Australian Government
Department of the Environment, Water, Heritage and the Arts

Biodiversity

Species Profile and Threats Database

Glossary

Bettongia penicillata ogilbyi — Woylie

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EPBC Act Status and Documents

EPBC Act Listing Status	**Listed as Endangered**
Listed Critical Habitat	
Listing & Conservation Advice	Threatened Species Scientific Committee (TSSC) (2009w). *Commonwealth Listing Advice on* Bettongia penicillata ogilbyi *(Woylie)*. [Online]. Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/66844-listing-advice.pdf.
	Threatened Species Scientific Committee (TSSC) (2009x). *Commonwealth Conservation Advice on* Bettongia penicillata ogilbyi *(Woylie)*. [Online]. Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/66844-conservation-advice.pdf.
EPBC Act Plans	Australian Government Department of the Environment and Heritage (AGDEH) (2005p). *Threat Abatement Plan for Predation, Habitat Degradation, Competition and Disease Transmission by Feral Pigs*. [Online]. Available from: http://www.environment.gov.au/biodiversity/threatened/publications/tap/pig.html.
	Department of the Environment, Water, Heritage and the Arts (DEWHA) (2008adf). *Threat Abatement Plan for predation by the European red fox*. [Online]. Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/biodiversity/threatened/publications/tap/foxes08.html.
	Department of the Environment, Water, Heritage and the Arts (DEWHA) (2008adg). *Threat Abatement Plan for predation by feral cats*. [Online]. Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/biodiversity/threatened/publications/tap/cats08.html.
	Department of the Environment, Water, Heritage and the Arts (DEWHA) (2009w). *Threat abatement plan for disease in natural ecosystems caused by* Phytophthora cinnamomi. [Online]. Canberra; ACT: Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/biodiversity/threatened/publications/tap/phytophthora.html.
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Naming

Scientific name	*Bettongia penicillata ogilbyi* [66844]
Family	Potoroidae:Diprotodonta:Mammalia:Chordata:Animalia (Mammals)
Species author	
Infraspecies author	(Waterhouse, 1841)
Reference	

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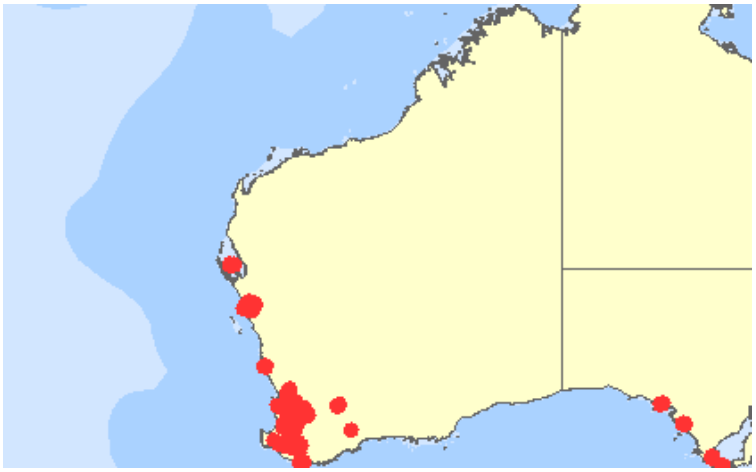
Distribution Map

Distribution map



This is an indicative distribution map of the present distribution of the species based on best available knowledge. See map caveat for more information.

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Legal Status

The current conservation status of the Woylie, *Bettongia penicillata ogilbyi*, under Australian and State/Territory Government legislation, and under international conventions, is as follows:

National: Listed as Endangered under the *Environment Protection and Biodiversity Conservation Act 1999.*

Western Australia: Listed as Rare or likely to become extinct under the *Wildlife Conservation Act 1950.*

South Australia: Listed as Rare under the *National Parks and Wildlife Act 1972.*

Victoria: At the species level, listed as Threatened under the *Flora and Fauna Guarantee Act 1988.*

NSW: The eastern subspecies, *Bettongia penicillata penicillata*, listed as Presumed Extinct under the *Threatened Species Conservation Act 1995.*

Northern Territory: At the species level, listed as Extinct under the *Territory Parks and Wildlife Act 2000.*

International: At the genus level, listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

At the species level, classified as Critically Endangered under the International Union for Conservation of Nature and Natural Resources (IUCN) Red List.

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Taxonomy

Scientific name: *Bettongia penicillata ogilbyi*

Common name: Woylie

Other common names: Brush-tailed Bettong or Brush-tailed Rat-kangaroo. Indigenous names include Woylyer and Karpitchi. This species is conventionally accepted.

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Description

The Woylie is a small potoroid marsupial with adult males weighing 1–1.8 kg and adult females weighing 0.75–1.5 kg. The head and body length is 300–360 mm for males and 280–350 mm for females; the tail length is between 250–360 mm (Van Dyck & Strahan 2008). Woylies are coloured grey to greyish brown dorsally and on the flanks, and pale greyish ventrally; the tail is dark and has a distinctive black brush at the end (Van Dyck & Strahan 2008). Woylies carry nesting material in the curled tip of their tail which is prehensile (adapted for grasping) (Christensen 1980; Troughton 1973).

