Terrestrial Invertebrate Biodiversity Assessment for the Gnangara Sustainability Strategy (GSS).

Brad Durrant

Wildlife Research Centre, Science Division

Department of Environment and Conservation, Woodvale WA 6026

Department of Environment and Conservation
Our environment, our future

Final Report.

May 2009

This document has been produced as part of the Gnangara 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 Gnangara groundwater system. For more information go to www.gnangara.water.wa.gov.au

Executive Summary

This report has sought to review existing knowledge and data for terrestrial invertebrate fauna on the Gnangara Mound. This information was to be used to assess the biodiversity values (richness, endemicity, habitat requirements and limitations) of the known terrestrial invertebrate fauna and communities, identify knowledge gaps, provide an overview of threats to these values and provide comment on the future direction for terrestrial invertebrate studies on the mound.

The knowledge and data readily available is a poor reflection of the information, particularly taxonomic and biogeographic data, locked up in local collections (not databased), primarily within the WA Museum collection. This has placed a heavy reliance on published and unpublished papers and theses, and work outside of the GSS study area, for this assessment, of which the vast majority of work has been tightly focussed on either a single location or a single taxonomic group. Much of the available museum data reflects the most common species found in urban areas and those groups which have received attention by local experts and/or have been part of large taxonomic revisions.

Assessing the richness and endemicity values of the Gnangara Mound and greater Swan Coastal Plain was limited to a handful of taxonomic groups which have had biogeographic studies conducted, some extending in to the south west of the state. These studies have shown that the Swan Coastal Plain has the potential to be a rich area with a reasonably high number of endemic species, when compared to adjoining regions. This is particularly significant given the recognition of the south west of Western Australia as a global biodiversity hotspot.

Environmental factors that appear to limit richness and distribution of species and communities act at both highly localised (habitat) and wider regional scales. Many of these factors are directly or indirectly related to rainfall, either through the amount of rain or seasonality, the moisture retention properties of the landscape, and the effect that these aspects can have on vegetation, leaf litter properties and decomposition. On the Gnangara Mound the most extreme levels of endemism would be found within landscapes such as the Yanchep caves, tumulus springs and the northern ironstones. These are all classified as threatened ecological communities (TECs) and all have a very high reliance on rainfall and moisture retention. These

areas have not been surveyed for invertebrate communities but are very likely to harbour a very high number of endemic species.

Biological factors that affect species distributions can be very restrictive as well, particularly those that involve slow growth/maturity rates, low fecundity and lack of dispersal capabilities. Taxa that have one or a combination of these factors have a high likelihood of being classified as a short range endemic (SRE). SREs are often associated with TECs as they are often relictual species that have been unable to adapt rapidly or effectively with the changing environment, most notably during the aridification of the south west.

Climate change, fire (inappropriate regimes) and habitat fragmentation/alteration pose the greatest risks to the stability of terrestrial invertebrate communities on the Gnangara Mound, but particularly to the survival of SRE taxa and the retention of sensitive habitats (TECs). However these threats do have the potential to improve conditions for some taxa, particularly common, fast adapting and introduced species.

The lack of available baseline knowledge specific to the Gnangara Mound on the taxonomic, biogeographical and ecological values of the terrestrial invertebrates presents a situation where management decisions are currently made based on potentially inappropriate data (either based on a different taxonomic group, landscape type, vegetation type or region) and generalised assumptions. Unlocking the data that is in local collections (by databasing) and focussing knowledge gain on the most at risk communities (associated with TECs) would provide an appropriate first step in understanding the terrestrial invertebrate communities on the Gnangara Mound.

Acknowledgments

I would like to thank all the local terrestrial invertebrate experts who gave up their valuable time to discuss this project. Dr. Mark Harvey, Dr. Terry Houston, Shirley Slack-Smith and Dr. Bill Humphreys for allowing access to the W.A. Museum's database. Andras Szito for access to Agriculture W.A.'s database. Dr. Allan Burbidge and Dr. Stephen van Leeuwen for their review of the draft version. The GSS workers at DEC Wanneroo for all their help with GIS data and references. The funding for this report was via the Western Australian Department of Environment and Conservation's contribution to the Gnangara Sustainability Strategy (GSS).

Table of Contents

List of Tables

List of Figures

1.0 Introduction

The Gnangara Sustainability Strategy (GSS) covers an area of 200 km^2 between the Swan River in the south, Moore Rover and Gingin Brook to the north, the Darling Scarp to the east and through to the coastline in the west (Figure 1). The area forms part of the Swan Coastal Plain, contains all of the north metropolitan area of Perth and overlies the Gnangara Mound. Extensive urbanisation coupled with significant agricultural use and extensive forestry practises has left much of the remaining native ecosystems highly fragmented and under continual pressure from several threatening processes. In addressing these threats the biodiversity values of the Gnangara Mound need to be assessed.

Invertebrates play essential roles in the functioning of ecosystems such as nutrient cycling, litter decomposition, and plant pollination (CONCOM 1989) and these functions may be compromised with long term reduction of invertebrate biodiversity (Van Heurck 2003). These direct effects are relatively easy to identify, and quantify, but the indirect ecological benefits can be easily overlooked as they are far less tangible. These include ecosystem stability, contribution to overall diversity and their role in natural systems that result in clean air and water, for example in karst systems. In terms of described species, arthropods are numerically dominant, comprising over 62% of all organisms and over 82% of all animal species (Hammond 1992; Hawksworth and Kalin-Arroyo 1995). In terms of biomass, invertebrates usually exceed that of vertebrates in the same area (New 1995) with ants alone believed to constitute about 30% of global terrestrial fauna biomass (Holldobler and Wilson 1991).

Invertebrates will, therefore, be an important component worthy of serious considerations in future plans for sustainable management of the GSS. This report aims to review existing knowledge of terrestrial invertebrates on the Gnangara Mound area, their biogeography, ecology, threats and conservation priorities.

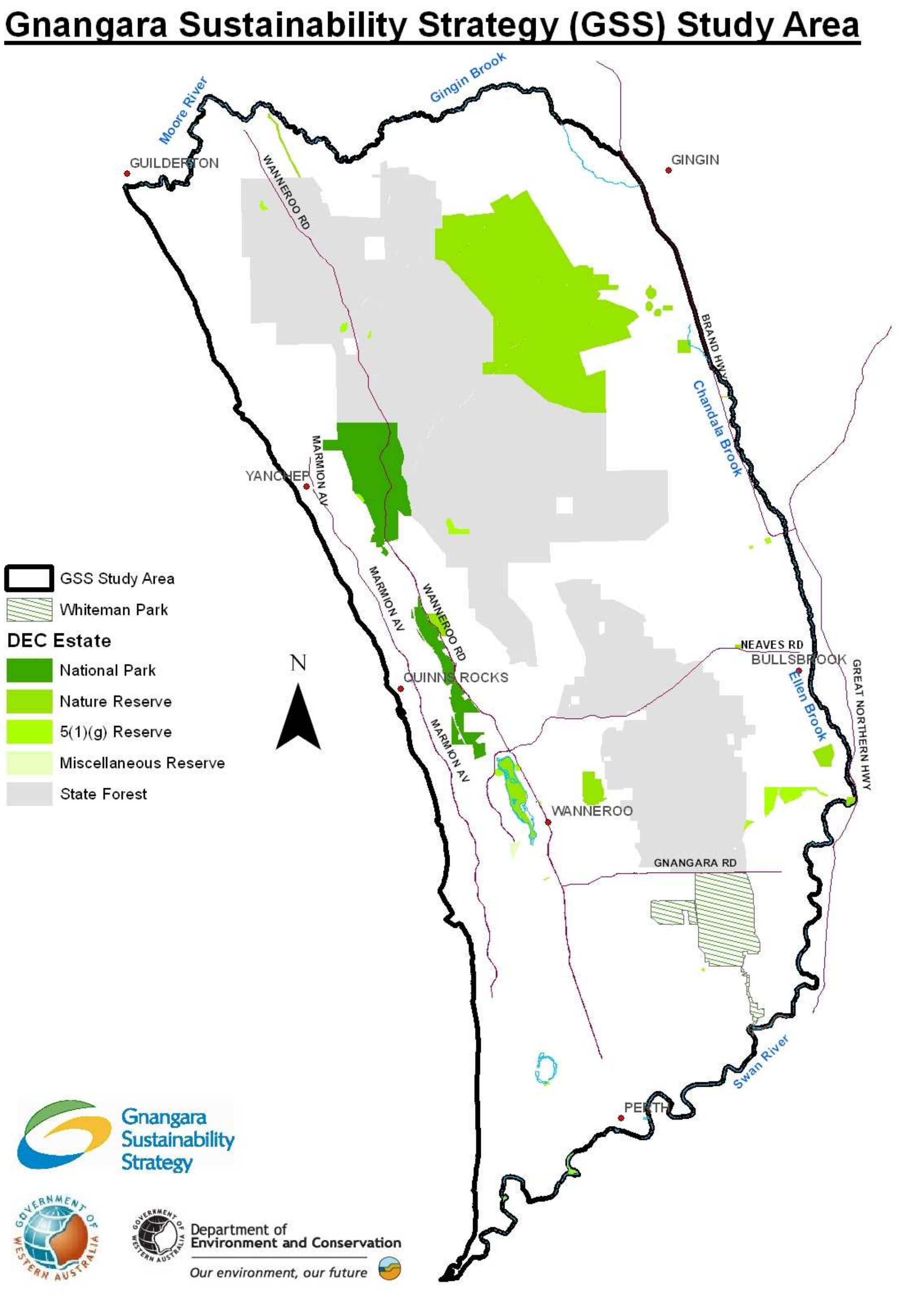

Figure 1: Map of the GSS study area.

2.0 Existing Knowledge and Data

The literature and relevant databases were assessed to gain an understanding of the extent of the knowledge available, the usefulness of this data in assessing the invertebrate biodiversity values of the GSS study area and the gaps that may hinder such an assessment.

Much of the work has been carried out by university staff and students, CALM/DEC and the Western Australian Museum (WAM) and covers a wide range of taxonomic groups. The majority of the work has been based on single taxonomic groups and the influence of environmental factors, natural and man-made, on their diversity, distribution, life history, etc.

Only two surveys have been conducted that have taken into account more than two taxonomic groups over a range of locations: Koch and Majer (1980) and the Urban Bushland Survey (UBS) (How *et al.* 1996; Harvey *et al.* 1997). Both of these looked at ground dwelling arachnids plus millipedes, centipedes, isopods, earthworms and land snails in the former and centipedes, cockroaches and baeine wasps in the latter. The UBS in particular has provided some baseline data for the Swan Coastal Plain. However with the high frequency of collection of unknown species the use of these data is limited until the relevant collections can be taxonomically standardised and ‘new’ taxa formally described. The inability to link one unknown species with the same entity from a different study is one of the biggest impediments to direct comparison between invertebrate datasets.

A number of individual taxonomic groups have been targeted for examination through the GSS area. These are terrestrial isopods (Judd 2004), carabid beetles (Guthrie 2001), earthworms (Abbott and Wills 2002) and ants (Rossbach and Majer 1983). All but Guthrie also surveyed outside of the GSS area, providing some wider context.

Other work in the area has focussed on the effects of fire (Koch and Majer 1980; Ladhams 1999; Radho-Toly *et al.* 2001; Williams 2003a; Main and Carrigy 1953; Barendse *et al.* 1981), fragmentation/disturbance (Harvey *et al.* 1997; Guthrie 2001; Majer and Brown 1986; Burbidge *et al.* 1992), introduced species/pests (Yates *et al.* 2005; Anjos *et al.* 2002; Paini 2004; Paini *et al* 2005) and natural vegetation/landscape variation (Harding 2000; Abbott and Wills 2002; Rossbach and Majer 1983; Judd 2004).

The two main databases of relevance to the study area are the WA Museum databases and Curtin University's ant collection database. Other databases available that also cover the GSS area have limited information for the Swan Coastal Plain. The Curtin University ant collection is fully databased with standardised names, making it an extremely useful tool for any ant studies in WA. The WA Museum databases are far less complete and comprise four different terrestrial invertebrate groups; insects, arachnids, terrestrial molluscs and troglofauna.

Within the two larger WAM databases, arachnids comprise 2384 records and insects 2209 records. The vast majority of the records can be broken down into four main types of species.

<u>Backyard species</u>: This group consists of animals that occur commonly around homes in the metropolitan area. Of particular note are the web-building spiders like *Minax* (Christmas spider), *Nephila* (golden orb spider), *Eriophora* (garden spider) and *Latrodectus* (redback spider), and wandering male trapdoor spiders that emerge after rains.

<u>Aesthetic/large species</u>: Species that stand out also constitute a large proportion of the database and overlap significantly with the previous group, i.e. many backyard species that are collected tend to be highly noticeable, like *Minax* and *Nephila*. Other non-backyard fauna that are commonly collected for their aesthetics include jewel beetles, dragonflies and butterflies.

