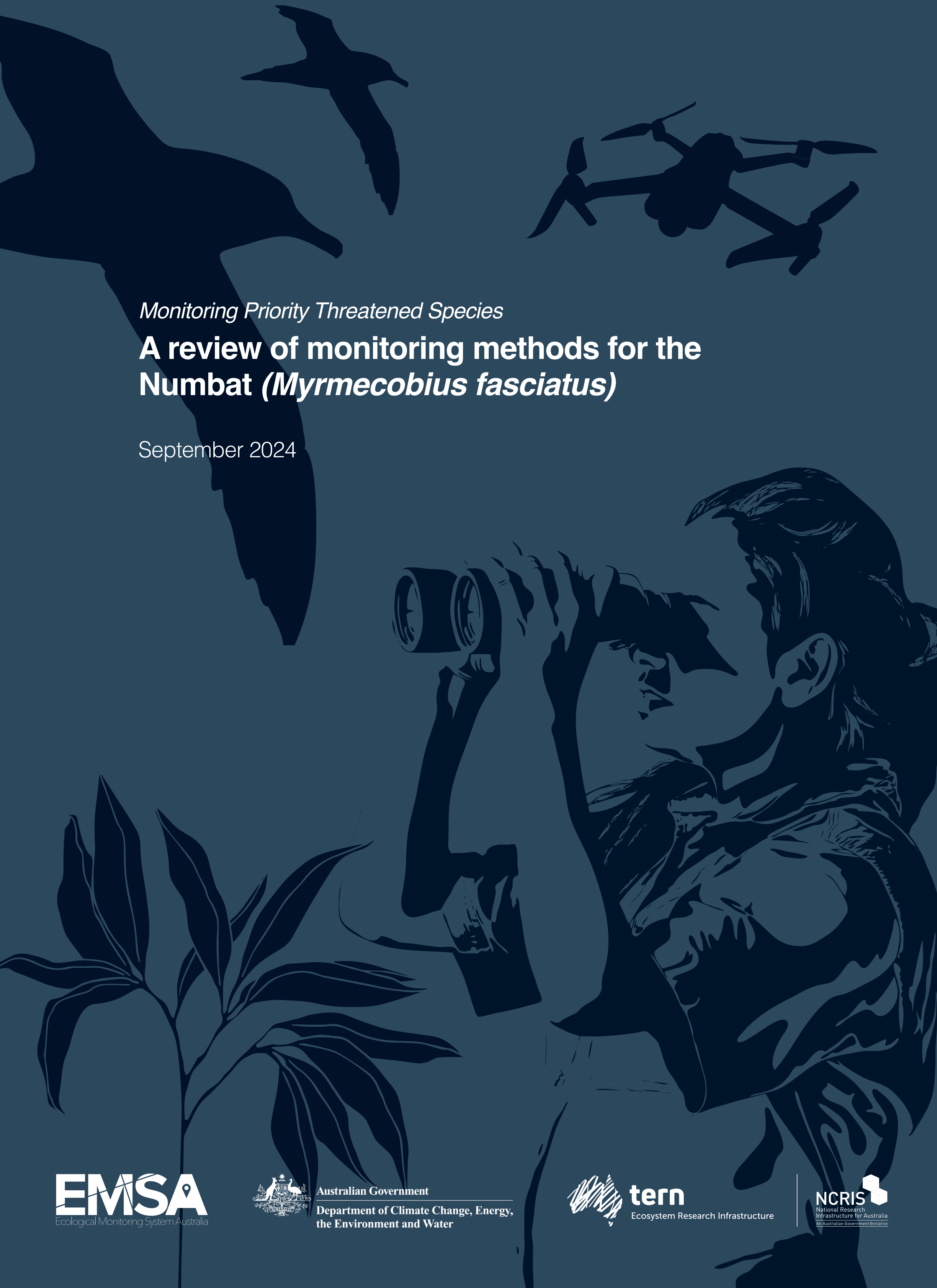

Monitoring Priority Threatened Species

A review of monitoring methods for the Numbat *(Myrmecobius fasciatus)*

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We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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About

This literature review collates information on one of the 110 priority threatened species identified in the *Threatened Species Action Plan 2022-2032* and has been reviewed by invited practitioners experienced in monitoring the species.

The *Survey Guidelines for Monitoring Threatened Species* project, a collaboration of the Department of Climate Change, Energy, the Environment, and Water (DCCEEW) and the Terrestrial Ecosystem Research Network (TERN), aims to improve our knowledge of threatened species by enhancing accessibility and sharing of quality scientific threatened species data. By developing best practice field survey guidelines and recommendations, practitioners will be better equipped to conduct standardised, repeatable surveys.

By identifying the monitoring methods typically implemented by practitioners, documenting and assessing the techniques known to work, and identifying opportunities to standardise the methods, we can move towards ensuring all monitoring is species-appropriate, comparable between practitioners and populations, and repeatable over time. Further, together with consistent terminology, guidelines, instructions, and data collection, we can refine efforts and resources to measure and share information. Data collected using robust, standardised methods will improve our knowledge of threatened species and underpin threatened species recovery at scale. This project is essential to establishing monitoring protocols and data repositories to enhance the accessibility and sharing of threatened species data.

TERN has prepared the literature reviews for the Department of Climate Change, Energy, the Environment, and Water. For further information, please visit the EMSA Threatened Species Survey Guidelines website. Additional information, particularly monitoring methods and techniques not included that should be considered, can be brought to the author's attention by emailing tern@adelaide.edu.au for consideration for future updates.