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Australian Distribution

Distribution

The Woylie is endemic to Australia and once occupied most of the Australian mainland, south of the tropics including the arid and semi-arid zones of Western Australia, the Northern Territory, South Australia, NSW and Victoria. By the 1970s, its distribution had been reduced to three locations in Western Australia: Perup forest, Tutanning Nature Reserve and Dryandra Woodland (DEC 2007; Van Dyck & Strahan 2008). Like many medium-sized terrestrial mammals formerly occurring in arid and semi-arid Australia, the species had retreated to the most mesic parts of its former range since European settlement (Burbidge & McKenzie 1989).

In 1975, the South Australian National Parks and Wildlife Service began a breeding program for the species at Para Wirra Recreation Park from animals sourced from Perth Zoo with the goal of providing stock to re-establish the species in South Australia. The first experimental releases were onto two small islands, Bird Club Island in 1979 and Venus Bay "Island A" in 1980, followed by two larger islands, St Francis Island in 1981 and Wedge Island in 1983 (Freegard 2007).

In Western Australia, wide scale fox baiting and reintroduction projects implemented under the *Western Shield* program, have led to an increase in the distribution and abundance of the Woylie (Orell 2004; TSSC 2009w; Van Dyck & Strahan 2008). In Western Australia, scattered Woylie populations may be found throughout the jarrah forest in the south-west corner of the state. Isolated populations also occur at Francois Peron National Park (NP), Kalbarri NP, Nambung NP, Julimar Forest, Avon Valley NP, Dryandra Woodland, Boyagin Nature Reserve (NR), Tutanning NR and North Karlgarin NR (DEC 2009).

Extent of occurrence

The extent of occurrence of the Woylie in 2006 was estimated to be 18 300 km^2. Only post 1995 records with a high or moderate certainty of identification were used (Freegard 2007). The table below presents extent of occurrence estimates.

Extent of occurrence estimates for the Woylie.

Year	Extent of occurrence (km^2)	Reference
Historic	1 771 786	Lomolino & Channell (1995)
Extant (as at 1983)	53 451	Lomolino & Channell (1995)
1992	Less than 1% of its former range	Nelson et al. (1992)
1995	17 000 (WA only)	Start et al. (1998)
2006	18 300	Freegard (2007)

Burbidge and Fuller (1984), and Burbidge and colleagues (1988) provided evidence that the Woylie was once the most common and widest ranging of all potoroids with a distribution covering most of the mainland south of the tropics. Finlayson (1958) produced a map describing its distribution from south-west Western Australia, across southern Australia to the Great Dividing

Range, and northward through much of Queensland (he included *Bettongia tropica*), eastern Northern Territory and northern South Australia (TSSC 2009w).

Oral history research involving Aboriginal people has confirmed that Woylies were even more broadly distributed in the central deserts than suggested by Finlayson (1958); they ranged over much of the Gibson Desert in central Western Australia and into the southern region of the Northern Territory (Burbidge & Fuller 1984; Burbidge et al. 1988).

A historical account of changes in abundance of Woylies is provided by W.G. Pearce (Freegard 2007) who reports that Woylies were plentiful in the Mt Barker district around 1902 but disappeared around 1903–04 (cause unknown). They were seen again around 1929 prior to the arrival of the fox but disappeared again once the fox was established.

Wood Jones (1925) mentioned that animals belonging to a species of *Bettongia* (later verified as *B. penicillata* in Finlayson 1958) were "swarming" on Saint Francis Island off the coast of South Australia in the 1880s. They were also common over most of South Australia at the beginning of the century (Wood Jones 1925).

Woylies are highly fecund and respond quickly to changes in their environment (e.g. removal of predators under the Western Australian *Western Shield* program led to an increase in the distribution and abundance of the Woylie). Additionally, successful translocations have improved both extent of occurrence and area of occupancy as evidenced under the *Western Shield* program (Orell 2004).

Area of occupancy

The current area of occupancy of the Woylie is estimated to be between 5600–6800 km^2 (Freegard 2007; Start et al. 1998) as summarised in the table below. These estimates were derived from a GIS analysis using 5 km^2 and 10 km^2 grid squares respectively.

Area of occupancy estimates for the Woylie.

Year	Area of isolated reserves & islands occupied (km^2)	Area of forest in south-west Western Australia occupied (km^2)	Total area of occupancy (km^2)	Reference
1995	-	-	Probably exceeds 2000	Start et al. (1998)
1995	248	575 (using 5 km^2 grid squares) 1800 (using 10 km^2 grid squares)	800 (using 5 km^2 grid squares) 2000 (using 10 km^2 grid squares)	Freegard (2007)
2006	3898	1675 (using 5 km^2 grid squares) 2900 (using 10 km^2 grid squares)	5600 (using 5 km^2 grid squares) 6800 (using 10 km^2 grid squares)	Freegard (2007)

Captive animals

Many zoos around the world keep Woylies in their collections. A total of 188 Woylies are currently held in 37 zoos registered with the International Species Information System (ISIS) (ISIS 2009).