<u>Local experts</u>: Much of the taxonomic work carried out at the WA Museum is, not surprisingly, driven by the interests of the research staff. Three commonly databased groups that illustrate this are the bees with 720 records (Dr Terry Houston), millipedes with 124 records (Dr Mark Harvey) and trapdoor spiders with 470 records (Dr Barbara Main).

<u>Recent taxonomic revisions</u>: A number of major arachnid taxonomy projects are underway or have been completed recently, and this is reflected in the arachnid

database. This has resulted in there being a large number of scorpions, Lamponidae and Lycosidae (wolf spiders) in the database.

These four groups constitute the vast majority of records in these two major databases but is a poor reflection of the true makeup of the WAM invertebrate collections. The two major impediments to the databasing of the collections is the lack of taxonomic work on many of the groups, meaning difficulties with sorting and standardising taxonomic units, and funding for both databasing and taxonomic work.

The mollusc database comprises terrestrial snails of which the vast majority (156 of 176 records) are from the genus *Bothriembryon*. This genus dominates the database for a range of reasons, for example members of this genus are large and the most noticeable land snails in the area and through the south-west. Secondly the genus is considered to have significant numbers of SRE taxa, primarily because of the inability of terrestrial snails to disperse. These two aspects of the group make it a high priority genus for invertebrate surveys. This has lead to funding being made available for taxonomic work and databasing (S. Slack-Smith, pers.comm). All the other databased taxa are from small snails that have been collected opportunistically.

The troglofauna database is based on a small amount of collecting at the Yanchep cave system. The collecting has been purely opportunistic and carried out by local speleologists. There has been no systematic survey of the Yanchep cave system for terrestrial invertebrates.

From the knowledge available in past research and databased collections there is little doubt that our understanding of the northern Swan Coastal Plain is extremely deficient. With such a high probability of encountering unknown species and little standardisation of taxonomic names the possibility of gaining an understanding of the true biodiversity values of the GSS study area based on our current knowledge of the fauna is very low.

3.0 Species richness and endemism

Terrestrial invertebrate numbers are difficult to estimate and are usually based on numerous assumptions depending on the type of study that the figures are drawn from. An example is the work of Erwin (1982) where he used his study on beetles in the canopy of the tropical species *Luehea seemanii* in Panama to formulate an estimate of global numbers. Using assumptions on the rate of host plant specificity and beetles comprising 40% of arthropod species, his study came up with an estimate of around 30 million global terrestrial invertebrate species, a figure many regard toward the upper limits of the true numbers. In the late eighties there was approximately 1.4 million described species of terrestrial invertebrates (Council of Europe 1987) with approximately 15-20 000 new species added each year (CONCOM 1989), so as a conservative estimate the current number of described species would be around 1.7 million.

Table 1 highlights the diversity of terrestrial invertebrates in Australia, with estimates of currently known families and species of major groups (Australian Faunal Directory). This is compared to the vertebrate fauna numbers on the right hand side of

Group	Families	Known Species	Group	Families	Known Species
Insects	1669	49 698	Amphibians	5	226
Spiders	82	3 033	Birds	186	869
Mites	400	2 871	Reptiles	16	917
Land snails	81	1 087	Mammals	48	386
Isopods	22	200			
Millipedes	37	230			
Earthworms	23	903			
Pseudoscorpions	39	161			
Harvestmen	28	199			

Table 1: The known diversity of terrestrial invertebrate groups in Australia (Australian Faunal Directory).

the table. The estimated number of Insecta are lower than recorded by CSIRO (1990), with numbers at 86 000. It is not clear why there is this discrepancy.

Hopper *et al.* (1996) tabled estimates of the various components of the Western Australian biota and rates of endemism. The terrestrial invertebrate estimates are shown in table 2. These estimates are largely based on the Western Australian Museum databases and local experts and need to be taken within the context that most of the State has not been surveyed for terrestrial invertebrate groups.

Groups	No. Species	% Endemism	Authority
INSECTA	c. 50 000	?	W.A. Museum unpubl. data
Butterflies	116	16%	Hay *et al.*, 1995
MYRIAPODA	c. 1000	c. 75%	M. Harvey unpubl. data
CHELICERATA	c. 10 000	c. 60%	M. Harvey unpubl. data

Table 2: Estimates of species richness and endemism in some terrestrial invertebrate groups in Western Australia.

However there have been four regional biodiversity surveys where ground-dwelling invertebrates have been a major component: the Kimberley rainforests, the Southern Carnarvon Basin survey, the Western Australian Agricultural region (Wheatbelt) survey and the Pilbara Region Biological survey. This work, although not covering the GSS study area, has provided us with an understanding of terrestrial invertebrate biodiversity values elsewhere in the State.

3.1 South West Western Australia as a biodiversity hotspot

The south west of Western Australia is internationally recognised as one of the world's top-20 biodiversity hotspots (Myers *et al.*, 2000) due largely to the remarkable radiations of the vascular flora. However it has become increasingly obvious that many terrestrial invertebrate groups are also highly diverse with very high levels of endemicity (Hopper *et al.*, 1996).

The only estimate of terrestrial invertebrate diversity in the south west has been by Abbott (1995), who aimed to summarise the current knowledge on forest entomology in Western Australia. Named species recorded totalled 1 747, occurring in 235 families and 24 orders. From this, four estimates were calculated in the hope of providing an insight into the true diversity in the south west forests. The estimates vary widely from 12 000 to 25 000, based on different approaches, but overall the suggestion is that only 10% of the fauna has been described (Abbott 1995).

The Department of Environment and Conservation's Agricultural Region survey can also provide some insight into the diversity of the south west. The araneomorph spiders were identified from this survey, which covered over 200 000 km^2 of the south west. From 304 quadrats a total of 622 ground dwelling araneomorph spider species were recorded at an average of 22 species per quadrat. In contrast the recent Pilbara Biological survey, in the northwest of Western Australia (Figure 2), captured 375 (from 294 quadrats over 180 000 km^2) ground dwelling spiders at an average of 13 species per quadrat and in the Carnarvon Basin survey 285 species (63 quadrats).

Another taxonomic group that has been covered extensively in the south west is the ants. Heterick (in press) has 498 species recorded from the South West Botanical Province (SWBP), as shown in figure 3. This compares to 743 species throughout the State.

These figures need to be taken in light of the limitations of direct comparison because of differences in sampling effort and technique, targeted species, etc. However they do give some indication of the south west being particularly rich for terrestrial invertebrates.

3.2 Swan Coastal Plain and GSS Study Area

There have been few studies where one of the primary aims was to document a component of the terrestrial invertebrate fauna on the Swan Coastal Plain.
The Urban Bushland Study (UBS) (How *et al.* 1996; Harvey *et al.* 1997) looked at selected terrestrial invertebrates from urban bushland remnants on the Swan Coastal Plain and is the only major biological survey in the area to sample this fauna. From 13 study sites the survey documented 148 spiders, 13 other arachnids, eight centipedes, 10 millipedes, one symphylan, 33 cockroaches and 25 baeine (parasitic) wasps. Of these, several spider families had not been recorded previously from the Swan Coastal

Plain and are normally rare in Western Australia. The survey also recorded two spider subfamilies and one wasp family not recorded previously in WA, one pseudoscorpion subfamily believed to be endemic to South Africa and a pseudoscorpion genus only

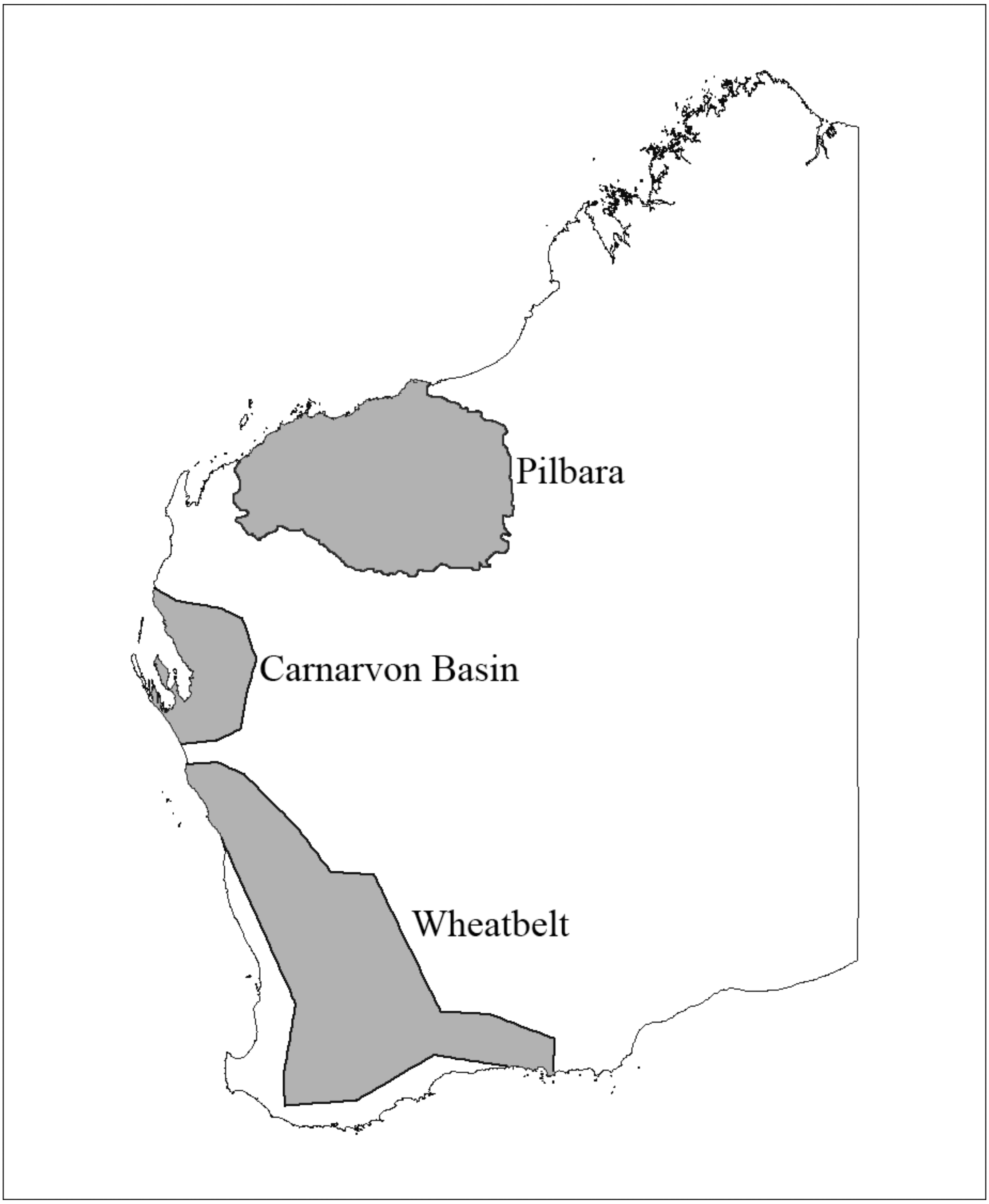

Figure 2: Map showing extent and placement of the Pilbara, Carnarvon Basin and Wheatbelt surveys in Western Australia.

known previously from the Aldabra Islands and Florida (United States). These significant discoveries, coupled with 82% of the spider species being new to science, show how little knowledge we have of the terrestrial invertebrates on the Swan Coastal Plain.

