Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

MAMMAL FAUNA OF THE GNANGARA SUSTAINABILITY STRATEGY STUDY AREA

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Executive Summary

In total, 33 native mammal species and 9 introduced mammal species have been recorded from the Northern Swan Coastal Plain (NSCP) of Western Australia since settlement of the Swan River Colony in 1829.

By the 1970's, over half of the 33 native mammal species that historically occurred across the NSCP were locally extinct, and all species had declined in distribution and abundance since they were first recorded by the early surveyors (Kitchener *et al.* 1978).

Following a comprehensive fauna survey of the NSCP by the WA Museum in 1977-78, twelve of the original 33 native mammal species, which includes 9 non-volant and 3 bat species, could still be confirmed as persisting.

Today, in 2008, ten non-bat mammal species are still reliably recorded as occurring in the Gnangara Sustainability Strategy (GSS) Study Area, which covers a large proportion of the NSCP.

The reasons for mammal decline are many and varied. No single attribute can be blamed for their downfall, with a more likely scenario being a combination of factors, some of which commenced before the arrival of the first settlers (Abbott 2008), but most of which were an interaction of threatening processes initiated by the land clearing to establish the Swan Colony.

Interestingly, the decline and disappearance of mammals from the NSCP contrasts with other vertebrate assemblages in the same area, such as the reptiles, which have remained relatively intact in the face of cumulative threatening processes (Storr *et al.* 1978).

Introduction

The Northern Swan Coastal Plain (NSCP) refers to the area north of the Swan River and south of Moore River. The Indian Ocean forms the western boundary and the Darling Scarp forms the eastern boundary. Within this NSCP, the Gnangara Sustainability Strategy (GSS) study area covers a large proportion of the NSCP, approximately 2,200 km^2, with Gingin Brook as the northern limit and Ellen Brook as the eastern limit. The following review refers to the NSCP rather than the GSS study area as the comparative list of fauna surveys have taken place both within and just outside of the GSS study area.

The NSCP experiences a Mediterranean climate with a hot dry summer extending from October to April and a mild wet winter from May to September (Seddon 1972). The landform units of the NSCP include the broad geomorphological systems of the Quindalup, Spearwood and Bassendean dunes with the youngest in the west and the oldest in the east. Landforms with heavier soils, such as the Pinjarra Plain and Yanga are present to lesser degrees in the east and south east. Most fauna studies have concentrated on the Quindalup, Spearwood and Bassendean dune systems. Vegetation complexes on the NSCP include Banksia woodland, proteaceous heathland, coastal scrub, Jarrah (*Eucalyptus marginata*) forest, Tuart (*Eucalyptus gomphocephala*) forest, and *Melaleuca spp./Eucalyptus rudis* wetlands and damplands.

Historical records indicate the mammal assemblage of the GSS study area was species rich, consisting of approximately 33 species (Kitchener *et al.* 1978). However, more recent survey suggests that mammals have suffered a high extinction rate, with relatively few species remaining extant in the area (Kitchener *et al.* 1978). A total of ten species of terrestrial native mammals have been reliably recorded in the GSS study area within the last 18 years (1990-2008) as they have either been captured and/or sighted by research scientists or fauna consultants.

This report aims to review the occurrence and persistence of mammal species on the NSCP by examining historical accounts and recent surveys, describing extant species' attributes and distributions, and assessing the threatening processes that have contributed to the widespread decline and/or disappearance of mammals in the area.

Historical Surveys

John Gilbert collected most of the species that are known from the Swan Coastal Plain in two expeditions between March 1839 to February 1840, and July 1842 to December 1843. Although species had been collected prior to these surveys, Gilbert's was the most comprehensive to that date (Kitchener *et al.* 1978). According to Kitchener *et al.* (1978) Shortridge then later undertook an organised collecting of mammals on the Swan Coastal Plain from 1904 to 1907. These and other early collections produced a total of 33 native mammal species that were recorded from the Swan River locality and interpreted by Kitchener *et al.'s* (1978) search of the literature and museum records as occurring on the Northern Swan Coastal Plain (NSCP). These 33 native mammal species are listed in Appendix 1, in addition to seven introduced mammal species recorded either before or during the WA Museum's 1977-78 survey. The table is broken into broad periods of time during which those species are recorded as having been sighted, trapped or collected in the greater Perth metropolitan region. However, as Kitchener *et al.* (1978) themselves comment, some of these records are uncertain as the locality data associated with early specimens was vague and were only included on the list as a result of having a "Swan River" or "Perth" locality label. This inclusion has subsequently not been supported with additional specimens or evidence. With further consideration of this list and the known habitat for some of the species with questionable records from the NSCP, it is more likely that only 21 of these 33 native mammals were either reliably recorded as occurring or were present on the NSCP (Appendix 1). However, for the purpose of this review, and to be consistent with the literature and other reports produced as part of the Gnangara Sustainability Strategy, the original suite of mammals on the NSCP will be referred to as consisting of 33 species.

Foundation Survey in Recent Times

In 1977-78 the WA Museum undertook a comprehensive survey to produce an inventory of the extant mammals on the NSCP (Kitchener *et al.* 1978). This survey comprised 24,443 trap nights and 315 man days and confirmed the persistence on the NSCP of only 12 of the original 33 native mammal species. The results of this survey are shown in Table 1, with the location in which each species were found (sighted, trapped or collected). The areas that were trapped were considered to be the most likely areas to still contain extant species

Table 1. Results from the 1977-1978 survey of the Northern Swan Coastal Plain by Kitchener *et al.* (1978) for the Western Australian Museum

	Locations of captures and / or sighting records											
Mammal Species	Gin Gin Reserve	Twin Swamps	Martyn	Yanchep NP	Neerabup NP	Burns Beach	Melaleuca Park	Wanneroo	Lake Jandebup	Lake Joondalup	Pinjarra Plain	Moore River NP (outside GSS)
Macropus fuliginosus	√	√		√	√	√	√	√	√	√	√	√
Macropus irma	√			√	√	√	√					√
Trichosurus vulpecula				√								
Tarsipes rostratus						√						
Isoodon obesulus							√	√				
Rattus fuscipes				√								
Hydromys chrysogaster									√	√		
Pseudomys albocinereus	√					√						√
Tachyglossus aculeatus						√		√				
Nyctophilus geoffroyi	√											
Vespadelus regulus		√					√					√
Chalinolobus gouldii	√			√				√				√
Vulpes vulpes	√			√	√	√	√					
Mustela putorius				√								
Felis catus	√	√	√	√	√	√	√				√	√
Oryctolagus cuniculus	√	√	√				√				√	
Rattus rattus		√		√		√	√					√
Mus musculus	√	√	√	√	√	√	√	√				√

as they were reasonably large tracts of relatively undisturbed vegetation and also provided representative communities of the major landform types on the plain, being Quindalup, Spearwood, Bassendean and Pinjarra Plain soils (Kitchener *et al.* 1978).

Other key surveys on the NSCP in recent times

In the 1990's How and Dell (2000) undertook a study that examined the conservation significance of inner urban remnants for maintaining ground vertebrates after 170 years of environmental modification. They recorded only seven native and six introduced mammal species across the 34 vegetation remnants sampled, which represented different landforms across the Swan Coastal Plain (not all within the GSS study area) and the remnants ranged in size from 1 ha to 338 ha. They did not record any bush rats (*Rattus fuscipes*), rakali (*Hydromys chrysogaster)* or ash-grey mice (*Pseudomys albocinereus)* that had been recorded in the 1977-78 museum inventory.

During How and Dell's (2000) 1990's surveys, the brushtail possum (*Trichosurus vulpecula)*, Western brush wallaby (*Macropus irma)*, Western grey kangaroo (*Macropus fuliginosus)* and quenda (*Isoodon obesulus)*, were recorded across different landform units but on few remnants. Quenda were active in remnants where dense vegetation was associated with low-lying landforms, particularly the various soil units on the eastern side of the NSCP. Quenda were absent from all near coastal sample sites (How and Dell 2000).

A fauna survey of Whiteman Park was undertaken in the early 1990's by CSIRO (Arnold *et al.* 1991). Five species of native mammal, the echidna (*Tachyglossus aculeatus*), quenda (*Isoodon obesulus*), honey possum (*Tarsipes rostratus*), Western grey kangaroo (*Macropus fuliginosus*), Western brush wallaby (*Macropus irma*), and 1 species of introduced mammal (House mouse, *Mus musculus*) were recorded in the Park at that time. Arnold *et al.* (1991) claimed that the presence of 3 of these species, the Western brush wallaby, honey possum and quenda were significant from a conservation perspective as urban development and *Phythophthora cinnamomi* (dieback disease) threaten populations of these species elsewhere. Whiteman Park was deemed able to sustain viable populations of these species if their habitats within the Park are managed appropriately.

The WA museum also conducted a spring survey of Whiteman Park 15 years earlier in 1975, and confirmed the presence of 5 native mammal species (Arnold *et al.* 1991). However, the 1975 study trapped ash-grey mice (*Pseudomys albocinereus*), which were not recorded in 1990 and the 1975 survey did not trap honey possums (*Tarsipes rostratus*), which were present in the 1990 survey. Neither survey could confirm the presence of brushtail possums (BTP, *Trichosurus vulpecula*), Western pygmy possums (WPP, *Cercartetus concinnus*), rakali (*Hydromys chrysogaster*) or bush rats (*Rattus fuscipes*), which are historically recorded from Whiteman Park (Arnold *et al.* 1991). In his discussion, Arnold *et al.* (1991) posed that the absence of BTPs and WPPs could be due to logging and fire and the absence of rakali and bush rats could be due to substantial changes that have taken place in the permanent wetlands. However Arnold *et al.* (1991) commented that Whiteman Park still represented an important link in the series of conservation areas on the NSCP.

