Yookamurra Wildlife Sanctuary

Ecohealth Report 2021

australian wildlife conservancy

Summary

Australian Wildlife Conservancy (AWC) has implemented an Ecological Health Monitoring Program (Ecohealth) to measure the changes in the status and trend of conservation assets, and threats to those assets across Yookamurra Wildlife Sanctuary (Yookamurra). Metrics from the program are reported in annual Ecohealth Reports and Scorecards. This is the Ecohealth Report for 2021. Values of metrics derived in this report were based on data collected during surveys carried out from 2008 to 2022. The complete set of metrics and their values are summarised in the accompanying Ecohealth Scorecard.

In implementing the Ecohealth program in 2021, AWC conducted 2,640 live trap nights, 128 transect surveys, 256 spotlight surveys, 72 audio-trap nights, 108 Standard Bird Surveys, and 3 Malleefowl Mound searches. Two surveys presented in this report were conducted in 2020: surveys for the reintroduced threatened plant Desert Phebalium (*Phebalium glandulosum macrocalyx*) and the Southern Hairy-nosed Wombat (*Lasiorhinus latifrons*).

The survey results reported here show that many wildlife on Yookamurra continue to be adversely affected by the record drought experienced in 2018-19, though some species and guilds are showing signs of recovery, and others have recovered to pre-drought levels. Only one of the four species of reintroduced mammals (the Bilby, *Macrotis lagotis*) is near pre-drought population levels; a second species (the Burrowing Bettong, *Bettongia lesueur*) is recovering towards those levels, while the other two species (Numbat, *Myrmecobius fasciatus*, and Brush-tailed Bettong, *Bettongia penicillata*) have yet to recover, and are at concerningly (Numbat) or alarmingly (Brush-tailed Bettong) low numbers. The supplemented population of Common Brushtail Possum (*Trichosurus vulpecula*) increased in 2021 from the 2020 population estimate, and this is also possibly due to improved rainfall in 2021. All assemblages (mammals, birds, and reptiles) improved in abundance and richness in 2021 compared to 2020 levels, also likely because of the improved rainfall conditions. The population of the reintroduced threatened plant Desert Phebalium declined through the drought and was still low when surveyed last in 2020 so it is yet unknown if it is on its way to recovery. Further improvements are likely to occur for all taxa with continued improved rainfall at Yookamurra.

Positive statuses for the Yookamurra populations of two key threatened species was observed: the Southern Hairy-nosed Wombat and the Malleefowl (*Leipoa ocellata*). The population of Southern Hairy-nosed Wombats in 2020 was estimated to be at least 2,100 individuals, based on burrow activity. This was the first Burrow Survey conducted at Yookamurra. Malleefowl activity remained stable, with two of three Malleefowl mounds active in 2020 found to be active again in 2021. Malleefowl are considered vulnerable both federally and in South Australia. Habitat on Yookamurra is likely marginal for this species, and the small but stable population is expected.

The recent surveys have identified species new to the sanctuary. Three native vertebrate species were recorded for the first time at Yookamurra in 2021, including two microbats: the Western Broad-nosed Bat (*Scotorepens balstoni*) and the Inland Forest Bat (*Vespadelus baverstocki*), and a passerine: the Scarlet Robin (*Petroica boodang*). Microbats were surveyed systematically for the first time in 2021, resulting in seven species being detected using acoustic monitors, including two new species for Yookamurra.

Interestingly, the difference in abundance of small vertebrates inside compared with outside the introduced predator-free Stage 1 fenced area (Stage 1) was mixed. There were a few indicators that had a larger density outside of Stage 1 [i.e., the Common Dunnart (*Sminthopsis murina*) showed a much higher abundance and Skinks showed a slightly higher abundance outside the fence], the remainder of indicators (i.e., Birds, including Ground-dwelling Birds and Honeyeaters; and Geckos) were only moderately different. This result is in line with recent research that demonstrated a mixed response to the predator-free fence from small vertebrates with many taxa being found at higher densities outside of the fenced areas. This is potentially due to predation by or competition with reintroduced mammals inside Stage 1 or ongoing effects of the low rainfall during 2018-19, which continues to impact species detections.

No fires occurred on Yookamurra in 2021, in line with our ongoing commitment to protect the critically important old-growth mallee habitat inside Stage 1 and elsewhere on Yookamurra.

Contents

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Introduction

Australian Wildlife Conservancy (AWC) currently owns, manages, or works in partnerships across 31 properties in Australia, covering almost 6.5 million hectares, to implement our mission: *the effective conservation of Australian wildlife and their habitats*. AWC relies on information provided by an integrated program of monitoring and research to measure progress in meeting its mission and to improve conservation outcomes.

AWC's Ecohealth Monitoring Program is designed to measure and report on the status and trends of species, ecological processes and threats on each of these properties (Kanowski et al. 2018). Data from the monitoring program are used to address the following broad questions relevant to our mission:

- 'are species persisting on a property?',
- 'are habitats being maintained?'
- 'are threats below ecologically-significant thresholds?'

For threatened and iconic species, including reintroduced species, AWC's monitoring program aims to obtain more detailed information related to their conservation management; for example, data on survival, recruitment, condition, distribution and/or population size.

The structure of the Ecohealth Program is as follows. AWC's Monitoring and Evaluation framework provides guidance on the development of the Ecohealth Monitoring Plans for each property managed by AWC: these plans describe the conservation values and assets of each property, the threats to these assets, and the monitoring program that will be used to track their status and trend, and to evaluate outcomes. Annual survey plans and schedules are developed to implement these plans. The outcomes of these surveys are presented in annual Ecohealth Reports and summary Ecohealth Scorecards.

This document is the second in the series of annual Ecohealth Reports for Yookamurra Wildlife Sanctuary (referred to here as Yookamurra). The companion Ecohealth Scorecard presents the indicators and their metrics in a summary format.