In terms of endemicity, 36.5% of the total invertebrate species in the survey

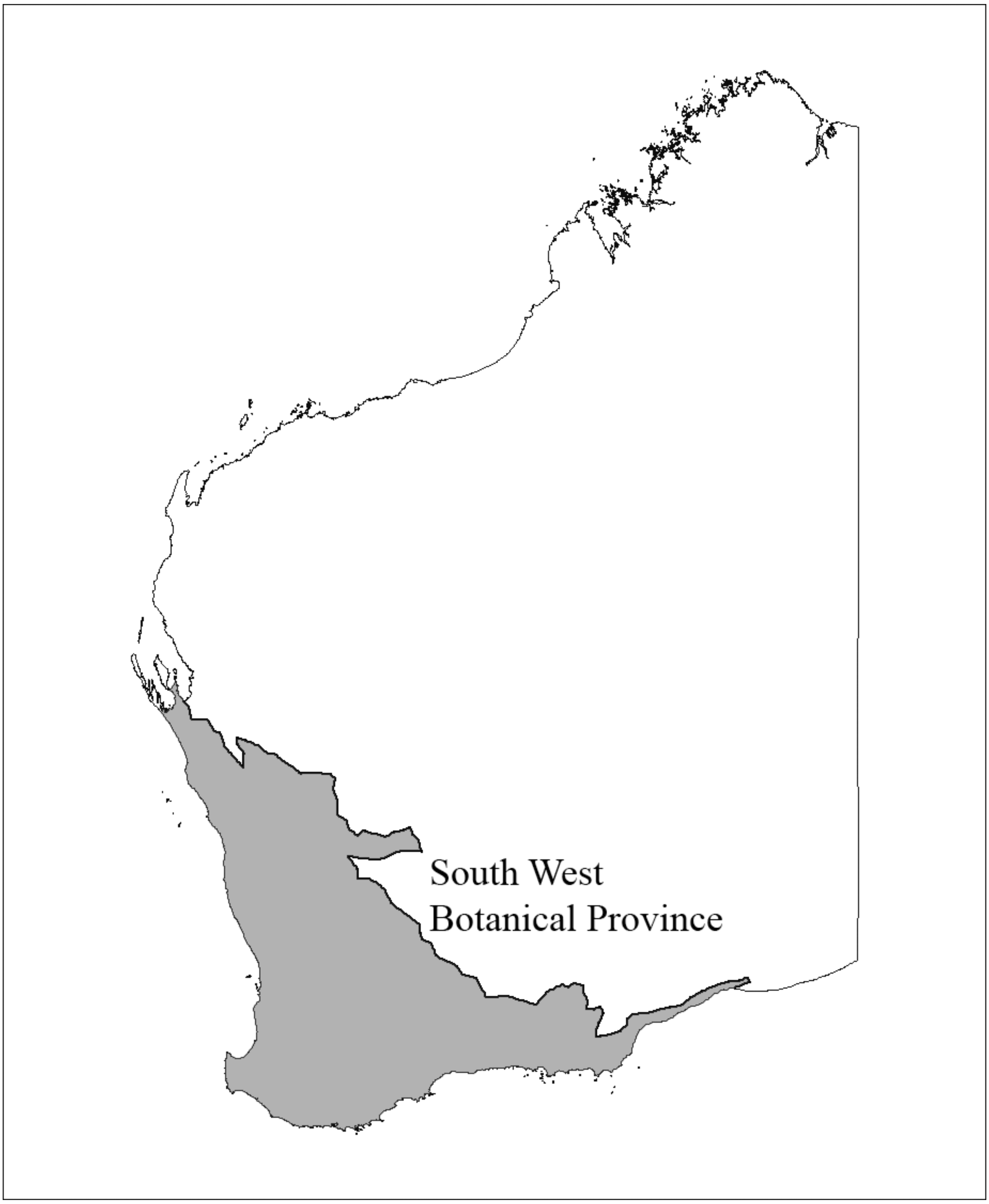

Figure 3: Map showing the extent and placement of the South West Botanical Province.

were recorded at only one location. The authors caution against using this figure as a clear indication of extreme endemism for two reasons. Firstly that some of the species were already known from outside of the Swan Coastal Plain and, for any number of reasons, the species was only found at one location during this survey. Secondly the sampling bias towards ground dwelling invertebrates, through the sole use of pit trapping, means arboreal species will appear far less frequently than they actually occur.

Heterick (in press) has summarised the ant fauna of the South West Botanical Province (SWBP) and provided data based on the IBRA regions. Table 3 below shows the total numbers of species in each IBRA region and the current known level of endemicity.

IBRA Region	No. of Spp.	Rate of Endemism (%)	Area/No. of Spp
Swan Coastal Plain (SWA)	218	7%	6979
Geraldton Sandplains (GS)	228	15%	16587
Avon Wheatbelt (AW)	268	17%	35130
Jarrah Forest (JF)	273	14%	16855
Mallee (MAL)	130	2.3%	61457
Warren (WAR)	93	4.3%	11234
Esperance (ESP)	156	6.4%	22805

Table 3: Summary of ant species numbers and rates of endemism in the South West Botanical District.

Compared to some of the other south west IBRA regions the Swan Coastal Plain has a moderate number of species and rate of endemicity, however when the size of the IBRA region is taken into account the Swan Coastal Plain has the highest ratio of species to area, although the amount of collecting on the Swan Coastal Plain will likely be significantly higher than in most of the other regions. Also, the rates of endemism in the Geraldton Sandplains and the Avon Wheatbelt are likely lower than indicated because one or more adjacent regions have not been included in this study, and as such many species that are regarded as endemic may well occur in these adjacent regions.

Another group that has undergone targeted study on the Swan Coastal Plain is the earthworms. Abbott and Wills (2002) collected 21 native earthworm species from the metropolitan area of the Swan Coastal Plain. Of these, five previously been described, three were known but not formally described and 13 previously unknown. Restrictive distributions were found for 14 species, four were only found north of the Swan River, nine were restricted to south of the Canning River and one between the Swan and Canning Rivers. The Swan River appears to act as a physical barrier for four species and the Canning an apparent barrier for 13 species (Figure 4) (Abbott and Wills 2002). The distribution of several species may be correlated to geomorphic units, but many of these species were only recorded less than three times, meaning that sampling artefacts may be influencing apparent distributions.

One other major taxonomic work is on terrestrial isopods in the south west by Judd (2004). The 70 taxa (of which 80% appeared to be new) showed a very high diversity with both widely distributed taxa and highly localised endemics. For the entire south west region a biogeographic model was derived, separating the fauna into ten distinct zones, see figure 5. Three of these zones cover the Swan Coastal Plain with zones 1, 2 and 3 having richness of 27, 13 and 30 respectively and rates of endemism of 7.4%, 0% and 10%. These three zones, along with the tall, wet southern forests, was seen as being particularly rich.

The final major work on the Swan Coastal Plain is the ground beetle (Carabidae) fauna surveys by Guthrie (2001). This study used material from the Urban Bushland Survey (How *et al.* 1996; Harvey *et al.* 1997), and new material collected specifically, from 14 bushland remnants (39 sites). Guthrie found the diversity of carabids (37 species) to be comparable to that reported for other Australian habitats. Carabid richness was found to increase toward the centre of the Swan Coastal Plain, with a range of one to 11 species. Seventeen species appeared to be restricted to a single geological system, with most restricted to either the Quindalup or Bassendean dune systems. However most of these are volant species which are not sampled reliably by pit trapping.

These major studies have given an indication of the richness and endemicity of the south west and the Swan Coastal Plain. However given the paucity of major studies and large gaps in the databases available it is very difficult to directly compare regions to gain a quantitative perspective.

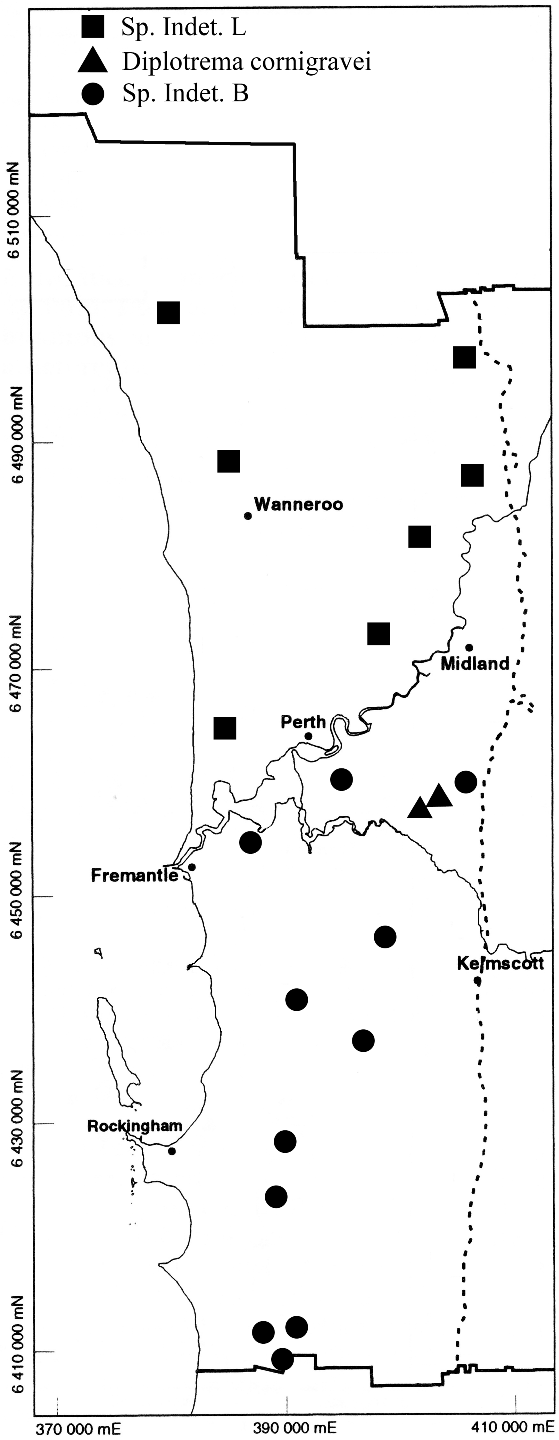

Figure 4: Map showing the Perth Metropolitan area indicating the Swan and Canning rivers with examples of restricted earthworm distributions (Modified from Abbott and Wills 2002).

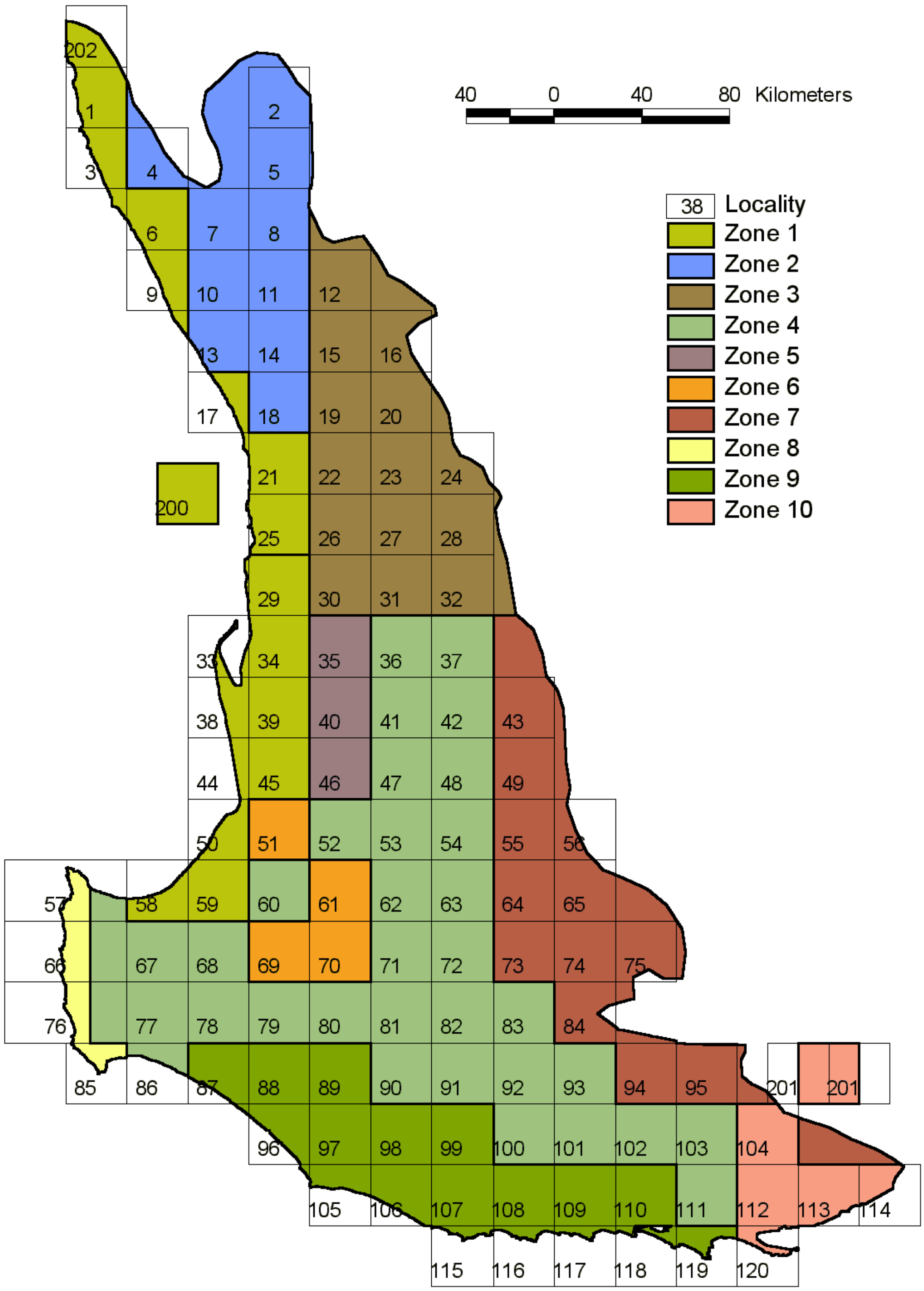

Figure 5: Biogeographical model of the south west in ten zones (From Judd 2004).