Translocated populations

Woylie populations have been established by translocations, with mixed success, to parts of their former range. There have been three translocation attempts in NSW (including one privately-owned sanctuary) between 1998–2005, 13 in South Australia (including one privately-owned sanctuary) between 1979–2001 and 53 in Western Australia (including two privately-owned sanctuaries) between 1977–2006 (DEC 2007). The table below summarises Woylie reintroductions that have been undertaken and their outcomes.

Summary of Woylie translocations (DEC 2007).

State	Number of release sites	Successful	Failed	Indeterminate	Number of Woylies released
NSW	3	0	2	1	273
South Australia	13	4	7	2	718
Western Australia	53	6	6	41	2405+
TOTALS:	69	10	15	44	3396+

Additionally, the Woylie recovery plan (Start et al. 1995) identified several translocation sites. It identified Venus Bay "Island A" (failed), Baird Bay unnamed island (failed), Wedge Island (failed), St Peter Island (successful), Yookamurra Sanctuary (indeterminate), Julimar SF (failed/ indeterminate) and Venus Bay Conservation Park (indeterminate) (Start et al. 1995). Other Woylie reintroduction sites are identified in the draft strategic plan for the *Western Shield* program (CALM 1999b).

Distribution fragmentation

The Woylie now occurs at 21 locations, and while some areas are isolated reserves and islands (particularly in South Australia), many have large numbers and the overall distribution is not considered severely fragmented (TSSC 2009w).

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Surveys Conducted

The Woylie has been the subject of considerable research and conservation efforts. The distribution is well known based on the extensive Woylie surveys conducted (Bellchambers 2001; Courtenay 1994; DEC 2007; Freegard 2007; Gillam 2006; Martin et al. 2006; Orell 2004; Priddel & Wheeler 2004; Van Weenen et al. 2009; Wayne 2008; Wayne et al. 2006).

In Western Australia, annual Woylie surveys are conducted under the *Western Shield* program at 42 sites (DEC 2009; Freegard 2007; Orell 2004). Additionally, Woylie populations are monitored at 13 sites in South Australia and three in NSW. An overview of Woylie surveys can be found in Freegard (2007) and Wayne (2008).

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Population Information

Abundance
Population size is difficult to calculate, but in 2006 estimates were made using two methods: using anecdotal estimates from experts the population was estimated to be 8000–11 000 individuals; while using population densities and extent of occurrence, the population was estimated to be 15 000 individuals (Freegard 2007). It is estimated that current numbers would be substantially lower than 2006 estimates because of further population declines. Additionally, the number of mature individuals is not known but likely to be lower than the 2006 estimates (TSSC 2009w).

Subpopulations
The Woylie was known to occur in 21 locations in 2006 (including three natural populations) (DEC 2007; TSSC 2009w). The size of subpopulations occupying isolated reserves and islands are easier to estimate than the contiguous habitat because the boundary of the subpopulation is known and the distribution/density of Woylies across the reserve/island is easier to determine. The number of mature individuals estimated to occur in South Australia is near 5000 (with the majority of individuals in the Wedge and St Peter Island subpopulations) (Freegard 2007). Woylie subpopulation estimates are summarised in the table below.

Projected trends and tenure for the Woylie subpopulations based on 2006 data (Freegard 2007).

Location	Tenure	Population origin	Estimated population (expert opinion)	Population trend
Venus Bay "Island A"	Conservation Park	Translocated	30	Stable
Wedge Island	Nature Reserve	Translocated	1500–3000	Stable at moderate densities
St Peter Island	Conservation Park	Translocated	2000–3500	Stable at moderate densities
Confidential Sanctuary	Conservation Reserve	Translocated	500	Stable
Tutanning	Nature Reserve	Extant	300	Stable
Batalling	State Forest	Translocated	400–500	Declined
Boyagin	Nature Reserve	Translocated	400–500	Moderate decline now stable
Dryandra	State Forest	Extant	400–500	Stable at low numbers
Avon Valley	National Park	Translocated	50	Declined
Paruna Sanctuary	Private property	Translocated	200	Stable
Venus Bay Peninsula	Nature Reserve	Translocated	150	Declined
Yookamurra Sanctuary	Private property	Translocated	70–80	Indeterminate
Perup/Lake Muir area	Nature Reserve/ State Forest/ National Park	Extant	1000	Declined
Walpole/Denmark area	National Park	Translocated	100	Declined
Northern/central jarrah forest	Nature Reserve/ State Forest/ National Park	Translocated	500	Declined
Sunklands/Pemberton area	National Park/ State Forest	Translocated	200	Declined
North Karlgarin	Nature Reserve	Translocated	40	Declined
Francois Peron	National Park	Translocated	50	Indeterminate
Kalbarri	National Park	Translocated	100	Indeterminate

Nambung	National Park	Translocated	50	Declined
Scotia Sanctuary	Private property	Translocated	30	Stable at low densities

Population trends

The Woylie has undergone a major reduction in population numbers historically, but as a result of significant conservation effort by Western Australia and South Australia since the 1970s, the population size and extent of occurrence increased for a period to about 1998. However, since approximately 2001, Woylie numbers have undergone rapid and substantial declines, the cause of which is not fully understood (Freegard 2007; TSSC 2009w; Wayne 2008).

