*, and *Menetia greyii*)
- 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

- Burning regimes need to ensure different fire ages in the long term, including retention of long-unburnt *Banksia* and *Melaleuca* that are important to species such as honey possum, quenda, rakali, *Neelaps calonotus* and *Menetia greyii*.
- Wetland biota on GGS at high risk from fire (direct effects and indirect impacts on water quality) include vegetation communities, threatened ecological communities (the stygofaunal assemblages in the Yanchep Caves aquatic root mats and organic mound springs), aquatic invertebrates, wetland birds, reptiles, frogs, fish and mammals).
- It is recommended that sites known to be important for these species (e.g. Honey possums, Quenda, Rakali) and communities (high priority wetlands) are designated as refugia and protected from further loss or modification and frequent fire.
- This report provides the basis for development of ecological burning regimes on the GGS based on plant vital attributes and habitat requirements of fauna.
- Monitoring of flora and fauna responses to any implemented fire regime should be undertaken to ensure species are responding as predicted and to feed into an adaptive management framework

## Introduction

Australia has been the most fire-prone continent on Earth for a long time (Bowman 2003), yet fire and the Australian environment remains a complex issue. Adaptations of flora and fauna to tolerate and survive in an environment where fire is prominent and frequent have developed over millions of years (Bowman 2003); indeed some biota have adaptations that lead them to rely on fire e.g. the seeds of some species of *Hakea* are released by heat during bushfire (Attiwill and Wilson 2003). The arrival of humans in Australia however has led to an increase in fires, and altered the interaction between the environment and fire.

Before humans arrived, Bowman (2003) suggests that fires were started by lightning and burned in large areas infrequently and created a broad-based mosaic in eucalypt savannas. The arrival of Aboriginal people presumably led to changes in fire patterns, using ‘firestick farming’ (Abbott 2003; Bowman 2003), whereby fires were lit frequently and burnt small areas. This regular and deliberate burning of parts of the landscape probably maintained a fine-scale vegetation mosaic of varying time since last fire across the landscape (Bowman 2003). For example, this regime was thought to be used by the Noongar Aboriginal people in the south-west of Western Australia (Bowman 2003). Recent depopulation of Aboriginal people in some desert areas has seen a major change in fire regimes and a decrease in the landscape mosaic of small patches at different post-fire ages (Burrows et al 2006).

Bushfire behaviour (i.e., its spread rate, intensity and flame dimensions) and its environmental and ecological impacts mainly depends on weather, topography, fuel characteristics (quantity, structure, distribution and moisture content), as well as suppression effort (Attiwill and Wilson 2006; Whelan *et al.* 2006). Fire intensity (rate of heat energy release) is a useful measure of the severity of a fire; its damage potential and suppression difficulty (Burrows *et al.* 2008).

Post fire responses of flora and fauna are related to their mortality in the fire, survival post fire, recolonisation, establishment, reproduction and population growth. In addition to fire severity, factors that impact on these attributes include habitat quality, such as food

availability, and predation. Fire response patterns also vary over time and space. They are thus affected by variations in fire behaviour, landscape and climate (Whelan *et al.* 2002).

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 are known as fire regimes, and are determined by factors including: intensity (how severe fires are), frequency (how often fires occur), fire interval (intervals between successive fires), 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 (e.g. 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 (Woinarski 1999), and may result in a loss of biodiversity and structural complexity over time (Burrows and Wardell-Johnson 2003). However, the term ‘inappropriate’ is relative – what may be an inappropriate fire regime for one species may be beneficial to another species (Whelan *et al.* 2006).

In fire-prone ecosystems, fire management involves the prevention and suppression of unplanned fires and the introduction of planned fire where appropriate. Of the factors that influence fire behaviour, only fuel quantity, structure and distribution can be effectively managed (Bowman 2003; Burrows *et al.* 2008). Therefore, fire regimes are commonly planned to reduce fuel quantity and flammability so as to reduce the severity and impact of wildfires (Attiwill and Wilson 2006). Prescribed burning refers to the planned use of fire to achieve specific land management objectives, where fire is applied under specific environmental conditions to a predetermined area.

Development of fire regimes that are optimal for biodiversity conservation is one of the major challenges in current fire management throughout Australia (Whelan *et al.* 2006). One approach is to determine fire regimes that are appropriate for a vegetation type and fire sensitive taxa based on vital attributes and life histories (Burrows *et al.* 2008; Friend 1999; Tolhurst 1999). The fire interval for each vegetation type and for fauna habitats needs to be determined by the needs of the flora and fauna at risk from extinction from too frequent or too infrequent burning.



Inappropriate fire regimes on the Gnangara groundwater system (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 2009a; Wilson and Valentine 2009). Management and recovery actions identified as necessary to protect biodiversity include control of predators, development of ecological linkages and refugia, and ecologically appropriate fire management (Government of Western Australia 2009a; Wilson and Valentine 2009). The interactions and compounding effects of threats must be taken into account when developing ecological fire regimes (Hobbs 2003).

This report was undertaken by DEC for the Gnangara Sustainability Strategy (GSS) to examine the impacts of fire on biodiversity on the GGS. This was addressed by a number of sub-projects carried out between July 2007 and June 2010. A summary of their findings are presented in this report, however more detailed information can be found in the relevant technical reports. The sub-projects included field studies to examine the response to time since fire by reptile, bird and mammal fauna (Davis 2009a; Valentine *et al.* 2009b) and food availability from *B. attenuata* and *B. menziesii* for Carnaby's Cockatoo in relationship to fire regimes (Valentine *et al.* 2009b).

Field studies to examine patterns of floristic diversity between sites with different times since last fire, and the post-fire juvenile period of plants were also undertaken (Mickle *et al.* 2010b). A major aim of these studies was to determine the appropriate fire interval (burn regime) for *Banksia* woodland on the Swan Coastal Plain. The post-fire juvenile period (time to first flowering after fire) can be used to guide minimum intervals between fires to conserve plant diversity (Burrows *et al.* 2008). Knowledge of fire responses and sensitive species is vital to implement ecologically-based fire regimes to conserve biodiversity and reach water balance goals in the GSS study area.

## 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 ha (Figure 1). The GGS 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 GGS 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 GGS is directly recharged by rainfall (Allen 1981; Government of Western Australia 2009b) and provides the city of Perth with approximately 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 (regionally important bushland) sites, threatened species, threatened ecological communities, and some 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 GGS (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 four meters in the centre of the Gnangara system 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 GGS (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).



Figure 1: Location and extent of the Gnangara Groundwater System

The draft GSS was released in 2009 (Government of Western Australia 2009a). 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 stormwater, 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. The implementation of the optimum fire regime that will maximise groundwater recharge, while maintaining biodiversity values was a further major recommendation.

Prior to the GSS program, understanding of biodiversity values, ecosystem processes and the dynamics of the GGS, particularly at landscapes scales, was inadequate (Government of Western Australia 2009b). Gaps in our capacity to measure impacts on biodiversity, landscape condition and ecosystem processes as a result of disturbances (e.g. climate change, changed water regimes, fire, and plant pathogens) are likely to result in ineffective management actions and low quality outcomes. The ability to develop successful planning relies on the quality of the biodiversity information (Pressey 1999; Wilson *et al.* 2005). Indeed, unless an adequate understanding of these issues is accomplished, justification of changed management actions in the face of potentially degrading impacts on biodiversity is difficult.

Manipulation of fire regimes on Crown land has been proposed as a cost effective option to enhance water yield to the GGS (Canci 2005; Yesertener 2007). Information from groundwater bore monitoring indicated that recharge of 0.5-2 m occurred 3-4 yrs post fire (Canci 2005; Yesertener 2007), and models and hydrograph analyses suggest that increased recharge was related to increased frequency of controlled burns in Banksia woodland (Vogwill *et al.* 2008).

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 PRAMS base case scenario incorporates a burning

regime whereby 10% of total native vegetation in the GSS study area is burnt (each year) on a 10-year rotational burning system. For example, the model assumes that the 10% vegetation burnt in 2008 will be re-burned in 2018.

The implementation of a fire regime that will maximise groundwater recharge while maintaining biodiversity values was a major GSS recommendation. While increasing the frequency of fire will likely result in increased groundwater re-charge, the environmental and biodiversity consequences of such a regime must be understood and the water yield and biodiversity balance, or trade-off, quantified. The GSS seeks to address these gaps by improving knowledge of the impacts of fire on biodiversity values on the GGS.

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 and other terrestrial ecosystems. In addition, other threatening processes are impacting on biodiversity in the region, including habitat clearing, fragmentation, altered fire regimes and impacts of *Phytophthora cinnamomi* and need to be considered when assessing impacts of fire (Government of Western Australia 2000; Mitchell *et al.* 2003).

This report aims to examine information from field studies undertaken for the GSS on the impact of fire on biodiversity, together with compilation and assessment of other relevant data.

## Fire Projects for the GSS

The Draft Strategy recommended that a fire regime that will maximise groundwater recharge, while maintaining biodiversity values, be implemented (Government of Western Australia 2009a). Due to the time limitation for the preparation of the Draft Strategy (July 2007 - June 2009) most of the projects were of relatively short duration and constrained in an ecological time-frame. However we consider that the data obtained provide new and important information for better understanding fire impacts on biodiversity in the study area and are an excellent baseline for future work. The information is essential for the development of optimum fire regimes for biodiversity conservation which is one of the

major challenges in current fire management throughout Australia (Burrows 2008; Gill and McCarthy 1998; Tolhurst 1999).

CSIRO undertook a major project to examine the effect of fire on ground water recharge on the GGS (Silberstein *et al.* 2010). This project was designed to determine the changes in water recharge to the groundwater table under native vegetation following prescribed fire. In addition a number of projects have been undertaken to firstly examine the impacts of fire on biodiversity on the GSS and secondly to develop optimum fire regimes to maximise and maintain biodiversity. They have drawn on work previously conducted within the GSS regarding the impacts of fire on fauna and flora, together with extensive field work undertaken over the period July 2007 to June 2010.

The GSS fire projects included:

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

This project was a prescribed burn-scale experiment undertaken by CSIRO to determine the changes in water recharge to the water table under native vegetation following fire, and the time course of recharge accompanying recovery of the vegetation after fire. CSIRO investigated the impact of fire on groundwater recharge by measuring differences in soil moisture profiles, groundwater response, rainfall, evapotranspiration and CFC dating measurements between the burnt and unburnt sites. It is hypothesised that there will be a higher amount of water recharge to the groundwater table from rainfall in the localised area of a burn, due to the lack of vegetation or leaf litter that reduces or prevents water from percolating down to the water table.

**2. *Impact of fire on biodiversity of the Gnangara groundwater system***

The second project, and the subject of this report, was undertaken by DEC for the GSS to examine the impact of fire on biodiversity. This was addressed by a number of sub-projects carried out between July 2007 and June 2010. A summary of their findings are presented in this report, 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).* A fauna survey was undertaken by DEC for the GSS to assess the current occurrence

and distribution of terrestrial vertebrate fauna across the GGS study area, to examine patterns in biodiversity with landscape features and to assess the susceptibility of taxa and communities to threatening processes such as declining groundwater levels and fire. One of the specific aims was to examine the response to time since fire by reptile and mammal fauna in the GGS.

- *Impact of fire on avifaunal communities* (Davis 2009a). This project was carried out to investigate the impact of prescribed burning regimes on the diversity, composition and abundance of avifauna within the GGS.
- *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 that occurred in January 2009.
- *Patterns of floristic diversity* (Mickle *et al.* 2009). This project assessed the current occurrence and distribution of plant taxa across the GGS fauna study sites, and examined plant species composition between landforms (Bassendean and Spearwood dunes), dominant 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 plants 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 (e.g. 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 black cockatoo in relationship to fire regimes on the GGS* (Valentine 2010). The aim of this study was to assess the food availability, in the form of fruiting cones, of *B. attenuata* and *B. menziesii* at sites of different time since fire. This information is then examined in relation to the calorific content of *Banksia*'s as a food item for Carnaby's black-cockatoo. 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 2010)***

The aim of this project undertaken by DEC for the GSS was to update the spatial fire history dataset using remote sensing information and DEC records for the GSS study area to more accurately analyse fire history, current fire regime and fire frequency. Landsat imagery was employed to check and update the fire boundaries, historic records were used to check the accuracy of the year since last fire for areas, examine the burning frequency within the study area over the last thirty years.

**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 GGS 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. 2010).***

The purpose of this report was to develop ecological burning regimes and fire management guidelines on the major areas of Crown Land managed by DEC on the GGS in relation to the impacts of such practices on biodiversity.



## Impacts of fire on flora

Fire has a direct impact on plants by affecting their growth, survival and reproduction (Burrows and Wardell-Johnson 2003). Many plants may tolerate the actual fire but cannot tolerate the stresses of the post-fire environment. Fire itself affects the structure of vegetation by consuming live and dead vegetation (Bond and Van Wilgen 1996), and the frequency of fire affects both the structure of vegetation and its floristic composition (Burrows and Wardell-Johnson 2003; Muir 1987). Changes in vegetation structure and composition can affect light penetration, soil moisture, soil nutrient levels and competition of juvenile plants with adult plants.

Plants have many adaptive vegetative and reproductive traits that enable them to persist in fire-prone environments (Gill 1981a). The survival of woody plants after fire can vary according to the level of protection of the bud by soil (e.g. subterranean buds, lignotubers) or bark (stem buds located beneath the bark) during a fire. In some plant species, reproduction may be enhanced as a result of fire through a flowering response (e.g. *Xanthorrhoea australis*), or through seed that is held on the plant being released, or through germination that is stimulated by fire (Gill 1981a).

Plant species are classified into two major classes with relationship to their post fire responses: sprouters and seeders (Burrows *et al.* 2008; Gill 1981b; Whelan 1995). Seeders (or obligate seeders) are species in which mature plants are killed by fire and depend either on seed for regeneration or germinate in woody capsules on the plant (bradysporous or serotinous species). They are more susceptible to population decline through inappropriate fire regimes. If a second fire kills a population of regenerating bradysporous plants before it reaches reproductive maturity, then it may decline and become locally extinct. Conversely, if fire is necessary to stimulate seedfall and germination, and the interval between fires is too long such that the parent plants die before a recruitment event, then the population could decline or become locally extinct. Serotiny (the canopy storage of seed for a prolonged period) is common in Australian sclerophyll vegetation (Cowling and Lamont 1985), and 76% of *Banksia* species are serotinous (George 1981).

Sprouters (or vegetatively regenerated) are species in which mature plants survive fire by resprouting (Gill 1981b). The most significant impact fire will have on these species is if the intensity of a fire is sufficient to kill the entire plant, or fires occur too frequently and there is insufficient time for resprouting plants to reach maturity, propagate and recruit to the population..

Conversely, if fire is necessary to stimulate flowering or seed germination, and the interval between fires is too long such that the parent plants die and the viable seed bank deteriorates before a fire recruitment event, then the population could decline or become locally extinct.

For sprouter species, as most of the heat from fire rises, protection of buds below ground is a very effective survival mechanism from above-ground fires (i.e. not peat fires). Even though trees may endure 100% leaf scorch during fire, these trees survive because their buds are protected by the bark. For the species that have subterranean buds, species can either produce basal buds that grow out to form shoots (i.e. still one individual plant) or possess root suckers that produce multiple stems after fire (Gill 1981a). Table 1 summaries the post-fire regenerations strategies used by Burrows (2008).

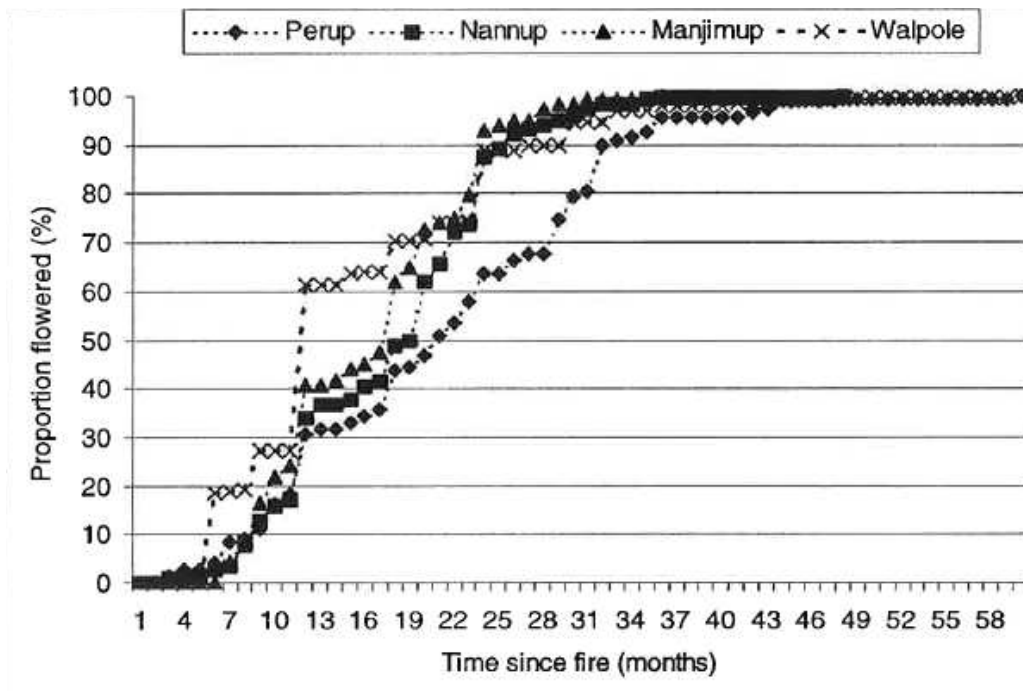
Two other categories include geophytes and fire ephemerals (Shedley 2007; Whelan 1995). Geophytes are a group of species that avoid the main impact of fire in time or space as they have bulbs, corms, tubers or rhizomes, and their above-ground growth takes place outside the normal season for fires (summer-autumn) (Bell *et al.* 1984). Fire ephemerals are also short-lived species that germinate in large numbers following fire (and utilise the nutrient-rich post-fire site) and often avoid fire by completing their life cycles within one year and before the next fire event. Fire ephemerals also produce seed that is stored in the soil, which germinates in response to heavy rainfall or disturbance (Bell *et al.* 1984; Shedley 2007).

**Table 1. Regeneration strategies based on Burrows *et al.* (2008)**

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

### ***Post-fire vegetation dynamics and fire regimes***

Post-fire vegetation dynamics tend to have similar patterns or post-fire seral stages (Ashton 1981; Bell and Koch 1980; Burrows 1994; Burrows and Wardell-Johnson 2003; Gill *et al.* 1999; Gould *et al.* 2007; Hobbs and Atkins 1990; Hobbs *et al.* 1984; McFarland 1988; Noble and Slatyer 1980; Russell and Parsons 1978; Specht 1981; Specht *et al.* 1958). Firstly, plant species richness is greatest in the first few years following fire before stabilising or decreasing. The cover and height of understorey vegetation increases rapidly post-fire before stabilising for a period of time and then declining. Total biomass also increases rapidly post-fire before stabilising and ultimately declining to a steady state. The proportion of dead vegetation increases with time since fire and then stabilises.



**Figure 2. Cumulative proportion of species to have reached flowering age with time since fire for 639 species from four locations in the south west forest region of Western Australia (Burrows 2008). A species was deemed to have reached flowering age when at least 50% of the population had flowered.**

The rate of change of vegetation structure and floristics is affected by the type of fire (e.g. intensity of fire). Seral stages are not distinct stages; rather, vegetation dynamics change continuously after fire (Burrows 2008). Using indicators of the post-fire rate of change in floristic composition and structure for a given ecological unit can help to interpret the transition between

the seral stages. An example is the juvenile period of the slowest maturing fire sensitive plant species within the major vegetation type (Tolhurst and Friend 2001).

The ability to flower and produce viable seed in inter-fire periods is fundamental to the persistence of vascular plants in fire-prone environments, especially the species that depend on seed stored on the plant (Burrows *et al.* 2008). Therefore it is vital to have an appropriate fire regime to ensure the persistence of all species. The frequency of fires is important and if the juveniles of serotinous species that store their seed on the plant are exposed to lethal fire before their first flowering, the species may be lost locally. On the other hand, species with short-lived seed or serotinous species that only regenerate after fire may decline in long unburnt areas (Bond and Van Wilgen 1996; Burrows and Wardell-Johnson 2003). The intensity of fires is also an important factor, with low intensity burns unable to germinate some species and high intensity burns damaging epicormic buds and viable seeds (Burrows *et al.* 1990; Yates *et al.* 1994).

While the majority of studies that have assessed the effects of fire on Australian plant communities have focused on time since fire the effects of multiple fires have been less intensively studied (Bowman *et al.* 1988; Bradstock *et al.* 1997; Cary and Morrison 1995; Fensham 1990; Fox and Fox 1986; Morrison *et al.* 1995). 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.

Short inter-fire intervals are associated with lower evenness in species composition than longer inter-fire intervals particularly with regard to obligate seeders whose adult plants are fire sensitive and do not survive fire normally (Bradstock *et al.* 1997; Cary and Morrison 1995; Fox and Fox 1986; Morrison *et al.* 1995). For example in a coastal sandstone shrubland–heath community high frequency of fire (several fires in short succession) reduced the frequency or density of a range of plant species (Bradstock *et al.* 1997). The dominant, serotinous obligate seeder *B. ericifolia* was most impacted together with a range of functional groups including resprouters. The results suggest that community composition and structure will be simplified by high frequency fire, and may result in community changes and lower floristic diversity.

Avoidance of short inter-fire intervals has become a major focus of management in Australia where obligate seeder plants exhibit floristic and structural prominence in fire-prone vegetation, (Bradstock *et al.* 1995; Conroy 1987; Gill and Nicholls 1989; Wouters 1993). The effects of inter-fire interval on plant species composition is however complex, the variation associated with inter-fire intervals is not necessarily solely related to the shortest inter-fire interval, but is related to combinations of inter-fire intervals through time (Cary and Morrison 1995; Morrison *et al.* 1995). Knowledge of the effects on longer sequences of short-interval fires (beyond two or three successive fires) is required. Another consideration is the scale of frequent fire effects and the consequences of heterogeneity of fire regimes in landscapes. Patches that are not burnt may act as refugia and sources of seeds for dispersal to other areas (Keith 1995). Many studies have focussed on fine-scale effect and it is difficult to extrapolate conclusions to the landscape scale.

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) fire intervals on species composition of plants, ants, beetles, vertebrates and macrofungi (Wittkuhn *et al.* in press). There was weak evidence of differences between Short-Short and Lon-Long/Very-Long regimes for 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. The study concluded that richness and composition was resilient to divergent fire interval sequences. Although the occurrence of a number of consecutive short was considered unlikely to have severe impacts, maintaining either only short or long intervals may alter species composition and, or abundance. Prescribed burning at an intermediate level of disturbance and incorporating variability in interval length was recommended for wildfire mitigation and biodiversity conservation.

Development of fire regimes that are optimal for biodiversity conservation is one of the major challenges in fire management throughout Australia (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 (Burrows 2008). Vital attributes such as regeneration requirements, post-fire regeneration strategies, and juvenile periods are useful criteria to determine minimum and maximum intervals between lethal fires for a particular ecosystem (Burrows 2008).

It is possible to identify the ‘key fire response species’ of each community using vital attributes. 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 lethal fires (Bradstock *et al.* 1996; Friend 1999; Gill and McCarthy 1998; Tolhurst 1999).

## Previous studies in the GSS study area

Despite the extent of the *Banksia* woodlands of the GGS and their proximity to Perth there have been few studies investigating their vegetation dynamics and the impact of fire on vegetation in these communities, especially in comparison to studies in the jarrah and karri forests of south-west Western Australia (e.g. Abbott 1999; Abbott *et al.* 1985; Adams *et al.* 2003; Burrows 2008; Burrows and Wardell-Johnson 2003; Burrows *et al.* 2008; Christensen and Kimber 1975; Kimber 1974; McCaw *et al.* 2003; Robinson and Bougher 2003; Van Heurck and Abbott 2003; Wooller and Calver 1988).

Studies that have investigated various aspects of the impact of fire on vegetation on the Swan Coastal Plain include Baird (1977), Lamont and Downes (1979), Cowling and Lamont (1985), Hopkins and Griffin (1989), Hobbs and Atkins (1990), and Lamont and Markey (1995). In addition, there are some studies on the impacts of fire on vegetation that have been conducted just outside the GSS study area (e.g. Hayward *et al.* 2008; Lamont *et al.* 2000).

### ***Flora responses to fire on the Geraldton Sandplain***

Several studies have examined fire responses of *Banksia* species and other species near Eneabba, 235 km north of Perth. Lamont *et al.* (2007) found that after two burns in ten years, the numbers of *B. attenuata* increased with each fire and *B. menziesii* decreased, due to different levels in seed production and fire tolerance. A post fire study of *B. attenuata*, *B. leptophylla*, *B. menziesii* and

*B. prionotes* (Cowling and Lamont 1987) found that seed release in serotinous species of *Banksia* is largely fire-dependant; however *B. menziesii* and *B. prionotes* both exhibit regular spontaneous follicle rupture in summer. In a seed bank study, a marked depletion of the Restionaceae seed bank after fire was found while for Epacridaceae seed banks persist in soil after fire regardless of fire response or life history (Meney *et al.* 1994). Between 90-100% of annual seed production of obligate seeder and resprouter Epacridaceae species deteriorate within two years. There was also no evidence of recruitment of any of the species studied after 10 years since last burn (Meney *et al.* 1994).

There was a correlation between a decrease in annual rainfall and an increase in average temperature with a decrease in plant height and an increase in the degree of serotiny for three *Banksia* species (*B. attenuata*, *B. menziesii* and *B. prionotes*) along a climatic gradient extending 500 km north of Perth (Cowling and Lamont 1985). This study concluded that the degree of serotiny in these three species is related to the fire characteristics of the site, which depend on plant height. In the northern-most site (Northampton), with a xeric scrub-heath, plant height was lowest and entire canopies of the *Banksia* species would be consumed by fire, promoting a massive release of seed. In the south-most site (King's Park), with a mesic woodland, cones would rarely come into contact with flames due to a greater plant height, and seeds are released spontaneously in interfire periods (Cowling and Lamont 1985).