Yookamurra Wildlife Sanctuary

Conservation values

Yookamurra is located in south-eastern South Australia and is 5,027 ha in extent (Figure 1). The property is located on the western edge of the Murray Darling Depression Bioregion in the northern section of the Murraylands region, between the Mt Lofty Ranges and the River Murray known as the Western Murray Plains.

At the time of European arrival, the Ngaiawang People occupied an area of approximately 388,000 hectares on the Western Murray Plains, in which Yookamurra is situated (South Australian Museum et al. 1977). This land was often shared with the Nganguraku People, part of the Ngarrindjeri Nation. Within this area the main focus of activity was the River Murray, located less than 10 km from Yookamurra's eastern boundary. The river provided a permanent water source and a continuous food supply. No material evidence of Aboriginal settlement or management has been found on Yookamurra itself, however there is no doubt that the plains away from the river were regularly utilised by Indigenous people (Tindale 1974; South Australian Museum et al. 1977; Clarke 1996). More generally, the structure and composition of Australian ecosystems, including those in the mallee, reflect a very long history of Indigenous interactions with the landscape and its resources (Flannery 1994; Gammage 2011; Rule et al. 2012; Clarke et al. 2021).

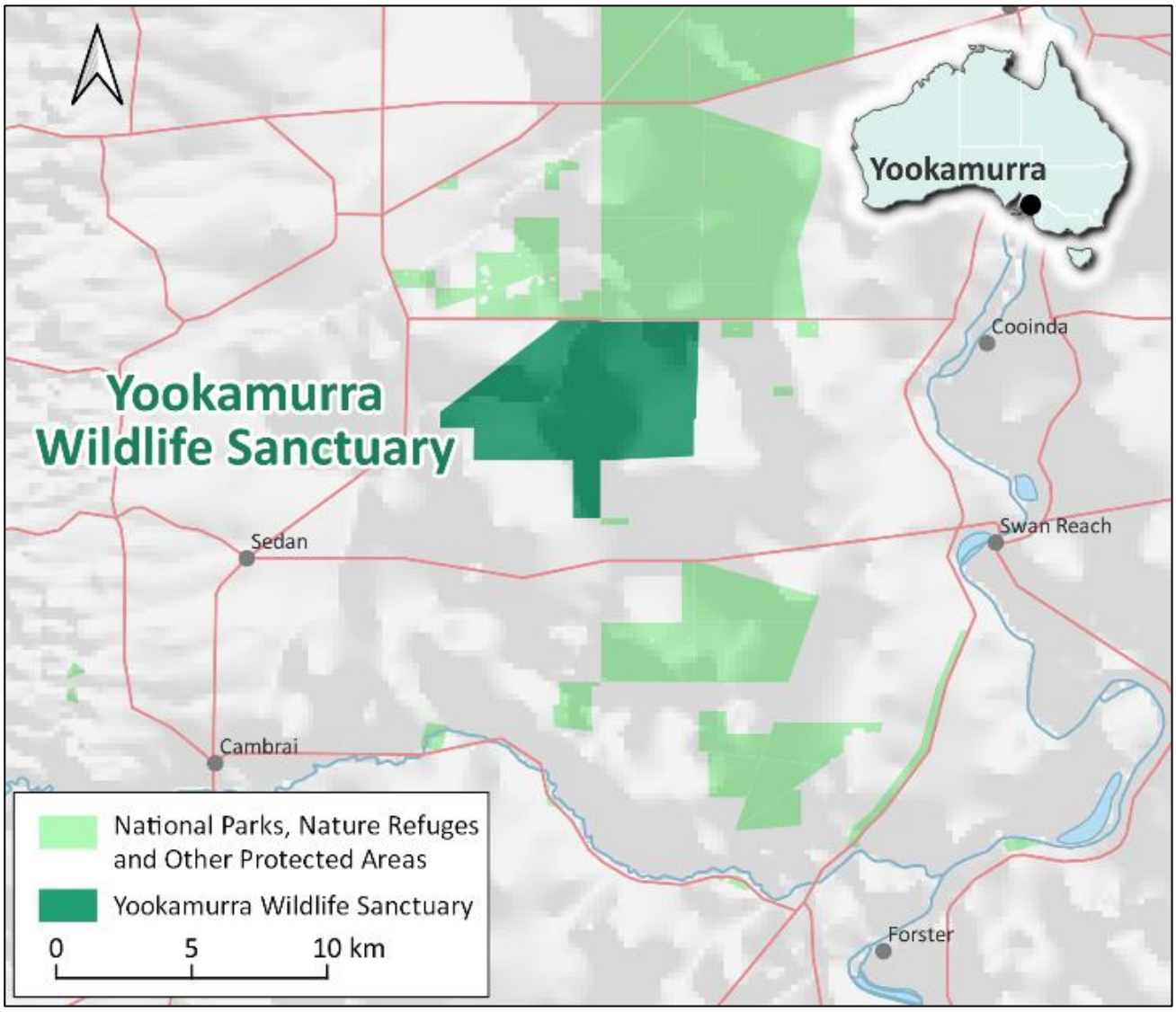

Figure 1. Location and regional context of Yookamurra Wildlife Sanctuary in south-eastern South Australia.

Charles Sturt and his expedition were the first Europeans to explore this part of the continent in early 1830. Leaseholds close to the river were quickly developed, land occupied by Yookamurra was 'Unallocated Crown Lands'. In 1861, land shortages in the more fertile districts led to the opening up of the marginal 'Hundreds', west of the River Murray; the 'Hundreds' were divided into Sections from approximately 120 to 200 hectares. Yookamurra falls within the 'Hundred of Fisher' and the 'Hundred of Bagot'; the property is made up of 21 separate land titles.