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1 Background

1.1 Species name

The common name Numbat (*Myrmecobius fasciatus*, Waterhouse, 1836) is derived from Australian Aboriginal terms including Noobat, Nombat, Nyoombot, and Nambart. Terms Wai-hoo, Wai-hao, Weeoo, Weeou, Wee-u, Weeu, Wi-u, Wiu, Walpurti, Mutjurarranypa, and Parrtjilaranypa also have been used by Aboriginal people to describe this species. Early European common names included Banded Anteater, Marsupial Anteater, and White-banded Bandicoot (Abbott 2001; Cooper 2011; Friend 2008; Strahan & Conder 2007; Troughton 1967; Wood Jones 1923).

1.2 Conservation status

The Numbat is listed as Endangered under the Environment Protection and *Biodiversity Conservation Act 1999* (Cth). The conservation status of the species in jurisdictions is outlined in Table 1.

The Numbat is also listed as Endangered under the IUCN Red List of Threatened Species because there are estimated to be less than 1,000 mature individuals, and there is an ongoing decline despite translocations. It also has a highly restricted and fragmented area of occupancy (AOO) where there are known threats (Woinarski & Burbidge 2016).

Table 1. National, international and state conservation status for the Numbat

Jurisdiction	Conservation status	Legislation/listing
Commonwealth	Endangered	*Environment Protection and Biodiversity Conservation Act 1999*
New South Wales	Extinct	*Biodiversity Conservation Act 2016*
Northern Territory	Extinct	*Territory Parks and Wildlife Conservation Act 1976*
South Australia	Endangered	*National Parks and Wildlife Act 1972*
Western Australia	Endangered	*Biodiversity Conservation Act 2016*
IUCN	Endangered	IUCN Red List of Threatened Species

1.3 Summary of data held in the Threatened Species Index

The Threatened Species Index (TSX) provides reliable and robust measures of change in the relative abundance of Australia's threatened and near-threatened species at national, state and regional levels. Understanding these changes in species populations is crucial for monitoring Australia's conservation progress and allows users to measure and report on the benefits of conservation investments and to justify and design targeted management responses. Currently, the index is restricted to birds, plants and mammals, with new groups to be added in the near future.

Table 2 summarises Numbat data held in the TSX. More information on the TSX, including how to contribute threatened species monitoring data to the index, can be found on the TSX website.

Table 2. Summary data held in the Threatened Species Index (TSX) for the Numbat

TSX information	Data held
Data held in the TSX	Yes
Number of data sources	3
Number of unique sites	4
Average time series length (years)	11.5
Average number of sampling years	10

1.4 Distribution and abundance

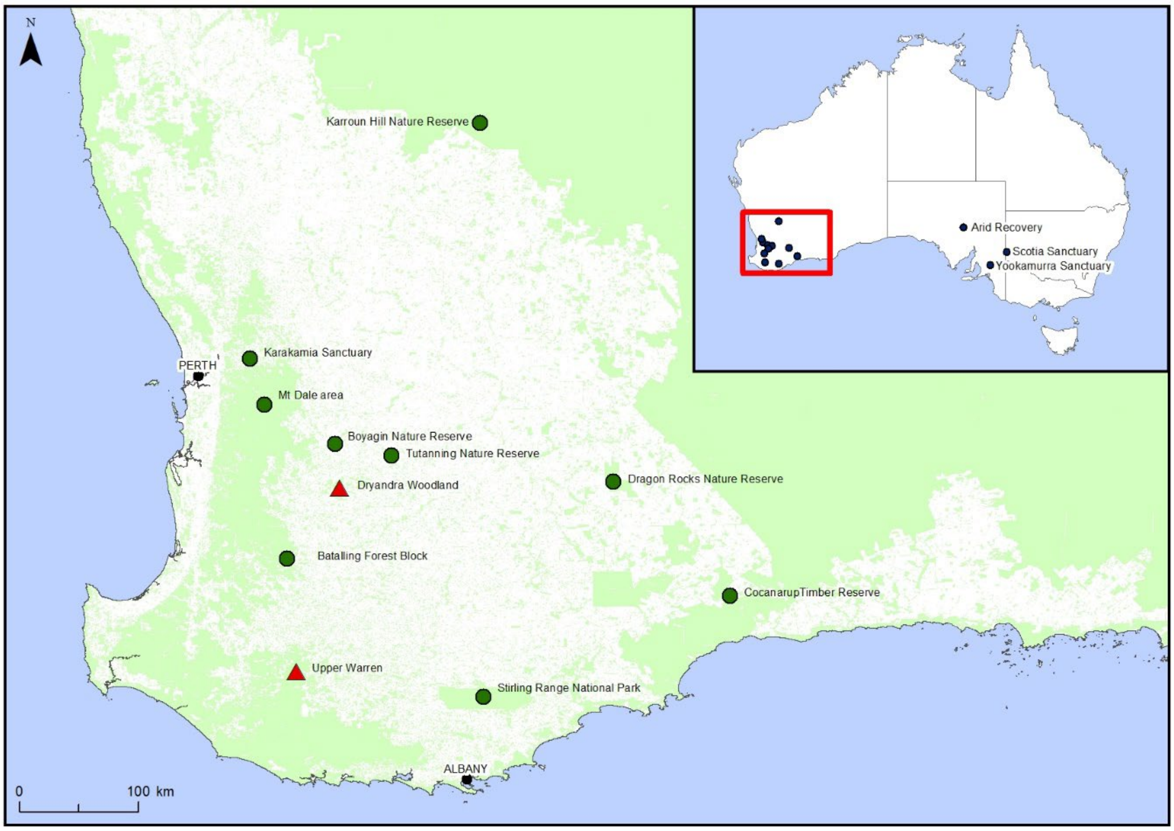
Historically, the Numbat was recorded across a wide arc stretching from western New South Wales and south-eastern South Australia, north to the southern border of the Northern Territory and across to the south-west of Western Australia (Friend 1990; Friend & Thomas 2003). Although not recorded in Victoria, the species is likely to have occurred in the north-west corner of the state (Friend & Page 2017).