## ***Flora responses to fire on the Swan Coastal Plain***

### **Responses of individual species**

In a review by Hopkins and Griffin (1989), the *Banksia* woodland on the Swan Coastal Plain was found to contain 13 long-lived perennial species that regenerated only from seed after 100% crown scorch. Six of these species were identified as fire sensitive and as having seed storage on the plant in bradyseeds. Species that stored seed on plant include *Banksia prionotes*, *B. sessilis*, *Hakea trifurcata*, *Hakea obliqua*, *Beaufortia elegans* and *Beaufortia squarrosa*. Species with seed storage in the soil include *Adenanthos cygnorum*, *Astroloma xerophyllum*, *Leucopogon striatus*, *Leucopogon cordatus*, *Lysinema ciliatum*, *Andersonia heterophylla*, and *Acacia pulchella* (Hopkins and Griffin 1989). In *B. prionotes*, adults are killed by fire (depending on intensity) but fire stimulates seeds to germinate. This fire response may be vulnerable to frequent, widespread fire events as seed regeneration may be insufficient to replace adults lost in the fire if

the canopy seed bank has not had sufficient time to recover from previous fire (Wooller *et al.* 2002).

Several of the key species in the GSS study area are resprouters, including *Banksia attenuata*, *B. grandis*, *B. ilicifolia*, *B. littoralis*, and *B. menziesii* (Enright *et al.* 1998). In these species adult trees can sometimes survive low to medium intensity fire due to their thick bark and also regenerate from lignotubers, which resprout following fire. Hobbs and Atkins (1990) suggest that both *B. attenuata* and *B. menziesii* do not depend on fire for recruitment in the *Banksia* woodlands on the Swan Coastal Plain. This concept is also supported by Cowling and Lamont (1985). There is a need to determine and compare fire induced and inter-fire recruitment rates.

The relationships between fire interval, extent of canopy seed storage (serotiny) and maximum rate of population increase was investigated for two of the key resprouter species in the GSS study area *Banksia attenuata* and *B. menziesii* by (Enright *et al.* 1998). The peak rate of increase for *Banksia attenuata* populations was for fire frequencies of 7 - 20 years with maximum at 13 years for those completely serotinous i.e. no seeds released except as caused by fire (Enright *et al.* 1998). At very short < 5 years and very long > 45 years fire intervals populations are predicted to decline to extinction, and degree of serotiny was irrelevant.

The probability of seedling recruitment for *Banksia attenuata* was low after most fires due to low seed survival and high seedling mortality over the first summer. The rare recruitment events are strongly related to summer rainfall and are extremely important in the population dynamics of this serotinous resprouter in regions of Mediterranean climate (Enright *et al.* 1998).

The apparent decline in *B. menziesii* in its northern geographical limits is likely to be related to the lower adult survivorship through fires and the negligible recruitment of the species and more frequent fires and drying climate (Cowling *et al.* 1990; Enright *et al.* 1998).

## **Responses in plant populations and communities**

There is little literature on the responses of plant populations and communities to fire on the Swan Coastal Plain. In the *Eucalyptus-Banksia-Casuarina* woodland of King's Park (Baird 1977), the first plants that grow after a mid-summer fire are *Xanthorrhoea* spp., followed closely



by sedges. A few weeks after the fire, new leaves of the cycad *Macrozamia* appear and deep-rooted shrubs sprout within 2-3 weeks. With the start of the winter rains there is growth of herbaceous plants and annual weeds, as well as an increase in growth of shrubs and seedlings. Shrub species are erect and vigorous for the first 2-3 years after the fire, and the percentage of dead wood and litter from trees increases with time since fire. In stands not burnt for 20 years or more, Baird (1977) found a suppression of the undergrowth and a large amount of leaf and twig litter build-up.

Using a series of stands, within remnant areas of low woodland dominated by *B. attenuata* and *B. menziesii*, ranging in age since last fire from 1 to > 44 years, Hobbs and Atkins (1990) examined long-term vegetation development post-fire. Species richness increased for the first five years after fire, and many shrub species reached their greatest density two years after fire, thereafter declining in density.

The season of a fire can have an effect on the rate and type of recovery of vegetation (e.g. growth, germination, flowering and fruiting) post-fire. For example, within remnant areas of low woodland dominated by *B. attenuata* and *B. menziesii* near Perth, autumn fires can promote seedling germination and regeneration (and may therefore be beneficial especially for seeder species), while spring fires may result in rapid vegetation recovery and greater species diversity (Hobbs and Atkins 1990). Autumn burns may result in less vegetation regrowth and may also increase invasion by non-native plant species (Hobbs and Atkins 1990). From this Hobbs and Atkins (1990) suggest that spring burning may be preferable in these remnant patches of *Banksia* woodlands.

Seasonal differences in the recovery of vegetation post-fire have also been recorded in the Jarrah woodlands in King's Park (Baird 1977). There was vigorous growth of *Xanthorrhoea* spp., fibrous monocotyledons and shrubs after a spring to early summer fire, with shoots of shrubs appearing within 3-6 weeks of the fire, and then growing more rapidly into the summer. While autumn burns are not necessarily unfavourable to the growth of shrubs, the growth of herbaceous plants was greater in autumn burns as compared to spring-early summer fires (Baird 1977).

North of the GSS study area, the responses of vegetation to fire in different seasons have also been studied. Cowling and Lamont (1987) examined the effects of autumn and spring burns on the recruitment of *Banksia* species (*B. menziesii*, *B. prionotes*, *B. leptophylla* and *B. attenuata*).

The rate of seed release from burnt cones of all four species was significantly slower after the spring burn compared to the autumn burn. In addition, the number of seedlings recruited per parent of all four species was less than half as high after the spring burn than the autumn burn (after the first winter) (Cowling and Lamont 1987).

### ***Fire responses of threatened ecological communities and declared rare flora***

Several threatened ecological communities and declared rare flora occur on the GGS (Valentine *et al.* 2009a). Interim Recovery Plans have been written for five of the ten declared rare flora that occur on the GGS (Brown *et al.* 1998; Evans *et al.* 2003). Known responses to fire of the ten species of declared rare flora are summarised in Table 2.

A number of adaptive management projects have been undertaken by the DEC Swan Coastal District that have examined the burn responses of several threatened ecological communities and declared rare flora on the Swan Coastal Plain. These include: *Banksia mimica* (fire response at different fire intensities); *Caladenia huegelii* (examined the Fraser Road population after a wildfire occurred in the 2007-2008 fire season); *Melaleuca huegelii*-*Melaleuca systema* *shrublands on limestone ridges* community type 26a described by (Gibson *et al.* 1994b) (fire response and percentage cover before and after a prescribed burn); *Macarthuria keigheryi* (fire response after a prescribed burn), *Perth to Gingin Ironstone Association* (examining this threatened ecological community after a major wildfire burnt the entire community), and fire response of two species of declared rare flora on Muchea Nature Reserve (*Darwinia foetida* and *Grevillea curviloba*). Based on this work recommendations have been made regarding the optimal fire and burning regimes for management and recovery of species and communities.

Table 2: Responses to fire of declared rare flora on the Swan Coastal Plain (from Wilson and Valentine 2009, chapter 7). Further scientific assessments are required for much of this information.

| Scientific Name  | Fire Responses  | References  |
|--|---|---|
| <i>Caladenia huegelii</i><br>(Geophyte: Survives 100% scorch)                              | <ul style="list-style-type: none"> <li>• Fire is considered detrimental if fire occurs between July to November (during vegetative and flowering stages).</li> <li>• Fire may be beneficial as summer fires promote flowering.</li> <li>• Field experiment showed that the Fraser Road population is in a degraded bush block in Banjup surrounded by sand mines. No prescribed burning is allowed for this species. Wildfire occurred in 2007/2008 season. Recent experiment overlaid 5 x 5 m plots in burnt area.</li> </ul>  | <ul style="list-style-type: none"> <li>• DEC (2008a)</li> <li>• Evans <i>et al.</i> (2003)</li> <li>• Brown <i>et al.</i> (1998)</li> </ul>                 |
| <i>Darwinia foetida</i>  | <ul style="list-style-type: none"> <li>• Frequent fires reduce vigour and seed bank.</li> </ul>   | <ul style="list-style-type: none"> <li>• Evans <i>et al.</i> (2003)</li> </ul>  |
| <i>Drakaea elastica</i><br>(Geophyte: Survives 100% scorch)                                | <ul style="list-style-type: none"> <li>• Fire is considered detrimental if fire occurs between April/July to November (during vegetative and flowering stages). Fire may kill plant during active growing period (late April-Oct). Indirect impacts of fire include loss of canopy cover and increased weeds.</li> <li>• Fire may be beneficial if fire occurs between November to June, which may open up the canopy and reduce competition, but species still needs to retain some canopy vegetative cover after disturbance in order to protect plant and its fungus from desiccation. Fire is not likely to impact during the species' dormant period (November to early April).</li> <li>• Field observation: species does not require fire to complete its life cycle. Increased competition with increased density of native understorey vegetation has been observed following fire, leading to a decline in some populations. Species does not generally endure repeated disturbance or the consequential habitat changes (e.g. fire/wildfire).</li> </ul> | <ul style="list-style-type: none"> <li>• DEC (2008a)</li> <li>• Evans <i>et al.</i> (2003)</li> <li>• Brown <i>et al.</i> (1998)</li> </ul>                 |
| <i>Eleocharis keigheryi</i>  | <ul style="list-style-type: none"> <li>• Field Observation: species can grow in areas that have been recently burnt, and can flower in the absence of fire (one plant up to 10 years since last fire).</li> </ul>   | <ul style="list-style-type: none"> <li>• Evans <i>et al.</i> (2003)</li> <li>• Brown <i>et al.</i> (1998)</li> </ul>  |
| <i>Epiblema grandiflorum</i><br><i>var. cyaneum</i>  | <ul style="list-style-type: none"> <li>• Fire is considered detrimental if fire occurs between June to December (during vegetative and flowering stages).</li> <li>• Autumn fire is thought to be the most appropriate for this species.</li> </ul>   | <ul style="list-style-type: none"> <li>• Stack <i>et al.</i> (2000).</li> <li>• Evans <i>et al.</i> (2003)</li> <li>• Brown <i>et al.</i> (1998)</li> </ul> |
| <i>Eucalyptus argutifolia</i>  | <ul style="list-style-type: none"> <li>• Fire is considered to be detrimental if fire frequency is less than every 5-8 years (the species flowers 3-4 years after regenerating from rootstock).</li> </ul>  | <ul style="list-style-type: none"> <li>• Evans <i>et al.</i> (2003)</li> </ul>  |
| <i>Grevillea curviloba</i><br><i>subsp. curviloba</i> & <i>G. curviloba subsp. incurva</i> | <ul style="list-style-type: none"> <li>• Fire is considered to be detrimental if fire is too frequent, as it can deplete rootstock reserves and soil bank.</li> </ul>   | <ul style="list-style-type: none"> <li>• Brown <i>et al.</i> (1998)</li> </ul>  |
| <i>Trithuria occidentalis</i>  | <ul style="list-style-type: none"> <li>• Fire is considered to be detrimental if fire occurs during flowering (Sept-Nov)</li> </ul>   | <ul style="list-style-type: none"> <li>• English and Phillimore (2000)</li> </ul>   |
| <i>Maranthius paralius</i>   | <ul style="list-style-type: none"> <li>• No information available</li> </ul>  |   |

## GSS Flora studies (2007 to 2010)

For the GSS projects there was a focus on identifying post-fire regeneration strategies, juvenile periods of flora species, identification of key fire response species, and changes in floristic diversity to help guide the development of suitable fire intervals for the GSS study area.

### ***Post-fire Regeneration Strategies***

Local area knowledge of plant regeneration strategies are important as it has been shown that regeneration strategies or timing of events such as juvenile periods of some plant species can vary across a plant's distribution (George 1981). A summary of past research on flora responses to fire is discussed in Bleby *et al.* (2009a - Table 7.2). They found that out of 1,337 known native vascular plant taxa occurring in a range of habitats on the GGS, only a small number (n = 438) were found to have post-fire regeneration strategies recorded. Even fewer (n = 42) had their fire responses recorded in studies conducted on the Swan Coastal Plain, highlighting that most fire response data has been obtained from habitats elsewhere in the plant's distribution. From these records, it was discovered that 37% of the native vascular plants are killed by 100% scorch and rely on stored seed or dispersed seed from adjacent sites. A further 53% surviving fire by utilising basal sprouts, epicormic growth, apical buds or soil suckers (Bleby *et al.* 2009a).

A field study was undertaken by DEC for the GSS in 2009-2010 in an area of *Banksia* woodland that underwent a prescribed burn (Mickle *et al.* 2010b). A total of 107 species from 32 families were recorded in the pre and post-fire floristic surveys; the dominant families being Proteaceae, Myrtaceae and Stylideaceae. The post-fire regeneration strategies were observed in the field for 60 of these species. Of these, only 5 species (8%) were recorded as being seeders (killed by fire).

Post-fire regeneration strategies of the other 47 species were supplemented from, the Vegetation Species List and Response Database (DEC 2008b). In total, twenty four species (22%) were recorded as being seeders (killed by fire), 72 % recorded as resprouting from a variety of underground structures (soil suckers or lignotubers), epicormic or apical growth, and 6% of unconfirmed or varied regeneration strategies.

## ***Juvenile Periods***

The post-fire juvenile period (time to first flowering after fire) can be used to guide minimum intervals between fires to conserve plant diversity. 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 (Friend *et al.* 1999), Burrows *et al.* (2008) suggested that the minimum fire interval be twice that of the juvenile period of the longest maturing plant species. They proposed that if burning was sufficiently patchy and of low intensity burns to spare all plants in a burn from being scorched, fire intervals could be reduced (Burrows *et al.* 2008).

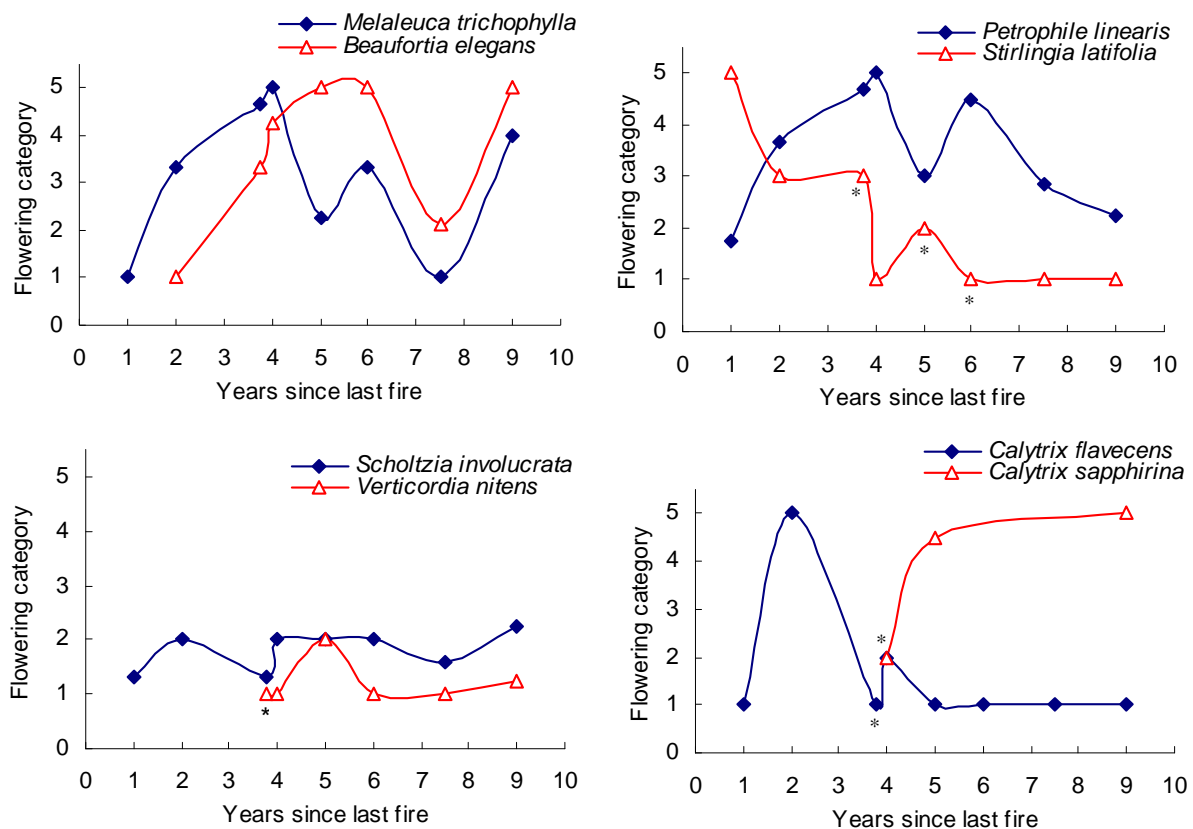
A field study by Mickle *et al.* (2010b) found that out of 107 observed plant species, a total of 71 (66%) species from 28 families reached their juvenile period in the 18 months following a prescribed burn in *Banksia* woodland on the GGS (Mickle *et al.* 2010b). Of the species that had reached their post-fire flowering period within 6 months of the burn, most (81%) were resprouters. Only 19% were annual seeders, and no perennial seeders had reached their juvenile period. Within 18 months of the burn, the proportion of seeders (20%) and resprouters (80%) reaching juvenile period had not changed, however some perennial seeders had reached juvenile period. It was expected that the majority of perennial seeders require greater than 18 months to reach juvenile period following fire.

## ***Examining juvenile periods across a fire chronosequence***

A fire chronosequence study at sites ranging from one to nine years since last fire was conducted in September and October 2009 (Mickle *et al.* 2010a). The study aimed to provide data from a wider range of fire ages, where plants killed by fire and regenerating from seed were better represented.

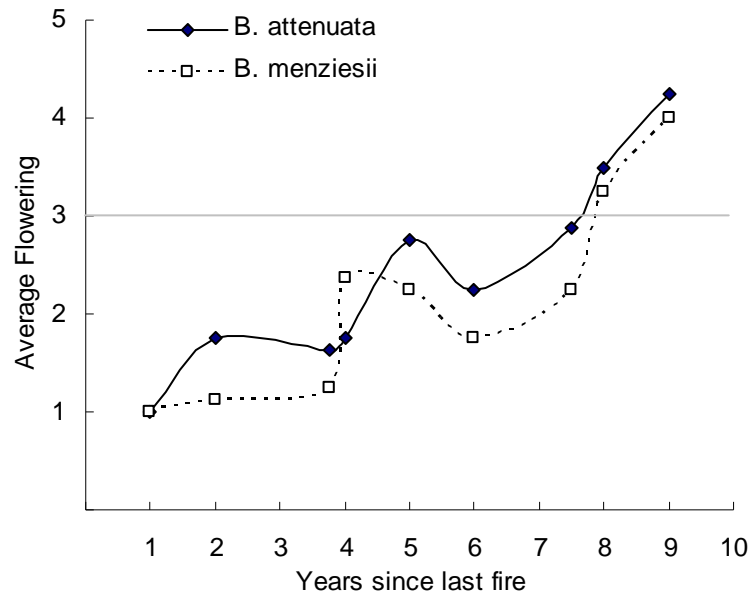
Nineteen observed plant species reached their juvenile period in the first 12 months following fire increasing to 30 species by 45 months post fire. Sixty species were found to reach juvenile period within five years (60 months) of fire although the exact timing could not be pinpointed for all species (Mickle *et al.* 2010a). Of the 60 species attaining juvenile period within 60 months, 35% regenerated by plant or soil-stored seed, and 65% by

sprouting from underground structures or apical or epicormic growth. The flowering patterns for 8 of these species can be seen in Figure 3.



**Figure 3. Average flowering category against years since last fire for 8 common *Banksia* woodland species across fire ages from one to nine YSLF. A species reaches juvenile period with a flowering category 3 or greater (represents 50% flowering or many flowers on some plants) (Mickle *et al.* 2010a). \* indicate flowering category based on a single replicate. Categories: (1) no flowering, (2) 25% flowering, (3) 50% flowering, (4) 75% flowering, and (5) 100% flowering.**

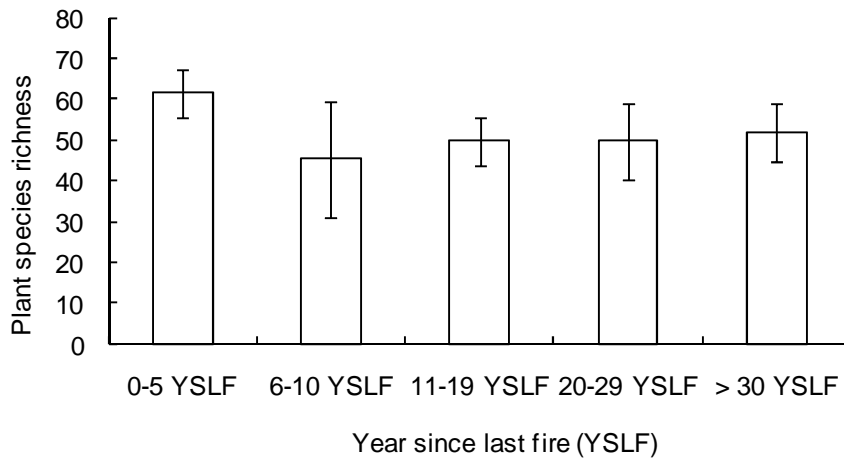
There was evidence that the juvenile period for two species, *Banksia attenuata* and *Banksia menziesii*, was attained more than 5 years following fire. However a decision was made to supplement this data with more field observations. The data was obtained in April 2010 when the sites were re-surveyed, and one new site was surveyed. The combined data for both surveys is shown in Figure 4. The data indicates that after 8 years, 50% of both *B. menziesii* and *B. attenuata* will be flowering 50% of the time.



**Figure 4. Average flowering for *B. attenuata* and *B. menziesii*. Values range in categories 1 to 5 according to Burrows et al (2008) scale where 1 is limited to no flowering observed in a population and 5 represents many flowers on many plants in the population. Category 3 represents 50% flowering in 50% of the population and indicates that a species has reached juvenile period. Data for Banksia species is based on data surveyed in spring 2009 (Mickle *et al.* 2010a) supplemented by April 2010 resurveying of the same sites (with the addition of a new site at 8 YSLB).**

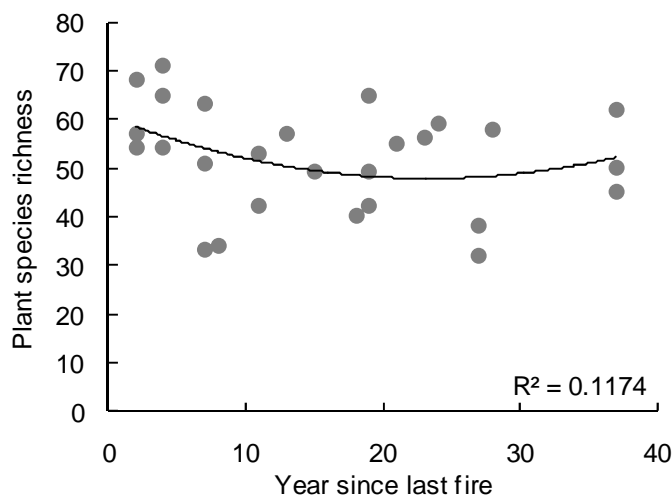
### ***Impact of fire on plant species richness***

Plant species richness with relationship to time since fire provides important information which (along with seed back quantity and durability) can be used to determine maximum interval between fires to sustain biodiversity (Burrows *et al.* 1999). An analysis of plant species richness at sites of different time since fire was undertaken for quadrat data at 28 sites obtained in Bassendean (landform) Banksia on the GGS.



**Figure 5. Mean ( $\pm$  95%CI) plant species richness in different time since last fire categories (n=28). All Bassendean landform Banksia sites that we collected plant flora records for. 0-5 YSLF = 6 replicates; 6-10 YSLF = 4 replicates; 11 – 19 YSLF = 8 replicates; 20-29 YSLF = 6 replicates; >30 YSLF = 4 replicates.**

There was no significant difference between means (ANOVA  $F_{4,23} = 2.053$ ,  $p = 0.120$ ) although there was a trend towards highest number of species in the most recently burnt habitat. It is likely that this is related to the presence of fire-emergent species (e.g. grasses, orchids) within a few years since fire (<5 yslf). There was also no significant correlation (either linear or 2<sup>nd</sup> order polynomial between species richness and time since last fire (Figure 6). It should be noted that in these analyses the Banksia woodland was not separated further into the floristically different I1 and J1 as has been recognised by Matiske Consulting Pty Ltd (2003). It is possible that analysis at the level of these floristically different communities may reveal significant differences between species richness and time since last fire.



**Figure 6. Plant species richness by years since last fire.**



## Flora Vital Attributes Summary

For the purposes of developing an ecological fire regime it is important to understand how plants respond to fire. The most important attributes for this assessment include post-fire regeneration strategy (method of persistence following a disturbance) and the juvenile period time (time to reach reproductive maturity) (Burrows *et al.* 2008; Shedley 2007; Tolhurst 1999). Juvenile period is defined as the time taken for at least half the population to reach flowering age (50% of the population flowering 50% of the time). 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). These attributes are used to select key fire response species and are then used to define maximum and minimum tolerable interfire periods for the land management unit or vegetation community in question.

Floristic surveys within the GSS area used the regeneration strategies as defined by Burrows *et al.* (2008, see Table 1). The species likely to be effected most by fire are those that rely on seeds for reproduction and are killed by fire.

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 Appendix 1.

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 3.

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 3) 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).

**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.

Table 3. 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 Appendix 1.