Throughout the property there is evidence of early pastoral settlement, including several ruins and 'woodcutter camps'. Some areas of the property were cleared for sheep (*Ovis aries*) grazing, as early as the late 1800s, to as recent as the 1940s, and some sections were cut for mallee wood to fuel paddle steamers. However, given the 'marginal' location and no permanent water sources on Yookamurra, establishment of pastoral pursuits were short-lived.

Yookamurra was established in 1989 by Earth Sanctuaries Ltd (ESL). In 1990, ESL built one of Australia's first large introduced predator-proof fences on the property to facilitate the reintroduction of locally-extinct mammals to a 1,100 ha fenced area (referred to hereafter as Stage 1). Feral herbivores (i.e. rabbits *Oryctolagus cuniculus*, hares, *Lepus europaeus* and goats, *Capra hircus*) were eradicated from the Stage 1 area in 1991. AWC acquired Yookamurra from ESL in 2002. The fence was upgraded in 2006–07, permitting the complete eradication of feral predators again, which to that point had threatened populations of species reintroduced to the Stage 1 area.

Yookamurra protects three major vegetation communities (Figure 2): the most common being Eucalyptus Mallee Forest and Mallee Woodland, which occupies 42.2% of the total sanctuary area, followed by Myoporum Woodland (35.3%) and chenopod shrubland (18.3%). Inside Stage 1, Eucalyptus Mallee Forest and Woodland, and Myoporum Woodland, are the dominant broad vegetation communities, which occupy 63.6% and 35.2%, respectively. The old-growth mallee on Yookamurra has significant conservation values from a regional perspective.

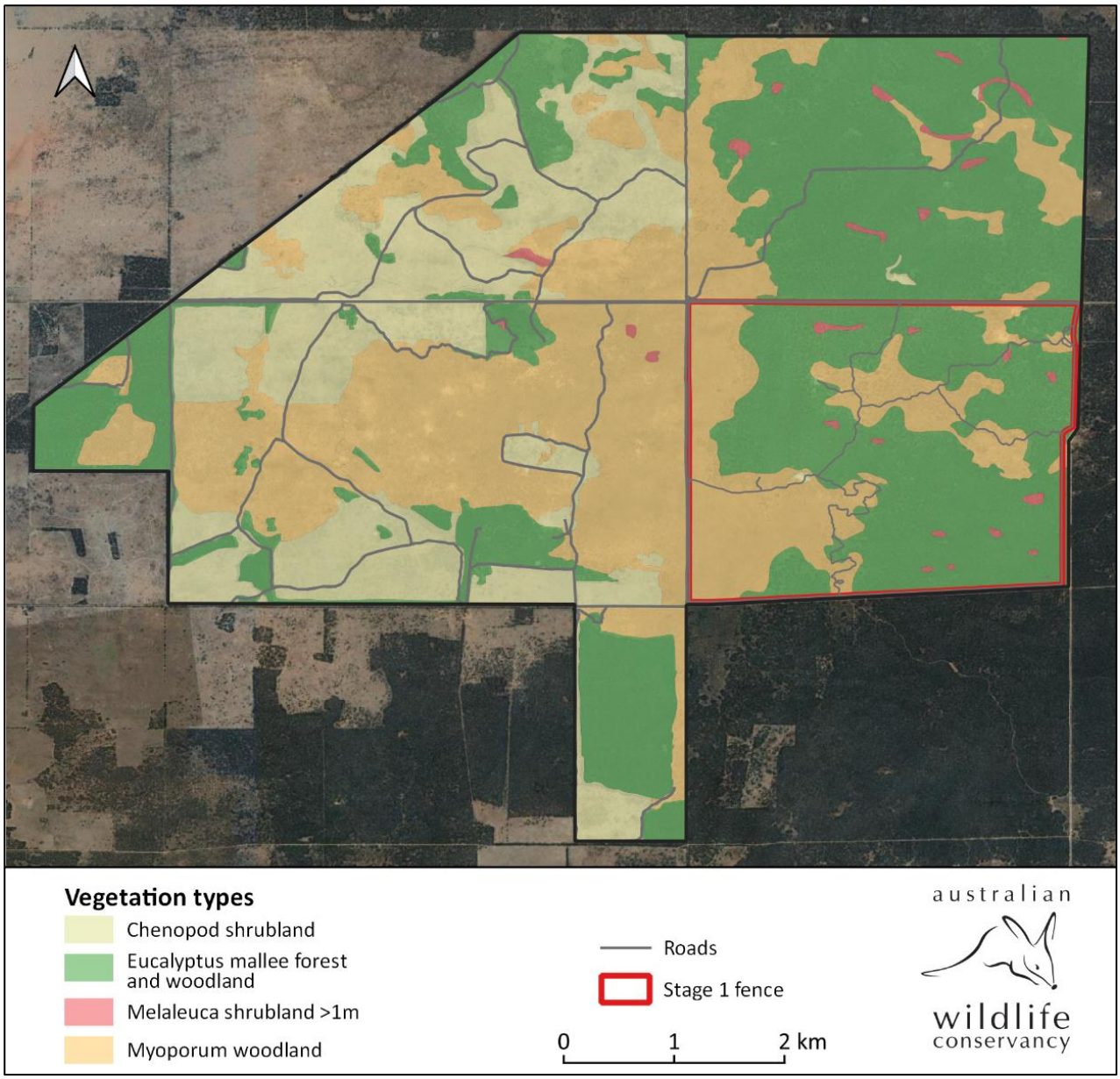

Figure 2. Map showing extent and distribution of broad vegetation types of Yookamurra Wildlife Sanctuary.

Yookamurra protects 164 native plant species, from 41 families. Of these, Peep Hill Hopbush (*Dodonaea subglandulifera*) is listed as Endangered nationally and in South Australia; while Desert Phebalium (*Phebalium glandulosum macrocalyx*) is listed as Endangered in South Australia. Both these threatened plants were reintroduced to Yookamurra in 1991, and persist on the property, though Peep Hill Hopbush occurs in low numbers likely due to the marginal habitat.