Various fauna surveys conducted by consultants (that have included field sampling) in the GSS study area since the WAM 1977-78 study have recorded very few native mammal species. *Macropus fuliginosus*, *Macropus irma*, *Tarsipes rostratus* and *Tachyglossus aculeatus* are the only native species to be regularly cited (Department of Conservation and Land Management 1993; Ecologia Environmental Consultants 1997). *Rattus fuscipes, Isoodon obesulus* (How *et al.* 1996; Kinhill Pty Ltd 1997), *Trichosurus vulpecula*, and *Hydromys chrysogaster* (Bamford and Bamford 1990) have only occasionally been recorded. Three introduced species, *Mus musculus*, *Rattus rattus* and *Oryctolagus cuniculus* are the most frequently recorded and abundant mammal species to appear in fauna survey lists (Harvey *et al.* 1997; How *et al.* 1996; Success Hill Action Group 1999).

However, many consultants have only completed a desk-top survey, providing a list to the developer of what **could** be in the area based on habitats within the subject area. These desk-top surveys always reference the WAM 1977-78 study, which has provided a much used inventory of what mammals are still occurring and where in the GSS study area and NSCP.

Extant Mammal Fauna on the GSS

The following table summarises the native ground-dwelling mammal species that have been recorded from the GSS study area within the last twenty years, since the WAM 1977-78 study, and also includes 7 introduced mammals known to currently occur within the GSS study area.

Table 2 Native mammal species (excluding bats) and introduced mammals recorded from the GSS study area (1990-2008).

Species Name	Common Name
Macropus fuliginosus	Western grey kangaroo
Macropus irma	Western brush wallaby
Tarsipes rostratus	honey possum
Isoodon obesulus	Southern brown bandicoot
Rattus fuscipes	bush rat
Hydromys chrysogaster	water rat
Tachyglossus aculeatus	echidna
Trichosurus vulpecula	brushtail possum
Dasyurus geoffroii	chuditch
Cercartetus conncinnus	Western pygmy possum
Vulpes vulpes	European red fox
Felis catus	feral cat
Sus scrofa	feral pig
Rattus rattus	black rat
Mus musculus	house mouse
Oryctolagus cuniuclus	European rabbit
Capra hircus	feral goat

This current inventory of ten native species contrasts dramatically with the suite of 28 non-bat species (the historical total of 33 species includes 5 bat species) that originally inhabited the Northern Swan Coastal Plain (NSCP), signifying dramatic decline and local extinction.

It should be noted that the WAM 1977-78 study did not record *Dasyurus geoffroii* or *Cercartetus concinnus* (Table 1), however both these species have been reported more recently (Brent Johnson pers. comm. 2007; Rob Davis pers. comm. 2008). The WAM study did however record *Pseudomys albocinereus,* which has now not been recorded since 1987 at Melaleuca Park (Friend 1996) and so does not appear on the above table. However this species, as well as the rarely recorded *Dasyurus geoffroii* and *Cercartetus concinnus* can not be discounted from continuing to persist in very low densities on the NSCP, although it is quite clear that their distribution and abundance has contracted and declined (Kitchener *et al.* 1978). The remaining 17 of the 28 original non-bat species that have now not been recorded since before the WAM 1977-78 survey are considered unlikely to still occur on the NSCP.

Species' distribution, habitat preferences, changes over time and threats

A summary of the habitat preferences and threatening processes impacting the extant mammal species in the GSS study area is located in Appendix Two.

The following is a summary of the distribution and habitat preferences of the mammal species currently persisting in the GSS study area and the threatening processes that may impact their persistence.

Macropus fuliginosus, Western grey kangaroo

Western grey kangaroos (WGK) are distributed across the southern portion of WA, and extend across to eastern Australia, overlapping in range with the Eastern grey kangaroo. WGK occupy areas where the rainfall is winter dominated, with an annual average of 303 mm (Coulson 2008). They are considered abundant across their distribution and on the NSCP they were historically recorded as abundant and continue to be recorded commonly today. In the WAM 1977-78 study they were recorded utilising woodland, shrubland and heath formations across all land units on the NSCP. Coulson (2008) notes that rainfall is the dominant influence on population dynamics of this species and in drought years females cease breeding and mortality may exceed 40%. Therefore threats to the WGK would include habitat loss from land clearing and declining annual rainfall levels.

Macropus irma, Western brush wallaby or black-gloved wallaby

The Western brush wallaby (WBW) is distributed from Jurien Bay in the north to Hyden in the wheatbelt and down to the south coast of WA. On the NSCP this species appears to have declined since the WAM study in 1977-78, in which Kitchener *et al.* (1978) cites that WBW were frequently sighted from both coastal sites in the west to Gingin in the east. There appears to be a strong population of this species in Whiteman Park where fox baiting is undertaken, and a fenced population at Landsdale Farm School (How *et al.* 1996), but elsewhere on the NSCP this species is not considered secure in status (Brent Johnson, personal comment 2008). On the NSCP Western Brush Wallabies prefer dense long-unburnt understorey vegetation for shelter and refuge, which may be associated with wetlands and damplands of both the Spearwood and Bassendean soils. Their preferred vegetation type is Eucalyptus/Banksia woodland with a dense understorey about one metre in height (Bamford and Bamford 1999a). In Whiteman Park they have been observed to favour foraging in burnt areas, demonstrating an association with habitats of differing seral stages (Arnold *et al.* 1991). Western brush wallabies have high fidelity to large home ranges of up to 50 hectares in size that include areas of dense and open vegetation (Arnold *et al.* 1991; Bamford and Bamford 1999b). Western brush wallabies are at risk from habitat loss, too frequent or too large fires and fox predation. In contrast to the NSCP, there are frequent sightings of the Western brush wallaby in the Jarrah forest east and south of Mundaring and wheatbelt reserves, where this species appears to have increased in the presence of fox baiting over the last decade (Alice Reaveley, Brent Johnson personal observation).

Tarsipes rostratus, noolbenger or honey possum

The distribution of the honey possum is from Kalbarri in the north, through the Kwongan sandplains (where they are common) and NSCP (including the Darling Scarp), through the south west and along the south coast of WA. Honey possums are restricted to suitable habitat containing flowering plants from the *Proteaceae*, *Myrtaceae* and *Epacridaceae* families, upon which their diet of nectar and pollen depends (Renfree 2008). They are known to return to burnt areas within 2 years post-fire and persist in a range of seral stages, however there is evidence suggesting a preference for older fuel age habitat ie 20+ years (Bamford 1986; Everaardt 2003; Richardson and Wooller 1991). Historically they were considered uncommon on the NSCP and the WAM 1977-78 survey only recorded one specimen at Burns Beach. This species has been recorded in other fauna surveys undertaken by consultants in the GSS study area since the WAM 1977-78 survey (Ecologia Environmental Consultants 1997). Honey possums are highly susceptible to habitat loss from both land clearing and dieback disease (*Phytophthora cinnamomi*), predation by cats, inappropriate fire regimes and food source restrictions caused by lowered groundwater affecting flowering capacity of vegetation (Phillips *et al.* 2004).

Isoodon obesulus, quenda or Southern brown bandicoot

In WA, the quenda is at the northern end of its distribution on the NSCP (ie Moore River) but occurs to the east in the Darling Range and through the south west to the south coast. A sub-species also occurs in south eastern Australia but is considered rare and scattered, compared to being historically recorded as one of the most abundant medium-sized mammals (Paull 2008). Across its range quenda can occupy habitat in forest, woodland, shrub and heath communities on sandy soils with dense low vegetation. Quenda feed on invertebrates and subterranean material such as bulbs and fungi. Historically this species was considered plentiful near Perth (Kitchener *et al.* 1978). However Kitchener *et al*. (1978) claimed that by the time of the WAM 1977-78 survey it was sparsely distributed on the NSCP in thickly vegetated damp areas and only two specimens were captured, one in the west (Pinjar Rd) and one in the east (Melaleuca Park). Currently on the NSCP it appears they are continuing to be sparsely distributed in areas of dense low vegetation that are associated with wetter riparian areas, with Whiteman Park, Ellenbrook and Twin Swamps Nature Reserves as known strongholds for secure populations of this species (fenced and/or baited land). In Whiteman Park Quenda live in low lying areas where thick ground cover provides suitable habitat. They forage mainly in areas with dense low vegetation, commonly found around damplands. According to (Bamford and Bamford 1994) it is the density of the vegetation that is significant, not the dampland per se. Quenda may benefit from a mosaic of fuel ages – sheltering in dense vegetation provided by older fuel age and foraging in recently burnt areas that provide growing vegetation and a range of invertebrate prey. Quenda on the NSCP are threatened by habitat loss, aridification, inappropriate fire regimes, loss of productivity and predation pressure by foxes and cats (Abbott 2008; Ecologia Environmental Consultants 1990; Paull 2008).