Trap survey success figures are available for Woylie monitoring sites in Western Australia and South Australia (Wayne et al. 2006). For example, capture rates from long-term monitoring and research has indicated that the Woylie population at Dryandra declined by 93% between 2000–06; the Upper Warren population(s) underwent a median decline of 95% between 2002–07; and the Woylie population at Batalling declined by 97% between 2002–07 (Wayne 2008). A concurrent Woylie decline of > 90% has also been observed at Venus Bay Peninsula in South Australia; while South Australian island populations appear to have remained relatively stable (J. Van Weenan 2008, pers. comm. cited in Wayne 2008; Wayne 2008). Wayne and colleagues (2006), and Freegard (2007) indicated that survey results are likely to underestimate the declines.

The rate of decline of affected populations has been rapid, up to 95% per annum (Freegard 2007). Declines were most significant in the most important (large and indigenous) populations, while the very small and/or low density, often isolated populations appear to be less affected (Wayne 2008). Overall the results show Woylie numbers declined by 70–80% between 2001–06; from 37 000–40 000 in 2001 to 8000–15 000 in 2006 as shown in the tables below. These declines are still continuing and there is little evidence of signs of a recovery (Freegard 2007).

Population estimates for Woylies in 2001 (Freegard 2007).

	Extent of occurrence (ha)	**Estimated population density (woylies/ha)**	**Estimated population (from density)**	**Estimated population (expert opinion)**
Venus Bay "Island A"	15	2	30	30
Wedge Island	947	2	1894	1500–3000
St Peter Island	3439	2	6878	2000–3500
Confidential Sanctuary	280	2	560	500
Dryandra	12 192	0.5	6096	6000
Batalling	8000	0.5	4000	3000
Perup/Lake Muir area	236 936	0.1	23 694	20 000
Tutanning NR	2369	0.1	237	300
Boyagin NR	4781	0.05	239	1500
Paruna Sanctuary	2000	0.05	100	100
Venus Bay Peninsula	1100	0.05	55	100
Yookamurra Sanctuary	1100	0.05	55	70–80
Walpole/Denmark area	8988	0.01	90	50
Northern/central jarrah forest	774 905	0.001	775	2000
Sunklands/Pemberton area	89 925	0.001	90	200
Lake Magenta NR	107 810	0.001	108	50
Francois Peron NP	52 590	0.001	53	50
Kalbarri NP	183 000	0.001	183	30
		TOTAL:	**45 000**	**37 000–40 000**

Population estimates for Woylies in 2006 (Freegard 2007).

	Extent of occurrence (ha)	**Estimated population density (woylies/ha)**	**Estimated population (from density)**	**Estimated population (expert opinion)**
Venus Bay "Island A"	15	2	30	30
Wedge Island	947	2	1894	1500–3000
St Peter Island	3439	2	6878	2000–3500
Confidential Sanctuary	280	2	560	500
Tutanning NR	2369	0.1	237	300

Batalling	8000	0.05	400	400–500
Boyagin NR	4781	0.05	239	400–500
Dryandra	12 192	0.05	610	400–500
Avon Valley NP	4370	0.05	219	50
Paruna Sanctuary	2000	0.05	100	200
Venus Bay Peninsula	1100	0.05	55	150
Yookamurra Sanctuary	1100	0.05	55	70–80
Perup/Lake Muir area	236 936	0.01	2369	1000
Walpole/Denmark area	8988	0.01	90	100
Northern/central jarrah forest	774 905	0.001	775	500
Sunklands/Pemberton area	89 925	0.001	90	200
North Karlgarin NR	5622	0.001	6	40
Francois Peron NP	52 590	0.001	53	50
Kalbarri NP	183 000	0.001	183	100
Nambung NP	18 400	0.001	18	50
Scotia Sanctuary	64 653	0.001	65	30
		TOTAL:	**15 000**	**8 000–11 000**
		Percent decline 2001–06 :	**67**	**72–78**

Population fluctuations
Woylies may be subject to significant natural cyclical fluctuations in numbers (Christensen et al. 1985). A severe decline in the abundance of Woylies was observed in the early 1970s, followed by a rapid increase. Christensen and colleagues (1985) predicted that a severe drop in numbers was inevitable. However, these cyclical changes have been studied for a relatively short period of time (most since the mid-1990s) and are therefore not well understood (TSSC 2009w). The majority of Woylie reintroductions have been to a modified landscape with introduced predators, and other sites may be subject to the same pressures, so the capacity for any increase in abundance over time may be disrupted. Cyclical patterns are not known in sympatric and analogous species which suggests such patterns may not necessarily apply to the Woylie (TSSC 2009w).

Cross breeding
No cross breeding of Woylies has been recorded.

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Populations in Reserves

Woylies have been recorded from seven nature reserves, 14 national parks, eight state forest areas, one timber reserve and two conservation parks (DEC 2007; Freegard 2007).