The east-to-west contraction of the Numbat's geographic range is evident from the latest records in different regions across its range (Friend 1990; Friend & Thomas 2003).This contraction commenced with the apparent decline of the species near the confluence of the Murray-Darling in the 1850s (Krefft 1866), and its disappearance near Adelaide soon after European settlement (Wood Jones 1923). The contraction was slow until the 1920s, when the introduced Fox (*Vulpes vulpes*) range rapidly expanded westward following the colonisation of the Rabbit (*Oryctolagus cuniculus*) from south-eastern Australia. In the 1960s, the species remained only in the Gibson Desert, surrounding areas, and the south-west of Western Australia. In 1982, no desert subpopulations remained and by 1985 the species was restricted to two areas in south-west Western Australia (Friend 1990), Dryandra Woodland (150 km south-east of Perth) and the Upper Warren region (including Tone-Perup Nature Reserve, Greater Kingston National Park and adjoining State Forest; 280 km south-south-east of Perth; Figure 1). These are the only remaining original Numbat subpopulations (Friend & Page 2017).

Since 1985, the Numbat has been translocated to 12 different sites within its former range, including two locations in South Australia and one in New South Wales (Figure 1). Of these 12 sites, four have self-sustaining subpopulations, where the population has persisted for at least five years after the most recent release (excluding exchanges for genetic management). This has expanded the current distribution of the species in the Jarrah Forest and Wheatbelt in Western Australia at Boyagin Nature Reserve (reintroduced in 1985) and Batalling State Forest (1992) and into South Australia at Yookamurra Sanctuary (1994) and New South Wales at Scotia Sanctuary (1999; Friend & Page 2017; Woinarski & Burbidge 2016). However, the Yookamurra and Scotia subpopulations occur within fenced predator exclusion areas (Hayward et al. 2015). The long-term success of initially successful re-introductions to Tutanning Nature Reserve (1989), Dragon Rocks Nature Reserve (1995), and Stirling Range National Park (1998) are currently under assessment since serious declines have been recorded (Woinarski & Burbidge 2016).

Fewer than 800 mature Numbats are estimated to remain in the wild, with less than 200 mature individuals in the largest subpopulation. Overall, the current population trend for the species is decreasing (Hayward et al. 2015; Woinarski & Burbidge 2016; Woinarski et al. 2014). Population estimates for the two remaining original subpopulations and twelve translocated subpopulations made in 2015 are outlined in Table 3.

Figure 1. Numbat subpopulation sites, including all translocation sites



Source: DPaW 2017

Note: Original subpopulations are shown as red triangles and Western Australian translocation sites as green circles. Cleared land is shaded white; remnant vegetation is shaded pale green (Friend & Page 2017).

Table 3. Numbat subpopulation estimates made in 2015

Site	Population estimate	Site	Population estimate
Dryandra Woodland	50–100	Yookamurra Sanctuary, SA	<50
Upper Warren	>100	Cocanarup Timber Reserve	Unknown
Batalling State Forest	50–100	Stirling Range National Park	Unknown
Boyagin Nature Reserve	50–100	Arid Recovery, SA	0
Dragon Rocks Nature Reserve	<50	Karakamia Sanctuary	0
Tutanning Nature Reserve	<50	Karroun Hill Nature Reserve	0
Scotia Sanctuary, NSW	>100	Mt. Dale Area	0

Source: *DPaW 2017*

1.5 Habitat requirements

The remaining subpopulations of Numbat occupy several different habitats, but only a small proportion of the range of habitats previously occupied by the species, which included *Eucalyptus* forest and woodland, *Acacia* woodland, and *Triodia* grassland. The key habitat requirements of the Numbat, based on habitats where the species currently occurs, and those occupied throughout its past range, include (Friend & Thomas 2003):

- Presence of termites in sufficient abundance – all research on the diet of the Numbat across its range indicates an almost complete dependence on termites (Calaby 1960).

- Sufficient cover – sufficient cover near ground level from thickets, or a combination of thickets, hollow logs, and other fallen debris, is required to provide refuge from predators.
- Sufficient openness – a sufficiently open understorey is required for feeding sites, ideally interspersed with thickets, hollow logs, and other fallen debris to provide refuge from predators.
- Presence of *Eucalyptus* species – most sites where Numbats occur and were previously recorded are characterised by *Eucalyptus* species, which provide logs and hollows and possibly higher termite densities. An exception to this may have been the apparent existence of Numbat subpopulations in arid *Triodia* tussock grasslands. However, these may have relied on proximity to woodland patches.

1.6 Biology and ecology

1.6.1 Description

Numbats are small marsupials with a combined head and body length of 200–250 mm and a tail length of 150–180 mm. Males attain body weights of up to 700 g, while slightly smaller, females attain body weights of up to 550 g. They have distinct body shape features, including a pointed nose, elongated jaw and exceptionally long tongue, which can protrude at least 5 cm or about the length of the head (Friend 2008).

The distinctive coat of the Numbat is reddish brown overall, most predominant on the head and upper back. They have a distinct horizontal black stripe through the eye. Partway down the back, faint white bands cross the body. These become stronger towards the rump and are accentuated by progressively darker and eventually jet-black bands in between. The number of white bands varies from 4–11, and they are often broken, with the two halves offset along the midline of the back. The unique pattern formed by these bands can be used as a distinguishing feature to identify individuals. The underside of the body is off-white, and the tail is covered with long brown hairs, many tipped with white. The underside of the tail near the body is distinctly red (Friend 2008).