3.3 Limiting Factors

Species richness and endemicity are potentially affected by a wide variety of different environmental and biological factors depending on the taxa involved. This section is aimed at providing an overview of the types of factors that can limit species richness and distribution. As there is limited to no knowledge for most groups, specific to the GSS study area, many examples are taken from the south west. Disturbance such as fire will not be discussed in this section as this is covered later in the report.

3.3.1 Habitat level factors

Soil and Litter

At this scale we are primarily dealing with species richness and the factors that allow a greater variety of organisms to coexist. There is also a degree of endemism associated with the habitat scale, a degree that would generally be seen as extreme endemism, or one associated with isolated habitats or pockets of refugia. As a general rule species richness in a habitat will be driven by its heterogeneity or complexity; the more complex the architecture of the habitat the greater the diversity of species (Hatley and MacMahon 1980).

A number of terrestrial invertebrate groups have shown relationships between habitat complexity and species richness including spiders (Halaj *et al.* 1998), ants (Lassau and Hochuli 2004), bees and wasps (Lassau and Hochuli 2005; Loyola and Martins 2008), beetles (Lassau *et al.* 2005), soil mites (Hansen 2000) and soil arthropods (Loyola *et al.* 2006). Habitat complexity is comprised of a range of physical and chemical attributes, in particular soil, litter (ground structure) and vegetative structure.

In the south west, soil and litter invertebrates have had some attention in regards to the influence of habitat scale variables. Di Castri (1973) showed that soil invertebrates are affected by soil organic levels, rather than moisture levels. Similarly McNamara (1955) found humus layer invertebrates in the south west are most diverse in shaded soils with a high organic content. The organic content of soil is largely determined by the litter input from the vegetation (Curry 1998).

Earthworms have been shown to be affected extremely by soil moisture, with mortality in temperate soils attributed to moisture shortages (Curry 1998). Abbott (1994) looked at the continent wide localities of available earthworm collections and found that they were restricted to the wetter margins of the continent and refuges in the interior which protected them from the extremes of soil dryness. In southern Australia rainfall accounted for more earthworm population variations than any other factor (Baker 1998). Abbott (1985) showed a gradient of annual rainfall was most important in predicting an increase in richness in the northern Jarrah forest of WA. With the climatic variables removed total potassium became most important. On the Swan Coastal Plain Abbott and Wills (2002) concluded that the low diversity was attributable to the low annual rainfall, poor soil fertility and simplified geomorphology.

A direct influence of soil type was found in the south west with soil and litter invertebrates across a range of classes. The lateritic “ironstone gravel” of the northern Jarrah forest had higher richness of soil and litter species than the loamy sites of the adjacent Murray River valley. However soil type didn’t change the richness of ant assemblages across the Swan Coastal Plain, although the composition of the assemblages did (Rossbach and Majer 1983).

The araneomorph spider work in the Western Australian wheatbelt (McKenzie *et al*. (2003); Harvey *et al.* 2004; Guthrie and Waldock 2004; Durrant 2004) revealed distinct relationships with rainfall and some broad soil characteristics. Of most note was the negative correlation between richness and salinity, both primary and secondary, except for the family Lycosidae (wolf spiders). This family however is often confined to riverine margins, sand dunes and salt lakes (McKay 1979; Hudson and Adams 1996; Moring and Stewart 1994). Durrant and Guthrie (2004) found that the inundated floors of WA salt lakes had distinct assemblages associated with them, with more than 120 species of terrestrial invertebrates not found in the adjacent woodland. There was also very few shared species between different lake systems, although the work was at a regional scale and none of the lakes were close to each other so the extent of local endemism is difficult to ascertain.

Soil texture and moisture retention capacity also plays a role in mygalomorph (trapdoor) spider distributions. With many trapdoor spiders being Gondwanan relicts they are particularly sensitive to unsuitable habitats. Along with soil qualities many rely on topography, vegetation and shade, litter cover and prey potential as fairly critical habitat variables (Main 1996).

From predators to detritivores, terrestrial isopods, at the habitat level, are more sensitive to superficial geology, site productivity and the nature of the surface organic matter. Organic matter was the primary factor in the wetter forested areas of the south west but in the northern region (including the Swan Coastal Plain) the physical properties of the habitat also played an essential role. This is likely due to the greater potential for drying out of the habitat and thus certain physical aspects (such as vegetation cover, slope and soil type) of the habitat can protect against this (Judd 2004).

One of the other major contributors to the complexity of a habitat is leaf litter. There are two main aspects to litter that contribute to its suitability and the structure of its invertebrate community; condition (Bultman and Uetz 1982; Schowalter 1985), including nutritional value, allelopathic content, temperature and moisture (Spain and Hutson 1983; Schowalter 1985) and its capacity as a habitat, including structural complexity, prey resources, litter energy content and microclimate (Uetz 1979). Ladhams (1999) took a range of leaf litter measurements as habitat variables to test against fire disturbance and spider and beetle communities. While there were few direct observations of the influence of litter on the spider and beetle populations, some relationships were revealed. The reliance of ground dwelling hunting spiders, in this case two lycosid (wolf spiders) species, on the availability of open ground was apparent. This was consistent with previous work by Uetz (1991) who observed lycosid abundances being higher in shallow compressed litter, and Bultman and Uetz (1982) who noted a negative relationship between litter depth and hunting spiders.

Arboreal/canopy

Canopy invertebrates have also been studied regularly in the south west as well as the bark communities, although less frequently. Like leaf litter bark has physical properties that make it appear to be more or less conducive to having rich invertebrate assemblages. Some previous work has suggested that smooth bark had less capacity for rich communities because of fewer microhabitats and less protection against harsh climatic conditions (Nicolai 1986, 1989), which was found for temperate forests in Europe (Nicolai 1986) and North America (Nicolai 1993). Majer *et al.* (2003) however found that the smoother bark of the wandoo and powderbark wandoo had much higher richness of invertebrates than the thicker more structured bark of Jarrah and Marri. One possible explanation was related to the differences in bark nutrients and other compounds, which play a role in bacteria, fungi and algae growth, but these variables were not recorded for this study. The more likely explanation is in the use of the trunk by ground and canopy dwelling invertebrates. Most likely the majority of the invertebrates found on the trunks, particularly on smooth bark species, are from either the canopy or the litter (Majer *et al.* 2002). This explanation fits in with previous findings by Majer and Recher (1988) that the canopy fauna of wandoo woodlands were richer than those of Jarrah and Marri. This work also highlighted the importance of trunks in facilitating the movement of insects through the forest with many bark species being caught in intercept traps.

With canopy invertebrates much of the focus has been on foliage and soil nutrients and their role in invertebrate diversity. Comparison work between Western Australian eucalypts and ones on the richer soils of the eastern states have shown a positive correlation between soil richness and richer canopy faunas (Majer *et al.* 1990, 1996, 2000; Recher *et al.* 1991, 1996a,b). Majer *et al.* (1992) also found much higher levels of foliar nitrogen and phosphorous in the eastern states eucalypts compared to the WA ones. This differed slightly from Majer *et al.* (2003) where wandoo and powderbark wandoo did not have consistently higher soil nutrients than the Jarrah and Marri at one of the sites. They were however lower in the landscape where moisture retention is much greater (McArthur 1991). Tassone and Majer (1997) also showed that the number of canopy invertebrates is not correlated with greater amounts of foliage.

3.3.2 Landscape to regional scale

At a wider scale richness, and in particular species distributions (endemism) are influenced by factors such as climate, topography, geomorphology and vegetation types. In the south west, at the biogeographic scale, animal and plant distributions are correlated with the rainfall gradient and the length of the summer drought (Beard 1990; Hopper *et al.* 1996). All these factors also potentially influence the habitat variables already discussed.

At broad feeding groups Koch and Majer (1980) looked at predators and decomposers and the influence of seasons on species richness. Decomposers on the Swan Coastal Plain, and just south east of the area (Dwellingup), had winter/spring activity correlated with the previous month's rainfall and relative humidity on the Swan Coastal Plain and previous month's rainfall at Dwellingup. The Swan Coastal Plain site had a shorter period of activity though, most likely associated with the eastern sites higher rainfall and humidity allowing a longer active season. At a further southern site (Manjimup) there was a lack of decomposers with the authors offering four explanations: unsuitability of low winter temperatures; unsuitability of extremely wet winter soils and litter; greater suitability of available summer rainfall or sampling artefacts. It is likely that all of these contribute in some way. Predators were found to be active throughout the year, except for decreases in activity associated with cool, moist conditions at the Dwellingup and Manjimup sites.

Climate, and particularly seasonality relating to rainfall, has been briefly discussed in terms of habitat level influences. In a wider context Abbott (1994) found few earthworms at sites with less than 400 mm of annual rainfall, and when they were present in these unfavourable conditions local aspects became more important. Wills and Abbott (2003) however also found that even when rainfall conditions are favourable refuge from insolation, through aspect and vegetation cover, are important. Jarrah forest earthworms are active (recorded in the upper 5.5cm of soil) only from May to November, thanks principally to the long, warm, and effectively rainless summers (Abbott 1985).

In the northern Jarrah, species richness of forest soil and litter invertebrates was highest during autumn, followed by winter, spring and then summer. Individual taxa and entire taxonomic groups showed preferences towards particular seasons (e.g. hymenoptera in early summer; collembola in autumn and winter) (Postle *et al.* 1991).

Recher *et al.* (1996), in comparing canopy invertebrate communities between eastern states and WA eucalypt forests, noted the higher seasonal variability in WA. This is most likely attributable to the more pronounced seasonal pattern of a Mediterranean climate in WA, where cold and wet winters followed by a hot and dry summer could limit arthropods. These seasonally dry landscapes have been shown to place restrictions on some invertebrate groups, for instance land snails, where assemblages tend to form in areas of greater moisture stability (Solem and McKenzie 1991; Stanisic 1997).

Harding (2000) also found that season played a major role in beetle activity. Autumn and spring were extremely important for overall beetle activity while winter had very low activity. Also at the family level, the Scarabeidae were most active during summer and the Heteroceridae during winter.

Terrestrial isopods in the south west have also been found to be influenced by steep rainfall gradients and the seasonality of rainfall, in combination with the physical attributes of the habitat. Two centres of high richness were found, one around Perth on the Swan Coastal Plain, and the other in the wet southern forests. The latter was found to have much higher numbers of localised endemic species (Judd 2004). As well, the distribution of scorpions in Australia suggests that temperature and rainfall patterns are the main influences, with little effect from vegetation and soil properties (Koch 1977; Polis 1990).

Differences in terrestrial invertebrate communities across vegetation types have also been studied in the south west with mixed results. We have already seen that differences occur between Jarrah and Marri and wandoo woodlands, both in diversity and composition. For ants Rossbach and Majer (1983) found no change in richness along two transects from the coast to the scarp on the Swan Coastal Plain, despite change in vegetation type and soils type. Similarly Harding (2000) found no difference in beetle species richness between Banksia woodlands, pasture and wetlands. For both these studies there were changes in species composition but not richness.

Physical barriers can also create areas of endemism by limiting further distribution. One example on the Swan Coastal Plain comes from the earthworm research by Abbott and Wills (2002). The Swan and Canning rivers break the northern Swan Coastal Plain into three parts, of which a number of earthworm species appear to be restricted, north of the Swan river, south of the Canning and in between the two water courses. These barriers are likely to be present for many non-volant species or species without some form of aerial dispersal.

The dune systems of the Swan Coastal Plain have also shown on numerous occasions to have some level of endemism associated with them. Harvey *et al.* (1997) found that there was an influence of landform on diversities but it wasn’t paramount, with the two sites on the Quindalup dune system showing the strongest similarities. Guthrie (2000) found the different landforms had different carabid beetle assemblages associated with them but no differences in richness. Earthworm diversity increased across the Plain from the Quindalup to the Spearwood and the Bassendean, but Abbott and Wills (2002) were unclear as to whether it was a reflection of the landform units themselves or species-area effects or habitat diversity. The ants showed similar to Harvey *et al.* (1997) in that the composition of the ant fauna changed across the units with little change in diversity (Rossbach and Majer 1985).

Overall there are numerous external factors that can play various roles in expanding or inhibiting richness and species distributions. It is clear that in the south west, including the Swan Coastal Plain, that moisture plays an extremely important role for many taxonomic groups, either directly though rainfall, seasonality and moisture retention properties of the landscape, or indirectly through the effect of moisture on vegetation, litter and decomposition. Such factors are likely, therefore, to be driving invertebrate species richness and assemblage composition in the GSS.

4.0 Significant Fauna

4.1 Known priority taxa

There are three listed priority invertebrate fauna species currently found in the GSS area. These are the graceful sun moth *Synemon gratiosa* Westwood (1877) and the two native bees, *Leioproctus douglasiellus* Michener, 1965 and *Neopasiphe simplicior* Michener (1965).