Over 220 species of native vertebrates are currently known or considered likely to occur on Yookamurra. These include 22 mammals (including four reintroduced species, as below), 124 birds, 65 reptiles, and four frogs. Seven of these species are listed as threatened nationally or in South Australia; another 20 species, predominantly birds, are listed as 'rare' in South Australia.

Very little information is available about the historical mammal assemblage of the area around Yookamurra. South Australian Museum records from the Murray Mallee date back to 1863, but those from 1889–1899 were mainly from the Riverland area, to the east of Yookamurra, while most records in the database are relatively recent – post the 1960s (Foulkes and Gillen 2000). Consequently, the historical mammal assemblage (prior to European occupation) must be extrapolated from records outside of the region and from the known habitat requirements of likely species. It is thought that at least 16 mammal species from the historical assemblage have been lost from Yookamurra. Four of the lost species are globally extinct, and 12 are regionally extinct.

Four of the regionally extinct mammals have been successfully reintroduced to the Stage 1 area on Yookamurra (Table 1): the Numbat (*Myrmecobius fasciatus*), Burrowing Bettong (Boodie; *Bettongia lesueur*), Brush-tailed Bettong (Woylie; *Bettongia penicillata*), and the Greater Bilby (*Macrotis lagotis*). Attempted reintroductions of two other threatened mammals, the Greater Stick-nest Rat (*Leporillus conditor*) and Plains Mouse (*Pseudomys australis*), were not successful in that these species have not persisted on the property (Table 1). One extant mammal, the Common Brushtail Possum (*Trichosurus vulpecula*) was supplemented with additional individuals during the 1990s.

Table 1. Source of mammal reintroductions and supplementations at Yookamurra.

Species	Founders
Numbat	15 (5 males, 10 females) from Dryandra in 1993
Greater Bilby	25 total: 2 from Territory Wildlife Park and 1 from Arid Zone Research Institute in 1996, 2 from Kanyana Wildlife Park in 1999, 20 from Scotia in 2018.
Common Brushtail Possum	Extant at Yookamurra, but supplemented with an unknown number of individuals from the Adelaide Hills Region in the 1990's.
Burrowing Bettong	28 total: 20 from Bernier Island in 1995, 8 from Dorre Island in 1999.
Brush-tailed Bettong	119 total: 37 (11 males, 26 females) from the SA Museum in 1991, 40 from Warrawong Sanctuary in 1993, 12 from Warrawong in 1995, 4 (3 males, 1 female) from Venus Bay in 1998, 26 (12 males, 14 females) from Scotia Sanctuary in 2020.
Greater Stick-nest Rat	64 total: 14 (7 males, 7 females) from Monarto Zoo in 1991, 14 (6 males, 8 females) in 1992, 22 (10 males, 12 females) in 1994, 4 (2 males, 2 females) in 1998, and 10 (5 males, 5 females) from Revesby Island in 1998. Did not persist.
Plains Mouse	243 total: 38 in 1992, 14 in 1993, 55 from Nature Education Centre in 1994, 24 from Scotia, Adelaide University, and other in 1998, 27 from PRU, Urrbrae School, Flinders University, and other in 1999, 85 from Urrbrae School in 2000. Did not persist.

Reptiles are a notably diverse component of the vertebrate fauna of Yookamurra. Fifty-two species of small–medium reptiles (skinks, dragons, geckos, blind snakes, pygopodids), 12 snakes, and one species of goanna are known or likely to inhabit Yookamurra. Three reptiles (all snakes) are listed as rare in South Australia; the Bardick (*Echiopsis curta*), Murray Darling Carpet Python (*Morelia spilota metcalfei*), and Eastern Bandy Bandy (*Vermicella annulata*), the two latter species are confirmed on the property. The presence of the Carpet Python on Yookamurra is particularly significant as existing records are largely from along the edges of the Murray River and not in mallee vegetation.

Threats

Feral animals

Yookamurra, like much of southern Australia, has been invaded by a range of feral animals, including sheep, goats (*Capra hircus*), house mice (*Mus musculus*), black rats (*Rattus rattus*), red foxes (*Vulpes vulpes*), feral cats (*Felis catus*), European rabbits (*Oryctolagus cuniculus*), and hares (*Lepus europaeus*). The feral predators and feral herbivores have been eradicated from Stage 1 and are subject to ongoing control on the remainder of the property.

Weeds

A total of 31 exotic plant species have been identified on Yookamurra, one of which is of national significance, African boxthorn (*Lycium ferocissimum)*, and another two are declared species, horehound (*Marrubium vulgare*) and Paterson's curse (*Echium plantagineum*; Biosecurity SA 2021).

Changed fire regimes

Pre-European fire regimes in the mallee are poorly documented (Clarke et al. 2021). Since European settlement, the mallee has been prone to occasional wildfires. The last fire event on Yookamurra was recorded in 2014, burning only 55 ha outside Stage 1. Aside from this isolated incident, there have been no notable wildfires recorded on Yookamurra or surrounding properties since 1931. From time to time, AWC implements small, prescribed burns to reduce fuel loads around infrastructure on the property.

Climate and weather summary

Yookamurra is located in the semi-arid zone, characterised by cool winters and hot, dry summers with sporadic rainfall throughout the year. Rainfall data has been collected on a daily basis since 1997 at Yookamurra using a standard Bureau of Meteorology (BOM) rain gauge. The closest weather stations are located in the Barossa Valley (60 km to the west) and the Riverland (145 km to the east).

Based on the locally-collected data (1997–2021), long-term annual average rainfall on Yookamurra is 272 mm (± 18 SE). The highest recorded annual rainfall was 494 mm in 2010. The lowest recorded annual rainfall was 124 mm in 2019. The two previous years (2017 and 2018) also received below average rainfall (Figure 3), such that the period 2017–19 represents the driest conditions on record on Yookamurra.