1.6.2 Reproduction and dispersal

Numbats have a highly synchronised seasonal reproduction pattern (Friend 2008; Hogan et al. 2012). From September, established males begin to move outside their winter home ranges. Their pre-sternal gland becomes active, exuding an oily liquid that stains the animal's red-brown ventral surface (Friend 2008). The male's testes enlarge with the onset of sperm production as the height of the mating season approaches and peaks in late December. The male cloacal region swells noticeably due to associated glandular enlargement (Friend 2008; Power et al. 2009). By January, males are ranging widely and roaming the home ranges of several females (Friend 2008).

Female Numbats come into oestrus (a period where they are reproductively active) during January, with the onset established by monitoring the sudden increase in epithelial cells in their urine. Young are not produced if mating does not occur in the following 48 hours (Friend 2008; Power et al. 2009). The gestation period lasts 14 days, after which up to four young are born from January to early February. The pink and hairless young, measuring about 10 mm in total length, attach themselves to the four teats within the female's pouchless mammary gland area (Calaby 1960; Friend 2008; Friend & Whitford 1986, 1993). Females are facultatively polyoestrous, meaning that they can become reproductively active again within the restricted breeding season if mating is initially unsuccessful. They can become oestrus again approximately 25 days after an earlier unsuccessful mating (Power et al. 2009), making it possible for some young to be born as late April (Calaby 1960; Friend & Burrows 1983).

Development of attached young is slow relative to other marsupials as they remain attached to the female for up to six months (Calaby 1960; Friend 2008). The female deposits her young in a nest (usually in a burrow) in late July or early August and continues to suckle them each night (Friend 1987, 2008; Friend & Burrows 1983). In early September, the young come to the nest's entrance each morning after the female has emerged, often before she departs to forage. During the first week or so, they do not move more than a few centimetres from the nest's entrance but subsequently make longer excursions. By mid-October, the young Numbats supplement their mother's milk with termites that they dig up for themselves and move up to 100 m from the nest while remaining in their mother's home range (Friend 2008). The female often moves her litter to a succession of nests in logs, trees or other burrows, particularly after the loss of any young to predators. In November, some young start to nest away from their mother and siblings within the maternal home range. In late November or early December, all young leave their maternal home range and disperse (Friend 1987, 2008).

Dispersal is rapid, rarely taking longer than a week from departure to establishment in the area where the young Numbats will spend the rest of their life. The species appears to disperse in straight-line movements when moving through suitable habitat. Radio-tracking of dispersing Numbats indicates that they rarely cross cleared land but often end up in suitable habitat at the edge of cleared land, sometimes after travelling along the boundary between suitable habitat and cleared land (Friend 2008).

Female Numbats breed in their first year, while males become sexually mature in their second year (Friend 1990; Friend 2008). So far, the greatest longevity for the species observed in the wild is five years. However, most Numbats do not achieve this age (Friend 2008).

1.6.3 Diet and foraging

Several of the Numbat's characteristic features stem from its specialised diet, which almost exclusively consists of termites (Isoptera), with some ants (Formicoidea) thought to be ingested incidentally (Friend 1989). The species shows no strong preference for any termite species, taking each species roughly proportionately to its abundance (Calaby 1960).

Numbats appear to spend much of the day feeding, with adults consuming up to 20,000 termites daily, or approximately 10 % of their body weight (Cooper & Withers 2004b; Friend 1986). Termites occur in mounds, tree trunks, or underground, where their subterranean feeding galleries spread out from their nests. Since Numbats are not strong enough to break into termite nests, they intercept termites in these feeding galleries. Numbats expose termites by digging in the upper 50 mm of the soil, turning over small pieces of dead wood, and scratching bark and decayed wood from old logs, stumps and fallen tree limbs (Calaby 1960; Christensen et al. 1984). The soil diggings are a distinctive shallow, conical excavation, rarely over 50 mm in depth, and of a similar diameter (Friend 2008).

1.6.4 Activity period

Unlike almost all other marsupials and other Australian terrestrial mammals, Numbats are strictly diurnal, emerging from their night refuges well after dawn and returning to one of their nests before dark. In summer, Numbats have a distinctly bimodal pattern of activity, being active during the mornings before a period of inactivity between midday and late afternoon, followed by a second period of activity before dusk. In winter, only one period of activity lasts four to six hours, from mid-morning to mid-afternoon. These activity patterns correspond closely to seasonal changes in termite abundance close to the soil surface, which in turn are influenced by ambient temperature and soil moisture (Christensen et al. 1984; Evans & Gleeson 2001; Friend 1986).

Weather also influences Numbat activity, with the species avoiding periods of low light intensity, high relative humidity, and rain (Calaby 1960; Cooper & Withers 2004a).

1.6.5 Nesting and refuge requirements

Numbats use hollows and burrows for several purposes, including nesting at night, resting during the day, and as refuges when under threat of predation. The species uses a large number of refuges within its home range during the day but frequents only a few night refuges in which a nest consisting of readily available plant material such as grass, leaves or shredded *Eucalyptus* bark is constructed (Christensen et al. 1984; Friend & Burrows 1983). Tree hollows up to 5 m above the ground and hollow logs on or near the ground with a single entrance and an internal diameter of 60–80 mm are preferentially selected (Christensen et al. 1984). Numbats construct their own burrows, typically consisting of a single, gently sloping shaft 1–2 m long that widens into a roughly spherical terminal chamber (Friend 2008).

When young become too large for their mother to carry while foraging, they are left in nests in hollows or burrows during the day and suckled there at night. In areas that lack hollow logs, or in summer, Numbats sometimes rest during the day under shrubs and fallen foliage. They may also take refuge from threats under this type of cover—however, no evidence of Numbats nesting at night under shrubs or fallen foliage (Friend 2008).