Rattus fuscipes, mootit or bush rat

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

Hydromys chrysogaster, rakali or water rat

Museum records show that the rakali is distributed around the coastline of Australia (DEC 2009). On the NSCP there are few records between Moore River and Swan River although they were inadvertently trapped in Loch McNess in Yanchep NP in 2007 (Brad Johnson, pers. comm. 2008) and recent sightings have been made at Lake Goolellal by Mike Bamford (Bamford pers. com. 2008). The WAM study in 1977-78 recorded individuals from Lake Jandabup and Lake Joondalup. Rakali live in the vicinity of permanent bodies of fresh or brackish water including lakes, rivers, streams, coastal beaches etc. near which they build dens at the end of tunnels in banks (Olsen 2008). On the NSCP this restricts them to the lakes and water bodies of the Spearwood system as most water bodies on the Bassendean dune system are ephemeral. Rakali are highly susceptible to loss of habitat through the contraction and drying out of lakes either through filling and draining for alternative land use, decreasing rainfall/drying climate and hydrological groundwater changes. Rakali are also susceptible to water quality degradation and predation by foxes and cats. Loss or reduction in size and quality of wetland areas would also affect the food resource for rakali, as they feed on large aquatic insects, fishes, crustaceans, mussels, frogs, lizards, water birds and tortoises etc (Olsen 2008; Woollard *et al.* 1978).

Tachyglossus aculeatus, echidna

The echidna is distributed right across Australia in most habitats, and although it is sparse in some parts of its range it is considered common and ubiquitous (Augee 2008). The WAM 1977-78 survey did not collect any specimens and Kitchener *et al.* (1978) claimed it was uncommon on the NSCP. Abbott's (Abbott 2008) records also confirm low abundance throughout the south west. Little is known of its habitat preferences on the NSCP other than it requires a supply of ants and termites, on which it feeds. Threats would include habitat loss and fox predation.

Trichosurus vulpecula, Common brushtail possum

The brushtail possum (BTP) is distributed from as far north as Geraldton, east into the wheatbelt and down to the south coast of WA. Historically this species was recorded as plentiful on the NSCP and 26 specimens were lodged at the museum between 1914 and 1975. The WAM study in 1977-78 only recorded one specimen from Yanchep National Park. BTPs can occur in many different habitats but generally prefer dry eucalypt forests and woodlands, with suitable trees providing hollows for nesting as a standing overstorey tree or as a hollow log on the ground. They have some ability to persist in the face of introduced predators and show a positive response to fox control (Brent Johnson, personal comment). Abbott (Abbott 2008) claims that disease has been the main contributor to possum decline in the northern part of its distribution. BTPs may still survive in very low numbers in isolated pockets of vegetation on the NSCP as there have been relatively recent records from Bold Park (How *et al.* 1996), Yanchep National Park (John Wheeler pers. comm. 2007), Lake Goolellal (Mike Bamford pers comm. 2009) and Ellenbrook Nature Reserve (DEC Swan Coastal district pers.com. 2009). There is also evidence that secure populations are persisting in some of the older suburbs to the north and west of Perth, which have mature trees in tree-lined streets and large backyards providing suitable refuge compared to the small-sized cleared blocks in new suburbs (Malaga Fauna Rehabilitation Centre, pers.comm. 2008). The Malaga Fauna Rehabilitation Centre receive a number of orphaned and/or injured possum joeys from suburbs such as Claremont, Floreat and City Beach every year. Whether BTP are persisting in suburbs because there is less predation or food is more readily available is unknown. According to Kerle & How (2008) the ability of this species to survive in towns and cities around Australia has obscured the significant reduction in its distribution and abundance. Despite the small number of records of BTP in vegetated areas away from suburbia, suitable habitat still exists for them to occupy. The main threats facing BTPs on the NSCP include loss of habitat, predation and too frequent fire in fragmented habitat.

Dasyurus geoffroii, chuditch or Western quoll

The current distribution of the chuditch is from Kalbarri in the north, through parts of the wheatbelt down to the south coast of WA. Historically common close to the Swan River, the Western Australian Museum has specimens from the NSCP collected during the 1900's, the most recent being from Yanchep in 1972. No chuditch were trapped during the WAM 1977-78 survey, nor have any been trapped in other surveys since then. However recent reports and road kills confirm its low level presence in the area (Brent Johnson, pers.com.; Mike Bamford pers.com.). These reports are infrequent and these individuals may be transient animals drifting down from the Darling Scarp population. On the NSCP this species would live in both woodland and heath vegetation, nesting in caves, burrows or tree/log hollows and feeding on invertebrates, freshwater crustaceans and terrestrial reptiles, mammals and birds. A top order carnivore, chuditch have large home ranges, with males ranging over 400 ha and females with a core area of 55-120 ha (in the Murray River Valley of WA, (Serena and Soderquist 2008). Chuditch are threatened by loss of habitat, corresponding loss of productivity, competition by other introduced carnivores and predation by foxes. They have responded well to fox control in other parts of WA.

Cercartetus concinnus, mundarda or Western pygmy possum

The distribution of Western pygmy possums (WPP) in WA occurs from Jurien Bay on the west coast to Eyre on the Nullabor in the east. They are also widespread and abundant in the temperate, semi-arid and arid regions across southern Australia (Carthew *et al.* 2008). WPP rely on nectar, pollen and insects for food and are usually found in association with a floristically diverse and often dense understorey of plants from the Proteaceae and/or Myrtaceae families. According to Carthew *et al*. (2008), they select habitat according to the availability of flowering plants rather than structural attributes, and are extremely mobile, moving around the landscape in search of flowers (this sounds similar to observations of honey possums on the NSCP). Availability of nesting sites was also found to determine the presence of Eastern pygmy possums (*Cercartetus nanus*) in a particular area (Harris 2007).

Kitchener *et al*. (1978) considered that this species was uncommon across the NSCP during the 1900's as only 20 specimens were lodged at the museum, ranging from the west to the east of the NSCP. Glauert (1933) in Kitchener *et al.* (1978) however, claimed it was a very common species close to Perth. The Western pygmy possum (WPP) was not caught during the WAM 1977-78 survey and since then the only record of their persistence in the GSS study area is from the Lexia Wetlands area in 2005 (Rob Davis, pers comm). They have also been trapped as recently as December 2006 in remnant vegetation south of Ioppollo Road, just east of the GSS study area. The WPP would be highly susceptible to habitat loss and fragmentation, cat predation, *Phytophthora cinnamomi*, fire management, and, as with honey possums, food source restrictions caused by lowered groundwater affecting flowering capacity of vegetation (Phillips *et al.* 2004).

Pseudomys albocinereus, noodji or ash-grey mouse

The distribution of the ash-grey mouse is from Bernier Island in the north, east into the wheatbelt and south east to the coast at Port Dempster. It inhabits low heath and shrubland vegetation on sandy soils of various depths and according to Morris (2008), there is little evidence to suggest it has declined significantly in recent times. The noodji would be in the middle of its distribution on the NSCP. It was historically recorded as occurring although there were few collections until the 1970's. The WAM 1977-78 study collected it in various sites from the west to the east of the NSCP in woodland and heath habitats on loamy Spearwood and loamy Bassendean soils (see Table 2). However the noodji has not been recorded from the NSCP since 1987 at Melaleuca Park (Tony Friend pers. comm. to Brent Johnson). There were also populations recorded from the Dandaragan Plateau in the north east in the 1980's (Bamford 1986; Burbidge *et al.* 1996) and captures from Ioppollo Road immediately to the east of the GSS study area in 2007 (Rob Davis pers. comm. 2007). Threats contributing to the decline in abundance and range of this species would include habitat loss, introduced predators (*Felis catus*), introduced competitors (*Mus musculus*), altered fire regimes and fragmentation. Ash grey mice commonly occur in areas with less rainfall so local drying might not be a major driving factor in their disappearance from the GSS study area.

Sminthopsis griseoventer, grey-bellied dunnart

A species that could still be persisting in the GSS study area…..
The grey-bellied dunnart is one of a complex of related species occurring in southern Australia (Dickman 2008). Its distribution in south west WA is restricted to the coastal plain and lateritic ranges in a narrow arc from just north of Geraldton to Cocklebiddy on the south coast. The NSCP would be in the middle of its range. This dunnart lives in a wide range of habitats from open woodland of Eucalyptus and Banksia, to low mallee, dense heath and seasonal swampland where it mainly feeds on invertebrates. The densest populations occur in coastal heath on sandy soils, usually at least 10 years after fire (Dickman 2008). This species is considered common and despite urban development, changes in the fire regime and clearing for agriculture over parts of its range, this species seems secure (Dickman 2008). Grey-bellied dunnarts used to be part of the *Sminthopsis murina* complex and were recorded as such by Kitchener *et al.* (Kitchener *et al.* 1978). Historically it was very uncommon on the NSCP with the only recent record being from 1940, if this can be considered reliable. However, it occurs very close to the GSS study area, in vegetation on Ioppollo Road (Rob Davis pers. comm. 2006). It was also recorded at Mooliabeenee on the Dandaragan Plateau north east of the GSS study area in the 1980's by Bamford (1986). Threats to this species on the NSCP would include habitat loss, reduced productivity, predation and inappropriate fire regimes.

Bats

Five bat species have been recorded historically in the GSS study area (Table 1).
No comprehensive bat surveys have been undertaken on the Northern Swan Coastal Plain since 1977-78 (Kitchener *et al.* 1978). The 1977-78 survey recorded 3 species of bat that still occurred in the GSS study area from the original 5 that were recorded (Table 2). These were *Nyctophilus geoffroyi* (Lesser long-eared bat), *Vespadelus regulus* (Southern Forest Bat) and *Chalinolobus gouldii* (Gould's Wattle Bat).

Subsequent to the 1977-78 study, few surveys have included bats in their survey effort and there has been no systematic or comprehensive study to assess their distribution, richness and abundance across the NSCP.

Bamford and Bamford (1994) undertook one evening of mist-netting in Whiteman Park, in which *Chalinolobus gouldii* (Gould's Wattled Bat) was captured. Jackson *et al*. (1975) also recorded *Vespadelus regulus (*Southern Forest Bat) in the Mussel Pool survey in 1975.