Synemon gratiosa

Synemon gratiosa is listed federally as Endangered under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999 and as Schedule 1 Rare or likely to become extinct under the WA Wildlife Conservation Act 1950. The graceful sun moth is restricted to the Swan Coastal Plain between Wanneroo in the north and Mandurah in the south. At least nine subpopulations have been recorded, all in very small areas of bushland, and numbers are very low (WAISS 1997; WA CALM 2005).

The graceful sun moth is a diurnal moth, similar in appearance to a butterfly, with brightly coloured hindwings and clubbed antenna (Common 1990; Nielson *et al.* 1996). Males establish small territories in open areas, often utilising tracks or firebreaks, making them easier to detect. Females however are believed to use male avoidance strategies after mating, a common behaviour in similar species. This is reflected in approximately 90% of detections being males (WA CALM 2005).

This species is under threat from a few quarters. Urban development has, in the past, been a major threat, although current known populations are now within areas set aside for conservation. These are either formal reserves or Bush Forever sites, although the latter does not provide as much security from clearing as the formal reserve system. The use of tracks by males makes them vulnerable to harm through recreational use by four wheel drive vehicles and maintenance work including grading and weed management (WA CALM 2005). Williams (2003) noted the vulnerability of the early stages of butterflies and diurnal moths to fire, both because of direct mortality from the fire and the loss of food supply afterwards. This, coupled with the species likely short (100 m) dispersal range and inability to disperse over unsuitable habitat (Williams 2003), makes recolonisation from unburnt areas very unlikely.

Neopasiphe simplicior

Neopasiphe simplicior Michener (1965) is listed as Critically Endangered under the federal EPBC Act 1999 and Schedule 1 Rare or likely to become extinct under the WA Wildlife Conservation Act 1950. This species is currently known from only one location, Forrestdale Lake Nature Reserve. With only 20% of all the original Swan Coastal Plain wetlands still remaining, it is extremely likely that any other suitable habitat for this species has been cleared (Houston 1994).

N. simplicior is a black, short tongued bee, smaller than other species belonging to the same genus. The species has been associated with the flowers of *Goodenia filiformis*, *Lobelia tenuior* and *Angianthus preissianus* (Houston 2000).

Past threats to the species include land clearing, draining of winter-wet depressions and fire (Houston 1994). It is also possible that competition from introduced honeybees may be a threat (Houston 2000). The threat of land clearing has been reduced due to the Nature Reserve (Class A) status of the bushland remnant. A large fire however could very well destroy the suitable habitat. The potential for climate change to impact on the wetlands is also a concern.

Leioproctus douglasiellus

Leioproctus douglasiellus Michener (1965) is not listed under the Commonwealth EPBC Act but is listed as Schedule 1 Rare or likely to become extinct under the WA Wildlife Conservation Act 1950. This species is known only from a few museum specimens from Pearce, WA in 1954 and Forrestdale Lake Nature Reserve in 1988, the same location as *Neopasiphe simplicior*. The only population considered to be extant is at Forrestdale Lake Nature Reserve.

The species is from the same family as *N. simplicior*, the Colletidae, commonly known as short tongued bees. It has been collected from flowers of *Goodenia filiformis* and *Anthotium junciforme*.

The threats to this species are the same as for *N. simplicior*.

4.2 Special habitats

Special habitats, or environments, can be viewed essentially as islands surrounded by a matrix of less favourable habitat and represent pockets of special and/or threatened insect diversity (Slaney and Weinstein, 1996). There are three types of specialised habitats unique to the GSS area, and these are listed as critically endangered Threatened Ecological Communities (TECs). They are the Yanchep Cave system, the Tumulus Mound Springs and the Northern Ironstones.

Yanchep Caves

The limestone cave system at Yanchep, in the northern part of the GSS, is a groundwater fed karst system consisting of more than 400 caves. The focus of much of the work at Yanchep has been on the aquatic root mats that are present in a handful of the caves that contain permanent water, a requirement for the persistence of the root mats. The terrestrial fauna of the cave system is poorly sampled with around 150 records in the WA Museum database, of which nearly all are identified only to Order. The fall in the water level in the Gnangara mound over the last 30 years has been largely attributed to decreasing rainfall, but there is a firm belief by Yanchep cave experts that climate alone cannot be wholly responsible as there have been much drier periods in the past and the communities have managed to survive (Blyth *et al.*, 2002). Some of the cave streams supporting the root mats have stopped running in summer, something that resulted in the complete loss of the root mat community in Gilgie Cave in 1996 after it completely dried out. Watering systems are now used to prevent the further loss of Yanchep cave root mats.

Tumulus Mound Springs

There are only six known permanent, uncleared peat mound springs in the GSS area. These springs are areas of organic matter, built up into a mound around a permanent spring fed by the Gnangara Mound. These springs used to be common but most have been cleared, drained or modified (Blyth and English, 1996). It is the permanency of the springs that make them specialised habitats, similar to the cave streams in Yanchep described above. Again, as with the Yanchep caves, much of the focus has been on the aquatic invertebrate communities, as these are at most immediate threat from changes in water flow. However the mound springs are just as reliant on the terrestrial vegetation, which is intrinsically linked to the terrestrial fauna communities that exist. No studies have been undertaken to establish the extent or function of the terrestrial invertebrate communities within these habitats.

Northern Ironstones

On the eastern side of the Swan Coastal Plain are the Northern Ironstone communities, areas of seasonal inundation by fresh water due to the poor drainage provided by the underlying lateritic ironstone and heavy clay soils. Many plant species in these communities are specially adapted to this shallow inundation and a distinctive herb layer. Reduction in rainfall and potentially any alteration in water tables may well result in the loss of the herb layer, at the very least (Meissner and English, 2005). No invertebrate work has been undertaken in these communities.

4.3 Other significant fauna

Beyond known restricted species and significant habitats there is still an overwhelming number of terrestrial invertebrates to consider, of which we generally have little to no knowledge of at the species level. Those that we do have knowledge of tend to be common species that are widely distributed (and usually in backyards) and/or are highly noticeable (aesthetically or because of their size). Significant fauna can be considered under two types of restrictions — rarity and limited distribution (endemism). Both of these aspects commonly go hand in hand but can just as easily be separated; rare species can occur over a large area and alternatively high abundances of a species can occur within a narrow range.

Both rarity and endemism can be difficult to determine as there can be any number of different factors contributing to these restrictions. There can however be some general assumptions made about the major contributing factors, particularly to endemism. Harvey (2002) explored the concept of short range endemism in a number of non-marine invertebrate groups. The work highlighted land snails, earthworms, velvet worms (onychophorans), some trapdoor spiders, shizomids, millipedes and terrestrial isopods (slaters) as terrestrial groups with significant numbers of likely short range endemics (SREs). This is based on our general understanding of their ecological requirements and life history attributes (reproductive strategies and dispersal capabilities). Climate variation, geological history and biotic interactions also play a role in shaping endemism (Ponder and Colgan, 2002; Main, 1982). Typically a SRE will exhibit poor dispersal capabilities, restriction to isolated habitats, slow growth and low fecundity (Harvey , 2002). One of the greatest drivers for the high level of short range endemism in Australia appears to be aridification since the splitting of Gondwana, and subsequent contraction of moist habitats that were more uniformly spread beyond the SW and eastern seaboard of Australia (Harvey, 2002; Hill, 1994).

5.0 Threatening Processes

5.1 Climate Change

Global climate change is regarded as one of the most significant threats to our natural world. The pressure that climatic changes will place on the world environment is still largely unknown at the local level but some generalisations have been made. Climate change will increase global temperatures, change rainfall patterns and increase in the frequency and intensity of extreme weather events. In very general ecological terms climate change will affect invertebrate physiology, phenology and distribution, which in turn will change all aspects of species interactions, community structure and composition (Samways, 2005).

In the Perth region it is expected that the future holds warmer temperatures and lower rainfall, including lower winter rain. This in turn will result in decreases in stream flow and groundwater recharge (Sadler (ed.), 2007; Ryan and Hope (eds), 2006).

Past changes to global climate have shifted bioclimatic zones and biogeographic barriers, affecting the distribution and abundance of flora and fauna. The current climate change situation however will be more rapid and will not allow for adaptation or movement of species into new environments (Arnold, 1988). The greatest barrier to predicting the effect of climate change on invertebrates is our lack of knowledge and, as such, taxa that have received very little attention will be very difficult to manage (Busby, 1988). Climate change is also seen to have great potential in increasing the advantage of exotic species over natives (Yen and Butcher, 1997).

Being ectothermic, invertebrates are sensitive to changes in temperature and as such would be expected to shift their geographical ranges in response to higher local temperatures, either latitudinally or to higher elevations (Samways, 2005). The potential for species to physically shift is still largely unknown, particularly in the face of habitat fragmentation, but is possibly more likely than adaptation *in situ* (Samways 2005), although Stockwell *et al.* (2003) discussed the potential for some large populations to adapt quickly, as in the case of chemical pesticide resistance, something they have termed “contemporary evolution”. This does however make a number of assumptions relating to the size of the adaptive hurdle and the pressure from other impacts, i.e. the need for multiple adaptations at the same time. Because the ability to shift is directly related to a species mobility, more sedentary species are at potentially greater risk. However the additional affect of habitat fragmentation makes the movement of populations extremely problematic.

As shown above, rainfall and other moisture related variables play very important roles in species diversity and distribution in the south west of WA. This has obvious implications for all invertebrate taxa with the persistence of relict Gondwanan species most likely to come under significant threat.

While all terrestrial invertebrate taxa will be affected by climate change it is the taxa that have long maturation periods and low dispersal powers that are the most likely to become locally extinct (Yen and Butcher, 1997), as well as fauna associated with isolated, sensitive habitats. Within the context of the significant fauna of the GSS area, SREs are obviously at risk. While many of these taxa may not be directly restricted because of climate, the reasons for their limited distribution are almost certainly tied to indirect changes, such as to vegetation, hydrology, other taxa, etc.

The three TECs listed in the previous section are all clearly threatened by climate change. They all rely heavily on either the permanent availability of groundwater (Yanchep Caves and Tumulus Springs) or the annual inundation that comes with good winter rainfall (Ironstone communities) and, with at least the first two, it has been demonstrated that without this, these communities will be permanently transformed. The magnitude of the loss of these systems is unknown given the lack of information on the terrestrial fauna of which, it can be reasonably assumed, a significant proportion would be highly localised.

5.2 Fire

The effect of fire on an invertebrate species or community depends on several variables including the season and intensity, the size of the fire and habitat requirements of dependant taxa (Yen and Butcher, 1997). There have been many studies on the responses of terrestrial invertebrates to fire, both natural and prescribed, with conclusions regarding appropriate fire regimes varied depending on the vegetation type and the taxa studied. Prescribed burning is used as a method of reducing fuel loads and thereby reduces the probability of occurrence of large, uncontrollable wildfires but secondarily as a tool for protecting and conserving the biota (Burrows and Abbott, 2003). Leaf litter, which is regarded as fuel to be reduced, is also an extremely important part of any habitat for invertebrates,. Frequent burning has been shown to impact on the amount, structure and distribution of leaf litter.

Invertebrate diversity relies on the complexity of the landscape mosaic to be at its maximum level, as no single habitat will include all invertebrate species (Van Heurck and Abbott, 2003). Fire plays a very important role in maintaining this mosaic and therefore a diversity of fire types (intensity, frequency etc) should help to promote biodiversity, given that variable fire regimes are chosen based on ecological relationships of the biota in the landscape (Burrows and Abbott, 2003).

During the fire

The ability of an invertebrate species to survive a fire is based on its own biological capabilities (flight/movement) and ecological traits (burrowing, aestivation times, habitat preference etc) and aspects of the fire that allow for patchiness and refuges during the burn.

No direct studies have been conducted on the mobility of invertebrates in relation to fire survivability but Whelan *et al.* (2002) predicted that the relationship between the distribution and size of unburnt patches and animal mobility will be crucial to survivability. This survivability would also likely be directly related to the speed of the fire. Groups like the early stages of butterflies (eggs, caterpillars and larvae) are extremely vulnerable to fire because of this lack of mobility (Williams 2003). Even for adult butterflies, which are able to fly, most species will not disperse over unsuitable habitat, leaving them even more vulnerable to fire (Williams 2003). The availability of refugia is also important when it coincides with aestivation or hibernation periods of species, as demonstrated for mites (Wallace 1961) and spiders (Main 1987). Both these groups showed higher survival rates when the fire season coincided with a period of dormancy.

A species having any part of its life cycle in the soil, or other protected refugia, may increase its chances for survival (Gander 1982; Warren *et al.* 1987; Delettre 1994). For example, wood eating termites, which nest in wood on the surface, have much lower survivability compared to litter harvesting termites, which nest in hard, dry soils (Abensperg-Traun and Milewski 1995). However in the case of western jewel butterfly larvae, who gain protection underground from fire, the lack of food resources afterwards most likely means low survival post fire (Williams 2003).