Populations that occur in nature reserves, conservation parks or national parks are not managed specifically for Woylies, but are managed generally for the conservation of flora and fauna. Populations occurring in state forest are not managed specifically for conservation, but are baited for foxes (DEC 2007).

In South Australia, secure subpopulations that occur in conservation parks include Venus Bay (peninsula), Venus Bay "Island A" and St Peter Island. Attempts have been made to establish additional occurrences on the mainland in conservation parks and national parks (Freegard 2007).

In both Western Australia and South Australia, reintroductions have occurred onto private property where a long term commitment to conservation efforts has been demonstrated. Woylies have been reintroduced to two private properties in Western Australia and three in South Australia (Freegard 2007).

Woylies have also been translocated to fenced wildlife sanctuaries that are effectively managed as wild subpopulations (two in Westeren Australia, one in South Australia and one in NSW). These sanctuaries are owned and managed by the Australian Wildlife Conservancy (Freegard 2007).

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Habitat

Historically, Woylies occupied habitat in a variety of climatic zones including mediterranean, semi-arid and arid. Habitat types ranged from forest to grassland, coastal and inland (Christensen & Leftwich 1980; Sampson 1971).

During the day the Woylie shelters under patches of dense undergrowth, logs and rock-cavities (Christensen & Leftwich 1980; Sampson 1971) and occasionally in burrows (Burbidge et al. 1988).

Gastrolobium thickets provide refuges for Woylies against introduced predators. Prior to widescale fox baiting, the Woylie's distribution had been reduced to a handfull of locations in Western Australia with the common characteristic of the presence of *Gastrolobium* thickets (e.g. *G. biloba*). *Gastrolobium* contains monofluoroacetic acid which is the compound present as sodium monofluoroacetate in the toxic bait '1080'. It is thought that habitat with *Gastrolobium* thickets provided the Woylie with refuge from introduced predators, partly because of the ability to physically hide in the bushes but also the local reduction in predator numbers caused by secondary poisoning (Start et al. 1998).

In the event of fire, unburnt patches of vegetation become refuges for Woylies. Woylies have been observed to remain in their nest until the fire front approaches, then move in front of the flames until an unburnt patch becomes available (Christensen 1980). If no unburnt patch is available they will double back through the flames at the edge of their home range to the safety of burnt ground, demonstrating fidelity to their home ranges (Christensen 1980).

The Woylie does not rely on any listed threatened ecological community. However, many locations where Woylies are found are also inhabited by other threatened species. The abundance of Woylies in the mid to late 1990s also meant that Woylies were often the first species translocated to sites, where releases of higher priority species were planned, to determine effects of feral predators (Priddel & Wheeler 2004).

Threatened species associated with Woylie habitat include the Chuditch (*Dasyurus geoffroii*), Southern Brown Bandicoot (*Isoodon obesulus*), Bilby (*Macrotis lagotis*), Numbat (*Myrmecobius fasciatus*), Brush-tailed Phascogale (*Phascogale tapoatafa*) and Western Ringtail Possum (*Pseudocheirus occidentalis*) (Orell 2004).

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Life Cycle

The generation length of the Woylie is 2–3 years (TSSC 2009w). Woylies live to approximately 4–6 years in the wild and can breed in their first year (Christensen 1995). In captivity, a male lived for over 14 years and was still breeding (Keynes 1989). On Wedge Island in South Australia, a Woylie first captured in 1999 was recaptured in 2006, making it at least 7 years old (Gillam 2006). Woylies have the potential to breed continuously, producing a maximum of three young in a year (Sampson 1971; Serventy 1970). A summary of the reproductive characteristics of Woylies is contained in the table below.

Reproductive characteristics of the Woylie.

Reproductive characteristic	Duration / number	Reference
Age of female sexual maturity	170–180 days	Christensen (1995)
Gestation	21.2 days	Smith (1992)
Number of pouch young	1, rarely 2	Christensen (1995); Sampson (1971)
Pouch life	90 days	Christensen (1995)
Maximum number of young produced in a year	3	Serventy (1970)

The highest mortality in *Bettongia* is associated with young-at-foot and subadult age categories, and is lowest for pouch young and mature individuals (Freegard 2008; Vernes 1999; Vernes & Pope 2002).

The proportion of females caring for young tends to be lower in the drier months when conditions for survival are harsher. Woylies produce a single young at a time, but twins have occasionally been observed (Sampson 1971). Woylies exhibit embryonic diapause, so it is possible for females to carry a blastocyst in the womb, young in the pouch and a young-at-foot (Smith 1989, 1996). It is not uncommon for a large proportion of females to be either carrying young or suckling a young-at-foot.

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Feeding

A wide range of food types have been recorded in the diet of the Woylie including leaf material, seasonal fruits and berries, roots, tubers, bark and invertebrates (Nelson 1989; Sampson 1971).

In south-west Western Australia, Woylies feed extensively on hypogeous fruiting bodies of ectomycorrhizal fungi (Christensen 1980; Lamont et al. 1985). At Boyicup in Western Australia, dependence on fungi as a food source is most pronounced over the dry summer–autumn period (Christensen 1980). At Venus Bay Conservation Park, Woylies were found to consume fungi in similar proportions to other bettong populations but there were fewer species available and roots and tubers were eaten when fungi availability was low (Lee 2003a). On Venus Bay "Island A" however, fungi was not found to be a significant dietary

component (Nelson 1989).