1.6.6 Home ranges, movements and interactions

Numbats are solitary and territorial, occupying home ranges exclusive to other individuals of the same sex. When a juvenile establishes its home range after dispersal, it remains in or close to that area for the rest of its life. The home ranges of males overlap with adjacent female territories, and habitat use by each sex changes during the year. In summer, female's home ranges contract, while males roam more widely to traverse the home ranges of several females as they come into oestrus (Friend 2008). One pair of established adults occupy approximately 50 ha of high-quality habitat at Dryandra Woodland and the Upper Warren region (Christensen et al. 1984; Friend 2008). In South Australia, radio tracking of newly translocated Numbats at Arid Recovery indicated similar home ranges of 67 ha in summer and 25 ha in autumn/winter (Bester & Rusten 2009) and mean home ranges of 28 ha for females and 96.6 ha for males were recorded, with seasonal variation (Hayward et al. 2015).

1.7 Threats

Like several medium-sized Australian mammals, historic declines in the range and population numbers of the Numbat have occurred since European settlement. The decline of the Numbat has been associated with predation by vertebrate pest species, clearing of habitat for agriculture and altered fire regimes (Friend 2008). Similarly, the key threats that affect the long-term survival of the remaining established, self-sustaining Numbat subpopulations include fox and cat predation, habitat fragmentation and disturbance, and inappropriate fire regimes (Friend & Page 2017).

The east-to-west contraction of the Numbat's range rapidly increased as the distribution of the introduced rabbit and fox expanded westward from south-eastern Australia. This is a strong indication that fox predation was a key factor in the decline of Numbats (Friend 1990). Furthermore, there is now an extensive body of evidence indicating that fox control benefits medium-sized mammal populations, including translocated populations of Numbat and other critical weight range mammals (Burbidge & McKenzie 1989; Friend & Thomas 2003; Groom 2010; Kinnear et al. 1998; Kinnear et al. 2002; Morris 2000). The translocated subpopulations in South Australia and New South Wales are within fenced enclosures that exclude foxes to mitigate their predation threat (Hayward et al. 2015).

All current known (original and translocated) subpopulations of the Numbat in Western Australia are in areas subject to fox control through the Department of Parks and Wildlife's Western Shield 1080 baiting program (Friend & Page 2017). However, feral cat abundance and predation pressure can increase in areas subject to fox control (Christensen & Burrows 1994; Marlow et al. 2015; Short et al. 1994), and the two original, and most of the translocated subpopulations are subject to feral cat predation (Friend & Page 2017). Further investigation is required to determine the impact of feral cat predation on Numbat subpopulations (Woinarski et al. 2014). The translocated subpopulations in South Australia and New South Wales are within fenced enclosures that exclude feral cats to mitigate their predation threat (Hayward et al. 2015).

The Numbat is known from several isolated subpopulations, most large enough to maintain self-sustaining subpopulations. However, the movement of individuals between subpopulations is required to maintain long-term genetic variability, which requires long-distance dispersal across cleared land. Although Numbats have been known to cross farmland, this rarely occurs in times of high population density. While projects are supporting the establishment of large-scale habitat linkages across highly cleared regions, none currently in place are likely to aid the movement of Numbats between subpopulations. Therefore, artificial movement and translocations of individuals is required to achieve genetic transfer between subpopulations and recolonisation after local subpopulation extinction (Friend & Page 2017).

Numbats occur in two areas of State forest subject to selective timber harvesting, the Upper Warren region and in management blocks adjacent to Batalling Block. Research is required to better understand the effect of timber harvesting on the resident Numbats and to further inform the development of the forestry guidelines specifically for Numbats (Friend & Page 2017).

Numbats are unlikely to be affected directly by fire. However, loss of cover, in the form of both logs and thickets, appears to increase mortality through exposure to predation, making the species potentially vulnerable to fire in its habitat (Friend & Page 2017). Long intervals between fires increase cover from predators through increased development of thickets. Fires at intervals of 20–30 years at Dryandra would allow Sandplain poison (*Gastrolobium microcarpum*) thickets to attain their maximum development before they degrade through the senescence of individual plants and require fire for regeneration (Burrows et al. 1987). Regular prescribed burns occur within forests in the Upper Warren region. Considering the threatened fauna species of the area, burns are generally prescribed to be mild in intensity and to create a finer scale mosaic of burnt/unburnt areas, but also consider rotational seasonal elements to provide more intense fires every 20–30 years for regeneration of thickets (Friend & Page 2017).

2 Existing monitoring

2.1 Overview of monitoring methods

In areas of suitable habitat within their range, Numbats can be detected by direct observations or via signs of activity, including tracks, scats and dens (DSEWPC 2011). Detection can be difficult since the species occurs in low densities, is not commonly encountered, and is not attracted to lures. Factors that may affect detection and monitoring include timing of dispersal, peak activity periods during summer and winter, proximity to refuges, and the size and arrangement of home ranges.

Key population monitoring indices include:

- Driven transects: relative abundance index (RAI) – number of sightings per 100 km. Absolute abundance can be estimated using distance sampling (perpendicular distance from the transect to where the individual was first observed).
- Walked transects: RAI – number of sightings per 100 m.
- Sign searches (tracks, scats and dens): RAI – proportion of plots with signs.
- Soil plot surveys (tracks): RAI – proportion of soil plots with tracks.
- Camera traps: RAI – camera trap detections per trap effort.

Occupancy modelling can be used to account for the probability of detection.

2.2 Monitoring resources

Existing monitoring resources for the Numbat include:

- The *Survey Guidelines for Australia's Threatened Mammals* recommend several survey techniques to detect Numbats (DSEWPC 2011).
- Scientific papers and reports that use driven transects to detect Numbats (Friend 1990; Hayward et al. 2015; Seidlitz et al. 2021b; Vieira et al. 2007).
- Scientific papers and reports that undertook searches for suitable Numbat habitat resources and signs of Numbat activity.
- Scientific papers and reports that use soil plot surveys to detect Numbat tracks.
- Scientific papers and reports that use camera trapping to detect Numbats.