In 2021, a total of 204 mm was recorded, making it the fifth consecutive below-average rainfall year. The average monthly rainfall was 12 mm per month, with November (49 mm) and December (0 mm) being the wettest and driest months, respectively (Figure 4). The largest rainfall event was experienced at the end of November, when 32 mm fell in two days.

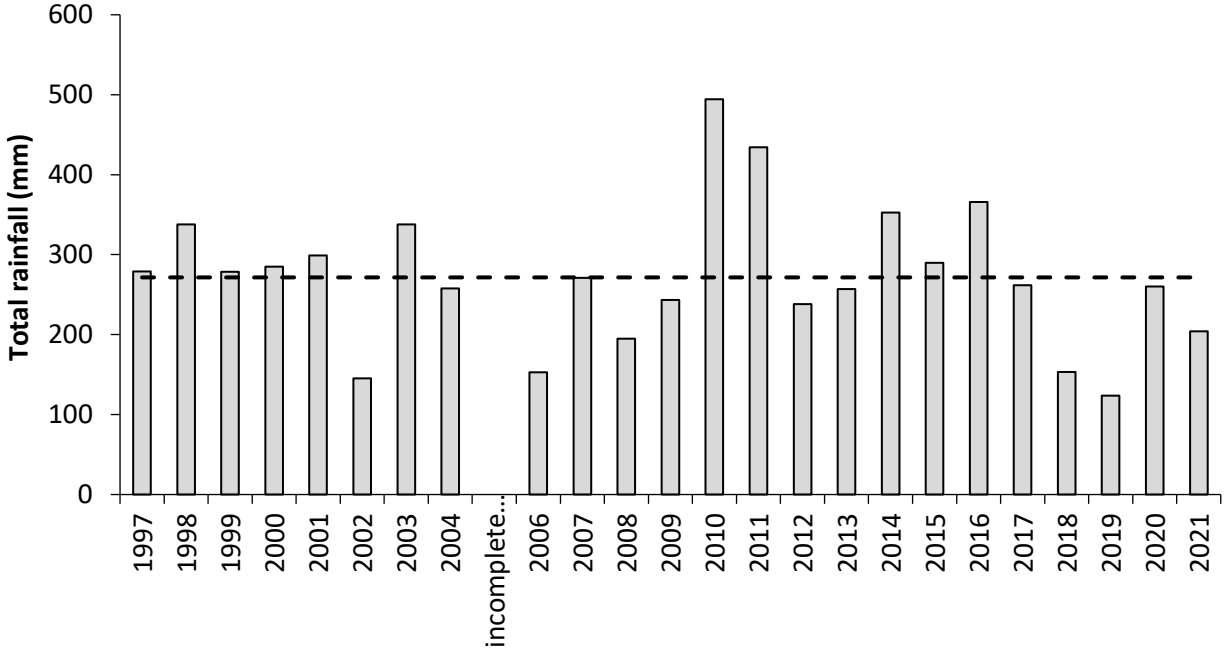

Figure 3. Annual rainfall at Yookamurra, 1997–2021. Dashed line = rainfall average, 1997–2021.

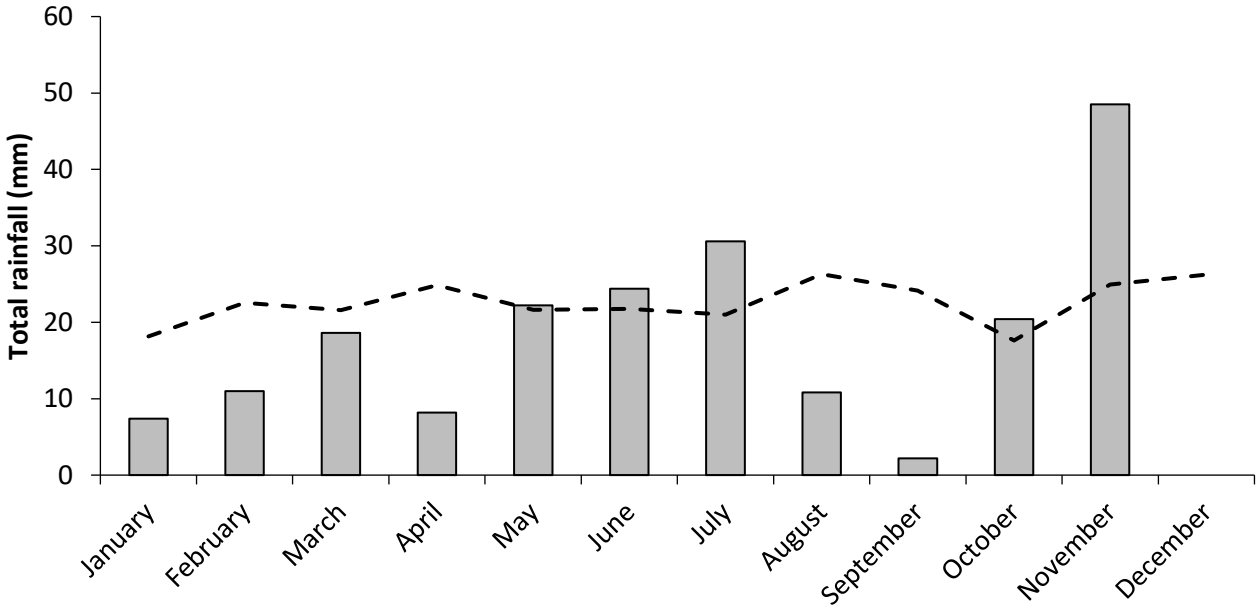

Figure 4. Monthly rainfall at Yookamurra in 2021. Dashed line = average monthly rainfall, 1997–2021**.**

Methods

Monitoring and evaluation framework

Yookamurra's Ecohealth Monitoring Program has been designed to measure and report on the status and trends of selected biodiversity and threat indicators on the property, using metrics derived from data collected through a series of purpose-designed surveys. Where possible, outcomes will be evaluated against performance criteria relevant to each species, guild or assemblage.