Main and Carrigy (1953) found that the two forms of land snail *Bothriembryon bulla* found in Kings Park had different ecological traits that allowed them a greater chance of surviving a fire event. One form had a very close association with the ground shrub *Jacksonia gracilis*, which tends to only scorch around the edges, leaving the majority of the plant unburnt and acting as a refuge. The other, melanic form digs deeper burrows allowing greater fire protection.

Successional changes post fire

The responses of invertebrates to fire are extremely varied and often conflicting between studies. Many invertebrate taxa appear to decline after fire and then recover quickly (Whelan 1995; Friends and Williams 1996), with spider richness in the Jarrah forest requiring between two and three years to recover (Brennan 2002; Van Heurck *et al.* 1997). However, many studies have found no change in invertebrate abundance after fire (e.g. Abbott *et al.* 1995; Collett and Newman 1995).

Ant abundances have been found to increase after fire but this may be due to increased activity rather than actual numbers (Whelan et al, 1980). Van Heurck *et al.* (1998) also found an increase in decomposer beetles for up to two years post fire and the biomass of large predatory beetles was significantly higher compared to an unburnt site four years after an autumn burn in the Jarrah forest.

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.* 2000).

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 (Whelan *et al.* 1980).

Barendse *et al.* (1981) 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) in Mallee Heath remnants in the south west found post fire invertebrate abundances and composition did not correlate with changes in floristics or vegetation structure.

Recolonisation

Unburnt refugia are extremely important for the recolonisation of burnt areas, from both the outside and from within. These can include unburnt patches of the original habitat, dense crowns of plants (Whelan *et al.* 1980; Main 1981; Gander 1982), thick layers of litter, (i.e. adjacent to large logs (Andrew *et al.* 2000)), thick bark on trees, subsurface (within the soil) and burrows (Main 1981; Warren *et al.* 1987).

The abundance and effectiveness of these refugia will be influenced by fire intensity (Whelan *et al.* 2002). Both the spatial distribution and size of unburnt patches will influence recolonisation rates. Scarce numbers of patches will provide fewer possibilities for recolonisation and smaller patches will likely have lower diversity (Whelan *et al.* 2002). Whelan and Main (1979) also found that the size of the burnt area influences recolonisation rates. Woodland grasshopper populations recovered more quickly in small burnt areas than in larger burnt areas.

The timing of juvenile stages, particularly for species with limited dispersal powers, can also influence rates. If dispersal periods coincide favourably with the timing of the fire then recolonisation may be quicker. Conversely with groups like mygalomorph spiders, where juveniles of many species disperse on the ground before constructing a new burrow, changes in the ground conditions (humidity, soil moisture, decreased prey availability and increased predation) (Majer 1984) may delay or reduce the effectiveness of dispersal.

5.3 Habitat Fragmentation/Alteration

Most habitat loss and fragmentation in Australia is a result of agricultural clearing and urbanisation (Burgman and Lindenmayer 1998). Alteration of ecosystems can occur also through urbanisation plus other impacts like weeds, trampling, etc that come about from recreational use.

Ants have been a common taxonomic group for disturbance studies as they are diverse and their community structure often reflects the environment they occur in, they react quickly to change (Anderson 1990) and often correlate with the composition of other invertebrate fauna (Majer 1983). On the Swan Coastal Plain ants were used to study the effects of urbanisation (Majer and Brown 1986) and as an indicator of disturbance at Yanchep National Park (Burbidge *et al.* 1992).

Majer and Brown (1986) recorded 24 ant species in Perth’s gardens not recorded by Rossbach and Majer (1983) in their previous work on the Swan Coastal Plain, indicating that a number of species are favoured by urbanisation. Conversely there were native species that were unable to colonise or persist in gardens. The build up of complexity and maturity of a garden over time was positively correlated with the complexity of the ant fauna.

At Yanchep National Park the areas of native vegetation that had been replaced by a garden or a plantation, exhibited the most altered ant community structure, although the richness in the gardens was still high as opposed to the relative monoculture of the plantations. The work by Burbidge *et al*. (1992) also found even slight disturbances (trampling, weed invasion, partial clearing) changed the species composition, although the main elements of the community were still present.

Interestingly the western jewel butterfly (*Hypochrysops halyaetus*), on the Swan Coastal Plain, appears to have habitat preferences that are more in common with post fire conditions or other disturbances that create open ground (Dover and Rowlingson 2004), making management of reserves difficult as these types of degraded conditions are usually seen as being in need of rehabilitation.

Fragmentation causes a direct decline in populations, reduced diversity and promotes changes in species composition (Abensperg-Traun *et al.* 1996; Smith 1998), although some species can benefit from fragmentation (e.g. Landsberg *et al.* 1990; Abensperg-Traun *et al.* 1996). Survivability in fragmented areas can be affected by remnant size and spatial isolation, dispersal ability, habitat loss and reduced quality of habitat for foraging, shelter, reproduction and susceptibility to extinction events (Lande 1993; Sarre *et al.* 1995; Knight and Fox 2000).

Harvey *et al.* (1997), in analysing a subset of the invertebrate results from the Urban Bushland Survey, found that bushland remnants on the Swan Coastal Plain showed a lot of variation in species richness. The four remnants used exhibited very high spider and cockroach diversities and moderate diversities for the other groups, highlighting the important role that remnants play in maintaining overall biodiversity. However the influence of factors such as remnant size and fire history were not taken into account.

The important role that dispersal plays in remnant populations is highlighted by metapopulation theory, based on subpopulations connected by a species ability to disperse (Levins 1970; Gilpin 1987; Hanski 1990). Highly mobile species will be more capable of maintaining surrounding populations and allowing them to recover more quickly from stochastic events like fire. Low dispersal species, like those that exhibit localised endemism, have far less capacity, placing more importance on the spatial arrangement of remnants.

5.4 Introduced Species

Although not a major threat to the invertebrate biodiversity values of the Swan Coastal Plain, the potential impact of introduced honey bees on the native bee population should be mentioned in light of the fact two of the Schedule 1 species are native bees.

It has only been in the last 25-30 years that honey bees have been seen as potentially detrimental to natural ecosystems, possibly acting as ineffective pollinators and competing with native pollinators (Paton 1996). Paini (2004) and Paini *et al.* (2005) looked at the impact of commercial honey bees (*Apis mellifera*) on the Australian native bee *Hylaeus alcyaneus* and feral honey bees on the solitary native bee *Megachile* sp.323 respectively. Both studies were undertaken at Northern Beekeepers Nature Reserve.

This work found that there was a large resource overlap between the commercial honey bee and *Hylaeus*, and over a two year period this became a negative impact (Paini 2004). An impact on *Megachile* by feral honey bees was not detected, although it was over a far shorter time period. One explanation was the high daytime temperatures that prevailed over eight weeks of the 12 week experiment meaning the feral honey bees spent more time foraging for water to cool the hive than foraging for nectar. If the nest was situated in a cool, protected environment, as is usually the case with feral honey bees, the results may well have been different (Paini *et al.* 2005).

The main threats to the terrestrial invertebrate biodiversity values in the GSS area and the Swan Coastal Plain are climate change, fire and fragmentation. While our understanding of fire and fragmentation is reasonable, compared to climate change, the lack of work specific to the local area still means a major reliance on work from the wetter south west, in the eastern states or overseas. While this can give some direction as to the impacts, the uniqueness of the fauna and the habitats make direct use of the data problematic. The creation and maintenance of a heterogenous landscape through the use of different fire intensities and ages is a broad approach that can be directed to fire regimes on the Gnangara Mound where terrestrial invertebrate communities are taken in to consideration. The use and control of fire near sensitive habitats and priority species would require a cautious approach.

Increasing our knowledge of the potential changes of reduced or varied rainfall and seasonality to vegetation and soil properties will provide an important step in understanding climate change implications on the terrestrial invertebrate communities on the Gnangara Mound.

6.0 Conclusions and Recommendations

The invertebrate fauna of the Swan Coastal Plain appears to be very rich for many groups (e.g. spiders, ants, cockroaches and isopods). This is despite the Plain being an area of low rainfall, poor soil fertility and simple geomorphology (Abbott 2002).

The research that has been carried out is varied in scope and targeted groups. Ants, spiders and beetles have been studied regularly because of the greater taxonomic certainty in these groups, ease of sampling and ecological aspects which make them more relevant to studies of disturbance regimes. Given the disturbances associated with urban areas much of the focus has been on the influence of fragmentation, fire, and habitat alteration.

The influence of rainfall seasonality and habitat complexity is clear for the south west, plus numerous other directly and indirectly related variables that appear to have an effect on species richness and distributions. The influence of these factors on fire is also apparent, and the important role that fire plays in maintaining habitat complexity and heterogeneity is clear.

Our understanding of the effects of climate change on invertebrate communities and species is still in its infancy but given the reliance in the south west of many habitats, communities and species on moisture related variables there is a high risk that changes in rainfall patterns and frequency will have major effects. While these changes will promote and allow the expansion and adaptation of many species those that are the most restricted, like the relictual Gondwanan taxa, will most likely go extinct as their isolated habitats are modified too quickly for them to adapt. While these studies provide us with some knowledge of the functioning of invertebrate communities and taxonomic groups, the data can be limited in its value because of the lack of taxonomic resolution and consistency available. To begin to understand the biodiversity values of this area we need to have a better understanding of the fauna present. For this to happen on the Swan Coastal Plain and the GSS area there needs to be further standardisation of major taxonomic groups. Databasing and standardising these groups in the WA Museum invertebrate collections should be a priority as the current available knowledge is a poor reflection of the knowledge actually held in the collection.

Secondly the invertebrate fauna of the currently known TECs should be surveyed as these communities are the most at risk from climate change. Our knowledge of the terrestrial invertebrate communities in these habitats is practically non-existent.

Lastly a comprehensive invertebrate survey of the Swan Coastal Plain using consistent sampling techniques and taxonomy would give us an understanding of the GSS study area and allow for some historical context with past research.

From a threat management perspective, protection, maintenance and improvement of the remaining bushland remnants, Yanchep caves, tumulus springs and the northern ironstones are very high priorities as these are the most likely areas to contain species of rare or potentially threatened terrestrial invertebrates and communities. Fire regimes, as a general rule, should result in a mosaic of burnt and unburnt patches to aid survival and recolonisation, and temporally an area should contain a range of different fire ages if possible, dependant on the size of the area. This should allow for a richer, more stable community to exist at a location with minimal disruption to the ecological functioning of that community.

7.0 References

Abbott I, van Heurck P, Wong L (1984). Responses to long-term fire exclusion: physical, chemical and faunal features of litter and soil in a Western Australian forest. *Australian Forestry* 47, pp. 237–242

Abbott, I. (1985). Influence of some environmental factors on indigenous earthworms in the northern jarrah forest of Western Australia. *Australian Journal of Soil Research.* 23: 271-290.

Abbott, I. (1994). Distribution of the native earthworm fauna of Australia: a continent-wide perspective. *Australian Journal of Soil Research* 32, pp. 117–126

Abbott, I. (1995). Prodromus of the occurrence and distribution of insect species in the forested part of the south-west Western Australia. *CALMScience.* 1(4): 365-464.
Abbott, I. and Wills, A. (2002). Distribution of the native earthworm fauna of the Perth metropolitan sector of the Swan Coastal Plain. *Pacific Conservation Biology*. 8: 196-210.

Abensperg-Traun, M. and Milewski, A.V. (1995) Abundance and diversity of termites (Isoptera) in unburnt vs. burnt vegetation at the Barrens in mediterranean Western Australia. *Australian Journal of Ecology* 20: 413-417.

Abensperg-Traun, M. and Smith, G.T. (1999). How small is too small for small animals? Four terrestrial arthropod species in different-sized remnant woodlands in agricultural Western Australia. *Biodiversity and Conservation*. 8: 709-726.

Abensperg-Traun, M., Smith, G.T., Arnold, G.W. & Steven, D.E. (1996) The effects of habitat fragmentation and livestock-grazing on animal communities in remnants of gimlet (*Eucalyptus salubris*) woodland. I. Arthropods. *Journal of Applied Ecology* 33: 1281-1301.

Andersen, A.N. (1990). The use of ant communities to evaluate change in Australian terrestrial ecosystems : a review and a recipe. *Proceedings of the Ecological Society of Australia* 16, 347-357.

Andrew, N., Rogerson, L. and York, A. (2000) Frequent fuel-reduction burning: the role of logs and associated leaf litter in the conservation of ant biodiversity. *Austral Ecology* 25, 99-107.

Anjos, N.D., Majer, J.D. and Loch, A.D. (2002). Occurrence of the eucalypt leaf beetle, *Cadmus excrementarius* Suffrian (Coleoptera: Chrysomelidae) in Western Australia. *Journal of the Royal Society of Western Australia.*

Arnold, G.W. (1988). Possible effects of climate change on wildlife in Western Australia. *In* G.I. Pearman (ed.) *Greenhouse: Planning for Climate Change*. CSIRO Publications, Melbourne.