Although the recovery plan for the Numbat does not provide details of survey techniques to monitor the species, it does summarise population monitoring that has been undertaken for the species. The Dryandra subpopulation has been annually monitored by driven transect surveys since 1981. A standard circuit has been driven since 1987 to allow comparison of sighting rates between years. The Upper Warren subpopulation has been monitored by similar methods since 1993. Monitoring is also undertaken at re-introduction sites. Driven transect surveys and searches for diggings have been undertaken at Boyagin since 1992 (Friend & Page 2017). Driven transect surveys and strip transects have been undertaken at Yookamurra and Scotia wildlife sanctuaries since 2010, with track counts recorded at Scotia between 2002–2012 (Hayward et al. 2015).

2.3 Survey methods

2.3.1 Driven transects

The *Survey Guidelines for Australia's Threatened Mammals* recommend daytime searches for active fauna conducted from a vehicle to detect Numbats (DSEWPC 2011). However, the guidelines do not provide specific recommendations for surveys from a vehicle. In vehicle surveys that have been undertaken for Numbats, speeds of 15–20 km/h have been recorded for vehicles driven along vehicle tracks in during peak activity hours (mornings and late afternoons/evening). Two observers record Numbat observations to determine an index of the number of observations per 100 km (Calaby 1960; Friend 1990; Hayward et al. 2015; Seidlitz et al. 2021b; Vieira et al. 2007). Driven transect survey methods to detect Numbats are summarised in Table 4.

Table 4. Methods overview of key studies using driven transect surveys

Study design	Survey effort	Location	Reference
• Bush roads and tracks driven slowly to look for Numbats.	• Between September 1954 and December 1956, visits lasting from 1–3 days were made to the area, usually once a month. • Area surveyed 3,885 ha	Dryandra Forest, WA	(Calaby 1960)
• Forest track transects driven at 15–20 km/h during the day to observe active Numbats. Sighting rate (sightings/100 km) used to provide a population size index.	• Two areas, 110 km of tracks driven in in each in 1981, 1984 and 1985. Additional 130 km of tracks driven in 1985. • Area surveyed 6,000 ha	Dryandra Forest, WA	(Friend 1990)
• Existing road transects driven at 20 km/h between 08:00–12:00 and 16:00–19:00, with two observers. For each Numbat sighting, its location, sighting angle relative to the transect and perpendicular distance from the sighting location to the transect (to estimate density) were recorded. Sighting rate (sightings/100 km) used to provide a population size index.	• Seventeen driving censuses in March 2006 (total 500 km, mean = 29.4 km, range = 5.6–53.3 km) • Area surveyed 4,000 ha	Scotia Sanctuary, NSW	(Vieira et al. 2007)
• Existing road transects driven at ~15 km/h between 07:00–10:00 and 17:00–21:00 in summer (December), with 3–4 observers. The location of each Numbat sighting was recorded. Sighting rate (sightings/100 km) used to provide a population size index.	• Mean of 787±73 km driven in 2010–2014 (Scotia) and 715±199 km driven in 2011–2013 (Yookamurra) • Area surveyed 4,000 ha (Scotia), 1,092 ha (Yookamurra)	Scotia and Yookamurra Sanctuaries, NSW	(Hayward et al. 2015)
• Existing road and track transects driven at ~15 km/h on warm, calm days, when temperatures did not exceed 28°C from mid-September to mid-December, 2017, with 4 observers. For each Numbat sighting, its location, and distance from the sighting location to the transect were recorded. Sighting rate (sightings/100 km) used to provide a population size index.	• Three existing monitoring transects utilised, A (~54 km), B (~56 km) and C (~61 km), driven seven times with an average period between surveys of 7 days (range = 6–10).	Upper Warren region, WA	(Seidlitz et al. 2021b)

2.3.2 Walked transects

The *Survey Guidelines for Australia's Threatened Mammals* recommend daytime searches for active fauna conducted on foot to detect Numbats (DSEWPC 2011). The guidelines recommend a speed of 10 metres per minute for surveys on foot. For each 1 ha survey site within a 5 ha area, one 100 m transect (or two if the observer's view is obstructed) should be used. At least four survey sites are required (Table 5).

Relative to driven transects, there has been limited use of walked transects to detect Numbats. Early studies found that Numbats took far less notice of motor vehicles than of persons on foot, with many more individuals seen while driving than when walking. Furthermore, disturbed individuals who entered a hollow log during driven transects generally reappeared after a short period, provided that the vehicle stopped and no passengers exited the vehicle (Calaby 1960).

Table 5. Methods overview of key studies using walked transect surveys

Study design	Survey effort	Location	Reference
• A speed of 10 metres per minute is recommended for surveys on foot.	• For each 1 ha survey site within a 5 ha area, one 100 m transect (or two if the observer's view is obstructed) should be used. At least four survey sites required. • Area surveyed 5 ha	n/a	(DSEWPC 2011)

2.3.3 Habitat resources and signs searches

The *Survey Guidelines for Australia's Threatened Mammals* recommend daytime searches for potentially suitable Numbat habitat resources and signs of Numbat activity, including tracks, scats and dens, as well as predator scats, owl casts or remains. Daytime searches are particularly recommended in mature wandoo woodland in Western Australia and areas with hollow logs and termite mounds. A two-hour search for every 1 ha survey site within a 5 ha area is recommended. Predatory bird/reptile/mammal nests/dens are recommended to be targeted for the collection of predator scats, owl casts or remains (DSEWPC 2011). Habitat resources and sign searches survey methods to detect Numbats are summarised in Table 6.