Reintroduced, key threatened, and iconic species

The Ecohealth program is focused on species of high conservation value, including **reintroduced species** (where present), and key **threatened** and '**iconic**' species (e.g., regional endemics, species with high public profile and other species of conservation importance because of the role they play in an ecosystem, etc).

Monitoring programs for reintroduced species in the establishment phase (i.e., within 5–10 years of establishment) are typically set out in a *Translocation Proposal*, along with success criteria to evaluate outcomes around survival, recruitment, population size, etc.

AWC will develop *Population Management Plans* to underpin management of long-established populations of reintroduced species, to ensure early detection of any serious issues that arise, and to trigger timely responses. These plans will specify a monitoring and evaluation program (e.g., Berry et al. 2021).

AWC will aim to develop *Conservation Plans* for the remaining (extant) threatened and iconic species, with similar objectives to Population Management Plans. These plans will specify metrics to monitor outcomes for target species against nominated performance criteria.

Vertebrate assemblages and surveillance species

AWC's mission involves the conservation of all wildlife, not only threatened or reintroduced species. For this reason, AWC's monitoring program extends to surveillance monitoring of faunal assemblages (mammals, birds, reptiles, frogs). The monitoring program aims to address questions relevant to the conservation of assemblages.

At the most basic level, the program seeks to establish whether all species that are known to occur on the property are persisting on the property (i.e., 'are all species present?').

With increasing information, the monitoring program can address more detailed questions relating to conservation of assemblages, such as 'have species maintained their distributions or abundance?' However,

the boom/bust conditions of most Australian environments can lead to large variations in the numbers of individuals in a population and the habitats or sites occupied by a species – these variations may not necessarily be informative in relation to the conservation of a species at a property over the long term.

AWC is currently working on developing an evaluation framework for surveillance monitoring of faunal assemblages. At present, we will continue to present data on a range of metrics relating to indicator species and guilds.

Indicators and metrics

On Yookamurra, 19 biodiversity (species, guilds, and assemblages) indicators have been selected for monitoring (Table 2). All these indicators are reported upon in this year's Ecohealth report.

Threat metrics are selected to monitor the status and trends of introduced weeds, predators and herbivores, and fire regimes. Three threat indicators have been selected for monitoring (Table 3); one of which is reported on in this report.

Table 2. Biodiversity indicators and metrics for Yookamurra in 2021.

Reintroduced vertebrates

Indicator	Survey name/methods	Metric	Performance criteria
Numbat (*Myrmecobius fasciatus*)	Numbat Survey/diurnal transects	Population estimate	TBD
Greater Bilby (*Macrotis lagotis*)	Bilby Spotlight Survey/spotlighting transects	Population estimate	TBD
Burrowing Bettong (*Bettongia lesueur*)	Bettong Survey/cage traps	Population estimate	TBD
Brush-tailed Bettong (*Bettongia penicillata*)	Bettong Survey/cage traps	Population estimate	TBD

Key threatened and iconic vertebrates

Indicator	Survey name	Survey method	Metric/s
Mammals			
Southern Hairy-nosed Wombat (*Lasiorhinus latifrons*)	Burrow Survey	Burrow census and occupancy	Population estimate
Common Brushtail Possum (*Trichosurus vulpecula*)	Possum Spotlight Survey	Spotlighting	Population estimate
Birds			
Malleefowl (*Leipoa ocellata*)	Mound Survey	Mound survey	Number of active mounds

Vertebrate assemblages and surveillance species

Indicator	Survey name	Survey method	Metric/s
Mammals			
Assemblage richness	All surveys listed for mammals, incidental observations	All survey methods listed for mammals	Number of species
Small mammals (guild)	Standard Trapping Survey	Pitfall traps	Abundance
Microchiroptera (microbats - guild)	Microbat Call Survey	Call detectors	Richness
Birds			
Assemblage richness	Malleefowl Mound Survey, Standard Bird Survey, incidental observations	All survey methods	Number of species

Indicator	Survey name	Survey method	Metric/s
		listed for birds	
All birds (diurnal)	Standard Bird Survey	20-min counts	Abundance, richness
Meliphagidae (honeyeaters - guild)	Standard Bird Survey	20-min counts	Abundance
Ground active birds (guild)	Standard Bird Survey	20-min counts	Abundance
Reptiles			
Assemblage richness	Standard Trapping Survey, incidental observations	All survey methods listed for reptiles	Number of species
All reptiles (excluding varanids and snakes)	Standard Trapping Survey	Pitfall traps, funnel traps	Abundance, richness
Gekkonidae (geckos - guild)	Standard Trapping Survey	Pitfall traps, funnel traps	Abundance
Scincidae (skinks - guild)	Standard Trapping Survey	Pitfall traps, funnel traps	Abundance

Key threatened and iconic plants

Indicator	Survey name/methods	Metric	Performance criteria
Desert Phebalium (*Phebalium glandulosum macrocalyx*)	Threatened Plants Survey/count	Population count	TBD

Table 3. Threat indicators and metrics for Yookamurra in 2021.