Australian Faunal Directory. Accessed on 9/01/2009
http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/home
Baker, G.H. (1998). The ecology, management and benefits of earthworms in agricultural soils, with particular reference to southern Australia. *In* C.A. Edwards (ed.) *Earthworm Ecology*. St Lucie Press, Boca Raton.

Barendse, W.J., Boulton, A.J., Collins, L.M., Craven, L., Pusey, B.J., Sorokin, L.M. and Ward, B.H.R. (1981). Spider's in King's Park – An appraisal of management. *Unpublished thesis*. University of Western Australia, Perth.

Beard, J.S. (1990). *Plant Life of Western Australia*. Kangaroo Press, Kensington.
Blyth, J. and English, V. (1996). Tumulus springs of the Swan Coastal Plain. *Landscope*. 11(3).

Blyth, J., Mutter, L., English, V. and Tholen, P. (2002). Threatened wildlife of the Yanchep caves. *Landscope*. 17(4).

Brennan, K.E.C. (2002). The successional response of spider communities following the multiple disturbances of mining and burning in Western Australian jarrah forest. *Unpublished Ph.D Thesis*. Curtin University of Technology, Perth.

Bultman, T.L. and Uetz, G.W. (1982). Abundance and community structure of forest floor spiders following litter manipulation. *Oecologia* 55: 34-41.

Burbidge, A.H., Leicester, K., McDavitt, S. and Majer, J.D. (1992). Ants as indicators of disturbance at Yanchep National Park, Western Australia. *Journal of the Royal Society of Western Australia*. 75: 89-95.

Burgman, M. A. and Lindenmayer, D. B. (1998). *Conservation biology for the Australian environment*. Chipping Norton, NSW, Surrey Beatty and Sons.

Burrows N and Abbott I (2003). Fire in south-west Western Australia: synthesis of current knowledge, management implications and new research directions. In *Fire in Ecosystems of South-West Western Australia: Impacts and Management* Backhuys, Leiden. pp. 437–452

Busby, J.R. (1988). Potential impacts of climate change on Australia's flora and fauna. *In* G.I. Pearman (ed.) *Greenhouse: Planning for Climate Change*. CSIRO Publications, Melbourne.

Collett, N.G. and Neumann, F.G. (1995). Effects of two spring prescribed fires on epigeal Coleoptera in dry sclerophyll eucalypt forest in Victoria, Australia. *Forest Ecology and Management* 76: 69-85.

Common, I.F.B. (1990). *Moths of Australia*. Melbourne University Press, Melbourne.
CONCOM (1989). 'Council of Nature Conservation Ministers – Australian statement on invertebrates', *Myrmecia*, vol. 25, pp. 123-125.

Council of Europe (1987). Recommendation No R(86)10 of the Committee of Ministers to member states concerning the charter on invertebrates. *Journal of Applied Ecology* 24: 315-319.

CSIRO (1990). *Insects of Australia* (2nd Edition). Melbourne University Press, Melbourne.

Curry, J.P. (1998). Factors affecting earthworm abundance in soils. *In* C.A. Edwards (ed.) *Earthworm Ecology*. St Lucie Press, Boca Raton.

Di Castri, F. (1973). Soil animals in latitudinal and topographical gradients of Mediterranean ecosystems. *In* F. Di Castri and H.A. Mooney (eds). *Mediterranean – Type Ecosystems: Origin and Structure*. Springer-Verlag, Berlin.

Dover, J.W. and Rowlingson, B. (2005). The western jewel butterfly (*Hypochrysops halyaetus*): factors affecting adult butterfly distribution within native *Banksia* bushland in an urban setting. *Biological Conservation*. 122: 599-609.

Durrant, B.J. (2004). Biogeographical patterns of zodariid spiders (Araneae: Zodariidae) in the wheatbelt region, Western Australia. *Records of the Western Australian Museum* Supplement. 67: 217-230.

Durrant, B.J. and Guthrie, N.A. (2004). Faunas of unflooded saline wetland floors of the Western Australian wheatbelt. *Records of the Western Australian Museum* Supplement. 67: 231-256.

Erwin, T.L (1982) Tropical forests: their richness in Coleoptera and other arthropod species. *Coleopterists Bulletin* 36:74-75.

Friend G.R. and Williams M.R. (1996). Impact of fire on invertebrate communities in mallee-heath shrublands of southwestern Australia. *Pacific Conservation Biology* 2: 244–267

Friend, G. and Williams, M. (1993). *Fire and invertebrate conservation in mallee-heath remnants*. Report to World Wide Fund for Nature.

Gilpin, M.E. (1987) Spatial structure and population vulnerability. *In* M.E. Soulè (ed.) *Viable Populations for Conservation*. Cambridge University Press, Cambridge.

Guthrie N.A. and Waldock J.M. (2004). Patterns on the composition of the jumping spider (Arachnida: Araneae: Salticidae) assemblage from the wheatbelt region, Western Australia. *Records of the Western Australian Museum. Supplement* 67: 203–216.

Guthrie, N.A. (2001). Aspects of the taxonomy and ecology of the ground beetle (Coleoptera: Carabidae) assemblage of the Swan Coastal Plain. *Unpublished thesis.* Edith Cowan University.

Halaj, J., Ross, D.W.and Moldenke, A.R. (1998). Habitat structure and prey availabity as predictors of the abundance and community organization of spiders in western Oregon forest canopies. *Journal of Arachnology* 26:203–220.

Hammond, P.M. (1992). Species inventory pp. 17–39 in Groombridge, B. (ed.) *Global biodiversity: Status of the earth's living resources*. London: Chapman and Hall.

Hansen, R.A. (2000). Effects of habitat complexity and composition on a diverse litter microarthropod assemblage. *Ecology*. 81(4): 1120-1132.

Hanski I. (1990). Density dependence, regulation and variability in animal populations. *Philosophical Transactions of the Royal Society of London, B, Biological Sciences* 330: 19-28.

Harding, D. (2000). A survey of coleoptera (beetles) at Whiteman Park, Western Australia. *Unpublished report*. Curtin University of Technology, Perth.

Harvey, M.S. (2002). Short-range endemism among the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics*. 16: 555-570.

Harvey, M.S., Sampey, A., West, P.L.J. and Waldock, J.M. (2000). Araneomorph spiders from the southern Carnarvon Basin, Western Australia: a consideration of regional biogeographic relationships. *Records of the Western Australian Museum* Supplement. 61: 295-321.

Harvey, M.S., Waldock, J.M., Guthrie, N.A., Durrant, B.J. and McKenzie, N.L. (2004). Patterns in the composition of ground-dwelling araneomorph spider communities in the Western Australian wheatbelt. *Records of the Western Australian Museum* Supplement No. 67: 257-291.

Harvey, M.S., Waldock, J.M., How, R.A., Dell, J. and Kostas, E. (1997). Biodiversity and biogeographic relationships of selected invertebrates from urban bushland remnants, Perth, Western Australia. *Memoirs of the Museum of Victoria*. 56(2): 275-280.

Hatley, C. L. and MacMahon, J.A. (1980). Spider community organization: seasonal variation and the role of vegetation architecture. *Enviromental Entomology*. 9: 632-639.

Hawksworth, D.L. and Kalin-Arroyo, M.T. (1995). Magnitude and Distribution of Biodiversity pp. 107–191 in Heywood, V. (ed.) (1995). *Global biodiversity assessment. Cambridge,* UK: Cambridge University Press.

Heterick, B. (In press). the Ants of South-western Australia: A Comprehensive Guide to the Fauna of the South-West Botanical Province.

Hill, R.S. (ed.) (1994). *History of the Australian Vegetation: Cretaceous to Recent*. Cambridge University Press, Cambridge.

Hölldobler, B., and E. O. Wilson. (1991). *The Ants*. Harvard University Press, Cambridge, Massachusetts, USA

Hopper, S.D., Harvey, M.S., Chappill, J.A., Main, A.R. and Main, B.Y. (1996). The Western Australian biota as Gondwanan heritage - a review. *In* S. Hopper, J. Chappill, M. Harvey and A. George (eds.). *Gondwanan Heritage: Past, Present and Future of the Western Australian Biota*. Surrey Beatty and Sons Pty Ltd, Chipping Norton.

Houston, T.F. (1994). Proposed addition deletion or change to the schedules of declared threatened or specially protected fauna or the reserve list. *Neopasiphe simplicior*. Department of Conservation and Land Management, Perth.

Houston, T.F. (2000). *Native Bees on Wildflowers in Western Australia. Special Publication No.2 of the Western Australian Insect Study Society Inc*. W.A. Museum, Perth.

How, R.A., Harvey, M.S., Dell, J. and Waldock, J.M. (1996). *Ground fauna of urban bushland remnants in Perth*. Report to the Australian Heritage Commission. Western Australian Museum.

Hudson, P. and Adams, M. (1996). Allozyme characteristics of the salt lake spiders (Lycosa: Lycosidae: Araneae) of southern Australia: systematic and population genetic implications. *Australian Journal of Zoology*. 44: 535-567.

Judd, S. (2004). Terrestrial isopods (Crustacea: Oniscidea) and biogeographical patterns from south-western Australia. *Unpublished thesis*. Edith Cowan university.

Knight, E.H. and Fox, B.J. (2000) Does habitat structure mediate the effects of forest fragmentation and human induced disturbance on the abundance of Antechinus stuartii? *Australian Journal of Zoology*. 48: 577-595.

Koch, L.E. (1977). The taxonomy, geographic distribution and evolutionary radiation of Australopapuan scorpions. *Records of the Western Australian Museum*. 8: 83-367.

Koch, L.E. and Majer, J.D. (1980). A phenological investigation of various invertebrates in forest and woodland areas in the south-west of Western Australia. *Journal of the Royal Society of Western Australia*. 63(1): 21-28.

Ladhams, E. (1999). The impact of fire on beetles, spiders and other litter dwelling invertebrates in dry-sclerophyll woodland. *Unpublished thesis*. Curtin University of Technology, Perth.

Lande, R. (1993) Risks of Population Extinction from Demographic and Environmental Stochasticity and Random Catastrophes. *American Naturalist* 142(6): 911-927

Landsberg, J., Morse, J. and Khanna, P. (1990) Tree dieback and insect dynamics in remnants of native woodlands on farms. *Proceedings of the Ecological Society of Australia* 16: 149-165.

Lassau, S.A. and Hochuli, D.F. (2004). Effects of habitat complexity on ant assemblages: can we generalise across scale? *Ecography* 27: 157-164.

Lassau, S.A. and Hochuli, D.F. (2005). Wasp community responses to habitat complexity in Sydney sandstone forests. *Austral Ecology*. 30: 179 – 187

Lassau, S.A., Hochuli, D.F., Cassis, G. and Reid, C.A.M. (2005). Effects of habitat complexity on forest beetle diversity: do functional groups respond consistently? *Diversity and Distributions*. 11(1): 73-82.

Levins, R. (1970). Extinction. pp. 77–107. *In* M. Gesternhaber (ed.), *Some Mathematical Problems in Biology*. American Mathematical Society, Providence, Rhode Island.

Loyola, RD & Martins, RP. (2008). Habitat structure components are effective predictors of trap-nesting Hymenoptera diversity. *Basic and Applied Ecology*, 9(6): 735-742.

Loyola, RD, Brito, SL & Ferreira, RL. (2006). Ecosystem disturbances and diversity increase: implications for invertebrate conservation. *Biodiversity and Conservation*, 15: 25-42.

Main, A.R. (1982). Rare species: precious or dross? *In* R.H. Groves and W.D.L. Ride (eds) *Species at Risk: Research in Australia*. Australian Academy of Science, Canberra.

Main, A.R. and Carrigy, M.A. (1953). Native snails of the genus Bothriembryon in King's Park, Perth. *The Western Australian Natuaralist*. 4(3): 49-59.

Main, B. Y. (1996). Microcosmic biogeography: trapdoor spiders in a time warp at Durokoppin. *In* S. Hopper, J. Chappill, M. Harvey and A. George (eds.). *Gondwanan Heritage: Past, Present and Future of the Western Australian Biota*. Surrey Beatty and Sons Pty Ltd, Chipping Norton.

Main, B.Y. (1981) Australian spiders: diversity, distribution and ecology. *In* A. Keast (ed.) *Biogeography and Ecology in Australia*: 807-852. Junk, The Hague.

Main, B.Y. (1987). Persistence of invertebrates in small areas: Case studies of trapdoor spiders in Western Australia. *In* D.A. Saunders, G.W. Arnold, A.A. Burbidge and A.J.M. Hopkins (eds.) *Nature Conservation. The Role of Remnants of Native Vegetation*. Surrey Beatty and Sons Pty Ltd.