During feeding activities at dawn, dusk or at night, Woylies make a large number of small diggings that disturb the soil surface. In a study site at Dryandra Woodland a digging rate of 38–115 diggings/Woylie/night was recorded which corresponds to approximately 6 tonnes of soil moved per Woylie per year (Garkaklis 2001).

Woylies are known to cache food such as the nuts from sandalwood trees (*Santalum spicatum*) and wheat seeds (Christensen 1980; Murphy et al. 2005; Sampson 1971). The seeds are buried and presumably the Woylie returns at a later date to consume the seeds or germinating plants.

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Movement Patterns

Seasonal or migratory movements have not been recorded for the Woylie. Daytime movements have been observed but the Woylie is predominantly nocturnal (TSSC 2009w). Woylies rest during the day in nests and forage at night. Nests are well-concealed, built over a shallow depression that are most commonly made using long grasses, but will use other material such as strips of bark (in the forest) or dried seagrass and/or *Triodia* (in arid coastal areas) (Christensen & Leftwich 1980; D. Armstrong 2006, pers. comm. cited in Freegard 2007).

If danger approaches they will wait until the last moment to flee from a nest. Predators with a keen sense of smell, such as the European fox, are able to detect the presence of the Woylie and successfully ambush them as prey (TSSC 2009w). When disturbed, Woylies move quickly with their head low and tail extended, sometimes colliding with obstacles in their haste to flee. They often become agitated when approached, sometimes resulting in physical injury, capture myopathy and ejection of pouch young. Females fleeing from a disturbance may also throw pouch-young and leave young-at-foot in the nest (Van Dyck & Strahan 2008).

Males and females occupy individual home ranges, each including a nesting and feeding area. Nesting areas are territorial but feeding areas may overlap (Martin et al. 2006). The size of home ranges varies between habitats and sites with males tending to have larger home ranges than females, enabling them to visit more than one female. The table below presents home range estimates for the Woylie.

Home range sizes calculated for Woylies (area in hectares).

Location	Males	Females	All	Reference
Tutanning NR, Western Australia	35.0	23.0	29.0	Sampson (1971)
Yendicup, Western Australia	35.0	15.4	33.0	Leftwich (1983)
Boyicup, Western Australia	8.7 feeding area with non-overlapping core of 2.1 (nest area)	7.5 feeding area with non-overlapping core of 2.7 (nest area)	N/A	Christensen (1980)
Confidential Sanctuary, Western Australia	N/A	N/A	5.4	Hide (2006)
Confidential Sanctuary, Western Australia	N/A	N/A	4.3	Hide (2006)
Lincoln NP, South Australia	N/A	N/A	17.6	Martin et al. (2006)
Venus Bay "Island A", South Australia	N/A	N/A	4.0	Nelson (1989)

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Survey Guidelines

Woylies have a distinctive black brush at the end of their tail which they use to carry nesting material (Christensen 1980; Troughton 1973). They build distinctive, but well hidden, nests most commonly under dense bushes and these may be observed to determine the presence of the species. In jarrah forest Woylies may be detected by observing bark strands removed from around the base of jarrah trees which are used in the construction of its nest.

Orell (2004) notes several methods of detecting Woylie occurrences: trapping, hair-tube sampling and surveying for diggings. Woylies are readily trapped in small cages traps (20 cm x 20 cm x 56 cm) baited with a mixture of rolled oats, peanut butter and sardines. Traps are usually placed at set intervals (usually 200 m) along tracks in the study site but sometimes are set in a grid pattern (Orell 2004). Woylies are noctural and so traps are set overnight and checked early in the morning. Trapping may be conducted at anytime of the year as there is no period to avoid trapping based on the developmental stage of young (Orell 2004). Woylies are prone to injury in the trap and to the ejection of young from the pouch (Van Dyck & Strahan 2008). Trained persons are therefore required to conduct surveys for Woylies via trapping.

Hair-tubes are a low-cost method of surveying for the presence of a range of species that requires no animal handling in the field and has the potential to provide some limited abundance data. However, expertise is required to process and identify hair

samples collected (Orell 2004).

Woylies contribute significantly to soil turn-over by their digging activities in search of food, and the presence of fresh diggings may be used to determine the presence of Woylies in an area (Orell 2004). However, Woylie diggings may be confused with other species, such as those by Southern Brown Bandicoot (*Isoodon obesulus*), and therefore similarly with hair-tube samples, the correct identification of diggings requires an experienced observer.

Sandpad analysis and spotlighting have also been successfully used to survey Woylies in Western Australia as part of the Woylie Conservation Research Project (WCRP) (Wayne 2008).

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Threats

Past threats

Many factors are likely to have contributed to the decline of the Woylie in different areas. Introduced predators (fox and cat) and habitat loss were among the principal factors thought responsible for historical declines (Burbidge & McKenzie 1989; Start et al. 1995).