Bamford and Bamford (1994) also consider that 4 other bat species should occur at Whiteman Park, including *Tadarida australis* (White-striped Freetail Bat), *Nyctophilus geoffroyi* (Lesser long-eared bat) and *Nyctophilus major* (Long-eared Bat).

Due to the lack of current data of their distribution and occurrence across the GSS study area, bats are not included in any further discussion within this review. Threatening processes affecting bats would include a decrease in fresh water sources such as lakes or swamps on which they depend for drinking supply.

Threatened Taxa

The WA government maintains the *WA Wildlife Conservation Act 1950,* which lists fauna species under Schedules based on their threatened status. The Department of Environment and Conservation (DEC) maintains a Priority list (2009) that applies priority management to certain species that are poorly known and/or conservation dependent.

Of the mammal species that have declined and/or disappeared from the NSCP during the last century, eleven species are currently gazetted under the *Wildlife Conservation Act 1950* as Schedule 1 – Fauna that is rare or likely to become extinct and one that is listed as Schedule 2 – Fauna presumed to be extinct. Nine of the eleven species are also listed as Vulnerable under the *EPBC Act 1999* (see Table 1).

For the species that currently persist within the GSS study area, DEC's Priority list (2009) for WA ranks *Hydomys chrysogaster* (rakali) and *Macropus irma* (Western brush wallaby) as Priority 4 and *Isoodon obesulus* (Southern brown bandicoot) as Priority 5. *Dasyurus geoffroii* (chuditch) are higher listed as Vulnerable.

From a distribution perspective, *Bettongia penicillata ogilbyi* (woylie), *Setonix brachyurus* (quokka) and possibly *Pseudocheirus occidentalis* (ringtail possum), were at the northern limit of their range before disappearing from the NSCP. Of the species currently persisting, *Isoodon obesulus* (quenda) and *Rattus fuscipes* (bush rat) are approaching the northern end of their distribution (DEC 2009). *Tarsipes rostratus* (honey possum) and *Macropus irma* (Western brush wallaby) are confined to the south west of WA. The remaining species have a much broader former distribution.

DEC's Nature Conservation Service Swan Region Plan 2009-2014 (DEC 2006) has included as one of its top ten priorities for the next five years to improve the status of two threatened mammal fauna pertinent to the GSS study area, *Dasyurus geoffroi* and *Setonix brachyurus*.

Extinctions and Threatening Processes

The following section examines the threatening processes that may have contributed to the decline and local extinction of mammal species on the NSCP and corresponding GSS Study Area and how particular species may have responded to these threats.

Mammal Response to Habitat Loss/Fragmentation due to Urbanisation

Of all the faunal groups present in a largely cleared landscape, the effect of habitat loss and fragmentation has had the most impact upon the mammal group of fauna due to their compromised home ranges and dispersal capacity (Friend 1987).

How and Dell's (2000) sampling of urban remnants in the 1990's recorded so few ground mammals during single or several successive annual cycles that the results indicated the great majority of small mammals are locally extinct on urban vegetation remnants. These remnants ranged in size from 1-350 hectares, with only Western grey kangaroos (*Macropus fuliginosus*), Western brush wallabies (*Macropus irma*) and quenda (*Isoodon obesulus*) recorded as persisting on the larger of these.

The lack of mammal species richness from most fauna surveys on the NSCP in the last thirty years indicates that the majority of species that were originally recorded from the NSCP may have been adversely affected by clearing of land for development. Habitat loss and fragmentation would promote initial decline due to the diminished availability of shelter and food resources, and then secondary pressures such as predation, too frequent and extensive fire, and isolation from other remnants would culminate in eventual local extinction. The decline of large-ranging species such as the brushtail possum and chuditch could be largely affected by the loss of suitable habitat.

According to How and Dell (2000), the data on mammals in urban remnants differs markedly with those described from small remnants of native vegetation in the WA wheatbelt. In the wheatbelt, mammals persist in remnant vegetation despite widespread clearing of land for agriculture that commenced around the turn of the century; areas as small as 30 hectares were found to provide valuable sanctuaries for surviving populations. High population density in an urban environment, coupled with associated consequences such as increased fire frequency and cat predation, could be one explanation for this contrast (How and Dell 2000). Further, How and Dell (2000) claim that the "urban development of suburbs and roadways are a far greater impediment to dispersal and recolonisation of isolated bushland patches than are the modified landscapes associated with cropping".

The local extinction of ground mammals on urban remnants, but their persistence on wheatbelt remnants, indicates that either the longer duration of isolation of remnants is critical or that fire, competition and predation play more significant roles in urban areas (How and Dell 2000).

Mammal Response to Fire

Nation-wide there is insufficient ecological evidence to claim an understanding of the long-term impact of fire upon fauna (Clarke 2008). Land managers involved in fire, be it prescribed burning or wildfire suppression, broadly assume that ecological fire management, which currently attempts to maintain the diversity of plant communities within a reserve or landscape, will also maintain faunal diversity (Clarke 2008).

“Typically, the assumption is made that pyrodiversity begets diversity in plant communities and plant community diversity begets faunal diversity” (Clarke 2008, p. 386).

However, animals respond differently to plants, which have numerous strategies for recovering from fire, such as resprouting from lignotubers or epicormic buds, hard woody protection, resilient seeds in the soil seed bank etc. (Clarke 2008). In contrast, for animals that survive fire, they face food shortage, lack of shelter leading to increased predation pressure, and consequently higher chances of mortality. The less mobile species may become extinct from the burnt area and recolonisation will depend upon on an adjacent undisturbed site (Clarke 2008).

Different mammal species have preferences for habitat with different seral ages and some mammals need to range over several habitat types with different fire histories to meet their daily or seasonal resource requirements (Keith *et al.* 2002). The following text highlights the response to fire by some of the mammals known to be persisting in the GSS study area, with a particular focus on honey possums (*Tarsipes rostratus)*, as a surrogate for other small marsupial species.

According to DEC’s Fire Management Guidelines for honey possums (Flaherty and Armstrong 2007), populations of this species would be impacted by large, high intensity burns that result in complete or near-complete burn-out over large areas. Individuals surviving the fire would have little chance, succumbing to starvation, lack of shelter and exposure to predation within a short period. In particular, an isolated remnant that has been burnt at high intensity would lack both food and refuge for survivors, nor opportunity for recolonisation from adjoining unburnt vegetation (How and Dell 2000). This could potentially lead to the local extinction of small mammal populations from the isolated remnant.

For mammal species to persist in the face of fire, recolonisation of areas burnt at high intensity depends upon adjacent unburnt areas from which to disperse. Alternatively the fire needs to have been mild, such as prescribed burns that leave unburnt pockets within the burnt area to provide shelter and food for surviving individuals and a source population as conditions improve to recover in number. From this unburnt habitat, many mammal species can facilitate rapid recolonisation of burnt areas (Bamford 1986; Flaherty and

Armstrong 2007). DEC's fire management guidelines for honey possums comment that populations of this species are able to reinvade burnt areas from unburnt pockets and feed upon a selection of plant species that rapidly regenerate from lignotubers or epicormic buds, as would other herbivorous and nectivorous species.

As a threatening process on the NSCP, wildfires or high intensity prescribed burns that consume tracts of vegetation with no adjoining unburnt vegetation (eg the isolated banksia fragments within the pines) could feasibly have caused the local extinction of populations of honey possums and other small mammals that would either perish in the fire or have no capacity to recolonise from close-by.

The fuel age of the vegetation adjacent to a fire or prescribed burn is also very important for the recolonising capacity of mammals. Species such as honey possums can persist in two year old vegetation but remain or increase in low numbers until at least 10 years after fire before their pre-fire abundance recovers (Bamford 1986; Richardson and Wooller 1991). This has been found to correlate with both the density of flowering and the length of flowering period, which increase with time since fire. Honey possum abundance is closely linked to food source availability, which in turn is associated with time since fire (Bamford 1986; Everaardt 2003). Therefore, if the vegetation adjoining an area subject to fire is less than 10 years old itself, the honey possum population within it would still be low and have limited capacity to recolonise the newly burnt area. Similarly, to burn an area with a fuel age of less than 10 years under prescribed conditions, expecting a honey possum population to remain viable through survival in unburnt pockets would be unlikely, as the population would still be too low in number to sustain loss and retain a viable population.

Turning to rodents such as *Rattus fuscipes* (bush rats), studies have shown that population recovery following fire is dependent on surviving animals rather than immigrants (Lunney 2008). Bush rats survive by eating fungi that rapidly emerge after fire. A subsequent population increase in the burnt area depends on rainfall. Fire followed by continuing drought keeps the bush rat population at a low level (Lunney 2008). *Pseudomys albocinereus* (ash grey mice) also respond rapidly to disturbance such as fire, recolonising a burnt area and reaching peak abundance 3-6 years post-fire (Bamford 1986). This response to fire is due to the increased plant species richness, productivity and availability of cover at this stage of regrowth, suitable to their life history requirements. Friend (1993) identified the life history parameters of this species that facilitates early post-fire colonisation. Friend (1993) in Drew (1998) suggests that the generalist/omnivorous diet and high reproductive potential (breed year round, early sexual maturation) of both *Pseudomys albocinereus* and *Mus musculus* in addition to their underground burrowing habits, ensures that they can quickly establish in areas of recent disturbance in the absence of native vegetation cover. Both species have been labelled as opportunists that can quickly occupy environments relatively free of competitors.