Main, B.Y. (1996). Terrestrial invertebrates in south-west Australian forests: the role of relict species and habitats in reserve design. *Journal of the Royal Society of Western Australia*. 79: 277-280.

Majer, J. D., H. F. Recher & S. Ganeshanandam (1992). Variation in foliar nutrients in *Eucalyptus* trees in eastern and Western Australian. *Australian Journal of Ecology*, 17, 383-393.

Majer, J. D., H. F. Recher, W. S. Perriman & N. Achuthan (1990). Spatial variation of invertebrate abundance within the canopies of two Australian eucalypt forests. *Studies in Avian Biology*. 13: 65-72.

Majer, J.D. (1984). Short-term responses of soil and litter invertebrates to a cool autumn burn in Jarrah (*Eucalyptus marginata*) forest in Western Australia. *Pedobiologia*. 26: 229-247.

Majer, J.D. (1985). Fire effects on invertebrate fauna of forest and woodland. *Symposium on 'Fire Ecology and Management in Western Australian Ecosystems'*. J.R. Ford (ed.).

Majer, J.D. and Brown, K.R. (1986). The effects of urbanisation on the ant fauna of the Swan Coastal Plain near Perth, Western Australia. *Journal of the Royal Society of Western Australia.* 69(1): 13-17.

Majer, J.D. and Recher, H.F. (1998). Invertebrate communities on Western Australian eucalypts: A comparison of branch clipping and chemical knockdown procedures. *Australian Journal of Ecology*. 13: 269-278.

Majer, J.D., Recher, H.F. and Ganesh, S. (2000). Diversity patterns of eucalypt canopy arthropods in eastern and western Australia. *Ecological Entomology*. 25: 295-306.

Majer, J.D., Recher, H.F. and Keals, N. (1996). Branchlet shaking: a method for sampling tree canopy arthropods under windy conditions. *Australian Journal of Ecology*. 21: 229-234.

Majer, J.D., Recher, H.F., Graham, R. and Gupta, R. (2003). Trunk invertebrate faunas of Western Australian forests and woodlands: Influence of tree species and season. *Austral Ecology*. 28: 629-641.

Majer, J.D., Recher, H.F., Heterick, B.E. and Postle, A.C. (2002). The canopy, bark, soil and litter invertebrate fauna of the Darling Plateau and adjacent woodland near Perth, Western Australia, with reference to the diversity of forest and woodland invertebrates. *Pacific Conservation Biology*. 7: 229-239.

Majer, J.M. (1983) Ants: bio-indicators of minesite rehabilitation, land-use and land conservation. *Environmental Management*. 7: 375-383.

McArthur, W.M. (1991). *Reference soils of South-Western Australia*. Western Australian Department of Agriculture, Perth.

McKay, R.J. (1979). The wolf spiders of Australia (Araneae: Lycosidae): 12. Descriptions of some Western Australian species. *Memoirs of the Queensland Museum*. 19: 241-275.

McKenzie, N.L., Burbidge, A.H., and Rolfe, J.K. (2003). Effect of salinity on small, ground-dwelling animals in the Western Australian wheatbelt. *Australian Journal of Botany* 51: 725-740.

McNamara, P.J. (1955). A preliminary investigation of the fauna of humus layers in the jarrah forest of Western Australia. *Forestry and Timber Bureau, Australia, Leaflet* 71, 16 p.

Meissner, R. and English, V. (2005). *Shrubland association on southern Swan Coastal Plain ironstone (Busselton area) (southern ironstone association) interim recovery plan, 2005-2010*. Department of Conservation and Land Management.

Moring, J.B. and Stewart, K.W. (1994). Habitat partitioning by the wolf spider (Araneae: Lycosidae) guilds in streamside and riparian vegetation zones of the Conejos River, Colorado. *Journal of Arachnology*. 22: 205-217.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. and Kent, J. (2000). Boidiversity hotspots for conservation priorities. *Nature*. 403, 853-858.
New, T. R. (1995). *An Introduction to Invertebrate Conservation Biology*. Oxford University Press, Oxford.

Nicolai, V. (1986). The bark of trees: Thermal properties, microclimate and fauna. *Oecologia* 69: 148-160.

Nicolai, V. (1989). Thermal properties and fauna on the bark of trees in two different African ecosystems. *Oecologia* 80: 421-430.

Nicolai, V. (1993). The arthropod fauna on the bark of deciduous and coniferous trees in a mixed forest of the Itasca State Park, MN, USA. *Spixiana* 16: 61-69.

Nielsen, E.S., Edwards, E.D. and Rangsi, T.V. (1996). *Monographs on Australian Lepidoptera*. CSIRO Publishing, Canberra.

Paini DR. (2004). The impact of the introduced honey bee (*Apis mellifera*) (Hymenoptera: Apidae) on native bees: A review. *Austral Ecology*. 29: 399-407.

Paini, D.R., Williams, M.R. and Roberts, J.D. (2005). No short-term impact of feral honey bees on the fecundity of an Australian native bee. *Apidologie*. 36: 613-321.

Paton, D.C. (1996). Overview of feral and managed honeybees in Australia: distribution, abundance, extent of interactions with native biota, evidence of impacts and future research. ANCA, Canberra.

Polis, G.A. (1990). Ecology. *In* G.A. Polis (ed.) *The Biology of Scorpions*. Stanford University Press, Stanford.

Ponder, W.F. and Colgan, D.J. (2002). What makes a narrow-range taxon? Insights from freshwater snails. *Invertebrate Systematics* 16: 571-582.

Postle, A.C., Majer, J.D. and Bell, D.T. (1991). A survey of selected soil and litter invertebrate species from the northern jarrah (*Eucalyptus marginata*) forest of Western Australia, with particular reference to soil-type, stratum, seasonality and the conservation of forest fauna. *In* D.Lunney (ed.), *Conservation of Australia's Forest Fauna*: 193-203. Royal Zoological Society of NSW, Mosman.

Radho-Toly, S., Majer, J.D. and Yates, C. (2001). Impact of fire on leaf nutrients, arthropod fauna and herbivory of native and exotic eucalypts in Kings Park, Perth, Western Australia. *Austral Ecology*. 26: 500-506.

Recher, H.F., Majer, J.D. and Ganesh, S. (1996). Seasonality of canopy invertebrate communities in eucalypt forests of eastern and western Australia. *Australian Journal of Ecology*. 21: 64-80.

Recher, H.F., Majer, J.D., and Ford, H.A. (1991). Temporal and spatial variation in the abundance of eucalypt canopy invertebrates: the response of forest birds. *Acta XX Congress Internationalis Ornithologicii*. New Zealand Ornithologist's Trust Board, Wellington.

Rossbach, M.H. and Majer, J.D. (1983). A preliminary survey of the Darling Plateau and Swan Coastal Plain near Perth, Western Australia. *Journal of the Royal Society of Western Australia*. 66(3): 85-90.

Ryan, B. and Hopes, P. (eds) (2006). Indian Ocean climate change initiative stage 2. Report of phase 2 activity January 2005-2006. Applying the methodological foundations of Stage 2 and updating regional interpretations from global climate modelling. *Indian Ocean Climate Change Initiative* (IOCI).

Sadler, B. (ed.) (2007). Climate change scenarios affecting the water supply/demand balance in Western Australia (Draft). Part 2 – Regional scenarios. *In* Climate Scenario Development for Western Australian Water Regions. Department of Water, Perth.
Samways, M.J. (2005). *Insect Diversity Conservation*. Cambridge University Press, Cambridge.

Sarre, S., Smith, G.T. and Meyers, J.A. (1995). Persistence of two species of gecko (*Oedura reticulata* and *Gehyra variegata*) in remnant habitat. *Biological Conservation* 71(1): 25-33.

Schowalter, T.D. (1985). Adaptations of insects to disturbance. *In* S.T.A. Pickett and P.S. White (eds). *The Ecology of Natural Disturbance and Patch Dynamics*. Sydney, Academic Press Inc.

Slaney, D.P., and Weinstein, P. (1996) Leaf litter traps for sampling Orthopteroid insects in tropical caves. *Journal of Orthoptera Research* 5: 51-52.

Smith, G.T. (1998) Density of the burrowing scorpion *Urodacus armatus* in relation to vegetation types: implications for population decline following agricultural clearing. *Pacific Conservation Biology* 4: 209-214.

Solem, A. and McKenzie, N.L. (1991). The composition of land snail assemblages in Kimberley rainforests. *In* N.L. McKenzie, R.B. Johnston and P.G. Kendrick (eds). *Kimberley Rainforests*. Surrey Beatty and Sons, Chipping Norton.

Spain, A.V. and Hutson, B.R. (1983). Dynamics and fauna of the litter layers. *In* K. Lee (ed.) *Soils: An Australian Viewpoint*. Academic Press, Melbourne.

Springett, J.A. (1976). The effect of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. *Australian Journal of Ecology*. 1: 77-82.

STANISIC, J., (1997) An area of exceptional land snail diversity: the Macleay Valley, north-eastern New South Wales. *Memoirs of the Museum of Victoria*, 56: 441−448.

Stockwell, C.A., Hendry, A.P. and Kennison, M.J. (2003). Contemporary evolution meets conservation biology. *Trends in Ecology and Evolution.* 18: 94-101.

Strehlow, K.H. (1993). Impact of fires on spider communities inhabiting semi-arid shrublands in Western Australia's wheatbelt. *Unpublished thesis*.

Tassone, R.A. and Majer, J.D. (1997). Abundance of arthropods in tree canopies of Banksia woodland on the Swan Coastal Plain. *Journal of the Royal Society of Western Australia*. 80: 281-286.

Uetz, G.W. (1979). The influence of variation in litter habitats on spider communities. *Oecologia* 40:29-42.

Uetz, G.W. (1991). Habitat structure and spider foraging. pp. 325-348. *In* S.A. Bell, E.D. McCoy, & H.R. Mushinsky. (eds.) *Habitat Structure: The Physical Arrangement of Objects in Space*. Chapman & Hall, London.

Van Heurck PF, Burbidge T, Wheeler I (2000). *Invertebrate biodiversity in the tingle and other forests of the Walpole-Nornalup National Park in south western Australia.* Department of Conservation and Land Management, Kensington

Van Heurck, P. and Abbott, I. (2003). Fire and terrestrial invertebrates in the south-west Western Australia. *In* I. Abbott and N. Burrows (eds.), *Fire and Ecosystems of South-West Western Australia: Impacts and Management*. Backhuys Publishers, Leiden.

Van Heurck, P., Friend, G. and Williams, M. (1998). Fire and invertebrate conservation in the central jarrah forest of south-western Australia. *Report to World Wide Fund for Nature*. Department of Conservation and Land Management & Eco-Insect Consultants.

Warren, S.C., Scifres, C.J. and Teel, P.D. (1987) Response of grassland arthropods to burning: a review. *Agriculture Ecosystems and Environment* 19: 105-130.

Western Australian Department of Conservation and Land Management (WA CALM) (2005). *Records held in CALM's Fauna Database and rare/priority fauna files*. WA CALM, Perth.

Western Australian Insect Study Society (WAISS) (1997). Watch out for the graceful sunmoth. *Western Australian Insect Study Society Inc. Newsletter*. February: 6.

Whelan, R.J. & Main, A.R. (1979). Insect grazing and postfire plant succession in southwest Australian woodland. *Australian Journal of Ecology.* 4: 387-39

Whelan, R.J. (1995). *The Ecology of Fire.* Cambridge University Press, Cambridge. (1st reprinting 1996)

Whelan, R.J., Landedyk, W. & Pashby, A.S. (1980). The effects of wildfire on arthropod populations in *Jarrah Banksia* woodland', *Western Australian Naturalist* 14: 214-220

Whelan, R.J., Rodgerson, L., Dickman, C.R. & Sutherland, E.F. (2002). Critical life cycles of plants and animals: developing a process based understanding of population changes in fire-prone landscapes. *In* R.A. Bradstock, J. Williams, J. & A.M. Gill (eds) *Flammable Australia: The Fire Regimes and Biodiversity of a Continent* pp. 94-124. Cambridge University Press, Cambridge.

Williams, M.R. (2003). Effect of fire on butterflies. *Western Wildlife*. 7(4): 1 & 4.
Wills, A. and Abbott, I. (2003). Landscape-scale species richness of earthworms in the Porongorup Range, Western Australia: influence of aspect, soil fertility, and vegetation type. *Biology and Fertility Soils*. 39: 94-102.

Yates, C.J., Hopper, S.D. and Taplin, R.H. (2005). Native flower visitor diversity and feral honeybees on jarrah (Eucalyptus marginate) in King's Park, an urban bushland remnant. *Journal of the Royal Society of Western Australia.* 88: 147-153.

Yen, A. and Butcher, R. (1997). *An Overview of the Conservation of Non-marine Invertebrates in Australia*. Environment Australia, Canberra.