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

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

## Impacts of fire on fauna

The interaction between Australian fauna and fire has received considerable attention (Catling and Newsome 1981; Fox 1996; Friend 1993; Whelan 1995; Wilson 1996) although the focus has been the impact of fire upon birds and mammals. Behavioural patterns and requirements for shelter and food are two major factors that affect the responses of taxa to fire (Friend 1993). For example, species that nest in tree hollows may avoid the acute effects of a low intensity fire. Conversely there may be limited food resources for sedentary species in the early post-fire period, whilst mobile species can migrate to unburnt patches to obtain food and shelter.

Similar to changes in the vegetation composition and structure over time following a fire, the composition of fauna (birds, mammals, reptiles and invertebrates) that use post-fire habitat can also change. A ‘habitat accommodation’ model developed to describe post-fire succession of small mammals describes how succession occurs in response to vegetation changes (Fox 1982; Fox 1996). Species enter the succession as their specific requirements are met, and decline in abundance as conditions become suboptimal. Species such as the eastern chestnut mouse (*Pseudomys gracilicaudatus*), which prefer open, floristically rich vegetation, recolonise early in the post-fire recovery period, while species such as the swamp antechinus (*Antechinus minimus*), which require dense ground cover, exhibit low population numbers up to 20 years after fire (Fox 1982; 1983; Wilson *et al.* 2001; Wilson *et al.* 1990). This model is generally supported by the results of studies in southern heathlands, heathy woodlands and arid grasslands (Masters 1993; Newsome *et al.* 1975; Recher *et al.* 1974; Wilson 1996; Wilson *et al.* 2001). The rate of recovery of vegetation not time *per se* has been shown to be most important in the successional process for mammals (Fox and Monamy 2007; Monamy and Fox 2000).

The effect of fire on reptile and frog communities is still largely unclear in Australia (Bamford and Roberts 2003; Friend 1993). Reptile information is based on studies in mallee woodlands, heathlands and savannah forests where reptilian diversity is high (Caughley 1985; Cogger 1969; 1989; Dickman *et al.* 1999; Letnic *et al.* 2004; Masters 1996; Pianka 1996; Trainor and Woinarski 1994; Valentine and Schwarzkopf 2009). Few studies have been undertaken in southern temperate areas (e.g. Humphries 1992; Lunney *et*

*al.* 1991). Studies suggest that many species of snakes and lizards are resilient to the short-term effects of fire, due to their preference for open microhabitats and use of burrows, whereas arboreal or surface-dwelling species are less protected (Fox 1978; Friend 1993). Although the longer-term relationships between reptiles and fire regimes are still uncertain, species respond in variable ways and the type of fire regime imposed may be critical in determining species response (Braithwaite 1987; Valentine and Schwarzkopf 2009). Succession of reptiles has been documented for arid *Spinifex* landscapes, where there is a strong relationship between shelter and foraging requirements of species and their abundance in successional ages (Cogger 1969; Dickman *et al.* 1999; Letnic *et al.* 2004; Masters 1996; Pianka 1996).

The knowledge of the effects of fire on birds in many environments is limited (Catling and Newsome 1981; Christensen and Abbott 1989; Christensen and Kimber 1975; Christensen *et al.* 1985; Cowley *et al.* 1969; McFarland 1993; Recher 1981; Recher and Christensen 1981). There have been few long-term studies of the ecological impacts of fire regimes, and the long-term consequences of fire management are poorly known (Woinarski 1999).

The impacts of fire on birds in heathlands have been reasonably well studied. During wildfires very high mortality rates have been reported (Fox 1978; Pescott 1983; Recher *et al.* 1975; Wegener 1984) while insectivores and some raptors may be attracted to fire fronts (Main 1981). In the early post fire months dead or dormant invertebrate and vertebrate prey attracts predators (e.g. Laughing Kookaburra, raptors, Pied Currawong, Australian Magpie), and seed produced by plants such as *Banksia* species attracts parrots and cockatoos (McFarland 1988; 1993; Roberts 1970). The regenerating vegetation in the first three years post fire remains comparatively open and herb and grass species are abundant. Open-habitat species such as swallows and martins commonly colonise this habitat (McFarland 1988). As the vegetation structure becomes more closed these species are lost and they are replaced by species reliant on denser vegetation such as Brush Bronzewing, Ground Parrot, Red-backed Fairy-wren and Southern Emu-wren (McFarland 1988; Smith 1987). In older heaths (>10–20 years post-fire) there may be a reduction in productivity or seed availability, and some of these bird species may decline or disappear (McFarland 1993).

Burbidge's (2003) review of the impacts of fire on birds in south west Western Australia found that bird species richness is highest in long unburnt vegetation (15 years post-burn) but is also high in habitat for several years following a fire. Only honeyeater species richness is reduced in burnt habitat for the first 3 years following fire. However post-fire habitat is favoured by species that have a preference for open habitat, e.g. birds of prey. Many species that prefer open habitat will remain in a burnt area and be the dominant species for 2-6 years post fire (Burbidge 2003).

The abundance of birds decreases to very low levels immediately following a fire but usually recovers within 2-3 years (Burbidge 2003). Insectivores generally increase in abundance after fire and can exceed pre-fire abundance for up to 7 years. Conversely, nectarivores decline following fire due to the reduction in the number of flowering *Banksias* in the burnt area. However it is fire intensity that is one of the biggest determinants of post-fire richness and abundance. Low intensity burns have the least impact on bird ecology (Burbidge 2003).

There are no species in south-west Western Australia that only occur in long-unburnt vegetation (Burbidge 2003), however Bamford (1985) found that the western thornbill (*Acanthiza inornata*), shining bronze-cuckoo (*Chrysococcyx lucidus*) and scarlet robin (*Petroica multicolor*) were more common in *Banksia* woodland unburnt for 11-12 years. Wooller and Calver (1988) noted significant decreases in the abundance of white-breasted robin (*Eopsaltria Georgiana*), golden whistler (*Pachycephala pectoralis*), splendid fairy-wren (*Malurus splendens*) and white-browed scrub-wren (*Sericornis frontalis*) following fire. Variations in abundance are linked to habitat structure and consequential foraging opportunities.

A study of repeated fire on Splendid Fairy-wren over a long period of 18 years in a southwestern Australian heath found that although in general, the birds survived fire it directly impacted on natality and juvenile survival, and indirectly affected population density, age structure, sex ratio and group composition (Brooker and Rowley 1991) (Russell and Rowley 1993). The repeated fires threatened this population and without recruitment from adjacent unburnt patches (for example, if this site had been a habitat fragment), it would have been eliminated by the fire regime (Brooker and Brooker 1994).

Provision of adequate areas of suitable seral stages across the landscape is especially important for this mobile species.

Inappropriate fire regimes are recognized as the main threat to many vulnerable and endangered Australian birds (Garnett 1992) and are a factor in the threatened status of approximately 51 nationally recognised threatened bird taxa (Woinarski 1999). In environments such as heath and mallee inappropriate fire regime is the main threat to most declining bird species. Most fire-sensitive threatened birds have low reproductive output and limited dispersal ability. The persistence of these species is further threatened by habitat fragmentation, which further impacts on their ability to recolonise following fire.

The impact of fire on invertebrates and the response patterns that invertebrates exhibit can be highly variable and difficult to detect, often more so than for vertebrates and plants (Campbell and Tinton 1981; Friend 1995; Whelan 1995; Whelan *et al.* 2002). This is due to several reasons. Most invertebrate studies lack robust experimental design, and adequate sampling (Friend 1995; Whelan 1995; Whelan *et al.* 2002). In addition, invertebrates are a diverse group and exhibit a wide range of life histories and morphologies and are found in many different habitat types. Fire-related responses may not be apparent when data is analysed at broad classifications such as class and order (Friend 1995; Whelan *et al.* 2002).

Fire directly impacts invertebrates by killing them, as well as indirectly by affecting their habitat. Some invertebrate species survive the direct effect of fire by either moving ahead of the fire front, by being protected in the soil or other refugia (e.g. termite mounds) or if they are dormant (Whelan *et al.* 2002). Some species may also survive due to the patchiness of a fire, providing refugia in the unburnt pockets (Whelan *et al.* 2002). Most invertebrates subsequently recolonise burnt areas from unburnt patches (Whelan *et al.* 2002), dense crowns of plants (Gandar 1982; Main 1981; Whelan *et al.* 1980), thick layers of leaf litter (Andrew *et al.* 2000), thick bark on trees, and soil under rocks and in burrows (Main 1981; Warren *et al.* 1987). Species recolonise at different rates, depending on their dispersal ability. The patchiness, intensity, extent and season will all influence the recolonisation capacity of invertebrates (Whelan *et al.* 2002).

Many invertebrate taxa appear to decline after fire and then recover quickly (Friend and Williams 1996; Whelan 1995), with little change in subsequent abundance (e.g. Abbott *et*



*al.* 1985; Collette and Neumann 1995). Some studies have found that populations of soil and litter arthropods will not recover to pre-fire population numbers during a five year inter-fire period, but other researchers have stated that populations will recover quickly.

Fire sensitive fauna are often recognised as those that have specific characteristics such as late seral stage habitat requirements, strong site fidelity, low fecundity, poor dispersal capacity and are vulnerable to other threats such as predation. Fire sensitive fauna are often associated with mesic habitats, wetlands and rock outcrops (Burrows 2008).

While the majority of studies that have assessed the effects of fire on Australian fauna communities have focused on time since fire, the effects of multiple fires have been less intensively studied. Fire frequency has strong impacts on community composition for plants and animals (Andersen *et al.* 2005; Peterson and Reich 2001). Repeated burning can lead to changes in habitat structure, and simplification of vegetation complexity with implications for fauna composition (Bowman *et al.* 1988; Christensen *et al.* 1981)

Fire frequency has been identified as a major factor influencing bird assemblages (Engstrom *et al.* 2005; Woinarski *et al.* 1999; Woinarski and Recher 1997). Although in tropical savannas birds seem to respond to time since fire (Woinarski *et al.* 1999) or whether or not a site was burnt (Woinarski 1990) in one study species richness and overall bird abundance was found to be lower in repeatedly burnt sites than either unburnt or site burnt once (Valentine *et al.* in prep.). In particular, abundance of frugivores and insectivores was lower in repeatedly burnt sites, probably due to the decline of a native fruiting shrub, *Carissa ovata*.

Frequent low intensity fires can reduce invertebrate abundance and species richness in subtropical *Eucalypt* forests (York 1999; 2000). Although tropical savannah arthropod communities tend to be resilient to fire (Andersen *et al.* 2005; Parr *et al.* 2004), burning does disadvantage certain arthropods and alter the overall composition of arthropod communities (Andersen and Muller 2000; Parr *et al.* 2004).

Although the effects of fire frequency on small mammals in southeastern Australia have been investigated predominantly the assessments have been limited to only several consecutive wildfires. Recolonisation at a site at Nadgee was monitored after two

wildfires (1972, 1980) and the responses of small mammals to changes in vegetation structure examined (Catling 1986; Catling and Burt 1995; Catling *et al.* 2001; Catling and Newsome 1981; Newsome and Catling 1979; Newsome *et al.* 1975). Abundance and species richness increased as the habitats increased in complexity with post fire age. A long term study by Recher *et al.* (2009) also assessed recovery of ground-dwelling, small mammals on a different plot in coastal eucalypt forest at Nadgee (1970-2005). Following an intense fire in 1972 numbers fell to the lowest level recorded and each species population became extinct on the plot 14-18 months later. One year later the site was recolonised and numbers peaked 6 to 7 years later. A less intense fire in 1980 did not lead to extinctions, but numbers of *A. agilis*, *A. swainsonii* and *R. fuscipes* declined under drought conditions. This long-term study demonstrated that differences in impacts are related to a number of factors including the intensity of fire, rainfall and drought. Increased frequency is predicted to impact on late successional species such as the swamp antechinus (*Antechinus minimus*), which requires dense ground cover, is extirpated after fire, and exhibits low population numbers up to 20 years after fire (Fox 1982; 1983; Wilson *et al.* 2001; Wilson *et al.* 1990).

In tropical savannah of northern Australia, total abundance and species richness, and the abundances of six of the seven most common small mammal species were all significantly affected by fire treatment (frequency and time-since-fire) making small mammals the most sensitive faunal group (Andersen *et al.* 2003; Andersen *et al.* 2005). Three species (northern quoll, *Dasyurus hallucatus*; fawn antechinus, *Antechinus bellus*; and northern brown bandicoot, *Isodon macrourus*) were most abundant in unburnt catchments, while other species were more variable but tended to be most abundant in unburnt catchments. A highly significant result was the importance of unburnt habitat for maintaining large populations especially for extinction-prone species, which have suffered serious population declines across northern Australia in recent decades.

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 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 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. 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. There is however 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).

A spatially explicit simulation model that was employed to assess the effects of fire regime dynamics on the malleefowl *Leipoa ocellata* incorporated home ranges, plant populations, and fires (prescribed and unplanned) and spatial patterns of fires (random versus non-random ignitions) (Bradstock *et al.* 2005). Results were affected particularly by the spatial pattern of prescribed burns, topography and probability of wildfire all of which were sensitive to fire-interval distributions on plant species and habitat. The study found that the persistence of populations would be dependant on a prescribed fire regime providing small patch burns (Bradstock *et al.* 2005). The study however emphasised that the dependence of fauna species on fire mediated habitat heterogeneity is highly variable and strongly dependent on species life-history traits, dispersal and territory sizes, together with landscape features.

Seral and habitat requirements for species that co-occur in a landscape can differ significantly. For example in the Eastern Otways, Victoria, the Swamp Antechinus, *Antechinus minimus*, is a late successional species (15-20 years) and slow recoloniser while in contrast the *Pseudomys novaehollandiae*, New Holland Mouse, is an early to mid-successional species (3-7 years) (Lock and Wilson 1999; Wilson 1991; Wilson *et al.* 2001; Wilson and Wouters 1996). For the former species protection of the limited critical habitat from frequent fire is crucial to ensure connectivity of populations and the long-term persistence of the species, while for the latter burning to achieve a series of optimal-aged (3-7 years) small habitat patches is required (Wilson and Wouters 1996). In this case the distribution of preferred habitat for the two species is understood and mapped (Gibson *et al.* 2004; Wilson *et al.* 1999). Further the habitats occur in different parts of the landscape

thus enabling fire management to be applied where there is a need for fire protection in one area, and fire-induced heterogeneity in the other.

## Previous studies in the GSS study area

Studies of the impacts of fire on fauna in the GGS are few. Kitchener *et al.* (1978) proposed that too frequent burning of vegetation may have threatened the persistence of mammal species on the Swan Coastal Plain. In the 1978 study, ash-grey mice (*Pseudomys albocinereus*) and honey possums (*Tarsipes rostratus*) were only trapped at two sites (Mullaloo and Burns Beach) in patches of vegetation that had remained unburnt (six years post-fire age) after extensive, high intensity fires. (How and Dell 2000) proposed that high intensity fire in small isolated vegetation remnants on the Swan Coastal Plain may lead to local extinction. Those individuals that survive fire are prone to starvation or predation due to lack of cover and food and there is little likelihood of colonisation from elsewhere in the urban matrix. Macropods such as the western grey kangaroo (*Macropus fuliginosus*) and the western brush wallaby (*Macropus irma*) favour burnt forest (Christensen and Kimber 1975).

Dell and How (1995) examined the response of reptiles to wildfire at Kings Park and found that the longest unburnt sites supported the highest lizard diversity, while the most recently burnt sites were found to have the lowest lizard diversity. Species numbers and abundance was lower in the first year post-fire but appeared to return to pre-fire levels by the second year post-fire. Migration from burnt to adjacent unburnt sites was apparent.

In contrast to other studies, Bamford (1986; 1992; 1995) did not find a relationship between total reptile species or number of captures, and time after fire in heathland and *Banksia* woodland habitats. He concluded that the overall effect of fire on reptiles was negligible, although a small number of species did exhibit clear post-fire seral responses. Some species were absent from early succession areas, while others were present in increased numbers, apparently favouring the more open ground. Whilst overall the assemblage did not change, fire effects may have been obscured by patterns of abundance across the landscape that were independent of fire history (Bamford and Roberts 2003). These studies focused on time since fire and did not examine fire intensity.

Studies undertaken by Bamford (1985; 1986) examined the impact of prescribed burns on mammals in *Banksia* woodland and assessed areas of varying fire ages at Mooliabeenee Nature Reserve north east of the GGS. Survival of most mammal species was high in places of uneven (patchy) burn as species were able to survive by moving to unburnt areas. The mean number of captures in the first year after fire was significantly less than that of all subsequent years. House mice (*Mus musculus*) and little long-tailed dunnarts (*Sminthopsis dolichura*) were more abundant 0 – 3 years after fire, ash-grey mice (*Pseudomys albocinereus*) between 3 – 6 years after fire, and honey possums (*Tarsipes rostratus*) and western pygmy possums (*Cercartetus concinnus*) were more abundant in 11 year old vegetation.

Much of the work on effects of fire on invertebrates in Western Australia has been conducted in the wetter south west forests. The invertebrate fauna on the Swan Coastal Plain however has been shown to respond in different ways. The greater regularity of seasonal climate and uniform landscape and fire regimes has lead to a more predictable succession following frequent moderate intensity fires on the Swan Coastal Plain, compared to the south west with less frequent high intensity fires and greater topographical/geological variability (Van Heurck and Abbott 2003). This has lead to a less predictable response and the favoured persistence of relict Gondwanan taxa in the south west (Main 1987; Van Heurck *et al.* 1998).

On the Swan Coastal Plain, in Jarrah-*Banksia* woodland, richness and abundance of invertebrates increased several weeks after a wildfire with some of this being attributed to the survival of arboreal species which had become more active on the ground (Barendse *et al.* 1981; Whelan *et al.* 1980) found that eight years was required for spider richness in *Allocasuarina-Banksia* woodland to recover after fire. The work also found some rare spiders only in areas unburnt for over 20 years, and that litter type and location was more important than time since fire for composition and richness.

In Kings Park (Ladhams 1999) the beetles and spiders showed no change in richness but significant changes in composition following fire. These changes were associated with changes in habitat availability for both beetles and spiders, as well as prey abundance and climate for the latter. The changes in habitat availability are primarily, for ground dwelling

invertebrates, based on changes in the leaf litter. The time since fire was found to be an important regulator of litter biomass, depth and living space.

Van Heurck *et al.* (1998) also looked at leaf litter variables in response to fire, although in the central Jarrah forest. Litter depth, cover and volume recovered after three years for both spring and autumn fires, with understorey shrubs recovering more rapidly after a high intensity autumn burn. The season of the fire was found to influence microhabitat diversity, with particular types of habitats being created by high intensity autumn fires only. Friend and Williams (1993) found post fire invertebrate abundances and composition did not correlate with changes in floristics or vegetation structure in Mallee Heath remnants in the south west.

## GSS Projects-fauna studies 2007 to 2010

The GSS projects focussed upon post-fire regeneration patterns of vertebrates and the identification of key fire response vertebrate species in order to help guide the development of suitable fire intervals for the study area.

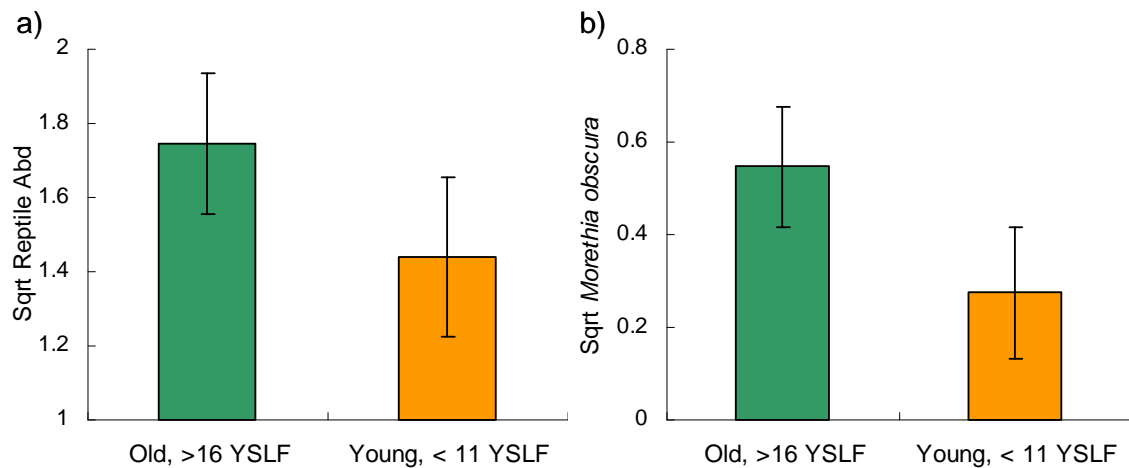
### ***Patterns of ground-dwelling vertebrate biodiversity (Valentine et al. 2009b).***

#### **Reptiles**

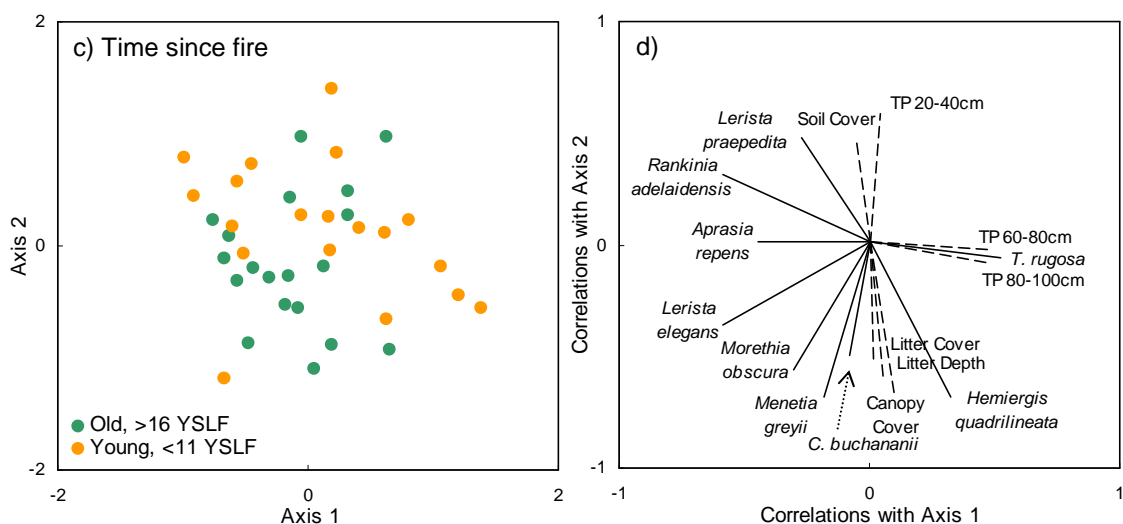
Results from the studies undertaken by DEC for the GSS indicate that the response of reptile communities to time since fire varied among different combinations of vegetation type (Banksia, Melaleuca, Tuart, Jarrah) and time since fire (Valentine *et al.* 2009b). The surveys found that overall reptile abundance, as well as the abundance of some specific species including *Morethia obscura* and *Lerista elegans*, was higher at sites with a fire age of at least 11 years since last burn (Figure 7, Swinburn *et al.* 2009; Valentine *et al.* 2009b).

The majority of the burrowing snake species, including the Priority listed elapid *Neelaps calonotus* were also captured at sites with a fire age of 11 YSLF or greater (Swinburn *et al.* 2009; Valentine *et al.* 2009b). This perhaps reflects a difference in resource availability between recently burnt and long unburnt sites. In previous studies, skink-consuming elapids tend to be absent, or in lower abundances in recently burnt habitat (Valentine and Schwarzkopf 2009).

Time since fire also influenced the assemblages or species composition of reptiles that occurred at sites which is shown by NMDS ordination (Figure 8a). Older sites (> 16 YSLF) predominantly are separated from younger sites, although there is some overlap which is likely to be due to some influence of habitat type. Analyses of correlations of the reptile species and habitat variables that are contributing to the ordination are shown in Figure 8b. Here species such as *L elegans*, *M. obscura* are associated with older sites, *R. adelaidensis* with younger sites.



**Figure 7. Significant differences in the mean ( $\pm$  95%CI) of a) reptile abundance and b) abundance of *M. obscura* between ‘old’ sites (those long unburnt, > 16 years since last fire) and ‘young’ sites ( those recently burnt, < 11 years since last fire).**



**Figure 8. NMDS ordination (Sorensen distance measure) on the assemblage of reptiles (n = 23 species) at 38 sites for time since fire. The ordination is in three dimensions (stress = 0.135), with axis 1 and 2 plotted ( $r^2 = 0.346$  and  $0.306$  respectively). (d) Correlations of species and habitat variables ( $r^2 > 0.2$ ) with NMDS ordination.**

Specific analyses examining the interaction between vegetation type and fuel age categories were undertaken for *Banksia* and *Melaleuca* sites. Our results indicated that reptile communities varied among different combinations of habitat and fuel age (Valentine *et al.* 2009b). Different reptile species tend to prefer different habitat attributes (Letnic *et al.* 2004), and these attributes will be in different supply in different vegetation types, and may be altered by burning. The differences between fuel ages were particularly



pronounced in *Melaleuca* sites. 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, and young fuel age *Banksia* sites often had species common in old fuel age sites (e.g. *Morethia obscura*). Particular species of fauna were associated with fuel age sites in different ways within the two habitat types. For example, reptile abundance was correlated with fuel age, however, this correlation was only significant within *Melaleuca* sites. This suggests that the response of reptiles to fire age is dependent upon habitat type.

Changes in the abundance of reptiles following burning is often linked to fire-induced changes in the resource availability of the post-fire environment (Friend 1993; Masters 1996). Because reptiles tend to occupy sites with suitable thermal, shelter, and food resources (Friend 1993; Letnic *et al.* 2004; Masters 1996), burning may have modified elements of the habitat in a manner undesirable to some species. The long unburnt sites contained deeper piles of litter, and those species with a preference for deeper litter, were observed in high abundances in the long unburnt sites. Typically, litter-associated lizards respond strongly to the removal of vegetation and are usually observed in high abundance in the least-disturbed sites, and their density is often correlated with variables of vegetation cover (e.g. litter cover; Greenberg *et al.* 1994; Masters 1996).