Arnold *et al.* (1991) commented that Western brush wallabies (WBW) need areas of thick, tall scrub for shelter that can only develop after many years following fire. Arnold *et al.* (1991) claimed, in proposing appropriate fire management to sustain the population of WBW at Whiteman Park, that their habitat should be burnt no more than once every 20 years and in patches of 50-100 hectares. The WBW have a very high fidelity to their home ranges, which are probably 50 ha or less in area and include areas of dense as well as more open vegetation (Arnold *et al.* 1991).

Mammal Response to Predation

The native mammals most vulnerable to predation are those that fall within a critical weight range (CWR) of 35g to 4500g (Burbidge and McKenzie 1989; 100g – 5000g Johnson and Isaac 2009), particularly if they are ground-dwelling, non-arboreal species and occur in low rainfall areas (Burbidge and McKenzie 1989; Johnson and Isaac 2009; McKenzie *et al.* 2007). Species below this CWR body mass threshold have persisted more successfully, as their higher population growth rates allow them to recover more quickly from declines due to predation (Johnson and Isaac 2009). Species larger than 5 kg are a less preferred prey size for foxes (and feral cats), and are mostly herbivores, having benefited from some of the land use changes (e.g. agriculture) in Australia (Johnson and Isaac 2009).

Mammals that fall within the critical weight range include the majority of the suite of species historically recorded from the NSCP, and their decline in both abundance and distribution from the NSCP, south west Western Australia and mammal decline more broadly across Australia is well documented as significantly attributable to predation by foxes and feral cats.

The presence of cats (*Felis catus*) predates European occupation, with Burbidge & McKenzie citing Carnegie (1898) as claiming desert Aborigines used cats as a common food item due to their abundance. The fox (*Vulpes vulpes*) was first released in Victoria in the 1860's and spread rapidly. However, Burbidge and McKenzie (1989) do not consider these predators to be directly responsible for mammal extinctions in Australia. Fox and cat predation may be the current primary factors causing continual decline and local extinction of remnant populations but the cause of the original decline may have been quite different.

On the NSCP, *Trichosurus vulpecula* (brushtail possum) and *Dasyurus geofroii* (chuditch) are examples of CWR species that have been recorded in this area in the last 50 years but now only persist at very low densities. Predation may be a significant contributor to their decline in both abundance and distribution across the GSS study area, but their initial vulnerability to predation was probably due to habitat loss, fragmentation and disease (Abbott 2008).

The quenda (*Isoodon obesulus*) is one of the few CWR mammals that persist with secure populations within the GSS study area (Bamford and Bamford 1994; DEC 2008). In Whiteman Park (WP), fox baiting commenced in 1990 and subsequent monitoring of the quenda population within the Park has shown it to be increasing in abundance in the presence of baiting (Bamford and Bamford 1994 Chris Rafferty pers. com. 2009). Quenda were trapped by the WA Museum in WP in 1975 but in lower numbers than the 1993 survey, suggesting that the population may have been suppressed by fox predation (Bamford and Bamford 1994). Friend (1996) claimed that the quenda has disappeared from much of its former range due to habitat destruction. Remaining quenda populations may have persisted in the GSS study area by inhabiting dense vegetation surrounding wetlands, which may provide some protection from foxes (Bamford and Bamford 1994). However, this observed preference for dense wetland-associated vegetation is probably correlated with fox predation, as there is evidence of diurnal activity and use of upland habitat in areas that are predator-free (Bamford and Bamford 1994).

Mammal Response to Decline in Wetlands, Rainfall and Groundwater Levels

Over a quarter of the Swan Coastal Plain (SCP) between Wedge Island and Dunsborough was originally wetland, often forming interconnected series of lakes and sumplands. The wetlands are the most biologically productive areas of the SCP and directly or indirectly support most of the wildlife (Seddon 1972).

However, the draining & filling of wetlands that occurred on the SCP during the 1900's was estimated as having destroyed 49% of wetlands between Yanchep and Rockingham by the late 1960's (How and Dell 1993) and over 60% by the 1990's (How and Dell 1993). Balla (1994) made an even higher claim that over 80% of the coastal wetlands have been lost or seriously degraded since European settlement, largely from landfill, drainage or urban and rural development. This decline is continuing today, with increasing threat to wetland longevity from declining rainfall and groundwater abstraction.

According to How & Dell (1993) the most serious consequence of wetland loss has been the corresponding loss of fringing forests and thickets. For mammals such as the quokka (*Setonix brachyurus*), whose habitat preference comprises this fringing wetland-associated vegetation, the loss of wetlands has directly contributed to the loss or decline of these species from the GSS study area and greater NSCP. Quokkas had already disappeared by the time the comprehensive WAM study was undertaken in 1977-78. Mammals that have declined in the GSS study area, but are still persisting in remaining wetland-associated areas, include bush rats (*Rattus fuscipes),* rakali *(Hydromys chrysogaster)* and quenda (*Isoodon obesulus).* These species prefer dense vegetation associated with swamps, lakes & waterways and all have declined markedly around Perth (How and Dell 1993). However, as Burbidge & McKenzie (1989) pointed out, it is only the quokka and rakali that are actually restricted to wetlands or swampy vegetation on the mainland. The other species occur in wetland-associated habitat but are not restricted to it.

Burbidge and McKenzie's (1989) study demonstrated that the lower the annual rainfall in an area of the state, the higher the decline and/or extinction of mammal species. In their study, the Darling District, in which the GSS study area falls, was placed at the upper end of rainfall levels and lower end of species at risk ie high proportion of species that were stable in status based on rainfall level. This 1989 study suggests that, subsequent to the study, recent declining rainfall in the GSS area could in part be contributing to the continuing decline in mammal species that persist in this area. This relationship was applicable for the critical weight range (CWR) species.

How (1978) also discussed the effect of hydrological changes on terrestrial fauna as part of the WAM study. How (1978) quoted Havel (1975) and Aplin (1976) as predicting a shift in vegetation towards the xeric end of the continuum, and the extent of this depending on the extent of water level change. These vegetation changes would lead to a decrease in the fauna occupying moister areas and a converse increase in species occupying more xeric vegetation associations. How (1978) also suggested that species diversity would also decrease as the vegetation associations became less heterogeneous.

For nectar-feeding species such as honey possums (*Tarsipes rostratus)* and Western pygmy possums (*Cercartetus concinnus)*, declining rainfall and a lowering groundwater table may affect the flowering period of the species on which these marsupials feed. Groom *et al*. (2000) found that three species of Banksia, in particular *Banksia ilicifolia*, and other deep-rooted shrub species upon which honey possums rely for food, were severely impacted by drought stress at an area within the GSS study area. This was attributed to a significant lowering of the groundwater table caused by the cumulative effects of groundwater abstraction and below average rainfall (Groom *et al.* 2000). Similar declines of Banksia populations on the Scott River plains (South Coast) due to a lowered ground water table (Groom *et al.* 2000) are thought to be the cause of a corresponding decrease in honey possum populations (Phillips *et al.* 2004). (How 1978) referred to Muir and Dell's (Muir 1983) work that showed the importance of soil-moisture to the duration and abundance of flowering. How (1978, p.21) states that "any change in the soil-moisture gradient will alter the flowering regime with major consequences for the birds and insects dependent on this food source, and which may themselves be important pollinating vectors of the plants".

Mammal Response to Phytophthora cinnamomi

Phytophthora cinnamomi, the soil-borne water mould that has been identified as a 'key threatening process' in the Australian environment (O'Gara *et al.* 2005) is widely distributed in Banksia woodland of the Swan Coastal Plain (Podger 1968; Shearer 1994). The presence of the plant pathogen affects susceptible species under favourable conditions causing plant death, extinction of populations of some flora species, changes to vegetation structure and a reduction in primary productivity within affected ecosystems. The taxa that appear to be the most susceptible to this plant disease include most of the Proteaceae family (e.g. *Banksia spp.*), some of the Papilionaceae family, and a few of the Myrtaceae family (e.g. *Eucalyptus marginata*) (Shearer *et al*. 2007).

Currently 9.6% of the known taxa in the GSS study area (128 of 1337 species) are susceptible to *P. cinnamomi* (Marnie Swinburn pers.com, 2009). However as less than 20% of the total taxa have been assessed for their susceptibility, there is likely to be a far higher percentage that is impacted (potentially closer to 50% based on the 53% of susceptible species in the proportion that have been studied).

Mammals are expected to be affected by the impact of *P. cinnamomi* due to the loss of major resources such as food and availability of nesting sites, together with habitat and protective cover (Garkaklis *et al.* 2004; Wilson *et al.* 1994) For specialised species such as honey possums (*Tarsipes rostratus*), for whom their main source of food are flowering plants in the *Myrtaceae*, *Proteaceae* and *Epacridaceae* families, the death by *P. cinnamomi* of taxa from these highly susceptible families will significantly reduce the volume, availability and diversity of food supplies. Other nectivorous species will be similarly affected. Insectivorous mammal species such as *Sminthopsis griseoventor* will also be affected by *P.cinnamomi*, as the reduction in flowering plants due to disease will trigger a decline in invertebrate biomass, prompting a ripple effect along the food chain. From a habitat perspective, bush rats (*Rattus fuscipes*) in the south west of Western Australia have been shown to dramatically decline in numbers in a disease-infected area, with a strong correlation between trap captures and the structure and density of vegetation (Whelan 2003). The height of vegetation above 40 cm in affected areas had been severely impacted and this was attributed to the loss of biomass of Phytophthora-susceptible species.