Indicator	Survey name/methods	Metric	Performance criteria
Pest animals			
Red fox (*Vulpes vulpes*)	Targeted Predator Survey	TBD	TBD
Weeds			
Weeds (Significant and WONS): African boxthorn (*Lycium ferocissimum*) Horehound (*Marrubium vulgare*) and Paterson's Curse (*Echium plantagineum*)	Targeted Search	TBD	TBD
Fire			
Extent of wildfire	Fire Scar Analysis	% of property	Eliminate wildfire occurrence in Stage 1

Survey types and history

To report on the Biodiversity and Threat Indicators, our survey teams conduct a variety of surveys repeated on a schedule of 1–5 years, as required to obtain timely information on each indicator. These include:

For key threatened and iconic species, including reintroduced species, a range of targeted surveys including:

- Numbat Survey
- Bilby Spotlight Survey
- Possum Spotlight Survey
- Bettong Survey
- Southern Hairy-nosed Wombat Burrow Survey
- Malleefowl Mound Survey
- Threatened Plants Survey

For vertebrate assemblages and surveillance monitoring of species, these include:

- Standard Trapping Survey
- Microbat Call Survey
- Standard Bird Survey

Eight of the ecological surveys were conducted at Yookamurra in 2021: Numbat Survey, Bettong Survey, Bilby and Possum Spotlight Surveys, Malleefowl Mound Survey, Standard Trapping Survey, Microbat Call Survey, and Standard Bird Survey. Below is a list of surveys reported upon in this Ecohealth Report (Table 4). The methodology is described and results of these surveys and computations are reported on in this document.

Table 4. Survey history and effort for Ecohealth surveys on Yookamurra reported on in this report.

Survey name	Effort (year)	Description/comment	Previous surveys
Numbat Survey	16 repeat transect surveys (2022)	8 transects inside Stage 1, sampled twice per day for 8 days	2015–20: 16 repeat surveys annually
Bilby Spotlight Survey	16 repeat spotlight surveys (2021)	8 transects inside Stage 1, surveyed twice per night for 8 nights (note in 2021, only one Bilby Spotlight Survey was conducted)	2015, 2017–2020: 16 repeat surveys, conducted twice annually
Possum Spotlight Survey	16 repeat spotlight surveys (2021)	8 transects inside Stage 1, surveyed twice per night for 8 nights	2020: 16 repeat surveys 2014, 2016: 10 x 1 km surveys
Bettong Survey	1,200 trap nights (2021)	2 surveys consisting of 50 sites inside Stage 1, 3 traps at each site, set for 4 nights each (note in 2021, two Bettong Surveys were conducted)	2020: 50 sites, 597 trap nights 2019: 50 sites, 600 trap nights 2018: 50 sites, 600 trap nights 2017: 50 sites, 600 trap nights 2016: 50 sites, 600 trap nights 2015: 450 trap nights 2014: 300 trap nights 2013: 300 trap nights 2012: 400 trap nights 2011: 300 trap nights 2010: 200 trap nights 2009: 200 trap nights
Southern Hairy-nosed Wombat Burrow Survey	1,169 burrows ground-truthed (2020)	1,169 burrows were found using Google Earth satellite imagery then individually assessed on ground	-
Malleefowl Mound Survey	3 mounds checked (2021)	Each Malleefowl mound checked and assessed for activity	2020: 3 mounds checked 2019: 2 mounds checked 2018: 2 mounds checked 2017: 2 mounds checked 2016: 2 mounds checked 2008–15: 1 mound checked

Survey name	Effort (year)	Description/comment	Previous surveys
Standard Trapping Survey	1,440 trap nights (2021)	24 sites surveyed, each site with 8 pitfall traps and 12 funnel traps, repeated over three days/nights (checked twice daily); sites stratified by major vegetation type.	2020: 24 sites, 1,440 trap nights 2019: 36 sites, 2,160 trap nights 2018: 24 sites, 1,440 trap nights 2017: 24 sites, 1,440 trap nights 2014: 18 sites, 1,080 trap nights
Microbat Call Survey	72 trap nights (2021)	24 sites surveyed, each site with 1 AudioMoth call detector, repeated over three nights	-
Standard Bird Survey	36 sites surveyed 3 times (2021)	20 minute – 2 ha survey. Completed at all 36 Standard Trapping Survey sites, repeated over three mornings.	2020: 36 sites surveyed 3 times 2019: 36 sites surveyed 3 times 2015: 18 sites surveyed 3 times
Threatened Plants Survey for Desert Phebalium	3 reintroduction sites checked (2020)	Each reintroduction site was visited and the number of reintroduced Desert Phebalium individuals was counted	2016–19: 3 sites checked

Survey design and methods

Numbat Survey

The reintroduced population of Numbats were monitored in November 2021 and January 2022 using diurnal surveys along eight road-based transects inside Stage 1 (Figure 5), over eight days. November is the optimal time of year to survey for Numbats as this is the time when juveniles are foraging independently and when they disperse from their natal home range to establish their own territories (Bester and Rusten 2009; Power et al. 2009). In 2021, unseasonably cold, windy, and rainy conditions during November resulted in a failed Numbat Survey, and a second survey was conducted in January 2022, using the same methods.

Transects located along the Stage 1 perimeter fence were 2,500 m in length. Internal transects were 1,250 m. Only one side of the road was surveyed (by one observer) along the 2,500 m fenceline surveys, whereas both sides of the road were surveyed (each side by an observer) in the internal 1,250 m surveys, ensuring all transects surveyed the same amount of area in total. Each transect was surveyed twice per day; once in the morning and once in the early evening. The technique involved driving (10–12 km/h) with two observers situated on the vehicle tray. When a Numbat was observed, the distance and angle from the observer to the Numbat was recorded, in addition to the angle to the middle of the transect (the road) using a high precision rangefinder (TruPulse 360R). A GPS was used to record location details and a portable weather station (Kestrel) was used to record weather data