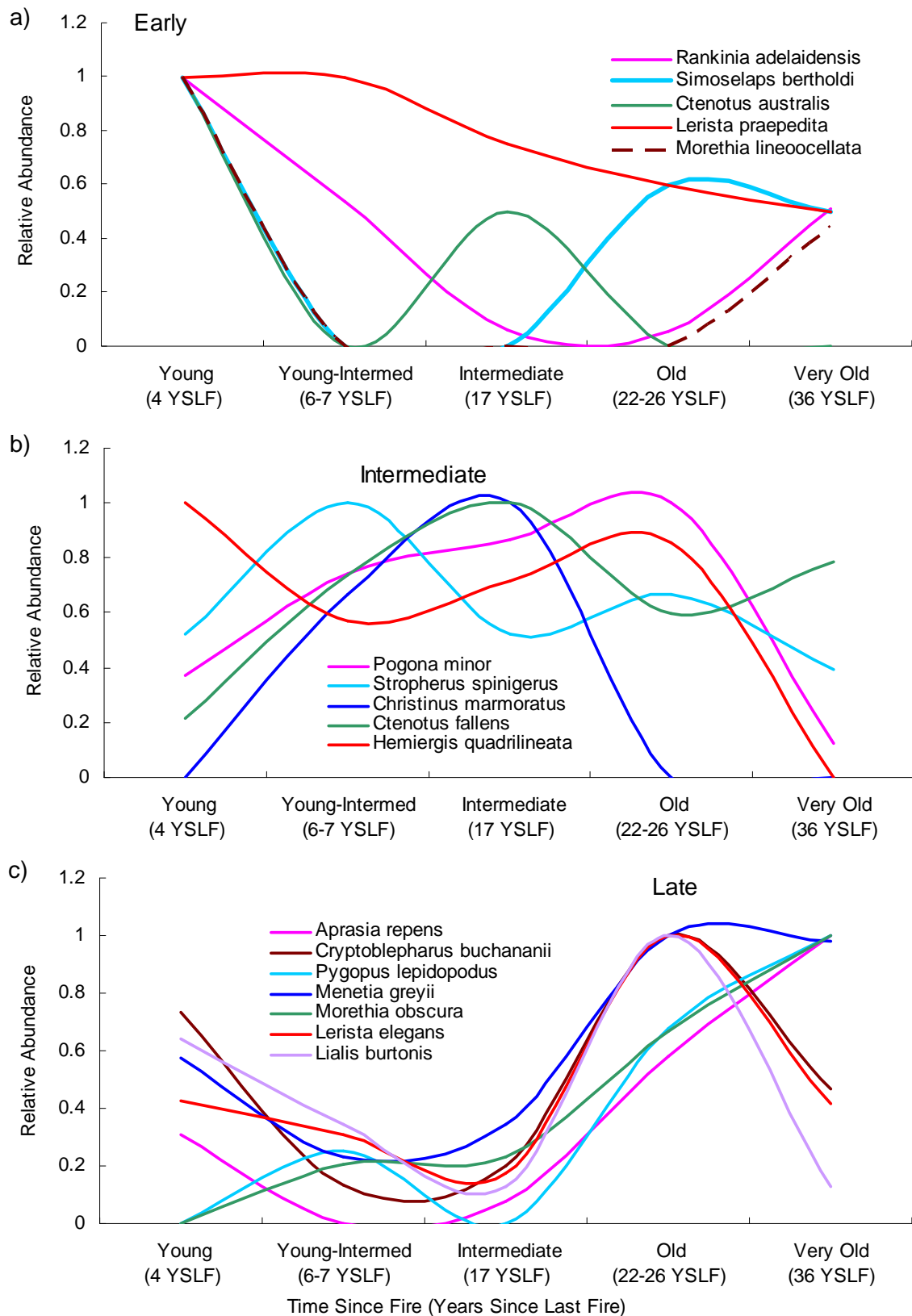
The succession of fauna with time since fire on the GGS was also examined by assessing relative abundance (species average abundance, divided by the maximal average abundance) in relationship to time since fire. This highlighted that the responses of reptiles to fire in *Banksia* woodland are complex. Reptile species tended to respond in different patterns to time since fire, with relative abundance estimates peaking at every fire age category for at least one species of reptile (Figure 9 and Table 4). Several species preferred recently burnt sites (e.g. *Morethia lineoocellata* and *Lerista praepedita*), whilst others were most abundant in intermediate fuel age sites (e.g. *Ctenotus fallens* and *Strophurus spinigerus*), and still other species in long unburnt sites (e.g. *Morethia obscura*, *Lerista elegans* and *Aprasia repens*). Furthermore, several species displayed a bimodal response to time since fire, with relative abundances peaking in both recently burnt and long unburnt sites (e.g. *Rankinia adalaidensis* and *Ctenotus australis*). This is likely to be related to changes in habitat features, not time since fire per se. Certain habitat characteristics of recently burnt and very long unburnt may be similar and preferred by some species. This

study indicates that a diverse range of post-fire habitat is necessary to cater for the species rich reptile fauna in the GSS study area.

**Table 4. Preferred fire age for reptile species, derived from species abundance analyses, multiple captures in only one fire age, and NMDS ordinations of reptile assemblages (Swinburn *et al.* 2009; Valentine *et al.* 2009b).**

| <b>Reptile Species</b>                | <b>Preferred Fire Age<br/>(years since last fire)</b> | <b>Method</b> |
|---------------------------------------|---|---------------|
| <i>Rankinia adelaidensis</i>          | <11 (young)   | 1,3           |
| <i>Lerista elegans</i>                | 11+ (old)   | 1,3           |
| <i>Morethia obscura</i>               | > 16 (old)  | 1,3           |
| <i>Aprasia repens</i>                 | >16 (old)   | 3             |
| <i>Menetia greyii</i>                 | >16 (old)   | 1,3           |
| <i>Neelaps calonotos</i>              | 11+ (old)   | 2             |
| <i>Tiliqua rugosa</i>                 | <11 (young)   | 3             |
| <i>Tiliqua occipitalis</i>            | <11 (young)   | 2             |
| <i>Ramphotyphlops australis</i>       | >16 (old)   | 2             |
| <i>Demansia psammophis reticulata</i> | >16 (old)   | 2             |
| <i>Delma concinna concinna</i>        | <11 (young)   | 2             |

1. Preferred fire age derived from species abundance analyses
2. Insufficient data for analysis however multiple captures in only one fire age (at least 2)
3. Preferred fire age derived from NMDS ordinations of reptile assemblages



**Figure 9. Successional responses of reptiles in *Banksia* woodland related to time since fire. Relative abundance estimated as a species average abundance divided by its maximal average abundance. Responses are separated into a) early, b) intermediate, and c) late.**

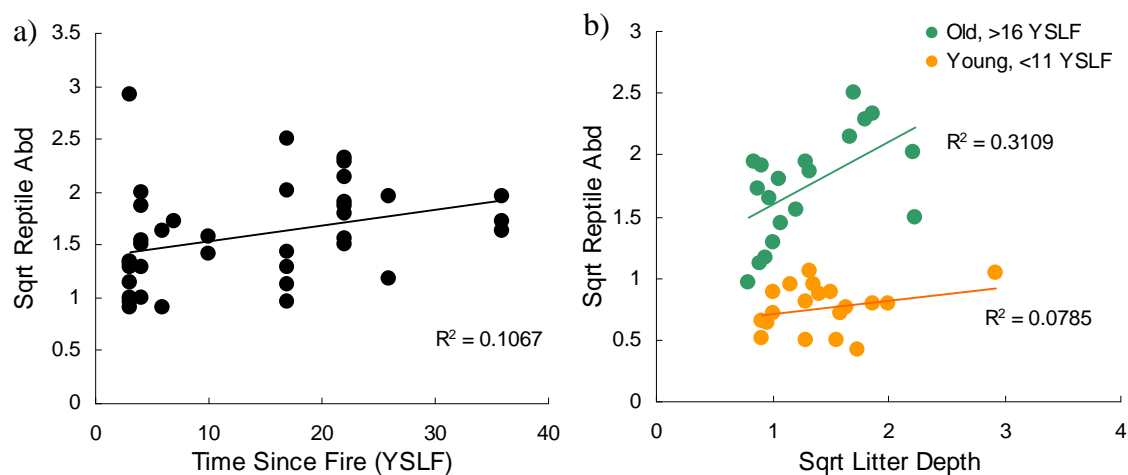
## Reptiles and habitat parameters

Habitat variables were also assessed further across the four habitat types (Banksia, Melaleuca, Tuart, Jarrah) to examine differences between time since fire. The number of plant species was correlated with reptile species richness (Pearson's  $r = 0.452$ ,  $P = 0.006$ , Figure 10), but not reptile abundance. However, reptile abundance was correlated with times since fire (Pearson's  $r = 0.327$ ,  $P = 0.045$ ; Figure 10), unlike reptile species richness. In addition, reptile abundance was correlated with a number of habitat parameters (Table 5), including positive associations with litter cover, canopy cover and litter depth, and negative associations with soil cover and a number of the touch pole count intervals (Table 5; Figure 10). The association of reptile abundance with litter depth indicated that the pattern was only significant in long unburnt sites (Figure 10), with trend lines indicating  $r^2$  values for the subset groups time since fire. Of the touch pole counts, the interval 20 – 40 cm was positively correlated with reptile diversity measures, and the number of plant species, but negatively correlated with the abundance of reptiles (Table 5; Figure 10). The number of plant species was negatively correlated with other touch pole count intervals (intervals > 40 cm; Table 5). Time since fire was significantly correlated only with litter depth (Table 5).

**Table 5. Pearson's correlations (r) of reptile abundance, species number, diversity, evenness, plant species number and fuel age with habitat variables at each site.**

|                   | Reptile Abundance | Reptile Species Richness | Reptile Diversity | Reptile Evenness | Flora Species   | Time since Fire |
|-------------------|-------------------|--------------------------|-------------------|------------------|-----------------|-----------------|
| Vegetation cover  | -0.017            | <b>0.396*</b>            | <b>0.373*</b>     | 0.192            | 0.276           | 0.170           |
| Litter cover      | <b>0.475**</b>    | -0.267                   | -0.173            | -0.192           | 0.128           | 0.170           |
| Soil cover        | <b>-0.466**</b>   | 0.133                    | 0.011             | 0.085            | -0.159          | -0.219          |
| Canopy Cover      | <b>0.447**</b>    | <b>-0.380*</b>           | -0.179            | -0.310           | -0.173          | 0.153           |
| Litter Depth      | <b>0.512**</b>    | -0.241                   | -0.019            | -0.084           | 0.046           | <b>0.433**</b>  |
| Touch pole counts |                   |                          |                   |                  |                 |                 |
| 0 – 20 cm         | -0.077            | 0.249                    | 0.289             | 0.209            | 0.180           | 0.098           |
| 20 – 40 cm        | <b>-0.336*</b>    | <b>0.504**</b>           | <b>0.361*</b>     | <b>0.331*</b>    | <b>0.375*</b>   | -0.206          |
| 40 – 60 cm        | <b>-0.430**</b>   | -0.016                   | -0.033            | 0.243            | <b>-0.346*</b>  | -0.286          |
| 60 – 80 cm        | <b>-0.346*</b>    | -0.115                   | -0.170            | 0.082            | <b>-0.623**</b> | -0.221          |
| 80 – 100 cm       | <b>-0.353*</b>    | -0.124                   | -0.209            | 0.039            | <b>-0.634**</b> | -0.264          |
| 100 – 150 cm      | -0.208            | -0.286                   | -0.277            | -0.072           | <b>-0.626**</b> | -0.249          |
| 150 – 200 cm      | -0.274            | <b>-0.390*</b>           | -0.255            | 0.020            | <b>-0.469**</b> | -0.298          |

Significant values are in bold (\*  $P < 0.5$ , \*\*  $P < 0.01$ ) and values approaching significance are identified ( $0.06 > P \geq 0.05$ ) Diversity calculated using Simpson's Diversity of Index (1-D), 0 (low) to 1 (high). Evenness derived from Shannon-Wiener Index with higher values representing a less variable community.



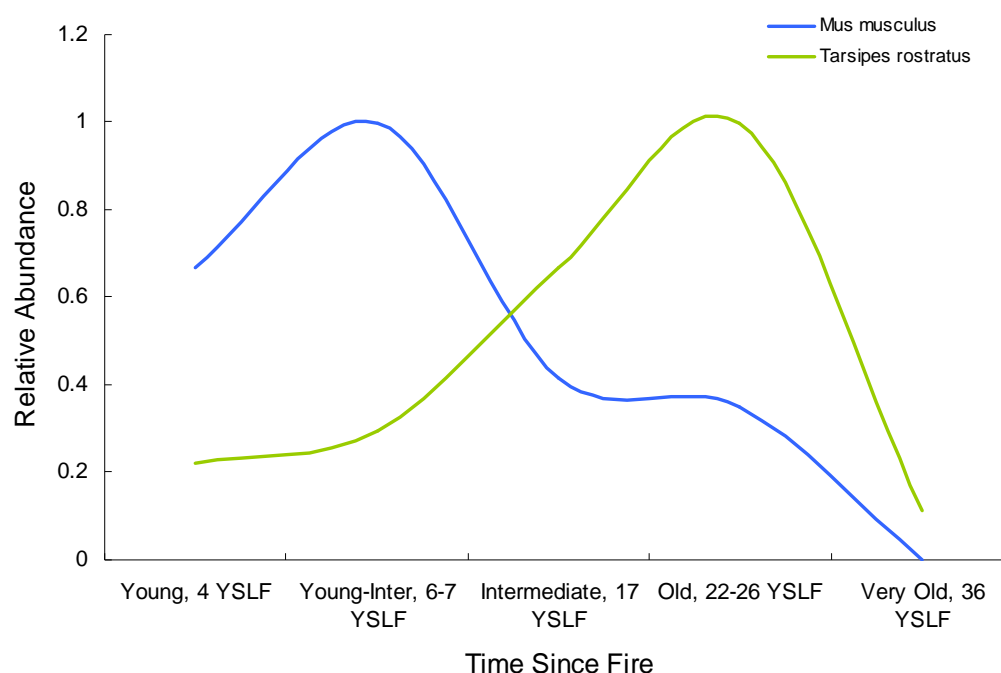
**Figure 10. a) Reptile abundance with time since fire, and, b) reptile abundance with litter depth, with times since fire categories identified. Linear trend lines are plotted for each graph, and an  $r^2$  value provided.**

## Mammals

Although a number of mammal species were captured during the GSS field studies including honey possum (*T. rostratus*), Quenda (*Isoodon obesulus fusciventer*), bush rat, moodit (*Rattus fuscipes*), Rakali (*Hydromys chrysogaster*), *Sminthopsis sp.*, echidna (*Tachyglossus aculeatus*), house mouse (*M. musculus*) and black rat (*Rattus rattus*), overall mammal capture rates were very low and there was little detailed information on their specific responses to fire (Valentine *et al.* 2009b). The exceptions were for *M. musculus* and *T. rostratus* and the response of these two mammal species to fire was clear. The house mouse (*Mus musculus*) preferred more recently burnt sites (Swinburn *et al.* 2009; Valentine *et al.* 2009b). In contrast, honey possums (*Tarsipes rostratus*) were more abundant in older sites, with peaks in relative abundance at sites 20 – 26 YSLF (Valentine *et al.* 2009b). Although honey possums (*Tarsipes rostratus*) are known to return to burnt areas within 2 – 4 years since fire (Bamford 1986; Everaardt 2003; Richardson and Wooller 1991), higher densities are recorded in older vegetation, with peaks in abundance in vegetation 20 – 30 years since last burnt (Bradshaw *et al.* 2007; Everaardt 2003). Our results were very similar, with low abundance in recently burnt sites (< 7 YSLF), followed by an increase in abundance as time since fire increased (Valentine *et al.* 2009b). However, in the *Banksia* woodland on the GGS we also noticed lower abundances in sites that have remained unburnt for a very long time (> 36 YSLB). Honey possums are dependent on nectar and pollen, particularly from plants of the Proteaceae, Myrtaceae and Epacridaceae

families (Wooller *et al.* 1984). Capture rates of honey possums are closely linked to food sources (Bradshaw *et al.* 2007) and have been correlated with the densities of flowers and the flowering periods of *Banksias* (Everaardt 2003). Hence, the impact of fire on honey possums will be related to the post-fire responses of target food species (Bradshaw *et al.* 2007).

Historically the Honey possum was considered uncommon on the northern SCP and the Western Australian Museum 1977-78 survey only recorded one specimen at Burns Beach. This species has been recorded in other fauna surveys undertaken by consultants on the GGS since the WAM 1977-78 survey (Ecologia Environmental Consultants 1997). Honey possums are highly susceptible to habitat loss from both land clearing and dieback disease (*Phytophthora cinnamomi*), predation by cats, inappropriate fire regimes and food source restrictions caused by lowered groundwater affecting flowering capacity of vegetation (Phillips *et al.* 2004).



**Figure 11. Successional responses of *Mus musculus* and *Tarsipes rostratus* in *Banksia* woodland (using relative abundance estimates) to time since fire.**

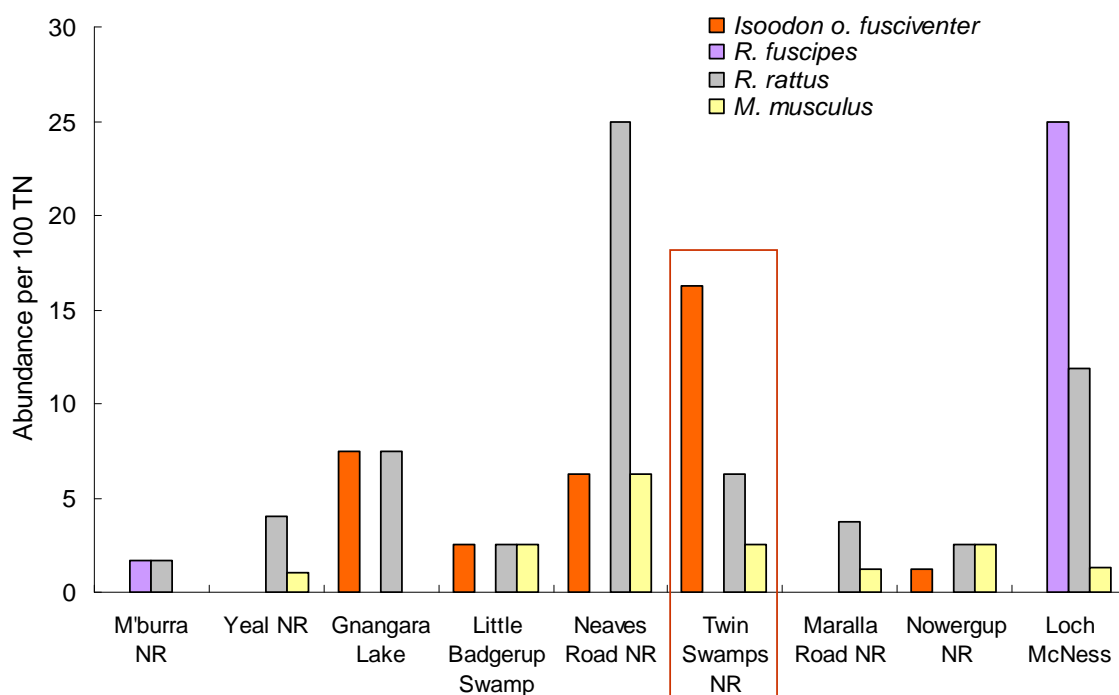


Figure 12. Abundance of four mammal species at sites targeted for trapping quenda. The abundance of quenda was highest at Twin Swamps Nature Reserve, which is fenced and baited to reduce predators. (M'burra NR = Muckenburra Nature Reserve).

The number of *H. chrysogaster* Rakali trapped at Lake Gooellal and Loch McNess, with minimal survey effort was surprising, indicating that these two lakes support reasonable populations of this species. The survival of Rakali is critically linked to the persistence of wetland eco-systems. Loch McNess has a history of frequent (and recent) fires. It has a low numbers of islands that could provide refugia habitat for water rats. This may result in Rakali utilising the banks more and being subjected to impacts from fires.

On the northern SCP Rakali are restricted to the lakes and water bodies of the Spearwood system as most water bodies on the Bassendean dune system are ephemeral. Rakali are highly susceptible to loss of habitat through the contraction and drying out of lakes either through filling and draining for alternative land use, decreasing rainfall/drying climate and hydrological groundwater changes. Rakali are also susceptible to water quality degradation and predation by foxes and cats. Loss or reduction in size and quality of wetland areas would also affect the food resource for rakali, as they feed on large aquatic insects, fishes, crustaceans, mussels, frogs, lizards, water birds and tortoises etc (Olsen 2008; Woollard *et al.* 1978).

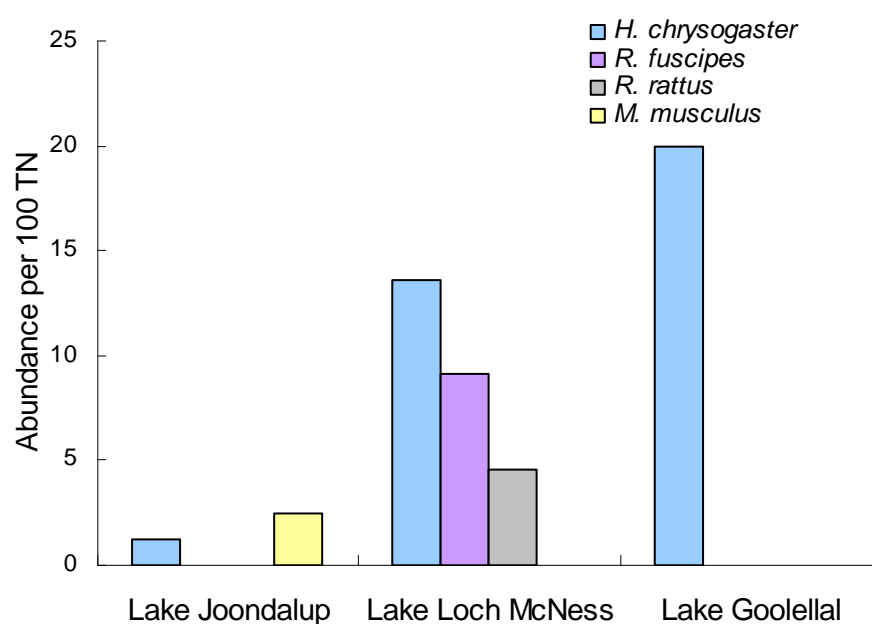


Figure 13. Abundance of three mammal species at sites targeted for trapping Rakali. The abundance of Rakali was highest at Lake Goolellal.

Valentine *et al.* (2009b) found the mootit or bush rat were only located in wetland habitat. The northern SCP is approaching the northern limit of their distribution. Three other sub-species are widespread in eastern and southern Australia and the species as a whole is considered common in abundance. On the northern SCP bush rats appear to prefer mesic environments providing dense understorey and ground cover. This appears consistent throughout all fauna studies that have been undertaken on the northern SCP. Prior to the WAM 1977-78 survey there had only been one specimen collected on the northern SCP, from Yanchep in 1975. In the 1977-78 survey they were again only trapped near Loch McNess in Yanchep National Park. In 2007 Turpin trapped bush rats in thickets of wetland-associated *Lepidoserma gladiatum* in the coastal dune swales west of Yanchep National Park (pers. comm. to Brent Johnson, 2008). These results indicate a preference for near-coastal habitats. This area, along the linear coastal strip (Quindalup Dunes), is largely proposed for urban development and is not considered a long term viable fauna habitat. Threats to this species include habitat loss, fragmentation, predation and inappropriate fire regimes (Lunney 2008).

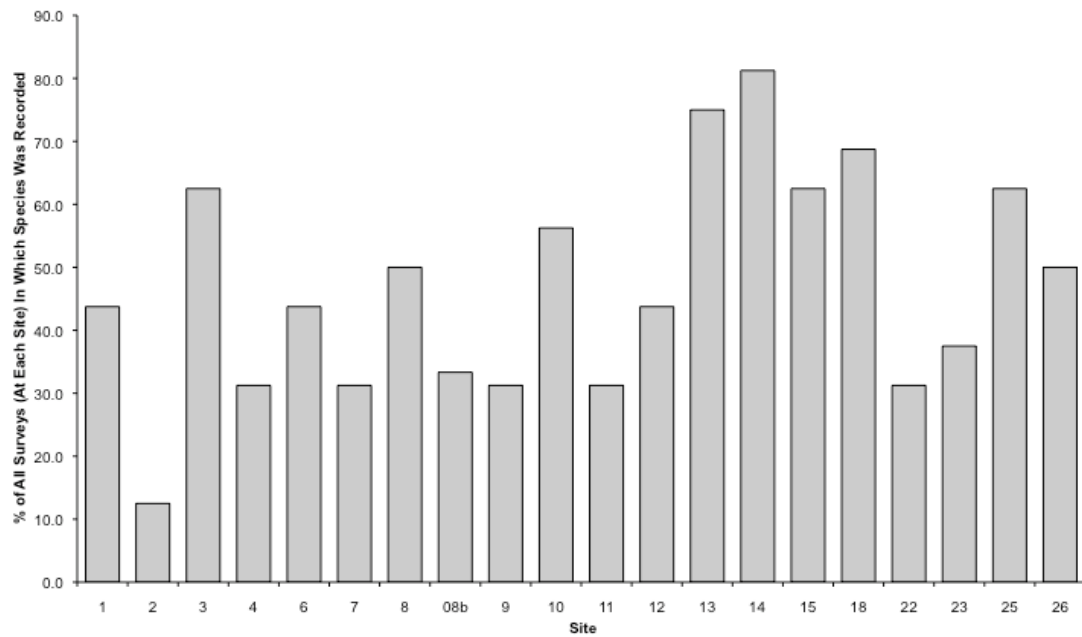


Southern brown bandicoot or quenda (*Isoodon obesulus*) were typically found in moist low-lying areas with dense mid-storey vegetation (Valentine *et al.* 2009b). Similarly, studies at Whiteman Park have indicated that quenda are persisting in the dense mid-storey level heath associated with wetlands (Bamford and Bamford 1994). When fox baiting was introduced at Whiteman Park, quenda both increased in number and began using upland areas as the threat of predation diminished (Bamford and Bamford 1994). Valentine *et al.* (2009b) found quenda were 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. In other parts of their range where baiting occurs, such as the jarrah forest on the Darling Scarp, quenda inhabit a variety of habitats including open woodland and upland areas. It is thought Quenda may be favouring the dense wetland-associated vegetation habitat type to a greater extent because of the presence of foxes. 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.