Table 6. Methods overview of key studies using habitat resources and signs searche surveys

Study design	Survey effort	Location	Reference
• Daytime searches for potentially suitable Numbat habitat resources and signs of Numbat activity, including tracks, scats and dens, as well as predator scats, owl casts or remains. Daytime searches are particularly recommended in mature wandoo woodland in Western Australia, and areas with hollow logs and termite mounds.	Two-hour search per 1 ha survey site. Area surveyed 5 ha	n/a	(DSEWPC 2011)
• Woodland traversed on foot searching for Numbat faeces and making observations on termite and ant abundance, possible predators, etc.	Between September 1954 and December 1956, visits lasting from 1–3 days were made to the area, usually once a month. Area surveyed 3,885 ha	Dryandra Forest, WA	(Calaby 1960)
• All significant areas of wandoo woodland searched intensively for Numbat diggings. Remains of two radio-collared Numbats and two fox scats containing Numbat remains found during the early stages of the study.	1981, 1983, 1985 and 1987. Area surveyed 2,000 ha	Boyagin Nature Reserve, WA	(Friend 1990)
• At each survey site, 10 plots (40 x 100 m) were searched by four observers for signs of Numbats (fresh diggings and scats) from mid-September to mid-December, 2017, with five plots located on each side of the transect, except six sites along border tracks where all plots were situated on the same side. Plots were placed adjacent with the long edge perpendicular to the transect. A central plot was reserved for camera trapping at each survey site (see Table 7). The remaining nine plots were used for sign surveys. During each sign survey, one plot was searched at each of the 50 survey sites. Within each site, plots were chosen randomly with no plot searched twice. Observers walked ~5 m apart in a straight line, searching for Numbat signs 2.5 m left and right, up one side of the plot (covering half of the plot width) and down the other side (covering the other half of the plot width). One or more Numbat signs on a plot during a survey was defined as a single Numbat detection at that survey site. When	Fifty existing signs survey sites along three driven transects utilised (see Table 3), 16–17 per transect, on average, 2.38 km apart (1.88–2.88 km). Seven 5 day surveys with an average period between surveys of 7 days (range = 6–10).	Upper Warren region, WA	(Seidlitz et al. 2021b)

Study design	Survey effort	Location	Reference
no signs were found, searches ended after ~20 minutes.			

2.3.4 Soil plot surveys

The *Survey Guidelines for Australia's Threatened Mammals* recommend soil plot surveys to facilitate the detection of Numbat tracks. For each 1 ha survey site within a 5 ha area, the soil should be raked smooth around at least two potential foraging or shelter sites. At least three survey sites are required and they should be set for three consecutive nights, raking smooth each morning after the tracks have been identified and recorded (DSEWPC 2011). Soil plot survey methods to detect Numbats are summarised in Table 7.

Table 7. Methods overview of key studies using soil plot surveys

Study design	Survey effort	Location	Reference
• Soil raked smooth around potential foraging or shelter sites. Soil plots set over consecutive nights, raking smooth each morning after the tracks have been identified and recorded.	• At least two potential foraging or shelter sites per 1 ha survey site. At least three survey sites required, set for three consecutive nights. • Area surveyed 5 ha	n/a	(DSEWPC 2011)
• Series of dirt tracks dusted for several kilometres in the early morning and the number of Numbat tracks counted in the afternoon. Track index of the number of tracks per kilometre.	• Repeated over four days within a season, between spring 2003 and autumn 2013 (stage 1), and summer 2009/10 and autumn 2013 (stage 2). • Area surveyed 4,000 ha (stage 1) 4,000 ha (stage 2)	Scotia Sanctuary, NSW	(Hayward et al. 2015)

2.3.5 Shelter site surveys

The *Survey Guidelines for Australia's Threatened Mammals* recommend conducting observations at dawn and/or dusk at potential Numbat shelter sites, such as a burrow or a hollow log with signs of activity around them (identified during daytime searches for potentially suitable habitat resources and signs of activity). Observers should be in position 30 minutes before dawn or dusk and watch for Numbats leaving or returning to their den for at least 1 hour (DSEWPC 2011). Shelter site survey methods to detect Numbats are summarised in Table 8.

Table 8. Methods overview of key studies using shelter site surveys

Study design	Survey effort	Location	Reference
• Observations conducted at dawn and/or dusk at potential Numbat shelter sites, such as a burrow or a hollow log with signs of activity around them (identified during daytime searches for potentially suitable habitat resources and signs of activity).	• Watch for Numbats leaving or returning to their den for at least 1 hour, from 30 minutes before dawn or dusk.	n/a	(DSEWPC 2011)
• Numbat night refuges (burrows, logs, trees) were located by radio-tracking after dark, once certain that individuals had ceased activity, to examine refuge conditions (i.e. temperature, gas composition, relative humidity). Conditions in unoccupied, previously used refuges also examined.	• Refuge conditions examined for 1–5 individuals for 3 nights in each season (12 nights total).	Dryandra Woodland, WA	(Cooper & Withers 2005)

2.3.6 Camera trapping

The *Survey Guidelines for Australia's Threatened Mammals* do not recommend the use of camera traps to detect Numbats (DSEWPC 2011). However, this technique may be suitable to obtain a relative abundance index (i.e. camera trap detections per trap effort; Seidlitz et al. 2021b), or to record observations at dawn and/or dusk at potential shelter sites with signs of activity around them, particularly if there are multiple potential shelter sites within a 1 ha survey site. Camera traps should be firmly mounted 2–5 m from and focused on the possible shelter site (DSEWPC 2011). They should be orientated in a southerly direction to avoid direct sun glare and toward clearings to avoid vegetation within the field of view to help prevent false triggers. Any vegetation that may cause false triggers should be carefully pruned or removed (DSEWPC 2011; Seidlitz et al. 2021b). Camera traps with a wide-angle detection zone installed at a height of 25 cm are recommended for Numbat detection (Seidlitz et al. 2021a). Camera trapping survey methods to detect Numbats are summarised in Table 9.