Mammal Response to Disease

The probability that some of the mammal species that historically occurred and/or still occur in the GSS study area have been affected by disease at some point in recent history is undeniable according to Abbott's (2008) comprehensive compilation of historical records. Abbott's (2008) reconstruction of events from the 1880's onwards demonstrates that 18 species either became extinct in WA or dramatically reduced in abundance due to disease. The arrival and establishment of foxes in the 1920's then triggered a second wave of near-extinctions. One of Abbott's (2008) main arguments for disease as a significant factor of decline is that despite early settlement in south-west WA, the original vegetation remained intact with minimal clearing until the 1890's. Land clearing is often apportioned the greatest blame for initiating if not causing mammal decline (even in this review) and yet the decline of mammal species in south west WA had begun well before land clearing took effect. Therefore other processes must have been operating and the evidence for disease as one of these protagonists is convincing (Abbott 2008).

Brushtail possums (*Trichosurus vulpecula*), a high-profile species that still occurs in low densities in the GSS study area, mostly in suburbia or semi-urban fringes, was once widespread and common on the NSCP (Kitchener *et al.* 1978). However this species became scarce in the early 1900's and this has been primarily attributed to disease (Abbott 2008). Abbott has collated many reports of tree hollows containing skeletons of possums, which is consistent with mass mortality caused by disease (Abbott 2006; 2008).

Other species such as *Pseudocheirus occidentalis*, *Dasyurus geoffroii*, *Macropus irma* etc., all recorded from the GSS study area, have also yielded evidence of mass mortality from disease at various points in time, resulting in varying degrees of impact to populations and the species as a whole. Although many other threats can play greater or lesser roles in mammal decline it is pertinent to include the often overlooked and largely unseen impact of disease in the realm of threatening processes, as is evident from the findings of the current dramatic decline of woylies (*Bettongia penicillata*) (Wayne 2009).

Mammal Response to Introduced Herbivores and Rodents

The publicly owned vegetation of the GSS study area is grazed and browsed by feral herbivores such as the pig (*Sus scrofa*), goat (*Capra hircus)* and rabbit (*Oryctolagus cuniuclus*). Remnants on private property are also impacted by stock such as cattle, sheep and horses. Introduced herbivores have led to massive and widespread changes in vegetation composition and cover across the state, caused by compaction of the soil by hooved animals, the diversion or export of nutrients and subsequent erosion (Burbidge and McKenzie 1989). Rabbits compete with native ground dwelling herbivores for food and shelter whilst pigs cause habitat destruction by uprooting vegetation and turning over vast areas of soil with their foraging digs and movement across the landscape. There is no evidence suggesting that introduced herbivores have singularly caused the decline of mammals on the GSS study area but are a significant presence adding pressure to the fragile environment in which many species are trying to persist.

From How and Dell's (2000) surveys of urban remnants in the 1990's the most abundant mammal species were those introduced since European settlement. Most fauna surveys report similar high frequency and abundance of introduced rather than native mammal species (see section 'Other key surveys in recent times'). As an example, in How and Dell's (2000) surveys, House mice (*Mus musculus)* were caught on all bushland remnants and were the most abundant and widespread of all mammal species recorded in their study, whilst the Black Rat (*Rattus rattus)* was collected at Kings Park, Bold Park and Mount Claremont. Other introduced species were recorded by sighting or tracks on all the larger remnants. The European rabbit (*Oryctolagus cuniculus)* was common in larger remnants and in adjacent agricultural areas and the Red Fox (*Vulpes vulpes*) occurred both in larger remnants and inner city bushlands such as Kings Park and Bold Park. The feral cat (*Felis catus*) was also widespread throughout urban areas and the Northern Swan Coastal Plain. Altogether, surveys in the 1990's reaffirmed earlier statements by How and Dell (1993) that these species, which have been introduced since settlement (other than the cat that was already here) are now a prominent and integral part of our fauna.

Regional Context

In contrast to the depauperate mammal assemblage in the GSS study area, fauna surveys within a close radius of the GSS boundary tell a different story. A survey of Boonanarring Nature Reserve in 1996, which is 15 km north of Gingin, yielded a mammal suite of 11 species, which included *Pseudomys albocinereus* and *Sminthopsis griseoventer*, 2 ground-dwelling species that have not been recorded from the GSS study area for a long time (Burbidge *et al.* 1996). Boonanarring Nature Reserve is 9250 ha in size and extends eastward from the Gingin Scarp onto the Dandaragan Plateau. It is considered biologically significant because apart from the Jarrah and Marri woodlands typical of the NSCP and Darling Range it contains the best and most extensive example of the poorly conserved Banksia woodlands on Dandaragan soils (Burbidge *et al.* 1996). It also represents the transition zone vegetation associations of the SCP, Darling Scarp and the Dandaragan Plateau, being the woodlands of the Muchea-Gingin area and the heaths (kwongan) of the Mogumber area. The last record of *Pseudomys albocinereus* in the GSS study area is from 1987 at Melaleuca Park and the last record of *Sminthopsis griseoventor (Sminthopsis murina* complex) is from Karrakatta in 1940.

Three additional ground dwelling mammals were also recorded by Bamford (1986) from Mooliabeenee, 10km south east of Boonanarring, during his trapping surveys from 1983-1985. These 3 species, *Cercartetus concinnus*, *Sminthopsis dolichura* and *Sminthopsis granulipes*, are therefore also occurring within close proximity to the GSS study area, from which they are historically recorded as inhabiting (Kitchener *et al.* 1978, see Table 2).

A vegetated area on Ioppollo Road, directly east of and adjacent to the GSS study area (Ioppollo Rd runs east from Brand Hwy, the eastern boundary of the GSS study area), was surveyed by Rob Davis in 2006 and yielded 4 native mammal species, *Tarsipes rostratus, Sminthopsis griseoventer, Cercartetus concinnus* and *Pseudomys albocinereus*. The record of these last 3 provides very recent evidence of their persistence only just outside the GSS study area in Banksia woodland/Bassendean soils similar to the eastern half of the GSS.

Threats such as predation, habitat loss and declining rainfall that are affecting mammal species in the GSS study area are also impacting the species on these reserves. The lack of comprehensive survey or seasonality of survey may partly explain the lack of recent records for species such as *P.albocinereus* and *C.concinnus* in the GSS study area, especially if these species are only persisting at low densities.

Summary

No one factor can explain the decline and disappearance of mammals from the GSS study area and greater Northern Swan Coastal Plain. The most interesting observation is that both small and medium sized mammals are still persisting in very close proximity to the GSS study area, to the north at Cooljarloo (Bamford and Bamford 2001), to the east on Ioppollo Road (Davis pers com. 2008) and to the south (How and Dell 2000).

Habitat loss, disease and fragmentation seem to be the initiator of decline, weakening the resilience of a population/s of a species to cope with further pressures. Subsequent threatening processes, particularly predation and intense fire lead to further decline, contraction of range and eventual disappearance altogether.

Habitat destruction and fragmentation, which began with land clearing by the founders of the Swan Colony, reduced the extent of vegetation and systematically broke up the remaining tracts of bush into isolated compartments that were not always connected. Secondary threats such as fire have become a significant threatening process due to this fragmentation, with intense or too frequent fire potentially causing local extinction from an isolated remnant with no capacity for its recolonisation. Habitat loss causes greater competition for the remaining refuge and food resources, and fragmentation provides boundary access by predators and exposure for animals moving between fragments of unconnected habitat. The interaction of foxes and habitat is also significant as both extent of vegetation and density of vegetation would not be so critical if foxes were absent.

Habitat loss has included the draining of many of the lakes, sumplands and damplands in the GSS study area, impacting refugial wetland-associated species. Hydrological changes from a lowering groundwater table, due largely to declining rainfall and groundwater abstraction, have also resulted in habitat loss by changing the floristic structure of the vegetation above the groundwater table. These floristic changes alter the food resources available to nectivorous and insectivorous mammal species by reducing the flowering capacity of drought-stricken plants and correspondingly impacting the invertebrate populations.

Management Recommendations for remaining native mammal species in the GSS study area.

Reducing the pressures that have compounded the effects of habitat loss and fragmentation upon the remaining native mammal species on the GSS study area seems paramount. Obvious short-term actions for land managers include:

1. The coordinated and integrated control and reduction of introduced species, particularly foxes and cats, on both conservation estate and remnant vegetation on off-reserve estate on the NSCP. Fox and cat control may be best achieved by fencing areas of high conservation value (areas providing habitat for a number of persisting species eg wetlands & wetland-associated vegetation), enabling removal of predators and restriction of their access.
2. Examining master burn plans proposed by DEC for the next 7 years and ensuring factors such as time since last burnt, proximity to unburnt vegetation of greater than ten years, and appropriate prescriptive burn conditions have been considered.
3. Implement recommendations such as the “Ecological Linkages” proposal to provide connectivity between remnant vegetation and alleviate the additional pressures on the isolated remnants currently scattered across the GSS study area. This will involve significant revegetation at significant cost.

Appendix

Appendix 1: Occurrence of mammal species on the Northern Swan Coastal Plain and the broad periods of time in which they have been recorded. (Arnold et al. 1991; Bamford 1986; Bamford and Bamford 1990; 1994a; b; 1999a; b; Burbidge et al. 1996; CALM 1993; DEC 2008; Drew 1998; Ecologia Environmental Consultants 1990; 1997; Friend 1996; How and Dell 2000; How et al. 1996; Kinhill Pty Ltd 1997; Kitchener et al. 1978).