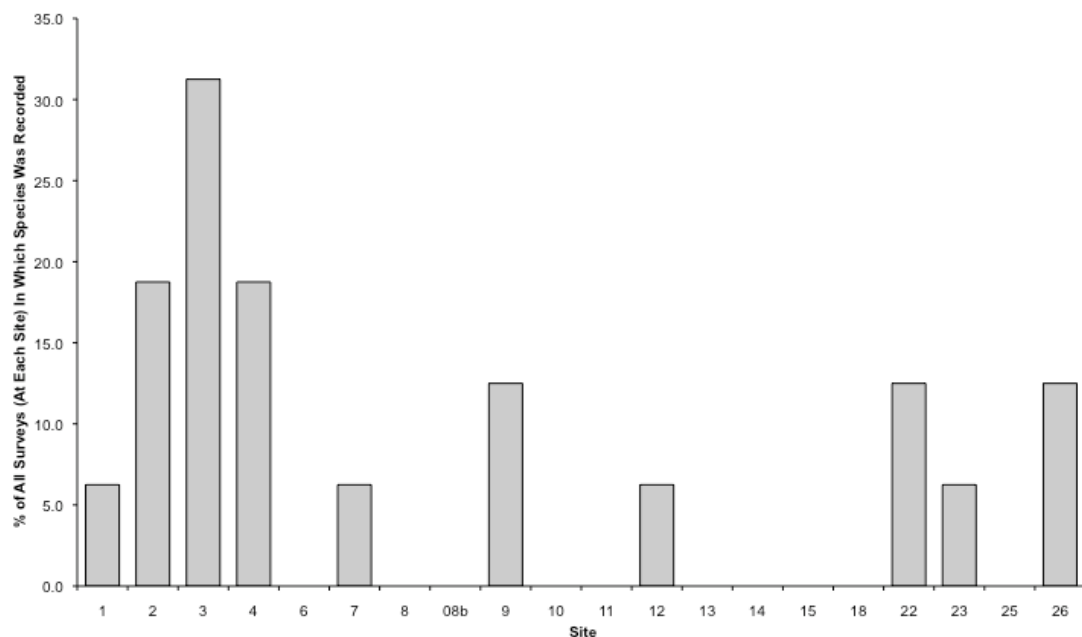
### ***Impact of fire on avifaunal communities (Davis 2009a)***

On the GGS bird density and species richness were highly variable across the 20 fire ages which ranged from one to 26 YSLF. There was no obviously discernable trend between fire age and bird density, with the highest bird densities occurring 9, 23 and 25 years post-burn and the lowest bird densities 2, 10 and 18 years post-burn. Species richness was less variable and was also highest at 9, 23 and 25 years post-burn and lowest at 2, 6 and 10 years post-burn.

Most species did not show any clear trend in terms of occurrence in relation to fire age, although Splendid Fairy-wrens (*Malurus splendens*) were more frequently recorded in longer unburnt areas (Figure 14) and Yellow-rumped Thornbills (*Acanthiza chrysorrhoa*) were more commonly observed in more recently burnt areas (Figure 15).



**Figure 14. Relative occurrence (number of surveys in which the species was recorded) for Splendid Fairy-wrens (*Malurus splendens*).**



**Figure 15. Relative occurrence (number of surveys in which the species was recorded) for Yellow-rumped Thornbills (*Acanthiza chrysorrhoa*).**

Studies have found that bird species richness is usually highest in long-term unburnt vegetation (15 years post-burn) but is also high for several years following a fire (Burbidge 2003). Species diversity can also increase and be higher in burnt areas for up to 3 years post-burn (Christensen *et al.* 1985). Although these results were not clearly reflected in this study, the highest mean density and total species richness occurred at the longest unburnt

sites (23 and 25 years post-fire). However, overall there was only a weak positive relationship between density, richness and time since fire.

Although time since fire was not significantly related to changes in species richness or density these measures were strongly correlated with the floral richness of sites and it is likely that the primary impacts of fire are likely to be on the structure and composition of vegetation at sites and this will in turn affect avifauna.

### ***Impact of fire on food availability for Carnaby's Cockatoo on the GGS (Valentine 2010)***

Carnaby's Black-Cockatoo is an endangered species, with less than 50% of the original population remaining (Garnett and Crowley 2000). A major threatening process includes habitat fragmentation and the removal of critical feeding resources (Cale 2003). The GSS study area is an important foraging area during the non-breeding season for Carnaby's Black-Cockatoo with both native *Banksia* woodlands and pine plantations recognised as important food resource (Perry 1948; Saunders 1974; 1980). Indeed, the GSS region has been identified by Birds Australia as one of Australia's 314 Important Bird Areas (IBA), primarily due to the regions known significance for providing foraging habitat for Carnaby's black-cockatoo (Dutson *et al.* 2009).

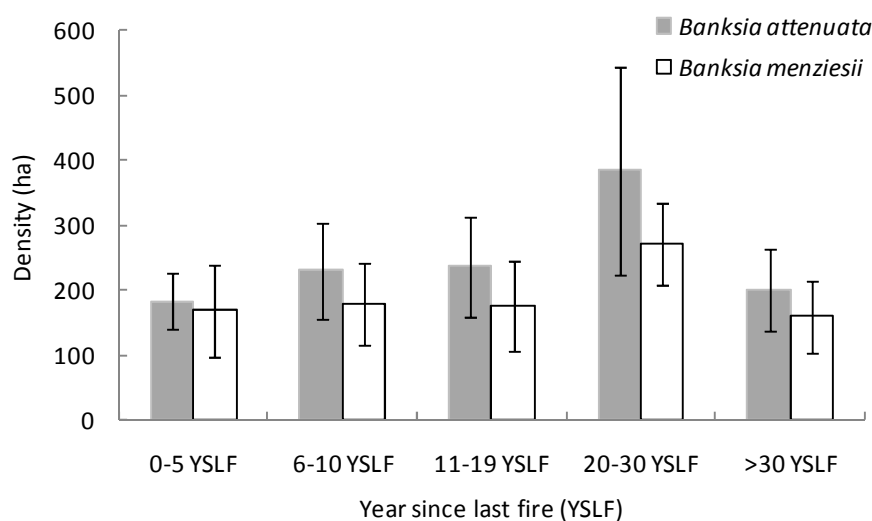
Although Carnaby's black-cockatoo traditionally forage upon mostly proteaceous plants, an expanding urban population and agricultural development has resulted in the removal of large sections of native vegetation. There has been a major shift in dietary composition from a traditional diet of mostly native seeds and nectar to seeds of pine from plantations (Higgins 1999; Saunders 1980)). The pine plantations in the GSS study area limit ground water recharge and will be harvested without replacement over the next 18 years (Government of Western Australia 2009b). The expected clear fall without replacement will potentially lead to a shortage of food for Carnaby's black-cockatoo (Cale 2003) (Garnett and Crowley 2000). Of the native feeding records on the Swan Coastal Plain, *Banksia* species accounted for nearly 50%, with the majority of records from the slender *Banksia*, *Banksia attenuata* (Shah 2006). This species, and the co-dominant *Banksia menziesii* are considered essential native food sources (Shah 2006).

Preliminary surveys of the food availability of banksias woodlands in remnant vegetation in the GSS indicated that food resources varied depending on a number of factors, including fire history (Valentine and Stock 2008). Given that fire is a common occurrence within the GSS study area, and one of the main tools available to land managers, understanding the changes in food availability with time since fire is potentially important for conserving food resources for Carnaby's black-cockatoo. The responses of *Banksia attenuata* and *B. menziesii* to fire are still largely unknown. This project measured a number of variables (including tree density, proportion of populations producing cones and the number of unopened cones per tree) of *Banksia attenuata* and *B. menziesii* in a range of Banksia woodland habitat varying in time since last fire (Valentine 2010). This information was then combined with the field metabolic requirements of Carnaby's black-cockatoo and the energetic values of *Banksia* cones (using Cooper *et al.* 2002) to derive estimates of the maximum number of Carnaby's black-cockatoos that could be supported by 1ha of habitat for 1 day (with the food resources of this habitat being depleted after this day, assuming that the return of the food sources will take one year).

The 39 sites surveyed were spread throughout the GSS banksias woodlands in a range of time since fire habitat. Sites were grouped into the following time since fire categories: 0-5 YSLF (9 replicates), 6-10 YSLF (10 replicates), 11-19 YSLF (12 replicate), 20-29 YSLF (4 replicates) and  $\geq 30$  YSLF (4 replicates). Due to the difficulty of finding older time-since last fire sites, the number of replicates within each category varies. In this report, we present some of the preliminary findings, for more detailed information refer to (Valentine 2010).

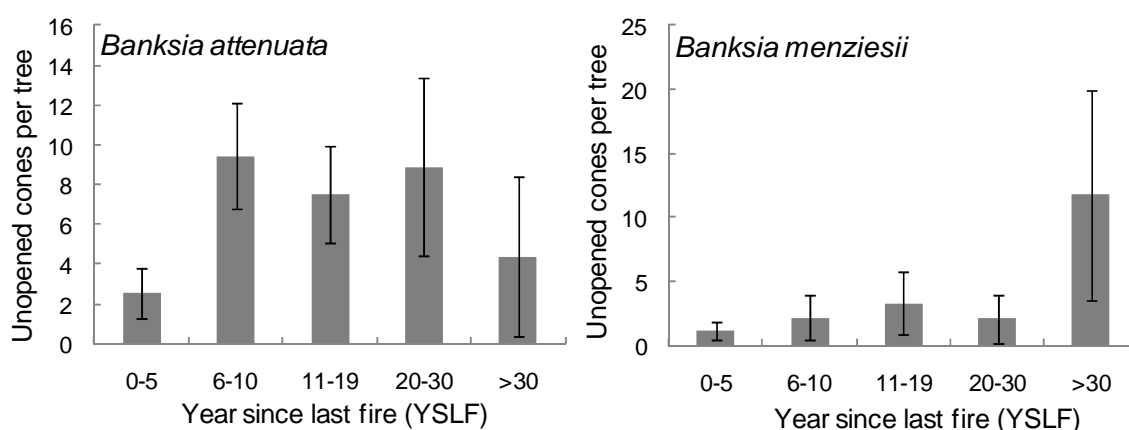
The density of *B. attenuata* was typically greater than that of *B. menziesii* in all sites however the density of both banksias did not vary significantly between fire-age categories, although there is a very slight tendency for higher density of plants in the 20-30 YSLF (Figure 16). The number of unopened cones per tree represents the standing crop of available food resources for Carnaby's black-cockatoo, and varied among fire age categories depending on the Banksia species. For *B. attenuata* there was a significant difference in the number of unopened cones per tree in different fire-age categories, with the highest number of unopened cones observed in the 6-10, 11-19 and 20-30 YSLF categories (Figure 17). For *B. menziesii* the number of unopened cones per tree was low in

all of the fire-age categories, with the exception of the  $\geq 30$  YSLF fire-age category (Figure 17).



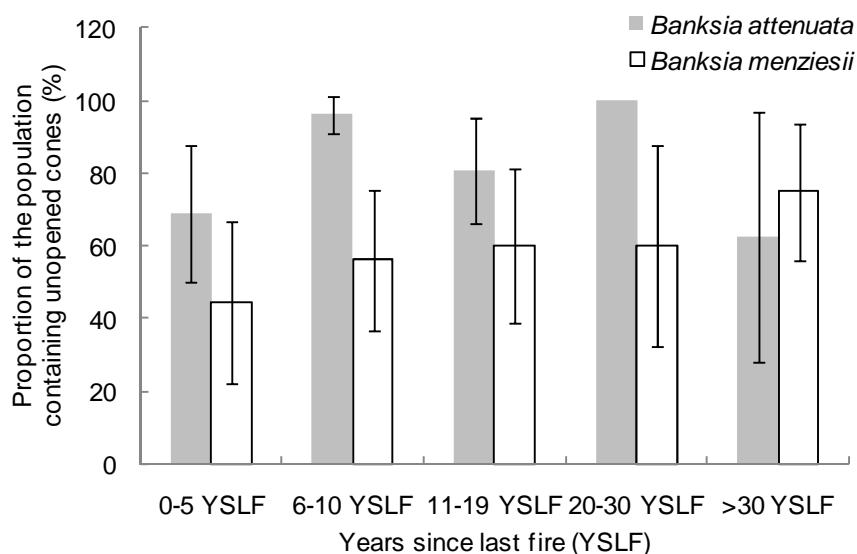
**Figure 16. Density (plants/ha  $\pm$  95%CI) of *B. attenuata* and *B. menziesii* among different time-since-last fire categories. No difference in density was detected.**

For *B. attenuata* there was a significant difference in the number of unopened cones per tree in different fire-age categories (Figure 17). The highest number of cones is observed in the 6-10, 11-19 and 20-30 categories. For *B. menziesii* there was a significant difference in the number of cones per tree in different fire-age categories with the highest number of cones is observed in the  $\geq 30$  fire-age category (although this data is variable) (Figure 17).



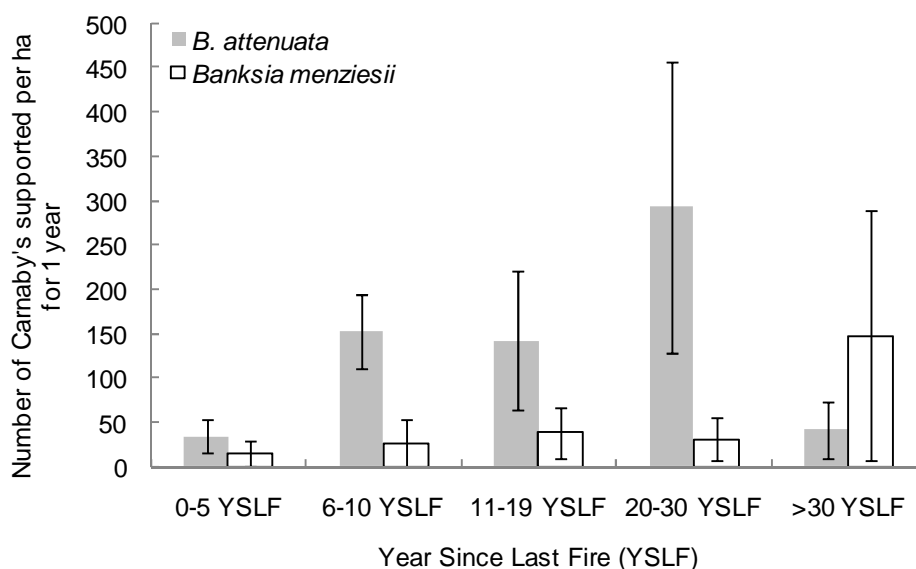
**Figure 17. The number ( $\pm$  95%CI) of unopened cones per tree for *B. attenuata* and *B. menziesii* in different time-since-last-fire categories.**

The proportion of *B. attenuata* trees containing unopened cones was greatest in the 6-10 YSLF and 20-30 YSLF categories (note that at the 4 sites in the 20-30 category, all trees surveyed contained unopened cones (Figure 18). However, for *B. menziesii* there was no significant difference in the proportion of trees containing unopened cones. The trend observed was for more trees in the  $\geq 30$  YSLF category to contain more unopened cones (Figure 18).



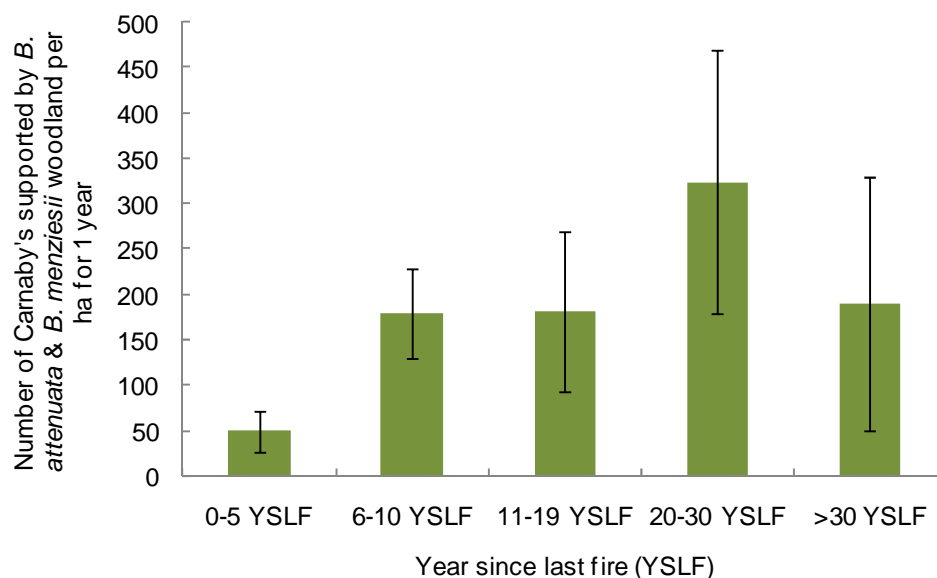
**Figure 18. Proportion of trees containing unopened cones for *B. attenuata* and *B. menziesii* in different fire-age categories**

By combining the data collected on *Banksia* productivity with data on the metabolic requirements of Carnaby's black-cockatoos (Cooper et al 2002), it is possible to estimate how many Carnaby's black-cockatoos could be supported in one ha of different time-since-fire habitat for one day. The number of Carnaby's black-cockatoos that could be supported varied between *Banksia* species and among the fire-age categories. Significantly higher numbers of Carnaby's black-cockatoo could be supported in the 6-10 YSLF, 11-19 YSLF and the 20-29 YSLF categories (Figure 19). Only a few (< 50) Carnaby's black-cockatoo could be supported in the youngest (0-5 YSLF) and the oldest (> 30 YSLF) fire-age categories. For *B. menziesii*, all fire-age categories supported < 50 Carnaby's black-cockatoos, with the exception of the >30 YSLF category, which could support on average 150 Carnaby's black-cockatoos, although this was variable among replicates (Figure 19).



**Figure 19. Number of Carnaby's ( $\pm$  95%CI) 1 ha of *B. attenuata* and *B. menziesii* could support for one day.**

By combining the two species, we can estimate the average number of Carnaby's black-cockatoos that are supported by both *Banksia* woodlands in the GSS in different fire-age categories (Figure 20). The 0-5 YSLF category supports the lowest number of Carnaby's black-cockatoos, with < 50 birds supported on average. The 6-10 YSLF, 11-19 YSLF and > 30 YSLF support on average ~ 175 Carnaby's black-cockatoos. The highest number of Carnaby's black-cockatoos that could be supported was observed in the 20-30 YSLF category, with an average of ~ 300 birds supported per ha (Figure 20). 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.



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

## Fauna Attributes Summary: for development of ecological fire regimes

Fire regimes can also be based on the vital attributes of vertebrate fauna (e.g. honey possum, quokka and quenda) (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 also a need to gain data and information on fauna life histories and habitat requirements, timed fire responses, habitat requirements linked to post-fire habitat changes (e.g. litter, understorey structure, cover, resources-seeds) and the spatial habitat distribution of species.

One useful approach is to categorise species responses in relationship to their changes in 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. More detailed response categories could include species that do not change in abundance after fire (Type 1), species that increase after fire by either moving into burnt areas or increasing in abundance (Type 2), species that exhibit an initial decline following fire and then increase to levels above pre-fire abundance (Type 3), species that show a long-term decline or extinction following fire (Type 4) and species



that decline immediately post-fire and do not recover for very long periods (Type 5). Fire response curves can be assigned for species where information is available, and in some instances estimated relative abundances will be possible.

Key Fire Response fauna species identified for the GGS are shown in Table 6. They were based on conservation status and data on the relationships to successional ages and response curves obtained from GSS field studies (Swinburn *et al.* 2009; Valentine *et al.* 2009b). It should be noted that the preferred ages for fauna were based on a study where the site ages surveyed did not include between 11 and 16 years. Thus more precise or accurate ages could not be estimated (Table 6).

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                    | Endim. ‡ | Cons status † | Preferred Fire Age <sup>∞</sup> | Meth. <sup>◇</sup> | Comments  |
|----------------------------------|---|--------------------------------|----------|---------------|---------------------------------|--------------------|---|
| <b>Invertebrates</b>             | <i>Synemon gratiosa</i>                   | Graceful sun moth              | LE       | E             | unknown                         |                    | Preference for <i>Lomandra</i> species; breed on grasses, sedges and rushes. Limited dispersal ability therefore lose food source after fire and become locally extinct. (DEWHA 2008) |
| <b>Amphibians</b>                | <i>Crinia insignifera</i>                 | 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)   |
| <b>Reptiles</b>                  | <i>Pseudemydura umbrina</i>               | 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)                                   |
|                                  | <i>Rankinia adelaidensis adelaidensis</i> | western heath dragon           | LE       |               | <11 YSLB                        | 1,3                | Significant preference for Banksia woodland   |
|                                  | <i>Aprasia repens</i>                     | sandplain worm lizard          | RE       |               | >16 YSLB                        | 3                  |   |
|                                  | <i>Delma concinna concinna</i>            | west coast javelin lizard      | LE       |               | <11 YSLB                        | 2                  |   |
|                                  | <i>Demansia psammophis reticulata</i>     | yellow-faced whip snake        | RE       |               | >16 YSLB                        | 2                  |   |
|                                  | <i>Lerista elegans</i>                    | west coast four-toed lerista   | WA       |               | >16 YSLB                        | 1, 3               |   |
|                                  | <i>Menetia greyii</i>                     | common dwarf skink             | AUS      |               | >16 YSLB                        | 1*, 3              |   |
|                                  | <i>Morethia obscura</i>                   | southern pale-flecked morethia | AUS      |               | >16 YSLB                        | 1**                |   |
|                                  | <i>Neelaps calonotos</i>                  | black-striped snake            | LE       | P3            | >16 YSLB                        | 2                  |   |
|                                  | <i>Pletholax gracilis gracilis</i>        | keeled legless lizard          | LE       |               | unknown                         |                    |   |
|                                  | <i>Tiliqua occipitalis</i>                | western bluetongue             | AUS      |               | >16 YSLB                        | 4                  |   |
| <i>Tiliqua rugosa</i>            | bobtail                                   | AUS                            |          | >16 YSLB      | 4                               |                    |   |
| <b>Overall Reptile abundance</b> |   |                                |          |               | >16 YSLB                        | 1**                |   |

|                | Species                            | Common Name              | Endim.‡ | Cons status† | Preferred Fire Age <sup>∞</sup> | Meth.◇ | Comments   |
|----------------|------------------------------------|--------------------------|---------|--------------|---------------------------------|--------|--|
| <b>Birds</b>   | <i>Calyptorhynchus latirostris</i> | 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)  |
|                | <i>Acanthiza chrysorrhoa</i>       | Yellow-rumped Thornbills | AUS     |              | Recently burnt                  | 7      | Species declining (Bleby <i>et al.</i> 2009b)  |
|                | <i>Malurus splendens</i>           | Splendid Fairy-wrens     | AUS     |              | Long unburnt                    | 7      | Nest placement in favoured plant, <i>Xanthorrhoea preissii</i> , increases with time since fire (Bleby <i>et al.</i> 2009a), Species declining (Bleby <i>et al.</i> 2009b) |
| <b>Mammals</b> | <i>Tarsipes rostratus</i>          | Honey Possum             | RE      |              | 20-26 YSLB                      | 1      | Known to return to burnt areas 2-4 years after fire (Everaardt 2003).  |
|                | <i>Isoodon obesulus</i>            | Quenda or Bandicoot      | WA      | P5           | unknown                         |        | Dense mid-storey level heath associated with wetlands. Increase in numbers where foxes are baited  |
|                | <i>Hydromys chrysogaster</i>       | Rakali or Water rat      | AUS     | P4           | unknown                         |        | Reliant of permanent wetlands.   |
|                | <i>Rattus fuscipes</i>             | Bush rat                 | AUS     |              | unknown                         |        |  |
|                | <i>Mus musculus</i>                | House mouse              | I       |              | <7years                         | 1**    |  |

‡ Endemism within Australia (at the taxa level) for each species: GSS (restricted 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 parameters and growth stages

Another approach to determine fire regimes involves identification of habitat parameters associated with the different post fire stages of different vegetation types that are important for individual species (MacHunter *et al.* 2009; McElhinny *et al.* 2006). Habitat parameters (such as % cover of understorey, canopy, litter, open ground, coarse woody debris, trees – various diameters at breast height, shrub composition etc.) can be linked with post fire stages and estimated fauna fire response curves. The Department of Sustainability & Environment (Victoria), is developing methods to use growth stages, in preference to age class distributions, and the known or predicted relationships between fauna and habitat growth stages (G. Friend *pers. comm.*). The relationship with growth stages is likely to be more precise than the relationship with age classes as there is often variability in habitat factors within categories of age class (YSLF) due to factors such as season of burn, type of fire (wildfire, prescribed burn), and post fire recovery conditions such as rainfall. The rate of recovery of vegetation and habitat parameters not time *per se* has been shown to be most important in the successional process for mammals (Fox and Monamy 2007; Monamy and Fox 2000). The aim of these approaches is thus to optimise these seral or growth stages so that species requirements are met and there is no loss of species due to absence of suitable seral or growth stages.

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 fire regimes for fauna should also be incorporated. This is particularly important with regards to factors such as patch size, connectivity between patches and the home ranges and dispersal capabilities of taxa.