Table 9. Methods overview of key studies using camera trap surveys

Study design	Survey effort	Location	Reference
• Compared detection rates of Numbats in captivity from Reconyx PC900 camera traps installed at heights ranging from 10–45 cm, and camera traps with different detection zone widths (Reconyx PC900, Swift 3C Standard and Swift 3C Wide-angle). The Swift 3C Wide-angle camera trap installed at 25 cm height is recommended for Numbat detection.	• Twelve Reconyx camera traps deployed in three rectangular Numbat enclosures to determine which height is most suitable for Numbat detection. Three different camera trap models deployed side-by-side to determine which detection zone width is most suitable for Numbat detection.	Perth Zoo, WA	(Seidlitz et al. 2021a)
• At each survey site, one central plot of 10 plots (40 x 100 m) had a camera trap deployed from September–December, 2017, with five plots located on each side of the transect, except six sites along border tracks where all plots were situated on the same side. Plots were placed adjacent with the long edge perpendicular to the transect. The remaining nine plots were used for sign surveys (see Table 5). Camera traps mounted on trees ~25 cm above ground, facing south to and towards forest clearings, central to the plot with a minimum distance of 30 m to the transect. Vegetation minimally pruned. Cameras set to take 10 images when triggered, with no delay between triggers, and sensor sensitivity set as high. Batteries and SD cards changed monthly. Detection defined as a trigger resulting in one or more images depicting a Numbat partially or wholly, with a period of 60 minutes used to separate detections.	• Fifty existing survey sites along three driven transects utilised (see Table 3), 16–17 per transect, on average, 2.38 km apart (1.88–2.88 km). One Reconyx PC900 camera trap deployed for 4 months per site.	Upper Warren region, WA	(Seidlitz et al. 2021b)
• Camera trapping undertaken for the purposes of a bait uptake trial. Reconyx HC600 or PC900 camera traps deployed along 5 km transects, 100 m apart, offset between 5–20 m from forest tracks, at a height of 20–30 cm above the ground. Cameras set to take 10 images when triggered, with no delay between triggers. Detection defined as a trigger resulting in one or more images depicting a Numbat partially or wholly, with a period of 60 minutes used to separate detections.	• Twenty transects, 50 camera traps deployed for 4 weeks per transect.	Upper Warren region, WA	(Thorn et al. 2022)

3 Key agencies and organisations involved in the species research and recovery

Key agencies, organisations or individuals identified as having been previously or currently actively involved in monitoring the Numbat include:

- Western Australia Department of Biodiversity, Conservation and Attractions
- Peel-Harvey Catchment Council
- Northern Agricultural Catchments Council
- Numbat Task Force
- Project Numbat
- Foundation for Australia's Most Endangered Species Inc. (FAME)
- Australian Wildlife Conservancy
- Dr Anke Seidlitz – recent PhD thesis on the development and application of survey methods to determine habitat use in relation to forest management and habitat characteristics of the Numbat in the Upper Warren region (Seidlitz 2021)
- Dr Sian Thorn – recent PhD thesis on the population and spatial ecology of the Numbat in the Upper Warren region (Thorn 2023).

4 Survey guideline recommendations

This literature review of the monitoring methods relating to the Numbat has identified key points to be considered when developing species-specific survey guidelines they include:

- Monitoring should target suitable habitat, with the key habitat requirements of the Numbat being the presence of termites in sufficient abundance, a sufficiently open understorey for feeding interspersed with thickets, hollow logs and other fallen debris for refuge, and the presence of *Eucalyptus* species.
- Monitoring should consider Numbat diurnal activity periods. In summer, Numbats have a distinctly bimodal pattern of activity, being active during the mornings before a period of inactivity between midday and late afternoon, which is followed by a second period of activity before dusk. In winter, only one period of activity lasts four to six hours from mid-morning to mid-afternoon.
- Monitoring should consider the influence of weather on Numbat activity, with the species avoiding periods of low light intensity, high relative humidity, and rain.
- Annual monitoring should be undertaken at the same time each year based on the Numbat's highly synchronised seasonal pattern of reproduction and dispersal. Monitoring in early December is recommended since all young leave their maternal home range and disperse in late November or early December. Detection is more likely during this period of maximum Numbat abundance.
- Monitoring should consider the home ranges of Numbats, ranging from approximately 25–100 ha based on seasonal variation.
- Driven transects have been the most widely used long-term monitoring method. Speeds of 15–20 km/h should be driven along the vehicle tracks in a study area during peak activity hours (mornings and late afternoons/evening), with observers recording Numbat observations to determine an index of the number of observations per 100 km.
- For long-term monitoring using habitat resources and signs searches, repeat searches should be undertaken at survey sites with an array of monitoring plots that are systematically searched, with the plot chosen randomly and no plot searched twice. One or more Numbat signs in a plot during a survey is defined as a single Numbat detection at that survey site.
- Sign surveys have been found to be more successful and cost-effective than driven transects or camera trapping for detecting Numbats in the Upper Warren region. Using occupancy modelling, sign surveys are appropriate to investigate changes in occupancy rates over time, which could serve as a metric for long-term Numbat monitoring (Seidlitz et al. 2021b).
- Camera traps may be suitable to obtain a relative abundance index (i.e. camera trap detections per trap effort), or to record observations at dawn and/or dusk at potential shelter sites, particularly if there are multiple potential shelter sites within a survey area and limited personnel. Camera traps with a wide-angle detection zone installed at a height of 25 cm are recommended for Numbat detection.

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