Predation
Introduced predators such as the European fox (*Vulpes vulpes*) and feral cat (*Felis catus*) are likely to have reduced the distribution of the species and declines in some areas have been linked to the arrival of these predators. Native predators such as the Carpet Python (*Morelia spilota*) and large birds of prey may also have impacted on Woylie popuations.

Resources
Historically, habitat alteration through land clearing, altered fire regimes and grazing have reduced the area of suitable habitat available to the species. Fire regimes have changed since European settlement with some habitat being burned more frequently, and changed intervals of fire frequency. This changed the vegetation composition, which in turn affected the available Woylie habitat (DEC 2007).

Competition for resources with grazing species such as the rabbit (*Oryctolagus cuniculus*) and other stock may also have been a factor in the decline of the Woylie, particularly in more arid areas.

Disease
Anecdotal evidence suggests disease may have caused the decline of many mammal species (including the Woylie) in Western Australia in the late 1800s to early 1900s (Abbott 2006).

Current and future threats

Threats that are currently being investigated as possible causes of the recent Woylie declines are described below (TSSC 2009w, 2009x; Wayne 2008).

Predation
While the cause of recent Woylie declines is unknown, they could be a result of changed interactions between predators or abundance of predators. For example removal of the European fox may have resulted in an increase in feral cat numbers that were previously limited by fox predation. Introduced predators, in particular the fox and feral cat are considered among the greatest threats to the survival of the Woylie - despite targeted management and research programs. However, given the lack of fox activity or density monitoring data associated with most of the recently observed Woylie declines, it is not possible to determine whether foxes may be a major agent of the decline.

Introduced predators have also been implicated as the cause of several failed reintroduction attempts. Cats, dogs (*Canus familiaris*) and foxes were identified as the main cause of mortality of reintroduced Woylie subpopulations at a number of sites (Delroy et al. 1986; DEH 2006; James et al. 2002; Priddel & Wheeler 2004). Cats were actually deliberately introduced to St Francis Island to exterminate the Woylies which were doing damage to garden produce (Wood Jones 1925).

Native predators also impact on the persistence of small and establishing populations, especially where the ecosystem has been significantly altered. Predation by Carpet Pythons and White-breasted Sea-eagles (*Haliaeetus leucogaster*) have been implicated in the failed Woylie translocation to St Francis Island in South Australia (DEH 2006) and Wedgetail Eagle (*Aquila audax*) predation contributed to the failed reintroduction to the Flinders Ranges in South Australia (Bellchambers 2001).

Habitat destruction
A contributing factor to the recent decline in Woylies could be habitat alteration caused by land clearing and grazing on private, state forest and pastoral areas. Habitat fragmentation and loss leads to changes in the abundance, availability and/or suitability of resources such as water, food, shelter, reproductive mates and territory. Habitat destruction can also be caused by feral pigs (*Sus scrofa*) and the presence of dieback caused by the exotic pathogen *Phytophthora cinnamomi* (DEC 2007). Particularly in more arid areas, competition for increasingly limited resources with grazing species such as the rabbit and other stock, is a

factor in Woylie declines (DEC 2007).

Woylies prefer patches of dense undergrowth, that provide continuous canopy and therefore refuges against introduced predators. Inappropriate fire regimes cause the loss of the protective understorey, rendering the landscape less suitable as habitat for years after the fire (DEC 2007).

Climate change may alter the availability of resources as rainfall and temperature patterns change, thereby acting as a threatening process. Climate change is likely to result in more frequent and intense dry season wildfires which could affect many vegetation communities (Hennessy et al. 2007).

Disease
Disease agents are possibly responsible for Woylie declines and can be categorised into the following groups: viral, bacterial, haemaparasites, endoparasites, ectoparasites, toxic and nutritional. Wayne (2008) has suggested that disease is likely to be a significant factor in the recent large declines in population size.

Direct human influence
Human influence could come in the form of disruption to natural behaviour associated with ecotourism and hand feeding of wild animals at key tourist destinations within the Woylie's range (Harvey 1999). The potential impacts of artificial feeding are closely linked with disease issues as increased local densities of Woylies may promote the transmission of some diseases.

Additionally, recent findings from the WRCP indicate that Woylie population declines are primarily driven by mortality (DEC 2009; Wayne 2009). Predation/scavenging by feral cats and foxes have been associated with most mortalities, but it is likely other factors, notably disease, are involved (predisposing individuals to predation/scavenging). A number of viruses and a couple of parasites are the subject of ongoing investigations. The WRCP found habitat loss/modification, food resources and fire are among the factors that do not appear to be causing the current population collapses (Wayne 2009).

Other threats
Catastrophic events such as wildfire threaten the continued survival of subpopulations in South Australia and Western Australia. Such fires are likely to be most catastrophic at sites where recolonisation from the surrounding area is not possible (eg islands and isolated reserves). The removal of vegetation on mainland sites by a severe wildfire will increase the rate of incursion by foxes, despite 1080 baiting, and expose survivng Woylies to higher levels of predation. This has the potential to drive a population to extinction. The likelihood of this occurring in Dryandra, Upper Warren or Batalling is very low due to the habitat types and fire management practices in these areas.