## Impact of fire on wetlands on GGS

Wetland soils and sediments are becoming more vulnerable to fire on the Swan Coastal Plain due to summer drying of surface sediments, which is affected by recent changes in climate, declining rainfall, increased use of groundwater by an increasing urban population, clearing of bushland, silviculture and horticulture, urban development (Horwitz *et al.* 2003; Horwitz and Smith 2005; Horwitz and Sommer 2005). Wetlands exposed to fire can result in the loss of organic matter and other chemical and physical changes (Horwitz and Sommer 2005). Semeniuk and Semeniuk (2005) consider that along with the hydrology of a wetland, the potential for soils and sediments to combust is related to annual fluctuations in the water table, the longer term climatic patterns and the distribution of flammable material within a wetland.

Comparatively little has been published on the effects of fires on wetlands, aquatic biota and water quality per se. Many plants and animals found in wetlands either require fire as part of their life history strategy, or can avoid, behaviourally or physiologically, the effects of fire. Other wetland biota cannot survive the direct effects of fire, and that such species are likely to be found in permanently wetter parts of the landscape where they have been able to evade fires over long periods of time (in ‘refuges’) (Horwitz *et al.* 2003; Horwitz *et al.* 2009).

The potential consequences of fire on wetlands and water quality have been categorised in terms of interrelated effects and all have trophic consequences, particularly when considered together with the direct effects of the fire on wetland biota (Horwitz and Sommer 2005; Horwitz *et al.* 2009).

- *Catchment effects* due to runoff and deposition, can result in short-term changes such as increased base cations, alkalinity, nutrient, sediments, and groundwater recharge.
- *Atmospheric effects* mostly short term, include rain of dissolved volatilised reactive and particulate compounds that have mild acidifying and/or fertilising effect.
- *Rehydration of burnt or overheated (organic) soils* a) alkaline consequences where ash can fertilise and increase productivity in the short term, or b) acidic consequences where acid sulfate soils are oxidized producing acidification.
- *Fire suppression* activities have different effects depending on the particular method.

- *Water movement* (taking water from or dumping it into a wetland) can inappropriately translocate species, disturb acid sulfate soils.

Increased frequency of controlled burns as proposed to enhance water yield on the GGS (Canci 2005; Yesertener 2007) must be evaluated in terms of the likely consequences for wetland ecology. For instance, there may also be a loss of heterogeneity in vegetation as species that are intolerant of frequent fire are gradually lost and age class structures change to reflect predominately early post-fire regeneration stages. This may drive the system to become more grassy and flammable. Burning around wetlands more often may increase the likelihood of fire entering wetland sediments, particularly if they are in a relatively dry state.

### **Wetland biodiversity: flora and fauna on GGS**

A range of wetland biodiversity is likely to be significantly impacted by inappropriate fire regimes. Vegetation at risk includes major complexes 1. *Typha-Baumea*, 2. *Melaleuca raphiophylla*, 3. *Melaleuca preissiana*, 4. *Melaleuca viminea*, 5. *Eucalyptus rudis*, 6. *Juncus kraussi*, 7. *Lepidosperma longitudinale*, 8. *Casuarina obesa* (Horwitz et al. 2009). Seven threatened ecological communities in the GSS study area that are considered to be wetland communities are also at risk, including:

- *Banksia attenuata* woodland over species-rich dense shrubland (community type 20a as described by (Gibson *et al.* 1994a)
- Aquatic root mat community of caves of Swan Coastal Plain (Yanchep Caves)
- Communities of tumulus springs (organic mound springs, Swan Coastal Plain)
- Woodlands over sedgeland in Holocene dune swales of the southern Swan Coastal Plain (community type 19b as described by (Gibson *et al.* 1994a)
- Herb rich saline shrublands in clay pans (community type 7 as described by Gibson *et al.* 1994)
- Forests and woodlands of deep seasonal wetlands of Swan Coastal Plain (community type 15 as described by Gibson *et al.* 1994)
- Perth to Gingin Ironstone Association (Northern Ironstones).

Aquatic invertebrates are at high risk from fire impacts. Studies of aquatic invertebrate taxa recorded from wetlands on the Gnangara groundwater system (Horwitz *et al.* 2009) has revealed a surprisingly high richness considering the comparatively small survey area and the degree of anthropogenic alteration of the plain. Rare and endemic invertebrate taxa are generally associated with rare wetland types such as cave streams and mound springs which provide a unique wetland environment with characteristic stygofaunal assemblages distinguishable from the unconfined aquifer (Sommer *et al.* 2008).

(Horwitz *et al.* 2009) identified high priority wetlands with ‘significant’ invertebrate fauna (in terms of aquatic invertebrate richness, endemism and/or rarity) (see Table 7). They include:

- aquatic habitats in cave systems in karstic areas around Yanchep
- permanent deeper surface waters in northern linear chain wetlands of the Spearwood interdunal system
- tumulus springs (organic mound springs) in the Ellen Brook region of the eastern Gnangara groundwater system
- surface waters in the Ellen Brook region of the eastern Gnangara groundwater system
- habitat complexes in large shallow wetland systems on the interface between Bassendean dune and Pinjarra Plain systems.

**Table 7. High priority wetlands on the Gnangara groundwater system in terms of richness, endemism or rarity criteria for aquatic invertebrate records. Wetlands are ordered from north to south. (adapted from Horwitz *et al.* in press).**

| High priority wetland   | Richness <sup>1</sup> | Endemism <sup>2</sup> | Rarity <sup>3</sup> | Wetland habitat descriptors  |
|---|-----------------------|-----------------------|---------------------|--|
| Yanchep Caves   |                       | LE                    | X                   | Underground karstic stream, root mat fauna   |
| Loch McNess   | X                     | RE                    |                     | Permanent lake, spring, karstic system, diverse littoral vegetation communities, low conductivity, low colour and low turbidity  |
| Lake Yonderup   | X                     |                       |                     | Permanent lake, karstic system, unconsolidated and consolidated organic soils, low conductivity, low colour and low turbidity  |
| Lake Nowergup   | X                     |                       |                     | Deep, permanent lake, Spearwood sands, diverse littoral vegetation communities, unconsolidated and consolidated organic sediment, low conductivity, low colour and low turbidity   |
| Lake Jandabup   | X                     | RE                    |                     | Semi permanent, weakly-coloured water, a mix of diatomaceous-organic sediment and leached Bassendean dune sands, relatively shallow, with a variable drying regime but mostly with complex littoral vegetation communities that are seasonally inundated |
| Twin Swamps   | X                     | RE                    | X                   | Discrete bodies of shallow seasonal surface water influenced by both the clays of the Pinjarra Plains (Guildford) and sands of the Bassendean dunes, with associated complex littoral vegetation communities and darkly stained water                    |
| Muchea/Peter's Spring, Kings Spring, Bullsbrook Channel, Edgerton Spring, Edgecombe Lake, Nursery Dam |                       | LE, RE                | X                   | Mound spring, or small (created) depression fed by spring  |
| Ellenbrook Nature Reserve   |                       | RE                    | X                   | Shallow seasonal clay-based wetland fed by surface run-off on Pinjarra Plain, with littoral vegetation   |

<sup>1</sup> Richness – more than 100 species and/or 65 Families shown with 'X'

<sup>2</sup> Endemism – wetlands with known local endemic species (LE; restricted to the Swan Coastal Plain bioregion) or with greater than 20% regional endemics (RE; restricted to the South-west Australian Floristic Region)

<sup>3</sup> Rarity – wetlands with more than 25% rare taxa shown with 'X'



A range of vertebrate fauna that occur in wetland habitats are at risk from inappropriate fire regimes. The water rat, or rakali, (*Hydromys chrysogaster*), requires permanent water for at least part of the year, dispersing to seasonal wetlands when conditions are suitable (Froend *et al.* 2004). Bamford and Bamford (2003) regarded wetlands and their margins to be a significantly productive habitat for the chuditch (*Dasyuris geoffroii*). They also referred to the preference of the southern brown bandicoot, or quenda, (*Isodon obesulus*) for denser vegetation and association with wetland habitats. The quenda and rakali are both listed as Priority 4 species by the Department of Environment and Conservation.

Storey *et al.* (1993) recorded 79 species of waterbirds on the Swan Coastal Plain. A list of 172 bird species (including about 15% land birds or vagrants) that have been observed or that are expected to make regular use of the area encompassed by the Gnangara groundwater system has been compiled by Bamford and Bamford (2003).

Five reptile species are associated with dense vegetation and seasonally damp soils around wetlands (Bamford and Bamford 2003). The western swamp tortoise (*Pseudemydura umbrina*) in particular is threatened by inappropriate fire regimes. It is listed nationally under the EPBC Act 1999 as critically endangered and in Western Australia is listed under the *Wildlife Conservation Act 1950* as rare or likely to become extinct. Internationally, the western swamp tortoise is listed as critically endangered on the 2008 *IUCN Red list of threatened species* as well as being listed under Family Chelidae of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Burbidge and Kuchling 2007). Only one viable population survives at Ellen Brook Nature Reserve with two other locations, Twin Swamps and Mogumber Reserve populations being maintained with translocated individuals (Burbidge and Kuchling 2007).

Because of their biology, frogs are likely to be sensitive to changes in landscape hydrology and the impacts of fire on wetlands. In 2009 field studies based on aural surveys of calling males were undertaken by the GSS at sixty-two sites at the main wetland types in the GGS: lakes (n=11), palusplains (n=14), sumplands (n=33) and watercourses (n=4) (Bamford and Huang 2009). Of the 13 frog species known from the area, nine species were recorded: *Crinia georgiana*, *Crinia glauerti*, *Crinia insignifera*, *Heleioporus eyrei*, *Limnodynastes dorsalis*, *Litoria adelaidensis*, *Litoria moorei*, *Myobatrachus gouldii*, and *Pseudophryne guentheri*. Two species sensitive to hydrological change (*C. glauerti* and

*C. insignifera*) were considered likely to decline rapidly due to reliance on small, shallow wetlands and near-annual recruitment (Bamford and Huang 2009; Huang 2009). One species (*P. guentheri*) was assessed as very sensitive to hydrological change due to a specific and inflexible breeding biology that relies on early winter rains and very shallow wetlands

## Resilience

Disturbances such as fire disrupt community structure by changing, temporarily or permanently, factors such as the availability of substrates and resources. They also alter the physical environment, including factors such as temperature and climate. There has been a focus on how communities exhibit resistance and resilience to disturbances, and their capacity for restoration (Scheffer *et al.* 2001; Walker *et al.* 2002). The ability of the biotic components of an ecosystem to withstand disturbances depends on the resilience and resistance of the system. *Resistance* can be defined as the capacity of the system to withstand change in structure and function. *Resilience* represents the capacity of a system damaged by disturbance to restore structure and function once the disturbance is removed (Carpenter *et al.* 2001; Peterson *et al.* 1998). The process involves the degree, manner and pace of restoration with some systems possessing the capacity to return to their prior state (Westman 1986).

While ecological phenomena normally vary within bounded ranges, rapid, nonlinear changes can be triggered by even small differences if threshold values are exceeded. It is important to understand and anticipate nonlinear responses and ecological thresholds because the outcomes of classical models commonly described in the literature, such as ‘Clementsian’ succession, may differ significantly for these situations. Models to describe such changes have been developed and are described as state-transition models. The main features of these models are the identification of alternative ‘states’ of the systems (vegetation complexes) that remain the same or change slowly, and a set of ‘transitions’ that can occur between states. In addition, certain ‘thresholds’ of environmental factors are essential for the states. If an ecosystem which has degraded has not crossed certain thresholds, transition back to the original state is possible; but if it has crossed certain

thresholds, transition back to the original state will not occur without management intervention.

In this project we do not have an understanding of the resilience and resistance of communities in the Gnangara groundwater system to disturbances such as inappropriate fire regimes. For example how resilient would vegetation and fauna communities and species be if a fire interval of < 6 years was implemented on the GGS for an extensive period of time. Further what level of fire frequency or intervals would approach or pass an ecological ‘threshold’ on the GGS that would degrade the system thus leading to loss of function or structure.

Measuring resilience is however difficult because it entails measuring the ability of the ecosystem to have disturbance and change without loss of function or structure. State and transition models are considered likely to improve our understanding of the groundwater-dependent vegetation communities of the Gnangara groundwater system mound (Pettit *et al.* 2007) and, subsequently adaptive management for these communities. The *Gnangara ecohydrological study* (Sommer and Froend 2009) is currently investigating models and applications for groundwater-dependent vegetation communities. This work may provide the basis for developing similar models for the potential for degradation or non linear transition states in relationship to fire regimes.

## **Interaction of fire impacts with other threats on GGS**

### **Climate change and fire regimes**

Wildfire is a global issue, and the key factors involved – climate/weather, fuels, ignition agents and people – will continue to change as they respond to global changes in climate (Flannigan *et al.* 2009). Climatic changes, in terms of increased temperatures, declining rainfall and longer drought periods, are expected to interact with fire primarily through an increase in fire-weather risk, with the number of very high or extreme fire danger days projected to increase significantly in the next 100 years (Flannigan *et al.* 2009; Hennessy *et al.* 2007). Predictions are that climate change will foster a general increase in area burned and fire occurrence (however there will be some areas with no change and some areas with decreases) and longer fire seasons for temperate and boreal regions. Changes in fire

intensity and severity in the future are difficult to predict and this area needs further research. Overall, it is expected that global fire activity will continue to increase as a consequence of climate change (Flannigan *et al.* 2009).

In Australia climate change may lead to complications of future fire management and prescribed burning. A report by CSIRO predicted that if the average summer temperature increases in south-eastern 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). Changes such as these are likely to be greatest in areas such as savannas that are the most fire-prone biomes. 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. Firstly, the *Banksia* woodland of the GSS study area are generally adapted to fire (Enright *et al.* 1998). In one GSS study area species, *Banksia prionotes*, adults are killed by fire, but fire stimulates seeds to germinate. This type of life history strategy is thought to be particularly vulnerable to frequent, widespread fire events, as seed regeneration may be insufficient to replace adults lost in the fire if the canopy seed bank has not had sufficient time to recover from previous fire (Wooller *et al.* 2002). Wooller *et al.* (2002) go on to suggest this will be particularly true when fires are widespread, since *Banksias* have limited dispersal potential. In the GSS study area, there are several species that are not killed by fire, but instead resprout from the original plant, such as *B. attenuata*, *B. grandis*, *B. ilicifolia*, *B. littoralis*, *B. menziesii* (Enright *et al.* 1998). In these species adult trees can sometimes survive low to medium intensity fire due to their thick bark, and regenerate from lignotubers, which resprout following fire. Enright *et al.* (1998) suggest that too frequent fires can still result in the local extinction of these species that resprout, but at a much slower rate than species where adults are killed by fire. If climate change conditions increase the frequency of fires, regenerating species, such as *B. prionotes*, are likely to be most at risk of decline. However, if fires become extremely frequent and/or the intensity of fires occurring is severe, other species, such as resprouters, will be unlikely to recover.

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 in 1985, which was followed by a series of other minor fires, the population size of a number of bird species, including the splendid fairy wren (*Malurus splendens*), western thornbill (*Acanthiza inornata*) and scarlet robin (*Petroica multicolor*) declined (Brooker 1998). Population declines were observed for eight years after fire and resulted in temporary cessation of breeding in western thornbills (*Acanthiza inornata*) and increased nest predation and parasitism in splendid fairy wrens (*Malurus splendens*). 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 the main factor currently contributing to the decline and local extinction of mammal species on the Swan Coastal Plain (Johnson and Isaac 2009; 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 *et al.* 2009) as yet, 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 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. Milburg and Lamont (1995) documented the invasion of remnant sclerophyll woodland vegetation by exotic species after fire and found that the number of pest plant species, as well as their frequency and cover, increased after fire, whilst the abundance of native species decreased. The most abundant pest plant species are perennial grasses *Eragrostis curvula* and *Ehrharta calycina*. It has been suggested that their abundance

increases the susceptibility to fire of the vegetation community, since grasses are normally an insignificant component of sclerophyll 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).

The first evidence of *P. cinnamomi* infestation in the GSS study area was observed in *Banksia* woodlands from aerial photographs taken in the 1940s, and more than 50% of the area had been destroyed 35 years later.

Analyses of the occurrence and distribution of the pathogen on the study area in 2009 established that 20,747 ha (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). Ninety-four percent of the infested area is on the Bassendean Dune system with only minor areas on the Spearwood system and Pinjarra Plain. Remote sensing using Landsat data, capable of distinguishing *P. cinnamomi* affected areas, was employed to assess impacts on vegetation cover with time using vegetation trend analysis.

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 *et al.* 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; 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 WA (Moore 2005). The occurrence of fire also compounded the pressure on post-fire establishment of some species (Moore 2005).



## **Refugia for increasing adaptive capacity and resilience**

For many declining and priority species and communities on the GGS that are threatened by inappropriate fire regimes, access to suitable refugia may be necessary for their survival. Providing key refuge sites can buffer species from the impacts of fire regimes. This approach has also been identified as being essential as climate change progresses (Isaac *et al.* 2008). Generally there is a need to obtain a greater understanding of the microhabitat buffering potential of natural refuges and such information is lacking for most GSS species and communities. However species and communities for which refugia do now or may play a critical role in their survival include:

### ***Western Swamp Tortoise***

Only one viable natural population survives at Ellen Brook Nature Reserve with two other locations, Twin Swamps and Mogumber Reserve populations being maintained with translocated individuals (Burbidge and Kuchling 2007). The reserves are critical refugia for this species and are highly managed -they are fenced and subject to predator control and fire control.

A key factor affecting the survival of adult tortoises is finding suitable aestivation sites during the summer. Natural aestivation sites vary from site to site, from naturally occurring holes in clay, to sites under leaf litter or in fallen logs. Mortalities occur during the aestivation period from fox predation, raven attacks, rat attacks and desiccation and fire (Burbidge *et al.* 2008). Research suggests mortalities are lowest in tortoises aestivating in underground aestivation sites, both in terms of a refuge from predators and from heat and drying. Preliminary studies of the use of artificial aestivating tunnels, installed to promote underground aestivation, suggest that these can protect tortoises at least from fire, and probably also from heat and predators.

### ***Southern Brown bandicoot (Isoodon obesulus) Quenda***

On the GGS Southern Brown bandicoot (*Isoodon obesulus*) or Quenda were typically found in moist low-lying areas with dense mid-storey vegetation (Valentine *et al.* 2009b). Similarly, studies at Whiteman Park have indicated that quenda are persisting in the dense mid-storey level heath associated with wetlands (Bamford and Bamford 1994). Indeed,

when fox baiting was introduced at Whiteman Park, quenda both increased in number and began using upland areas as the threat of predation diminished (Bamford and Bamford 1994). In our study (Valentine *et al.* 2009b), quenda were 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. In other parts of their range where baiting occurs, such as the jarrah forest on the Darling Scarp, quenda inhabit a variety of habitats including open woodland and upland areas. It is considered that quenda may be favouring the dense wetland-associated vegetation habitat type to a greater extent because of the presence of foxes. Hence, the persistence of quenda in unbaited areas in the GSS study area is strongly reliant on dense wetland-associated vegetation. It is recommended that sites known to be important for quenda are protected as designated refugia from further loss or modification and frequent fire. Wetland sites are likely to be particularly high quality sites which will offer protection.

### ***Honey Possum***

Honey possums (*Tarsipes rostratus*) were more abundant in older sites, with peaks in relative abundance at sites 20 – 26 YSLF (Figure X.3; Valentine *et al.* 2009b). Although honey possums are known to return to burnt areas within 2 – 4 years since fire (Bamford 1986; Everaardt 2003; Richardson and Wooller 1991), higher densities are typically recorded in older vegetation, with peaks in abundance in vegetation 20 – 30 years since last burnt (Bradshaw *et al.* 2007; Everaardt 2003). Our results were very similar, with low abundance in recently burnt sites (< 7 YSLF), followed by an increase in abundance as time since fire increased (Valentine *et al.* 2009b). Honey possums are dependent on nectar and pollen, particularly from plants of the Proteaceae, Myrtaceae and Epacridaceae families (Wooller *et al.* 1984). Capture rates of honey possums are closely linked to food sources (Bradshaw *et al.* 2007) and have been correlated with the densities of flowers and the flowering periods of *Banksias* (Everaardt 2003). Hence, the impact of fire on honey possums will be related to the post-fire responses of target food species (Bradshaw *et al.* 2007). Based on this information burning regimes need to ensure retention of long-unburnt vegetation for this species. Fire management guidelines for honey possums have been developed by DEC Fire Management Services (Fire Management Guidelines No S2, 2008). It is recommended that honey possum distribution maps (where available) be

consulted and that prescribed fire should concentrate on frequency, the intervals between successive fires and scale as important factors for the species. They should aim to produce a mosaic of recently burnt and long unburnt vegetation and limit mortality of mature age food plants. It is recommended that sites known to be important for honey possum distribution and habitat on the GGS are protected as designated refugia from further loss or modification and frequent fire.

## **Development of ecological burning regimes for GGS**

Development of fire regimes that are optimal for biodiversity conservation is one of the major challenges in current fire management throughout Australia. The aim is to determine fire regimes that are appropriate for the vegetation type and fire sensitive taxa. The fire interval for each vegetation type and for fauna habitats needs to be determined by the needs of the flora and fauna at risk from extinction from too frequent or too infrequent burning. To determine appropriate fire intervals, life attribute data is required for species within different vegetation types.

Development of “Guidelines for ecological burning regimes for the GGS” has been based on this current report summarizing the known impacts of fire on biodiversity, vital attributes and key fire response species, and incorporating information on spatial fire history analysis (Wilson *et al.* 2010). The report also incorporated a number of specific ecological management objectives identified and developed recently (Gnangara Sustainability Fire Workshop 2010). The objectives identified were:

- Develop age-class distribution (percentage of ideal) for vegetation communities and spatial mosaic
- Increase areas of long unburnt for vegetation and fauna communities
- Maintain refugia for significant species and wetlands
- Monitor age classes, refugia, flora and fauna
- Adopt an adaptive management approach

## Discussion

### Impacts on biodiversity

Although fire is a major disturbance regime of the GSS study area, and the impact of inappropriate fire regimes has been identified as a significant threat to biodiversity conservation (DEC 2009), our understanding of the impacts on biodiversity on the area are limited. The Draft Gnangara Sustainability Strategy recommended that the optimum fire regime that will maximise groundwater recharge, while maintaining biodiversity values, be implemented (Government of Western Australia 2009a).

The aims of this report were thus to review previous information on the role of fire in ecological communities and the responses of biodiversity to fire on the Gnangara groundwater system, and to review the results of the recent fire projects carried out by DEC GSS between July 2007 and June 2010. This information would provide the foundation to determine the optimal fire regimes that will maintain biodiversity values and that are appropriate for vegetation type and fire sensitive taxa. The fire interval for each vegetation type and for fauna habitats needs to be determined by the needs of the flora and fauna at risk from extinction from too frequent or too infrequent burning.

Up until recently the information on the impacts of fire on biodiversity on the Gnangara groundwater system has been largely limited to studies on declared rare flora and threatened ecological communities, and on fauna in urban fragments. There have been few studies of the impacts of fire on frogs, reptiles and mammals (Bamford and Roberts 2003). The DEC GSS projects (2007-2020) included field studies to examine patterns of floristic diversity between sites with different fire ages, and to assess post-fire juvenile period of plants (Mickle *et al.* 2010b). Field studies to examine the response to time since fire by reptile, bird and mammal fauna (Davis 2009a; Valentine *et al.* 2009b) and food availability from *B. attenuata* and *B. menziesii* for Carnaby's Cockatoo in relationship to fire regime were also undertaken (Valentine *et al.* 2009b). A major aim of these studies was to determine the optimal fire regime for species and communities on the GGS. Knowledge of fire responses and sensitive species is vital to implement ecologically based fire regimes to conserve biodiversity.

Development of ecological fire regimes has commonly been based on plants as they are the first trophic level of terrestrial ecosystems (Burrows 2008). Vital attributes such as regeneration requirements, post-fire regeneration strategies, and juvenile periods are useful criteria to determine minimum and maximum intervals between lethal fires to conserve plant diversity (Burrows *et al.* 2008). The plant vital attributes and criteria used to select key fire response species for the GGS included juvenile period (greater than 48 months), regeneration strategy (any species 100% killed by fire relying on seed for reproduction), conservation status (DRF), endemism (GSS endemic), lifeform (from grasses to tall trees), and longevity (annuals and perennials). A total of 184 species were selected and ranked by importance, and twenty nine of these were identified as the key fire response species. The key plant species identified included the dominant *Banksia menziesii* and *Banksia attenuata* whose post-fire juvenile period on the GGS was estimated at 8 YSLF. 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 (Friend *et al.* 1999), Burrows *et al.* (2008) suggested that the minimum fire interval be twice that of the juvenile period of the longest maturing plant species. Arising from the information and data collected on juvenile period and post-fire regeneration strategies on the GGS a minimum fire interval of 8-16 years is recommended for *Banksia* woodlands and *Melaleuca*. This is based on twice the maximum juvenile period of 4 to 5 years for key flora species relying on seed storage for reproduction and a maximum juvenile period of 8 years for resprouting species (including the dominant *Banksia* species, see Table 3). A maximum interval of 40 years was recommended and is a conservative estimate based on the work of Enright *et al.* (1998) regarding the maximum age of *Banksia* species. These recommendations are also supported by information on the peak rate of increase for *Banksia attenuata* populations which occurred for fire frequencies of 7- 20 years, with a maximum rate of increase at 13 years for completely serotinous populations (Enright *et al.* 1998). Further at very short (< 5 years) and very long (> 45 years) fire intervals populations are predicted to decline to extinction and degree of serotiny is irrelevant.