Mammal Species from the Northern Swan Coastal Plain	**Common Name**	**WA Wildlife Conservation Act 1950**	**Federal EPBC Act 1999**	**Validity of record as historically occurring on NSCP & significant aspects of their distribution in relation to the GSS study area**	**1800 - 1850**	**1850-1900**	**1900-1950**	**1950-1977**	**1977-2000**	**2000-2007/8**
Macropus fuliginosus	Western Grey Kangaroo			Reliable	√	√	√	√	√	√
Macropus Irma	Western Brush wallaby			Reliable	√	√	√	√	√	√
Macropus eugenii	Tammar wallaby			Unlikely according to Abbott (2008)		√	√		√	
Petrogale lateralis lateralis	Black-footed Rock-Wallaby	Schedule 1	Vul	Unlikely		√				
Onychogalea lunata	Crescent Nailtail Wallaby	Schedule 2	Ex	Unlikely, more likely to have occurred in the Darling Range		√		√ cave deposit		
Bettongia penicillata ogilbyi	Brushtail Bettong	Schedule 1		Reliable.Northern end of distn.	√	√	√			
Bettongia lesueur lesueur	Burrowing Bettong	Schedule 1	Vul	Unlikely.	√	√		√ cave deposit		
Setonix Brachyurus	Quokka	Schedule 1	Vul	Reliable. Northern end of distn.	√		√	√		
Lagostrophus fasciatus fasciatus	Banded Hare-wallaby	Schedule 1	Vul	Unlikely		√				
Trichosurus vulpecula	Brush-tailed Possum			Reliable			√	√	√	√
Pseudocheirus occidentalis	Western Ringtail Possum	Schedule 1	Vul	Unlikely. No specimens from NSCP. Northern end of distn.	√		√	√		
Cercartetus concinnus	Western Pygmy Possum			Reliable		√	√	√		√

Mammal Species from the Northern Swan Coastal Plain	Common Name	WA Wildlife Conservation Act 1950	Federal EPBC Act 1999	Validity of record as historically occurring on NSCP & significant aspects of their distribution in relation to the GSS study area	1800 - 1850	1850-1900	1900-1950	1950-1977	1977-2000	2000-2007/8
Tarsipes rostratus	Honey Possum			Reliable		√	√	√	√	√
Isoodon obesulus	Southern Brown Bandicoot			Reliable			√	√	√	√
Macrotis lagotis	Greater Bilby	Schedule 1	Vul	Unlikely		√	√			
Dasyurus geoffroii	Chuditch	Schedule 1	Vul	Reliable		√	√	√	√	√
Antechinus flavipes	Mardo			Unlikely, more likely to have occurred in the Darling Range.	√	√	√			
Parantechinus apicalis	Dibbler	Schedule 1	Vul	Reliable				√ cave deposit		
Phascogale tapoatafa spp.	Brush-tailed Phascogale	Schedule 1		Reliable (Abbott 2008). Northern end of distribution	√					
Sminthopsis crassicaudata	Fat-tailed Dunnart			Unlikely, more likely to have occurred in the Darling Range.			√	√		
Sminthopsis murina	Common Dunnart			Unlikely	√					
Sminthopsis granulipes	White-tailed Dunnart			Unlikely			√			
Myrmecobius fasciatus	Numbat	Schedule 1	Vul	Unlikely, occurred south east of Swan River.	√		√			
Rattus fuscipes	Southern Bush Rat			Reliable				√	√	√
Rattus tunneyi	Tunney's Rat			Unlikely				√ ?		
Pseudomys albocinereus	Ash Grey Mouse			Reliable	√			√	√	
Hydromys chrysogaster	Water Rat			Reliable			√	√	√	
Tachyglossus aculeatus	Echidna			Reliable			√	√	√	√
Nyctophilus geoffroyi	Lesser Long-eared Bat			Reliable			√	√	√	
Vespadelus regulus	Southern Forest			Reliable			√	√	√	

Mammal Species from the Northern Swan Coastal Plain	Common Name	WA Wildlife Conservation Act 1950	Federal EPBC Act 1999	Validity of record as historically occurring on NSCP & significant aspects of their distribution in relation to the GSS study area	1800 - 1850	1850-1900	1900-1950	1950-1977	1977-2000	2000-2007/8
	Bat									
Chalinolobus gouldii	Gould's Wattle Bat			Reliable				√	√	√
Chalinolobus morio	Chocolate Wattled Bat			Reliable				√		
Tadarida australis	White-striped Freetail-bat			Reliable			√	√		
Canis familiaris	Dingo			Reliable	√	√	√	√		
Vulpes vulpes	Red fox			Reliable			√	√	√	√
Mustela putorius	Ferret			Reliable					√	
Felis catus	Feral Cat			Reliable	√			√ no date	√	√
Rattus rattus	Black Rat			Reliable					√	√
Mus musculus	House Mouse			Reliable					√	√
Oryctolagus cuniuclus	European Rabbit			Reliable			√	√	√	√
Sus scrofa	Feral pig			Reliable					√	√
Capra hircus	Goat			Reliable						√

Wildlife Conservation Act 1950 – Wildlife Conservation (Specially Protected Fauna) Notice 2008

Schedule 1 = Fauna that is rare or likely to become extinct.

Schedule 2 = Fauna presumed to be extinct.

EPBC Act 1999 = Environmental Protection & Biodiversity Conservation Act 1999

Ex = Extinct

Vul = Vulnerable

Appendix 2 Current threatening processes presumed to affect extant mammal species in the GSS study area.

Species	Habitat Preference	Habitat loss & fragmentation	Inappropriate fire frequency, size or intensity	Fox predation	Cat predation	Dieback disease eg *Pythophthora cinnamomi*	Lack of food resources eg due to lowered groundwater table	Aridification	Competition
Macropus fuliginosus	Woodland, shrubland & heath communities across all landforms where rainfall is winter dominated.	√						√	
Macropus irma	Dense long-unburnt understorey vegetation for shelter & refuge, on Spearwood & Bassendean soils, may be associated with wetlands & damplands. High fidelity to home range (50 ha), forage in open recently burnt areas.	√	√	√					
Tarsipes rostratus	Dense proteaceous heathland, preference for older fuel age habitat providing flowering density. Restricted diet of nectar & pollen.	√	√	√	√	√	√	√	
Isoodon obesulus	Dense low vegetation in forest, woodland, shrub & heath communities. Away from the coast, the preference for dense low veg is associated with dampland/wetland areas.Shelter in long unburnt, forage in newly burnt.	√	√	√	√		√	√	

Species	Habitat Preference	Habitat loss & fragmentation	Inappropriate fire frequency, size or intensity	Fox predation	Cat predation	Dieback disease eg *Pythophthora cinnamomi*	Lack of food resources eg due to lowered groundwater table	Aridification	Competition
Species	**Habitat preference**								
Rattus fuscipes	Mesic environments, comprising dense understorey and ground cover. Riparian vegetation.	√	√		√		√		
Hydromys chrysogaster	Permanent bodies of fresh or brackish water including lakes, rivers, streams & coastal beaches.	√		√	√		√	√	
Tachyglossus aculeatus	Unknown, 2 trapped on Spearwood soils.	√		√					
Trichosurus vulpecula	Eucalypt forest & woodland, with tree or log hollows available for nesting.	√	√	√					
Dasyurus geoffroii	Woodland & heath vegetation, logs for nesting.	√	√	√					√
Pseudomys albocinereus	Low heath & shrubland vegetation.	√	√		√				√
Cercartetus concinnus	Floristically diverse and dense understorey of Proteaceous & Myrtaceous plants.	√	√		√	√	√	√	
Sminthopsis griseoventer	Open woodland, low mallee, dense heath & seasonal swampland.	√	√		√	√	√		

Species	Habitat Preference	Habitat loss & fragmentation	Inappropriate fire frequency, size or intensity	Fox predation	Cat predation	Dieback disease eg *Pythophthora cinnamomi*	Lack of food resources eg due to lowered groundwater table	Aridification	Comp etition
Bats (5 species)	Variable. Trees with hollows.	√					√	√	

References

Abbott I. (2006) Mammalian faunal collapse in Western Australia, 1875 - 1925: the hypothesised role of epizootic disease and a conceptual model of its origin, introduction, transmission, and spread. *Australian Zoologist* **33**, 530 - 61.

Abbott I. (2008) Historical perspectives of the ecology of some conspicuous vertebrate species in south-west Western Australia. *Conservation Science Western Australia* **6**, 1-214.

Aplin T. E. H. (1976) Consequences of variation of the water table level: vegetation and flora. In: *Groundwater Resources of the Swan Coastal Plain* (ed B. A. Carbon) pp. 126-37. CSIRO Publications, Perth, WA.

Arnold G. W., Smith G. T. & Brooker M. G. (1991) Whiteman Park fauna survey: final report: prepared for the State Planning Commission, Whiteman Park, Western Australia. CSIRO Division of Wildlife and Ecology.

Augee M. L. (2008) Echidna (*Tachyglossus aculeatus*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 36-9. Reed New Holland Publishers, Sydney, Australia.

Balla S. A. (1994) Wetlands of the Swan Coastal Plain: their nature and management. Department of Environmental Protection, Perth, Western Australia.

Bamford M. J. (1986) The dynamics of small vertebrates in relation to fire in *Banksia* woodland near Perth, Western Australia. PhD Thesis, Murdoch University, Perth.

Bamford M. J. & Bamford A. R. (1990) *Yellagonga Regional Park: a preliminary survey of vertebrate fauna*. Department of Conservation and Land Management, Perth, Western Australia.

Bamford M. J. & Bamford A. R. (1994) Survey of the Quenda *Isoondon obesulus* and other medium-sized, native mammals, December 1993. Department of Planning and Urban Development, Perth, Western Australia.

Bamford M. J. & Bamford A. R. (1999a) The estimation of the number of Western Grey Kangaroos in Whiteman Park; May-June 1999. Whiteman Park Authority, and Department of Planning and Urban Development, Perth, Western Australia.