South Australia populations have low genetic diversity and so may be more severely affected by a disease or other change in environmental conditions.

Burbidge and McKenzie (1989) showed that most terrestrial Australian mammals in the weight range of 35 g to 5.5 kg mean adult body weight have declined or become extinct. The Woylie falls within this "critical weight range".

A thorough quantitative analysis showing probability of extinction has not been undertaken for the Woylie. However, a preliminary Population Viability Analysis was conducted for the Woylie by McComb and colleagues (1994) who modelled the effect of four scenarios (a 10 or 20 year burn cycle with or without fox baiting). This study found that the likelihood of Woylie persistence, predicted extinction time and the rate of genetic loss were all predicted to improve for Woylies if either foxes were baited (ie juvenile survival improved) or if burning cycles were increased from 10 to 20 years.

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Threat Abatement and Recovery

Minister's reason for recovery plan decision
In May 2009, the Minister for the Environment, Heritage and the Arts stated that there should be a recovery plan for the Woylie because it has experienced significant declines in extent of occurrence and population size since European settlement, and is currently undergoing a severe decline. While this decline may be cyclical and the Woylie may naturally recover, the impact of feral predators and other threats on this cyclical process is not known.

An updated state recovery plan for the Woylie is currently being drafted by the Western Australia Department of Environment and Conservation (DEC) (Freegard 2008).

Existing management plans
A recovery plan was first written for the Woylie by Hall and colleagues (1991) and was substantially revised by Start and colleagues (1995). A plan of management for Woylies in South Australia was developed by Nelson and colleagues (1992). A review of the conservation status of the Woylie that resulted in the delisting of the species in 1996 was conducted by Start and colleagues (1998). The Woylie is also mentioned in the management plans for various conservation reserves and sanctuaries in which it occurs. For example, Dryandra Woodland Management Plan (CALM 1995), Islands of the Western Eyre Peninsula Management Plan (DEH 2006) and Karakamia Sanctuary Management Plan (Wykes 1994).

Research priorities
Considerable conservation and monitoring work is underway in relation to the Woylie. The most important priority is research into the reasons for the sudden decline in Woylie numbers, particularly in the large indigenous populations.

Current research (TSSC 2009x):

- WCRP (DEC 2009; Wayne 2008, 2009). Phase 1 aimed to diagnose the cause of the Woylie declines. Phase 2 began in mid-2008 and aims to further investigate causes identified in Phase 1.
- Mesopredator release is being undertaken by DEC Science Division. The project aims to investigate the relationship between introduced predators (foxes and cats) and various native species in 1080 baited and unbaited sites.

Recommended areas of research (TSSC 2009x):

- The impacts of disease on important Woylie populations and associated hygiene practices that could be established in those populations.
- Altered baiting regimes to better target the direct predators of the Woylie.

Local and regional priority actions
The following regional priority recovery and threat abatement actions are underway to support the Woylie recovery (TSSC 2009x):

- In South Australia, several ecosystem reconstruction/revegetation projects are being undertaken (e.g. Ark on Eyre, Bounceback) and the reintroduction of the Woylie has been considered as a desirable outcome following the restoration work and implementation of feral animal control programs at these sites.
- In Western Australia, fox and cat baiting under the *Western Shield* program is aimed at improving the conservation status of many species. Reintroduction projects under the same program also benefit a range of species including the Woylie.

The Woylie was not mentioned in any national threat abatement plans because it was not considered a threatened species when these documents were written. Should these documents be revised, the Woylie could be listed as an affected species for plans covering the impacts of the European fox (DEWHA 2008adf), feral cat (DEWHA 2008adg), possibly *Phytophthora cinnamomi* (DEWHA 2009s), and feral pigs (AGDEH 2005p) (TSSC 2009x).

Future priority actions
Although much is being done for the conservation of the Woylie several further actions are suggested (TSSC 2009x).

- Fire regimes - the development and implementation of a suitable fire management strategy for Woylie locations may be a priority where fire regimes could cause loss of protective understorey.
- Conservation information - raise awareness of the Woylie within the local community.

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Management Documentation

The Commonwealth Conservation Advice on *Bettongia penicillata ogilbyi* (Woylie) (TSSC 2009x) and the Woylie recovery plan (Start et al. 1995) provide guides to conservation actions, threat abatement and management strategies for the Woylie. An updated state recovery plan is currently being drafted by DEC (Freegard 2008).

Additional Woylie conservation and management advice is given by CALM (1995, 1999b), DEC (2009), DEH (2006), Delroy and colleagues (1986), Hide (2006), Martin and colleagues (2006), McComb and colleagues (1994), Nelson and colleagues (1992), Wayne (2008) and Wykes (1994).

Suitable management actions may also be found in the Commonwealth threat abatement plans AGDEH (2005p), Commonwealth of Australia (2009s), DEWHA (2008adf) and DEWHA (2008adg).

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Caveat

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Citation: Department of the Environment, Water, Heritage and the Arts (2009). *Bettongia penicillata ogilbyi* in Species Profile and Threats Database, Department of the Environment, Water, Heritage and the Arts, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed 2009-12-24T16:58:40.