A number of adaptive management projects have been undertaken by the DEC Swan Coastal District that have examined the burn response of several threatened ecological communities and declared rare flora on the Swan Coastal Plain. These include: *Banksia mimica*; *Caladenia huegelii*; *Melaleuca huegelii*- *Melaleuca systema* shrublands on

*limestone ridges* community type 26a described by Gibson *et al.* (1994b); *Macarthuria keigheryi* (fire response after a prescribed burn), *Perth to Gingin Ironstone Association*, *Darwinia foetida* and *Grevillea curviloba*. Fire management plans and recommendations have been made and include; restricting fire to times outside of vegetative and flowering seasons, restricting fire frequencies that reduce vigour and seed banks, conducting burns to promote flowering.

The DEC GSS project on the effects of year since fire on ground-dwelling vertebrates has advanced our understanding of the impacts of fire on the vertebrates and provided strong evidence for post-fire seral responses of reptiles and mammals. A significant finding was that overall reptile abundance, as well as the abundance of some specific species, was higher in long unburnt sites. Burrowing snake species, including the Priority listed *Neelaps calonotos* and lizards such as *Menetia greyii* were captured at sites of old fuel age. This is likely to reflect a difference in resource availability; vegetation and litter cover between recently burnt and long unburnt sites. In contrast several reptile species preferred recently burnt sites, whilst others were most abundant in intermediate fuel age sites. 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 calonotos* and *Menetia greyii*.

Few mammals were trapped, but the response to post fire age of those that were captured was clear. While the introduced *Mus musculus* was more abundant in recently burnt sites, *Tarsipes rostratus* (honey possums) had low abundance in recently burnt sites (< 7 YSLB), with a peak in relative abundance at sites 20 – 26 YSLB. These results were similar to previous studies in more southern populations where higher densities are recorded in older vegetation 20 – 30 YSLB (Bradshaw *et al.* 2007; Everaardt 2003). Capture rates of honey possums are closely linked to food sources (Bradshaw *et al.* 2007) and have been correlated with the densities of flowers and the flowering periods of *Banksias* (Everaardt 2003). Hence, the impact of fire on honey possums will be related to the post-fire responses of target food species (Bradshaw *et al.* 2007). Based on this information burning regimes need to ensure retention of long-unburnt vegetation for this species. Distribution maps for the species are available for the GGS together with fuel age data.

Fire management guidelines for honey possums have been developed by DEC Fire Management Services (Fire Management Guidelines No S2, 2008). It is recommended that honey possum distribution maps (where available) be consulted and that prescribed fire should concentrate on frequency and scale as important factors for the species. They should aim to produce a mosaic of recently burnt and long unburnt vegetation and limit mortality of mature age food plants. The information obtained from the GSS studies provides a strong basis for development of an ecological burning regime for this species.

Although we obtained minimal data in our trapping surveys for species such as quenda (*Isoodon obesulus*), rakali (*Hydromys chrysogaster*) and bush rat our observations provide support for preferred fire regimes on the GGS. Quenda (Priority 4 species) were typically found in moist low-lying areas with dense mid-storey vegetation and only found in high densities at Twin Swamps Nature Reserves which is both fenced and fox baited for protection of the critically endangered Western Swamp Tortoise (Valentine *et al.* 2009b). Similarly, studies at Whiteman Park found that quenda persist in the dense mid-storey level heath associated with wetlands, and only increased in number and use of upland areas after fox baiting (Bamford and Bamford 1994). In jarrah forest of the Darling Range where baiting occurs quenda inhabit a range of habitats including open woodland and upland areas. It is possible that on the GGS quenda may be favouring the dense wetland-associated vegetation habitat type to a greater extent because of the presence of foxes and lack of baiting. Hence, the persistence of quenda in unbaited areas on the GGS is strongly reliant on dense wetland-associated vegetation. Based on this information burning regimes need to ensure retention of long-unburnt wetland-associated vegetation for this species.

Substantial populations of *Hydromys chrysogaster* (Rakali), a Priority 4 species, were found at Lake Gooellal and Loch McNess. 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 which is located within Yanchep National Park has a high frequency of fires (Sonneman and Kuehs 2010). The lake also has few islands that could provide fire free habitat for water rats. This information would support the provision of burning regimes to ensure retention of wetland-associated vegetation particularly along lake edges and the banks for this species.

The mootit or bush rat were only located in wetland habitat in the GGS fauna studies (Valentine *et al.* 2009). This appears consistent with other records on the northern SCP where bush rats appear to prefer mesic near-coastal habitats that provide dense understorey and ground cover, for example at Loch McNess and in coastal dune swales in Yanchep National Park. Based on this information burning regimes need to ensure retention of long-unburnt wetland-associated vegetation for this species also.

For many declining and priority species and communities on the GGS that are threatened by inappropriate fire regimes, access to suitable refugia, particularly of long unburnt vegetation, may be necessary for their survival. Providing key refuge sites can buffer species from the impacts of fire regimes. This approach has also been identified as being essential as climate change progresses (Isaac *et al.* 2008). One species for which refugia now plays a critical role in its survival is the western swamp tortoise (*Pseudemydura umbrina*) which is listed nationally under the EPBC Act 1999 as critically endangered. Only one viable population survives at Ellen Brook Nature Reserve with two other locations, Twin Swamps and Mogumber Reserve populations being maintained with translocated individuals (Burbidge and Kuchling 2007). The reserves are critical refugia for this species and are highly managed -they are fenced and subject to predator and fire control.

Information obtained for the honey possum including distribution maps, fuel age data and the need to ensure retention of long-unburnt vegetation may provide the basis for identifying refugia for this species. It is recommended that sites known to be important for the species are designated as refugia and protected from further loss or modification and frequent fire. Further important work needs to be done to identify appropriate scale of burning around such refugia for provision of linkages.

Information obtained for species such as quenda, rakali and bush rat provide support for the need to ensure retention of long-unburnt wetland-associated vegetation for these species on the GGS. It is recommended that sites known to be important for the species are designated as refugia and protected from further loss or modification and frequent fire. Wetlands with high vegetation cover which offers protection would be particularly good quality sites suitable for refugia.



A range of wetland vegetation is likely to be significantly impacted by inappropriate fire regimes including major complexes such as *Typha-Baumea*, *Melaleuca rhapsiophylla*, *Melaleuca preissiana*, *Melaleuca viminea*, *Eucalyptus rudis*, *Juncus kraussi*, *Lepidosperma longitudinale*, *Casuarina obesa* (Horwitz *et al.* 2009) and threatened ecological communities such as: *Banksia attenuata* woodland over species-rich dense shrubland, Aquatic root mat community of Yanchep Caves, communities of tumulus springs (organic mound springs, Woodlands over sedgelands in Holocene dune swales. 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 characteristic stygofaunal assemblages distinguishable from the unconfined aquifer (Horwitz *et al.* 2009; Sommer *et al.* 2008). 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). About 10% of these are land bird species that use vegetation around wetlands, 5% are vagrants or introduced, and of the remainder, around half of the species are waterbirds. 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 or modification and frequent fire.

Other potential consequences of fire on wetlands and water quality have interrelated effects and trophic consequences, particularly when considered together with the direct effects of the fire on wetland biota described above (Horwitz and Sommer 2005). They include; catchment effects operating through the processes of runoff and deposition that can result in elevated base cations, increased alkalinity, elevated nutrient concentration, and sediment input, atmospheric effects that include the return to the ground via rain of dissolved volatilised reactive and particulate compounds that have a mildly acidifying and/or fertilising effect in wetlands; and rehydration of burnt or overheated (organic) soils can have either alkaline consequences, in which case the ash can act to fertilise and increase productivity in the short term, or it can have acidic consequences where acid sulfate soils are oxidised, in which case the effects are the same as described above for acidification. Designation of refugia and protection from frequent fire would result in prevention or protection from these degradation processes.

The GSS study area is an important foraging area during the non-breeding season for the Critically Endangered Carnaby's Cockatoo. Major threatening processes include habitat fragmentation and the removal of critical feeding resources (Cale 2003). The productivity of key *Banksia* species *Banksia menziesii* and *Banksia attenuata* in relationship with fire age was investigated in order to assess food availability for Carnaby's (Valentine 2010; Valentine *et al.* in prep.). These studies have advanced our understanding of the impacts of fire on these key species and food availability. Significantly different numbers of Carnaby's could be supported in different fire-age categories of *B. attenuata* with the lowest in the 0-5 YSLF and the > 30 YSLF categories, and the highest in the 6-10, 11-19 and 20-30 YSLF (Valentine 2010). For *B. menziesii* there was a very strong trend for higher number of Carnaby's to be supported in >30 YSLF categories. Thus combined (*B. attenuata* and *B. menziesii*) there was a significant difference in the numbers of Carnaby's supported by different fire-age categories; the lowest was in the 0-5 YSLF category and the highest in the 20-30 YSLF. The numbers of Carnaby's supported was also high in the 6-10, 11-19 YSLF categories (Valentine 2010). To maximise food availability for Carnaby's it is recommended that burning regimes are developed to increase or maximise the areas of *Banksia* woodlands in the 6-10, 11-19 20-30 YSLF. This will be particularly important as 22,000 ha of pines plantations that currently supply food for Carnaby's are removed as a major recommendation under the GSS by 2028 (Government of Western Australia 2009a).

## Development of ecological fire regimes

There is a need to develop ecologically appropriate fire regimes in the GSS study area that are based on sound, evidence-based rationale for habitat requirements for flora and fauna, minimum and maximum fire return intervals. Determination of fire regimes based on flora involves identification of the vital attributes of plant species in each community and subsequently 'key fire response species' for each community. Having now identified the key species over the GGS it is possible to determine the time interval between fires required to conserve species, i.e. the maximum and minimum intervals between lethal fires (Bradstock *et al.* 1996; Friend 1999; Gill and McCarthy 1998; Tolhurst 1999).

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). There is now a need to develop ecologically appropriate fire regimes in the GSS study area that ensures that there will be a fuel age frequency distribution that approaches the theoretical distribution and estimate the proportion of landscape required in various fuel age classes / seral stages. The negative exponential function can be aromatised by the GGS key fire response species attributes (e.g. juvenile period, longevity of fire sensitive species) to set minimum and maximum fire intervals. The actual age distribution of the vegetation (e.g. *Banksia* woodlands, *Melaleuca*) or landscape unit (GGS) can then be compared to the theoretical age distribution to identify age classes over or underrepresented. These can then be assessed for burning if over represented, or exclusion if underrepresented.

Another approach to determine ecological fire regimes is to use growth stages, in preference to age class distributions, and the known or predicted relationships between fauna and habitat growth stages (G. Friend *pers. comm.*). This involves identification of habitat parameters (such as % cover of understorey, canopy, litter, open ground, coarse woody debris, trees – various diameters at breast height, shrub composition etc.) associated with the different post fire stages of different vegetation types that can be linked with post fire stages and estimated fauna fire response curves (MacHunter *et al.* 2009; McElhinny *et al.* 2006).

In order to compile information on the burning history and actual age class distribution in the GSS study area, it is necessary to assess fire frequency area, fire interval and distribution based on DEC fire records and analyses of Landsat imagery. As part of the GSS fire projects this has been addressed in *Spatial fire history analysis in the GSS study area* (Sonneman and Kuehs 2010). Further the theoretical frequency distribution of different vegetation complexes and landscape units have been calculated and compared to the actual age distribution to identify age classes over or underrepresented in *Guidelines for ecological burning regimes for the Gnangara Groundwater System* (Wilson *et al.* 2010). Options for the spatial of arrangement and scale of the various burn patches/fuel ages are also discussed.

Determination of fire regimes based on fauna involves identification of the vital attributes of species in each community and subsequently ‘key fire response species’ for each community. The ‘key fire response fauna species’ on the GGS need to be identified also. 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. 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.

The GGS studies have identified that the dependence of fauna species on fire mediated habitat heterogeneity 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 (e.g. rakali, Bush rats, Quenda) as designated as refugia. Regimes need to incorporate spatial aspects of fauna species distribution, habitat and home ranges to develop appropriate scale of burning around refugia, and for provision of linkages. There is thus a need for further work to be undertaken to incorporate spatial aspects of fire sensitive fauna distribution, habitat and home ranges in fire regimes.

Determining the options for the scale and spatial arrangement of the various fuel ages for fauna is a very complex subject, about which we have little information. It is recommended that aspects be implemented in an adaptive management framework. These issues are assessed further in *Guidelines for ecological burning regimes for the Gnangara Groundwater System* (Wilson et al. 2010).

## Factors that increase impacts of inappropriate fire regimes

In Australia climate change may lead to complications of future fire management and prescribed burning. The frequency of very high and extreme fire danger days are predicted to increase by 4-25% by 2020 and by 15-70% by 2050 (Hennessy *et al.* 2007). 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. Species such as *Banksia prionotes*, where adults are killed by fire, but fire stimulates seeds to germinate, are thought to be particularly vulnerable to frequent, widespread fire events (Wooller *et al.* 2002). This is related to the fact that seed regeneration may be insufficient to replace adults lost in the fire if the canopy seed bank has not had sufficient time to recover from previous fire, and that they have limited dispersal potential (Wooller *et al.* 2002). Species that are not killed by fire, but instead resprout from the original plant, such as *B. attenuata*, *B. grandis*, *B. ilicifolia*, *B. littoralis*, *B. menziesii* can sometimes survive low to medium intensity fire. Enright *et al.* (1998) suggest that too frequent fires can still result in the local extinction of these species, but at a much slower rate than species where adults are killed by fire.

Frequent, widespread, and or severe fires are likely to severely impact many fauna species in the GSS study area, for example, the honey possum (*Tarsipes rostratus*), the splendid fairy wren (*Malurus splendens*), western thornbill (*Acanthiza inornata*) and scarlet robin (*Petroica multicolor*) and Western Swamp Tortoise. There is a need to determine the extent of such impacts under different climate change scenarios.

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 ha (10 %) of the GGS area is infested with *P. cinnamomi* causing 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.

## 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
- are based on a minimum fire interval of 8-16 years (twice juvenile period) and a maximum interval of 40 years for *Banksia* woodlands and *Melaleuca*
- ensure that there will be different fire ages over time in the long term, and a fuel age frequency distribution that approaches the theoretical distribution
- 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, due to habitat features including litter and food sources
- ensure retention and protection of long-unburnt wetland-associated vegetation known to be important for species as designated as refugia
- 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
- are based on the productivity of *Banksia menziesii* and *Banksia attenuata* 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
- 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

As part of the GSS fire projects some of these recommendations have been addressed in *Guidelines for ecological burning regimes for the Gnangara Groundwater System* (Wilson *et al.* 2010).

In order to compile information on the past burning history in the GSS study area, it is recommended that:

- assessments of fire frequency area, fire interval and distribution based on DEC fire records and analyses of Landsat imagery are completed
- the theoretical frequency distribution of different vegetation complexes is calculated in order to assess the ecological aspect of the current fire regimes; and
- reviews of DEC fire management operations are completed, including: the fire planning framework; conditions such as weather that impact fire management

As part of the GSS fire projects some of these recommendations have been addressed in *Spatial fire history analysis in the GSS study area* (Sonneman and Kuehs 2010) and *Fire management operations on the GSS study area* (Muller 2010).

**Additional recommendations are that:**

- additional botanical work be undertaken to determine juvenile flowering periods for more of the plant species on the GGS
- the implications for fire regimes following the replacement of pine plantations with strategic ecological linkages and a parkland (major recommendations of GSS) be assessed
- monitoring of fauna post-wildfire (e.g. Yanchep) be continued
- work be undertaken to predict changes to wildfire and fire management under future climate scenarios over the next 40 years
- work be undertaken to incorporate spatial aspects of fire sensitive fauna distribution, habitat and home ranges in fire regimes



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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 1), conservation status, endemism, lifeform (a range of structural components from grasses to tall trees), and longevity (where known).

1 GSS data from floristic 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)

| Family           | Species   | Conservation Status <sup>3</sup> | Endemism <sup>4</sup> | GSS <sup>1</sup>        |                             |                           |                             |                         | Burrows <sup>2</sup>    |                             |                           |                  |           |
|------------------|---|----------------------------------|-----------------------|-------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|-------------------------|-----------------------------|---------------------------|------------------|-----------|
|                  |   |                                  |                       | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Banksia (16) <sup>6</sup> | Melaleuca (12) <sup>6</sup> | Chrono (9) <sup>7</sup> | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Locality                  | Lifeform         | Longevity |
| Mimosaceae       | <i>Acacia alata</i>   |                                  |                       |                         |                             |                           |                             |                         | 20                      | 2                           | Mt Cooke                  | Medium shrub     |           |
| Mimosaceae       | <i>Acacia benthamii</i>   | P2                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                           |                  |           |
| Mimosaceae       | <i>Acacia cyclops</i>   |                                  |                       |                         |                             |                           | 1                           |                         | 24                      | 2                           | Perth coastal             | Medium shrub     | Perennial |
| Mimosaceae       | <i>Acacia pulchella</i>   |                                  |                       | <45                     | 2                           |                           | 7                           |                         | 22                      | 2                           | Mt Cooke                  | Medium shrub     |           |
| Mimosaceae       | <i>Acacia stenoptera</i>  |                                  |                       |                         |                             |                           | 1                           |                         | 36                      | 2                           | Brookton                  | Small shrub      | Perennial |
| Proteaaceae      | <i>Adenanthos cygnorum subsp. chamaephyton</i>                    | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                           |                  |           |
| Poaceae          | <i>Aira cupaniana</i>   |                                  |                       |                         |                             | 6                         | 6                           |                         | 9                       | 2                           | Mt Cooke                  | Annual grass     | Annual    |
| Casuarinaceae    | <i>Allocasuarina fraseriana</i>                                   |                                  |                       |                         |                             |                           |                             |                         | 36                      | 6                           | Walpole                   | Understorey tree | Perennial |
| Poaceae          | <i>Amphipogon turbinatus</i>                                      |                                  |                       | 24                      | 4                           | 3                         | 5                           |                         | 12                      | 4                           | Manjimup                  | Perennial grass  | Perennial |
| Epacridaceae     | <i>Andersonia lehmanniana</i>                                     |                                  |                       | <45                     | ?2                          |                           |                             | 4                       | 36                      | 4                           | Dandaragan                | Small shrub      | Perennial |
|                  | <i>Angianthus micropodioides</i>                                  | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                           |                  |           |
| Haemodoraceae    | <i>Anigozanthos humilis</i>                                       |                                  |                       | 12                      | 4                           |                           |                             | 9                       | 24                      | 4                           | Mogumber                  | Perennial herb   | Perennial |
| Haemodoraceae    | <i>Anigozanthos humilis subsp. Badgingarra (S.D. Hopper 7114)</i> | P2                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                           |                  |           |
| Goodeniaceae     | <i>Anthotium junciforme</i>                                       | P4                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                           |                  |           |
| Papilionaceae    | <i>Aotus cordifolia</i>   | P3                               | RE                    | 18                      | 2                           |                           |                             |                         |                         |                             |                           |                  |           |
| Asteraceae       | <i>Arctotheca calendula</i>                                       |                                  |                       |                         |                             |                           | 1                           |                         | 9                       | 2                           | Mt Cooke                  | Annual herb      | Annual    |
| Epacridaceae     | <i>Astroloma xerophyllum</i>                                      |                                  |                       |                         |                             |                           |                             |                         | 48                      | 2                           | Badgingarra National Park | Small shrub      | Perennial |
| Poaceae          | <i>Austrostipa compressa</i>                                      |                                  |                       | <24                     | 2                           | 4                         | 5                           |                         | 6                       | 2                           | Walpole                   | Annual herb      | Annual    |
| Poaceae          | <i>Austrostipa macalpinei</i>                                     |                                  |                       |                         |                             | 1                         | 1                           |                         | 12                      | 2                           | Stirling Range            | Perennial grass  | Perennial |
| Proteaaceae      | <i>Banksia attenuata</i>  |                                  |                       | 90                      | 5                           | 16                        | 2                           | 9                       | 24                      | 6                           | Perth                     | Understorey tree | Perennial |
| Proteaaceae      | <i>Banksia grandis</i>  |                                  |                       |                         |                             | 1                         |                             |                         | 24                      | 6                           | Nannup                    | Understorey tree | Perennial |
| Proteaaceae      | <i>Banksia ilicifolia</i>   |                                  |                       |                         |                             | 5                         | 2                           |                         | 24                      | 6                           | Nannup                    | Overstorey tree  | Perennial |
| Proteaaceae      | <i>Banksia littoralis</i>   |                                  |                       |                         |                             |                           | 4                           |                         | 24                      | 6                           | Pemberton                 | Understorey tree | Perennial |
| Proteaaceae      | <i>Banksia menziesii</i>  |                                  |                       | 96                      | 5                           | 12                        | 1                           | 9                       | 24                      | 6                           | Perth                     | Tall shrub       | Perennial |
| Scrophulariaceae | <i>Bartsia trixago</i>  |                                  |                       |                         |                             |                           |                             |                         | 9                       | 2                           | Mt Cooke                  | Annual herb      | Annual    |
| Myrtaceae        | <i>Beaufortia elegans</i>   |                                  |                       | <45                     | 2                           | 5                         | 2                           | 7                       | 24                      | 1                           | Cataby                    | Small shrub      | Perennial |

| Family           | Species   | Conservation Status <sup>3</sup> | Endemism <sup>4</sup> | GSS <sup>1</sup>        |                             |                           |                             |                         | Burrows <sup>2</sup>    |                             |                    |                |           |
|------------------|---|----------------------------------|-----------------------|-------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|-------------------------|-----------------------------|--------------------|----------------|-----------|
|                  |   |                                  |                       | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Banksia (16) <sup>6</sup> | Melaleuca (12) <sup>6</sup> | Chrono (9) <sup>7</sup> | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Locality           | Lifeform       | Longevity |
| Euphorbiaceae    | <i>Beyeria cinerea subsp. cinerea</i>           | P3                               | NE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Asteraceae       | <i>Blennospora doliiformis</i>                  | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Rutaceae         | <i>Boronia purdieana</i>                        |                                  |                       | <45                     | 2                           |                           |                             | 8                       |                         |                             |                    |                |           |
| Rutaceae         | <i>Boronia ramosa</i>                           |                                  |                       | <24                     | 2                           |                           |                             | 4                       |                         |                             |                    |                |           |
| Papilionaceae    | <i>Bossiaea eriocarpa</i>                       |                                  |                       | 12                      | 5                           | 1                         | 2                           | 9                       | 12                      | 5                           | Walpole            | Small shrub    | Perennial |
| Asteraceae       | <i>Brachyscome iberidifolia</i>                 |                                  |                       |                         |                             |                           |                             |                         | 12                      | 3                           | Manjimup           | Annual herb    | Perennial |
| Poaceae          | <i>Briza maxima</i>                             |                                  |                       |                         |                             | 7                         | 2                           |                         | 6                       | 8                           | Walpole            | Annual herb    | Annual    |
| Poaceae          | <i>Briza minor</i>                              |                                  |                       |                         |                             |                           |                             |                         | 6                       | 8                           | Walpole            | Annual herb    | Annual    |
| Colchicaceae     | <i>Burchardia congesta</i>                      |                                  |                       | 12                      | 4                           | 12                        | 2                           | 9                       | 24                      | 11                          | Cataby             | Perennial herb | Perennial |
| Orchidaceae      | <i>Caladenia flava</i>                          |                                  |                       | <48                     | 4                           |                           | 1                           | 7                       | 9                       | 11                          | Mt Cooke           | Geophyte       | Perennial |
| Orchidaceae      | <i>Caladenia huegelii</i>                       | DRF                              | RE                    |                         |                             |                           |                             |                         | 9                       | 11                          |                    |                |           |
| Dasypogonaceae   | <i>Calectasia sp. Pinjar (C. Tauss 557)</i>     | P1                               | GSS                   | 24*                     | 4*                          |                           |                             |                         |                         |                             |                    |                |           |
| Myrtaceae        | <i>Calytrix flavescens</i>                      |                                  |                       | 24                      | 5                           | 9                         | 1                           | 9                       | 30                      | 2                           | Stirling Range     | Small shrub    | Perennial |
| Myrtaceae        | <i>Calytrix sapphirina</i>                      |                                  |                       | <60                     | 5                           |                           |                             | 3                       |                         | 5                           | Eneabba            | Small shrub    | Perennial |
| Cyperaceae       | <i>Carex tereticaulis</i>                       | P1                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Lauraceae        | <i>Cassytha racemosa</i>                        |                                  |                       |                         |                             |                           |                             |                         | 24                      | 2                           | Walpole            | Climber        | Perennial |
| Centrolepidaceae | <i>Centrolepis drummondiana</i>                 |                                  |                       | 12                      | 2                           | 5                         | 1                           | 3                       |                         |                             |                    |                |           |
| Asteraceae       | <i>Cirsium vulgare</i>                          |                                  |                       |                         |                             |                           |                             |                         | 12                      | 3                           | Walpole            | Annual herb    | Perennial |
| Proteaceae       | <i>Conospermum stoechadis subsp. stoechadis</i> |                                  |                       | 12                      | 5                           |                           |                             | 5                       |                         |                             |                    |                |           |
| Epacridaceae     | <i>Conostephium minus</i>                       |                                  |                       | <45                     | 25                          | 3                         |                             | 6                       |                         |                             |                    |                |           |
| Epacridaceae     | <i>Conostephium pendulum</i>                    |                                  |                       | 12                      | 5                           | 8                         | 3                           | 8                       | 60                      | 5                           | Northern Sandplain |                | Perennial |
| Haemodoraceae    | <i>Conostylis bracteata</i>                     | P3                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Haemodoraceae    | <i>Conostylis juncea</i>                        |                                  |                       | <45                     | 4                           | 8                         |                             | 8                       |                         |                             |                    |                |           |
| Haemodoraceae    | <i>Conostylis pauciflora subsp. euryrhipis</i>  | P4                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Haemodoraceae    | <i>Conostylis pauciflora subsp. pauciflora</i>  | P4                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Asteraceae       | <i>Conyza bonariensis</i>                       |                                  |                       |                         |                             |                           |                             | 2                       | 12                      | 3                           | Walpole            | Annual herb    | Annual    |
| Orchidaceae      | <i>Corymbia calophylla</i>                      |                                  |                       |                         |                             |                           |                             |                         | 48                      | 6                           | Walpole            |                | Perennial |
| Crassulaceae     | <i>Crassula colorata</i>                        |                                  |                       | 12                      | 2                           |                           |                             | 3                       |                         |                             |                    |                |           |