Bamford M. J. & Bamford A. R. (1999b) A study of the Brush or Black-gloved Wallaby Macropus irma (Jourdan 1837) in Whiteman Park. Whiteman Park Authority, Perth, Western Australia.

Bamford M. J. & Bamford A. R. (2001) Cooljarloo Environmental Management Programme: Fauna studies 2000. Tiwest Joint Venture, Perth.

Burbidge A. A. & McKenzie N. L. (1989) Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. *Biological Conservation* **50**, 143-98.

Burbidge A. H., Boscacci L. J., Alford J. J. & Keighery G. J. (1996) A biological survey of Boonanarring nature reserve. *CALMScience* **2**, 153-87.

Carthew S. M., Cadzow B. R. & Foulkes J. N. (2008) Western Pygmy Possum (*Cercartetus concinnus*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 215-7. Reed New Holland Publishers, Sydney, Australia.

Clarke M. F. (2008) Catering for the needs of fauna in fire management: science or just wishful thinking? *Wildlife Research* **35**, 385-94.

Coulson G. (2008) Western Grey Kangeroo (*Macropus fuliginosus*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 333-4. Reed New Holland Publishers, Sydney, Australia.

DEC. (2006) Draft: Nature Conservation Service, Swan Region Plan 2006 - 2009. WA Department of Environment and Conservation,, Perth, Western Australia.

DEC. (2008) Trapping data from monitoring survey of Isoodon obesulus populations at Ellenbrook and Twin Swamps Nature Reserves. Department of Environment and Conservation Swan Coastal District, Wanneroo.

DEC. (2009) Naturemap: Mapping Western Australia's Biodiversity. Department of Environment and Conservation, URL: http://naturemap.dec.wa.gov.au/.

Department of Conservation and Land Management. (1993) Fauna studies in water supply reserve 34537, adjacent to Neerabup National Park. Water Authority of Western Australia, Leederville, Western Australia.

Dickman C. R. (2008) Grey-bellied Dunnart (*Smithopsis grieseoventer*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 141-3. Reed New Holland Publishers, Sydney, Australia.

Drew M. (1998) Patterns in terrestrial vertebrate fauna populations in Banksia woodlands of Whiteman Park. Murdoch University, Perth, Western Australia.

Ecologia Environmental Consultants. (1990) Southern brown bandicoot *Isoodon obesulus* Biological assessment survey. City of Mandurah Town Planning, Mandurah.

Ecologia Environmental Consultants. (1997) Mitchell Freeway: Romeo Road to Perth-Lancelin Road: biological assessment: Main Roads Western Australia.

Everaardt A. (2003) The impact of fire on the Honey Possum, *Tarsipes rostratus*, in the Fitzgerald River National Park, Western Australia (PhD Thesis). Murdoch University, Perth.

Flaherty C. & Armstrong R. (2007) Fire Management Guideline No. S2 - Honey Possum. p. 10. Department of Environment and Conservation, Perth.

Friend A. (1996) The Department of Conservation and Land Management Bandicoot Survey 1991 - 1996. In: *Database of Bandicoot sightings reported by the public*. Department of Conservation and Land Management, Como, Western Australia.

Friend G. R. (1993) Impact of fire on small vertebrates in mallee woodlands and heathlands of temperate Australia: A review. *Biological Conservation* **65**, 99-114.

Friend J. A. (1987) Local decline, extinction and recovery: relevance to mammal populations in vegetation remnants. In: *Nature Conservation: The Role of Remnants of Nature Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J. M. Hopkins) pp. 53-64. Surrey Beatty & Sons, Chipping Norton.

Groom P. K., Froend R. H. & Mattiske E. M. (2000) Impact of groundwater abstraction on a Banksia woodland, Swan Coastal Plain, Western Australia. *Ecological Management & Restoration* **1**, 117-24.

Harris J. M., Goldingay, R. L., Broome, L., Craven, P., Maloney, K. S. (2007) Aspects of the ecology of the Eastern Pygmy Possum Cercartetus nanus at Jervis Bay, New South Wales. *Australian Mammalogy* **29**, 39 - 46.

Havel J. J. (1975) The effects of water supply for the city of Perth, Western Australia, on other forms of land use. *Landscape Planning* **2**, 75-132.

How R. A. (1978) The environment of the northern Swan Coastal Plain. Consideration of faunal changes and recommendations. In: *Faunal Studies of the Northern Swan Coastal Plain - consideration of past and future changes* pp. 1-53. Western Australian Museum, Department of Conservation and Environment, Perth, Western Australia.

How R. A. & Dell J. (1993) Vertebrate Fauna of the Perth metropolitan region: consequences of a modified environment. In: *Urban Bush Management* (ed M. Hipkins) pp. 28-47. Australian Institute of Urban Studies, Western Australia.

How R. A. & Dell J. (2000) Ground vertebrate fauna of Perth's vegetation remnants: Impact of 170 years of urbanization. *Pacific Conservation Biology* **6**, 198-217.

How R. A., Harvey M. S., Dell J. & Waldock J. M. (1996) Ground Fauna of Urban Bushland Remnants in Perth: Report to the Australian Heritage Commission.

Jackson M., Morris K., Harold G. & Kitchener D. (1975) A spring, 1975, biological survey of the proposed mussel pool complex and recommendations for its future development. Western Australian Museum, and University of Western Australia, Perth, Western Australia.

Johnson C. N. & Isaac J. L. (2009) Body size and extinction risk in Australian mammals: back to the Critical Weight Range. *Austral Ecology* **34**, 35-40.

Keith D. A., McCaw W. L. & Whelan R. J. (2002) *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. Cambridge University Press, Cambridge, UK.

Kerle J. A. & How R. A. (2008) Common Brushtail Possum (*Trichosurus vulpecula*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 274-6. Reed New Holland Publishers, Sydney, Australia.

Kinhill Pty Ltd. (1997) Perth to Darwin National Highway, Reid Highway to Maralla Road. Shire of Swan, Perth, Western Australia.

Kitchener D. J., Chapman A. R. & Barron G. (1978) Mammals of the northern Swan Coastal Plain. In: *Faunal Studies of the Northern Swan Coastal Plain - a consideration of past and future changes* pp. 54-92. Western Australian Museum, Department of Conservation and Environment, Perth, Western Australia.

Lunney D. (2008) Bush Rat (*Rattus fuscipes*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 685-7. Reed New Holland Publishers, Sydney, Australia.

Morris K. D. (2008) Ash-grey Mouse (*Pseudomys albocinereus*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 611-3. Reed New Holland Publishers, Sydney, Australia.

Muir B. G. (1983) Drainage, swamp structures and vegetation succession at Melaleuca Park - northern Swan Coastal Plain. pp. 27 - 39. Western Australian Herbarium Research Notes.

O'Gara E., Howard K., Wilson B. A. & Hardy G. E. S. J. (2005) Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 1 - A Review of Current Management. In: *A report funded by the Commonwealth Government Department of the Environment and Heritage*. Centre for *Phytophthora* Science and Management, Murdoch University, Western Australia.

Olsen P. D. (2008) Water Rat (*Hydromys chrysogaster*). In: *The Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 662-4. Reed New Holand Publishers, Sydney, Australia.

Paull D. J. (2008) Southern Brown Bandicoot (*Isoodon obesulus*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 180-2. Reed New Holland Publishers, Sydney, Australia.

Phillips R., S. , Tomlinson S., Jennings B. & Holley R. (2004) Summer ecophysiology of the honey possum (*Tarsipes rostratus*) on the south coast of Western Australia (Honours thesis). University of Western Australia.

Podger F. D. (1968) Aetiology of jarrah dieback and disease of dry sclerophyll *Eucalyptus marginata* Sm. forests in Western Australia. In: *Science*. University of Melbourne, Melbourne.

Renfree M. B. (2008) Honey Possum (*Tarsipes rostratus*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 258-60. Reed New Holland Publishers, Sydney, Australia.

Richardson K. C. & Wooller R. D. (1991) The effects of fire on Honey Possum populations. Report prepared for World Wide Fund for Nature, Perth, Western Australia.

Seddon G. (1972) *A Sense of Place. A Response to an Environment, The Swan Coastal Plain, Western Australia.* University of Western Australia Press.

Serena M. & Soderquist T. (2008) Western Quoll (*Dasyurus geoffroii*). In: *Tha Mammals of Australia - 3rd Edition* (eds S. M. Van Dyck and R. Strahan) pp. 54-6. Reed New Holland Publishers, Sydney, Australia.

Shearer B. L. (1994) The major plant pathogens occurring in native ecosystems of south-western Australia. *Journal of the Royal Society of Western Australia* **77**, 113-22.

Shearer B. L., Crane C. E., Barrett S. & Cochrane A. (2007) *Phytophthora cinnamomi* invasion, a major threatening process to conservation of flora diversity in the South-west Botanical Province of Western Australia. *Australian Journal of Botany* **55**, 225-38.

Wayne A. (2009) Woylie declines: what are the causes? Information Sheet 7/2009. Science Division. Department of Environment and Conservation.

Whelan J. (2003) The impacts of *P. cinnamomi* (Cinnamon fungus) on the abundance and mycophageous diet of the bush rat (*Rattus fuscipes*) (Honours thesis). Murdoch University, Perth, Australia.

Woollard P., Vestjens W. J. M. & MacLean L. (1978) The ecology of the Eastern Water Rat *Hydromys chrysogaster* at Griffith, N.S.W.: food and feeding habits. *Australian Wildlife Research* **5**, 59 - 73.