| Family         | Species   | Conservation Status <sup>3</sup> | Endemism <sup>4</sup> | GSS <sup>1</sup>        |                             |                           |                             |                         | Burrows <sup>2</sup>    |                             |                     |                 |           |
|----------------|---|----------------------------------|-----------------------|-------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|-------------------------|-----------------------------|---------------------|-----------------|-----------|
|                |   |                                  |                       | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Banksia (16) <sup>6</sup> | Melaleuca (12) <sup>6</sup> | Chrono (9) <sup>7</sup> | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Locality            | Lifeform        | Longevity |
| Cyperaceae     | <i>Cyathochaeta teretifolia</i>                 | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Goodeniaceae   | <i>Dampiera linearis</i>                        |                                  |                       | 12                      | 5                           | 4                         | 3                           | 5                       | 10                      | 4                           | Mt Cooke            | Small shrub     | Perennial |
| Myrtaceae      | <i>Darwinia foetida</i>                         | DRF                              | LE                    | >48*                    | 2*                          |                           |                             |                         |                         |                             |                     |                 |           |
| Dasypogonaceae | <i>Dasypogon bromeliifolius</i>                 |                                  |                       | <45                     | 4                           | 5                         | 2                           | 3                       | 6                       | 7                           | Nannup              |                 | Perennial |
| Restionaceae   | <i>Desmocladus flexuosus</i>                    |                                  |                       | <45                     | 4                           | 5                         | 3                           | 7                       |                         |                             |                     |                 |           |
| Papilionaceae  | <i>Dillwynia dillwynioides</i>                  | P3                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Sapindaceae    | <i>Dodonaea hackettiana</i>                     | P4                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Orchidaceae    | <i>Drakaea elastica</i>                         | DRF                              | LE                    |                         |                             |                           |                             |                         | 12                      | 11                          |                     |                 |           |
| Droseraceae    | <i>Drosera menz</i>                             |                                  |                       | 12                      | 4                           | 1                         |                             | 9                       | 8                       | 11                          | Perup               |                 | Perennial |
| Droseraceae    | <i>Drosera occidentalis subsp. occidentalis</i> | P4                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Droseraceae    | <i>Drosera pallida</i>                          |                                  |                       | 24                      | 4                           | 1                         | 2                           | 2                       | 12                      | 11                          | Manjimup            |                 | Perennial |
| Poaceae        | <i>Ehrharta longiflora</i>                      |                                  |                       |                         |                             |                           | 1                           |                         | 12                      | 3                           | Walpole             |                 | Annual    |
| Cyperaceae     | <i>Eleocharis keigheryi</i>                     | DRF                              | RE                    | 4 to 72*                | 9*                          |                           |                             |                         |                         |                             |                     |                 |           |
| Orchidaceae    | <i>Elythranthera brunonis</i>                   |                                  |                       | <60                     | 4                           | 2                         | 1                           | 5                       | 24                      | 11                          | Stirling Range      |                 | Perennial |
| Orchidaceae    | <i>Epiblema grandiflorum var. cyaneum</i>       | DRF                              | GSS                   | 12                      | 11                          |                           |                             |                         |                         |                             |                     |                 |           |
| Myrtaceae      | <i>Eremaea beaufortoides</i>                    |                                  |                       | <45                     | 5                           | 2                         |                             | 6                       | 36                      | 5                           | Jurien Bay          |                 | Perennial |
| Myrtaceae      | <i>Eremaea pauciflora</i>                       |                                  |                       | 24                      | 5                           | 1                         | 1                           | 3                       | 48                      | 2                           | Jurien Bay          |                 | Perennial |
| Myrtaceae      | <i>Eucalyptus argutifolia</i>                   | DRF                              | LE                    | 48*                     | 5 or 6*                     |                           |                             |                         |                         |                             |                     |                 |           |
| Myrtaceae      | <i>Eucalyptus gomphocephala</i>                 |                                  |                       |                         |                             |                           |                             |                         | 48                      | 6                           | Swan Coastal Plain  |                 | Perennial |
| Myrtaceae      | <i>Eucalyptus marginata</i>                     |                                  |                       |                         |                             |                           |                             |                         | 48                      | 6                           | Nannup              | Overstorey tree | Perennial |
| Myrtaceae      | <i>Eucalyptus rudis</i>                         |                                  |                       |                         |                             | 1                         | 5                           |                         | 48                      | 6                           | Perup               |                 | Perennial |
| Myrtaceae      | <i>Eucalyptus todtiana</i>                      |                                  |                       |                         |                             | 4                         |                             |                         | 48                      | 6                           | Northern Sandplains |                 | Perennial |
| Myrtaceae      | <i>Eucalyptus x mundijongensis</i>              | P1                               | GSS                   | 48*                     | 5 or 6*                     |                           |                             |                         |                         |                             |                     |                 |           |
| Santalaceae    | <i>Exocarpos sparteus</i>                       |                                  |                       |                         |                             |                           | 1                           |                         | 18                      | 2                           | Walpole             |                 | Perennial |
| Fabroniaceae   | <i>Fabronia hampeana</i>                        | P2                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Rubiaceae      | <i>Galium murale</i>                            |                                  |                       |                         |                             |                           | 1                           |                         | 12                      | 2                           | Manjimup            |                 | Annual    |
| Papilionaceae  | <i>Gastrolobium capitatum</i>                   |                                  |                       | <45                     | 2                           | 5                         | 1                           | 7                       |                         |                             |                     |                 |           |
| Papilionaceae  | <i>Gompholobium aristatum</i>                   |                                  |                       |                         |                             | 1                         |                             |                         | 24                      | 2                           | Nannup              |                 | Perennial |
| Papilionaceae  | <i>Gompholobium confertum</i>                   |                                  |                       |                         |                             |                           | 1                           |                         | 22                      | 2                           | Nannup              |                 | Perennial |

| Family        | Species                                     | Conservation Status <sup>3</sup> | Endemism <sup>4</sup> | GSS <sup>1</sup>        |                             |                           |                             |                         | Burrows <sup>2</sup>    |                             |                     |                 |           |
|---------------|---|----------------------------------|-----------------------|-------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|-------------------------|-----------------------------|---------------------|-----------------|-----------|
|               |   |                                  |                       | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Banksia (16) <sup>6</sup> | Melaleuca (12) <sup>6</sup> | Chrono (9) <sup>7</sup> | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Locality            | Lifeform        | Longevity |
| Papilionaceae | <i>Gompholobium scabrum</i>                 |                                  |                       |                         |                             | 1                         |                             |                         | 30                      | 2                           | Stirling Ranges     | Medium shrub    | Perennial |
| Papilionaceae | <i>Gompholobium tomentosum</i>              |                                  |                       | <45                     | 2                           | 9                         | 3                           | 6                       | 20                      | 2                           | Nannup              |                 | Perennial |
| Haloragaceae  | <i>Gonocarpus pithyoides</i>                |                                  |                       | <24                     | 5                           | 1                         | 2                           | 4                       |                         |                             |                     |                 |           |
| Proteaceae    | <i>Grevillea curviloba subsp. curviloba</i> | DRF                              | GSS                   | 6 to 72*                | 2 or 5*                     |                           |                             |                         |                         |                             |                     |                 |           |
| Proteaceae    | <i>Grevillea curviloba subsp. incurva</i>   | DRF                              | RE                    | 6 to 72*                | 2 or 5*                     |                           |                             |                         |                         |                             |                     |                 |           |
| Proteaceae    | <i>Grevillea evanescens</i>                 | P1                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Proteaceae    | <i>Grevillea thelemanniana</i>              | P4                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Haemodoraceae | <i>Haemodorum loratum</i>                   | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Haemodoraceae | <i>Haemodorum spicatum</i>                  |                                  |                       | 24                      | 4                           | 4                         | 1                           | 5                       | 12                      | 11                          | Stirling Range      |                 | Perennial |
| Proteaceae    | <i>Hakea costata</i>                        |                                  |                       |                         |                             | 2                         |                             |                         | 72                      | 1                           | Northern Sandplain  |                 | Perennial |
| Proteaceae    | <i>Hakea varia</i>                          |                                  |                       |                         |                             |                           |                             |                         |                         | 1                           | Stirling Range      |                 | Perennial |
| Lamiaceae     | <i>Hemiandra pungens</i>                    |                                  |                       |                         |                             | 2                         |                             |                         | 33                      | 2                           | Mt Cooke            | Medium shrub    |           |
| Dilleniaceae  | <i>Hibbertia huegelii</i>                   |                                  |                       | 12                      | 5                           | 4                         | 2                           | 24                      | 5                       | 5                           | Northern Sandplain  |                 | Perennial |
| Dilleniaceae  | <i>Hibbertia hypericoides</i>               |                                  |                       | 12                      | 5                           | 7                         | 4                           | 9                       | 5                       | 5                           | Mt Cooke            |                 | Perennial |
| Dilleniaceae  | <i>Hibbertia spicata subsp. leptotheca</i>  | P3                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Dilleniaceae  | <i>Hibbertia subvaginata</i>                |                                  |                       | 24                      | 5                           | 1                         | 2                           | 9                       |                         |                             |                     |                 |           |
| Apiaceae      | <i>Homalosciadium homalocarpum</i>          |                                  |                       |                         |                             | 5                         | 1                           |                         | 9                       | 2                           | Mt Cooke            | Annual herb     | Annual    |
| Papilionaceae | <i>Hovea trisperma</i>                      |                                  |                       |                         |                             | 2                         |                             |                         | 42                      | 2                           | Perup               |                 | Perennial |
| Asteraceae    | <i>Hyalosperma cotula</i>                   |                                  |                       |                         |                             |                           | 2                           |                         | 9                       | 2                           | Mt Cooke            | Annual herb     | Annual    |
| Apiaceae      | <i>Hydrocotyle callicarpa</i>               |                                  |                       |                         |                             | 1                         | 1                           |                         | 22                      | 2                           | Mt Cooke            | Annual herb     |           |
| Myrtaceae     | <i>Hypocalymma angustifolium</i>            |                                  |                       |                         |                             | 2                         | 3                           |                         | 48                      | 5                           | Avon Wheatbelt      |                 | Perennial |
| Cyperaceae    | <i>Isolepis marginata</i>                   |                                  |                       | 12                      | 2                           | 5                         | 1                           | 6                       | 6                       | 8                           | Walpole             |                 | Perennial |
| Papilionaceae | <i>Isotropis cuneifolia subsp. glabra</i>   | P2                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Papilionaceae | <i>Jacksonia floribunda</i>                 |                                  |                       |                         |                             | 5                         |                             |                         | 24                      | 2                           | Northern Sandplain  |                 | Perennial |
| Papilionaceae | <i>Jacksonia sericea</i>                    | P4                               | LE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Papilionaceae | <i>Jacksonia sternbergiana</i>              |                                  |                       |                         |                             | 1                         |                             |                         |                         | 1                           | Geraldton Sandplain |                 | Perennial |
| Papilionaceae | <i>Kennedia prostrata</i>                   |                                  |                       |                         |                             |                           | 1                           |                         | 19                      | 2                           | Mt Cooke            | Prostrate shrub |           |
| Sterculiaceae | <i>Lasiopetalum membranaceum</i>            | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                 |           |
| Asparagaceae  | <i>Laxmannia sessiliflora</i>               |                                  |                       |                         |                             | 1                         |                             |                         |                         | 2                           | Northern Sandplain  |                 | Perennial |

| Family          | Species                           | Conservation Status <sup>3</sup> | Endemism <sup>4</sup> | GSS <sup>1</sup>        |                             |                           |                             |                         | Burrows <sup>2</sup>    |                             |                     |                  |           |
|-----------------|-----------------------------------|----------------------------------|-----------------------|-------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|-------------------------|-----------------------------|---------------------|------------------|-----------|
|                 |                                   |                                  |                       | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Banksia (16) <sup>6</sup> | Melaleuca (12) <sup>6</sup> | Chrono (9) <sup>7</sup> | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Locality            | Liferform        | Longevity |
| Asparagaceae    | <i>Laxmannia squarrosa</i>        |                                  |                       | <24                     | 2                           | 1                         | 5                           |                         |                         |                             |                     |                  |           |
| Goodeniaceae    | <i>Lechenaultia floribunda</i>    |                                  |                       |                         |                             | 2                         | 2                           |                         | 2                       | Northern Sandplain          |                     | Perennial        |           |
| Goodeniaceae    | <i>Lechenaultia magnifica</i>     | P1                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                  |           |
| Epacridaceae    | <i>Leucopogon conostephioides</i> |                                  |                       | <45                     | 2                           | 6                         | 2                           | 6                       | 60                      | 2                           | Northern Sandplain  |                  | Perennial |
| Epacridaceae    | <i>Leucopogon squarrosus</i>      |                                  |                       | <45                     | 2                           |                           |                             | 6                       |                         |                             |                     |                  |           |
| Stylidiaceae    | <i>Levenhookia pusilla</i>        |                                  |                       |                         |                             |                           | 2                           |                         | 10                      | 8                           | Perup               |                  | Annual    |
| Lobeliaceae     | <i>Lobelia tenuior</i>            |                                  |                       |                         |                             | 1                         | 1                           |                         | 6                       | 8                           | Walpole             |                  | Annual    |
| Dasyopogonaceae | <i>Lomandra caespitosa</i>        |                                  |                       | <45                     | 4                           | 2                         | 1                           | 2                       | 33                      | 4                           | Walpole             |                  | Perennial |
| Dasyopogonaceae | <i>Lomandra hermaphrodita</i>     |                                  |                       | <36*                    | 4 or 5*                     |                           |                             |                         |                         |                             |                     |                  |           |
| Dasyopogonaceae | <i>Lomandra maritima</i>          |                                  |                       | <36*                    | 4 or 5*                     |                           |                             |                         |                         |                             |                     |                  |           |
| Restionaceae    | <i>Lyginia barbata</i>            |                                  |                       | 24                      | 4                           |                           |                             | 9                       | 21                      | 5                           | Walpole             |                  | Perennial |
| Epacridaceae    | <i>Lysinema ciliatum</i>          |                                  |                       | <48                     | 2                           | 1                         |                             | 6                       | 24                      | 8                           | Nannup              |                  | Perennial |
| Pittosperaceae  | <i>Marianthus paralius</i>        | DRF                              | LE                    | 24*                     | 2 or 5*                     |                           |                             |                         |                         |                             |                     |                  |           |
| Haloragaceae    | <i>Meionectes tenuifolia</i>      | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                  |           |
| Myrtaceae       | <i>Melaleuca preissiana</i>       |                                  |                       |                         |                             | 1                         | 7                           |                         | 24                      | 6                           | Mt Cooke            | Understorey tree |           |
| Myrtaceae       | <i>Melaleuca systema</i>          | TEC                              |                       | ? 18-84*                | ? 1,4,5,6,9*                |                           |                             |                         |                         |                             |                     |                  |           |
| Myrtaceae       | <i>Melaleuca trichophylla</i>     |                                  |                       | 24                      | 5                           | 6                         | 1                           | 9                       | 36                      | 5                           | Geraldton Sandplain |                  | Perennial |
| Myrtaceae       | <i>Melaleuca viminea</i>          |                                  |                       |                         |                             |                           |                             |                         | 60                      | 1                           | Perup               |                  | Perennial |
| Asteracea       | <i>Millotia myosotidifolia</i>    |                                  |                       |                         |                             | 2                         | 1                           |                         | 12                      | 8                           | Walpole             |                  | Annual    |
| Haloragaceae    | <i>Myriophyllum echinatum</i>     | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                     |                  |           |
| Rubiaceae       | <i>Opercularia vaginata</i>       |                                  |                       |                         |                             | 3                         | 1                           |                         | 24                      | 2                           | Stirling Range      |                  | Perennial |
| Iridaceae       | <i>Patersonia occidentalis</i>    |                                  |                       | 12                      | 4                           | 9                         |                             | 9                       | 36                      | 2                           | Stirling Range      |                  | Perennial |
| Proteaceae      | <i>Persoonia saccata</i>          |                                  |                       |                         |                             | 1                         |                             |                         | 13                      | 5                           | Nannup              | Understorey tree | Ephemeral |
| Proteaceae      | <i>Petrophile linearis</i>        |                                  |                       | 24                      | 5                           | 13                        | 2                           | 9                       | 25                      | 5                           | Nannup              |                  | Perennial |
| Proteaceae      | <i>Petrophile macrostachya</i>    |                                  |                       |                         |                             | 3                         |                             |                         | 48                      | 5                           | Northern Sandplain  |                  | Perennial |
| Proteaceae      | <i>Petrophile serruriae</i>       |                                  |                       |                         |                             | 1                         |                             |                         | 32                      | 1                           | Perup               |                  | Perennial |
| Rutaceae        | <i>Philothea spicata</i>          |                                  |                       | 12                      | 5                           | 6                         |                             | 8                       | 21                      | 4                           | Mt Cooke            | Medium shrub     |           |
| Haemodoraceae   | <i>Phlebocarya ciliata</i>        |                                  |                       | <45                     | 4                           | 8                         | 1                           | 6                       | 18                      | 5                           | Walpole             |                  | Perennial |
| Loganiaceae     | <i>Phyllangium paradoxum</i>      |                                  |                       | 12                      | 2                           | 11                        | 5                           | 9                       | 12                      | 2                           | Walpole             |                  | Annual    |

| Family        | Species                         | Conservation Status <sup>3</sup> | Endemism <sup>4</sup> | GSS <sup>1</sup>        |                             |                           |                             |                         | Burrows <sup>2</sup>    |                             |                    |                |           |
|---------------|---------------------------------|----------------------------------|-----------------------|-------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|-------------------------|-----------------------------|--------------------|----------------|-----------|
|               |                                 |                                  |                       | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Banksia (16) <sup>6</sup> | Melaleuca (12) <sup>6</sup> | Chrono (9) <sup>7</sup> | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Locality           | Lifeform       | Longevity |
| Thymelaeaceae | <i>Pimelea sulphurea</i>        |                                  |                       | 12                      | 2                           |                           |                             | 2                       | 24                      | 5                           | Northern Sandplain |                | Perennial |
| Asteraceae    | <i>Podotheca chrysantha</i>     |                                  |                       | <45                     | 2                           | 1                         |                             | 6                       |                         |                             |                    |                |           |
| Asteraceae    | <i>Podotheca gnaphalioides</i>  |                                  |                       | 12                      | 2                           | 7                         | 5                           | 4                       |                         | 2                           | Northern Sandplain |                | Perennial |
| Euphorbiaceae | <i>Poranthera microphylla</i>   |                                  |                       |                         |                             | 3                         | 5                           |                         | 9                       | 2                           | Mt Cooke           | Annual herb    | Perennial |
| Asteraceae    | <i>Quinetia urvillei</i>        |                                  |                       |                         |                             | 2                         | 1                           |                         | 9                       | 2                           | Mt Cooke           | Annual herb    | Annual    |
| Myrtaceae     | <i>Regelia ciliata</i>          |                                  |                       |                         |                             | 3                         | 1                           |                         | 60                      | 5                           | Swan Coastal Plain |                | Perennial |
| Asteraceae    | <i>Rhodanthe pyrethrum</i>      | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Primulaceae   | <i>Samolus junceus</i>          |                                  |                       |                         |                             |                           |                             |                         | 33                      | 2                           | Walpole            |                | Perennial |
| Aizoaceae     | <i>Sarcozona bicarinata</i>     | P3                               | GSS                   |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Cyperaceae    | <i>Schoenus caespitius</i>      |                                  |                       | 24                      | 4                           | 4                         |                             | 8                       |                         |                             |                    |                |           |
| Cyperaceae    | <i>Schoenus curvifolius</i>     |                                  |                       | 48                      | 4                           | 8                         | 1                           | 8                       | 24                      | 11                          | Stirling Range     |                | Perennial |
| Cyperaceae    | <i>Schoenus natans</i>          | P4                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Solanaceae    | <i>Solanum nigrum</i>           |                                  |                       |                         |                             |                           |                             |                         |                         | 8                           | Walpole            |                | Perennial |
| Asteraceae    | <i>Sonchus asper</i>            |                                  |                       |                         |                             |                           | 1                           |                         |                         | 3                           | Walpole            |                | Biennial  |
| Asteraceae    | <i>Sonchus oleraceus</i>        |                                  |                       |                         |                             |                           | 3                           |                         |                         | 3                           | Walpole            |                | Annual    |
| Rhamnaceae    | <i>Spyridium globulosum</i>     |                                  |                       |                         |                             |                           | 4                           |                         | 6                       | 2                           | Walpole            |                | Perennial |
| Euphorbiaceae | <i>Stachystemon axillaris</i>   | P4                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Proteaceae    | <i>Stirlingia latifolia</i>     |                                  |                       | 12                      | 5                           | 5                         |                             | 9                       | 24                      | 5                           | Northern Sandplain |                | Perennial |
| Stylidiaceae  | <i>Stylidium adpressum</i>      |                                  |                       |                         |                             |                           | 3                           |                         |                         | 2                           | Northern Sandplain |                | Perennial |
| Stylidiaceae  | <i>Stylidium araeophyllum</i>   |                                  |                       | <45                     | ?4                          | 7                         | 1                           | 5                       |                         |                             |                    |                |           |
| Stylidiaceae  | <i>Stylidium bicolor</i>        |                                  |                       | <48                     | ?4                          |                           |                             | 2                       |                         |                             |                    |                |           |
| Stylidiaceae  | <i>Stylidium brunonianum</i>    |                                  |                       |                         |                             |                           | 3                           |                         | 9                       | 2                           | Manjimup           | Perennial herb | Perennial |
| Stylidiaceae  | <i>Stylidium calcaratum</i>     |                                  |                       |                         |                             |                           | 2                           |                         | 7                       | 2                           | Perup              | Annual herb    | Ephemeral |
| Stylidiaceae  | <i>Stylidium crossacephalum</i> |                                  |                       | <45                     | ?4                          | 3                         |                             | 7                       |                         |                             |                    |                |           |
| Stylidiaceae  | <i>Stylidium diuroides</i>      |                                  |                       | <24                     | ?4                          |                           |                             | 7                       |                         |                             |                    |                |           |
| Stylidiaceae  | <i>Stylidium longitubum</i>     | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Stylidiaceae  | <i>Stylidium maritimum</i>      | P3                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |
| Stylidiaceae  | <i>Stylidium repens</i>         |                                  |                       |                         |                             | 1                         | 4                           |                         | 24                      | 2                           | Northern Sandplain |                | Perennial |
| Stylidiaceae  | <i>Stylidium repens</i>         |                                  |                       |                         |                             | 1                         |                             |                         | 24                      | 2                           | Northern Sandplain |                | Perennial |



| Family           | Species                                     | Conservation Status <sup>3</sup> | Endemism <sup>4</sup> | GSS <sup>1</sup>        |                             |                           |                             |                         | Burrows <sup>2</sup>    |                             |                    |                |           |  |
|------------------|---|----------------------------------|-----------------------|-------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|-------------------------|-----------------------------|--------------------|----------------|-----------|--|
|                  |   |                                  |                       | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Banksia (16) <sup>6</sup> | Melaleuca (12) <sup>6</sup> | Chrono (9) <sup>7</sup> | Juvenile Period (mnths) | Regen <sup>5</sup> Strategy | Locality           | Lifeform       | Longevity |  |
| Stylidiaceae     | <i>Stylidium rigidulum</i>                  |                                  |                       | <24                     | ?2                          | 5                         | 3                           | 5                       |                         |                             |                    |                |           |  |
| Stylidiaceae     | <i>Stylidium schoenoides</i>                |                                  |                       |                         |                             | 2                         |                             |                         | 7                       | 2                           | Perup              | Perennial herb | Perennial |  |
| Papilionaceae    | <i>Templetonia retusa</i>                   |                                  |                       |                         |                             |                           | 3                           |                         | 48                      | 2                           | Swan Coastal Plain |                | Perennial |  |
| Anthericaceae    | <i>Thysanotus thyrsoides</i>                |                                  |                       |                         |                             | 2                         | 1                           |                         |                         | 2                           | Avon Wheatbelt     |                | Perennial |  |
| Apiaceae         | <i>Trachymene pilosa</i>                    |                                  |                       | 12                      | 2                           | 12                        | 9                           | 8                       | 12                      | 2                           | Perup              |                | Annual    |  |
| Stackhousiaceae  | <i>Tripterococcus paniculatus</i>           | P1                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |  |
| Hydatellaceae    | <i>Trithuria occidentalis</i>               | DRF                              | GSS                   | <12*                    | 2*                          |                           |                             |                         |                         |                             |                    |                |           |  |
| Asteracea        | <i>Ursinia anthemoides</i>                  |                                  |                       |                         |                             | 12                        | 5                           |                         | 12                      | 2                           | Northern Sandplain |                | Annual    |  |
| Lentibulariaceae | <i>Utricularia multifida</i>                |                                  |                       |                         |                             |                           |                             |                         | 6                       | 2                           | Walpole            |                | Annual    |  |
| Myrtaceae        | <i>Verticordia lindleyi subsp. lindleyi</i> | P4                               | RE                    |                         |                             |                           |                             |                         |                         |                             |                    |                |           |  |
| Myrtaceae        | <i>Verticordia nitens</i>                   |                                  |                       |                         |                             | 4                         |                             |                         | 0                       | 2                           | Avon Wheatbelt     |                | Perennial |  |
| Papilionaceae    | <i>Viminaria juncea</i>                     |                                  |                       |                         |                             |                           | 3                           |                         | 0                       | 2                           | Walpole            |                | Perennial |  |
| Asteracea        | <i>Waitzia suaveolens</i>                   |                                  |                       |                         |                             | 2                         |                             |                         | 12                      | 2                           | Perup              |                | Annual    |  |
| Apiaceae         | <i>Xanthosia huegelii</i>                   |                                  |                       | 24                      | 5                           | 7                         |                             | 9                       | 32                      | 5                           | Perup              |                | Perennial |  |