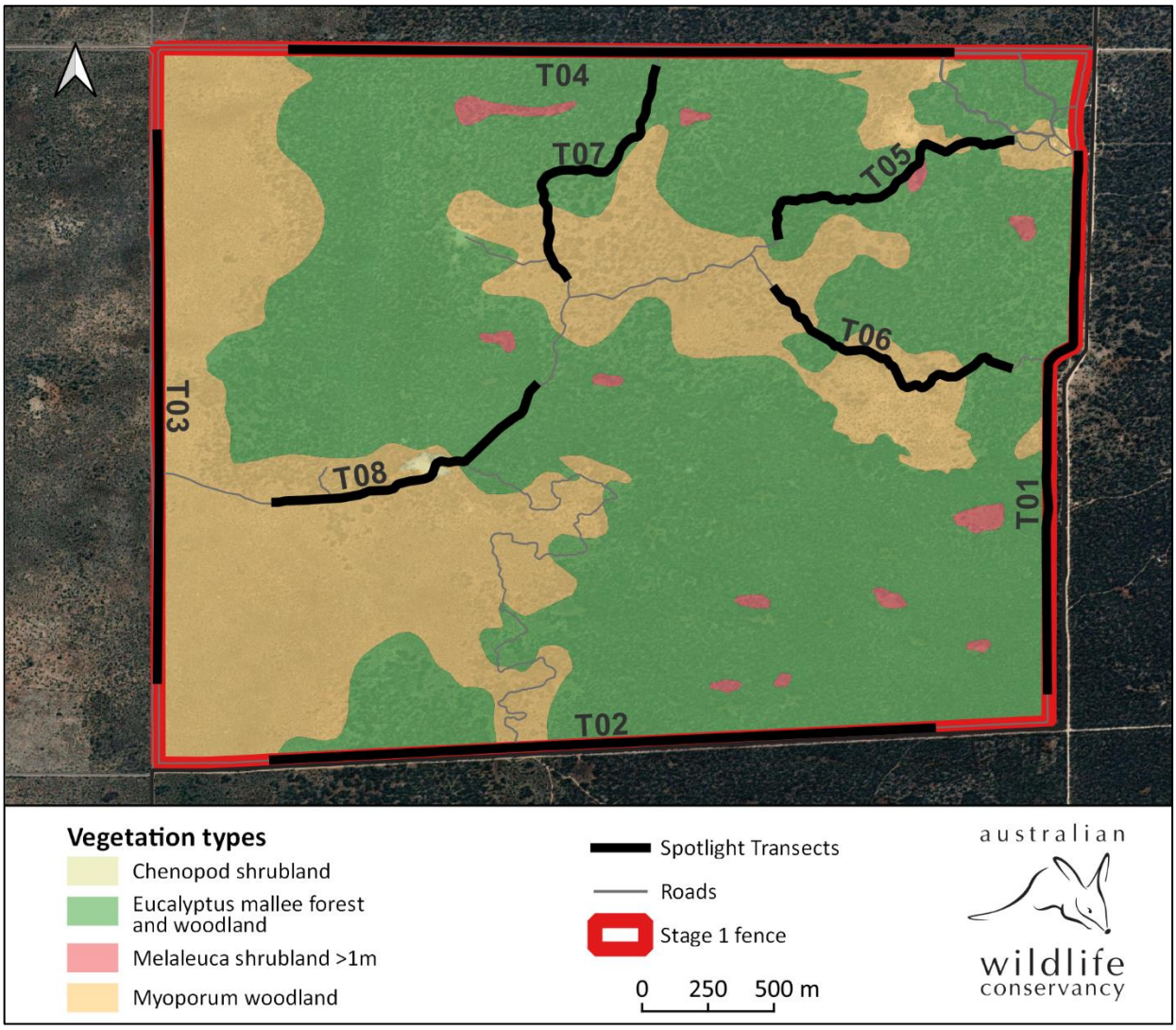

Figure 5. Location of the eight strip-plot transects inside Stage 1 of Yookamurra used to monitor Numbat, Bilby, and Common Brushtail Possum populations.

Greater Bilby and Common Brushtail Possum Spotlight Surveys

The reintroduced population of Bilbies and the extant (with supplementation) population of Common Brushtail Possums were monitored inside the Stage 1 area. Spotlight surveys were conducted along eight road-based transects (Figure 5) over eight nights. Transects located along the Stage 1 perimeter fence were 2,500 m in length and internal transects were 1,250 m. Only one side of the road was surveyed (by one observer) along the 2,500 m fenceline surveys, whereas both sides of the road were surveyed (each by an observer) in the internal 1,250 m surveys, ensuring all transects surveyed the same amount of area in total. Each species was surveyed separately to ensure focused effort. That is, each species was surveyed for eight nights each, and only the species being surveyed were recorded during that survey. Each transect was surveyed twice per night for each species. The technique involved driving (10–12 km/hr) with two observers situated on the vehicle tray spotlighting for the target species. All Bilbies and Possums detected during Spotlight Surveys were recorded, and only those found within 9 m and 15 m of the transect, respectively, were included in data analyses. These transect widths have been determined by reviewing the median perpendicular distance from the transect line for conducted surveys, as per Roshier et al. (2014). Surveys were carried out in Autumn (March). In previous years the Bilby Survey was conducted twice, but in 2021 the Bilby Survey was conducted only once due to a large population size estimated in the first survey, and due to consistently lower numbers seen in prior September surveys suggesting seasonal changes in activity or breeding, making March the preferred survey time for this species.

In 2014 and 2016, Common Brushtail Possums were surveyed through ten, off-road, walking spotlight transects stratified by major habitat type, each 1 km in length. Two people walked each transect; one scribed, whilst the other observed both sides of the transect. When a possum was sighted, the angle from the midline of the transect was recorded using a compass or protractor and a rangefinder was used to record the distance of the possum from the observer. These measurements were used to calculate the perpendicular distance of the possum to the transect line.

Bettong Survey – Burrowing and Brush-tailed Bettongs

Reintroduced populations of Burrowing and Brush-tailed Bettongs were surveyed with cage traps. Fifty permanent monitoring sites were spaced 400–500 m apart along road networks within Stage 1 (Figure 6).

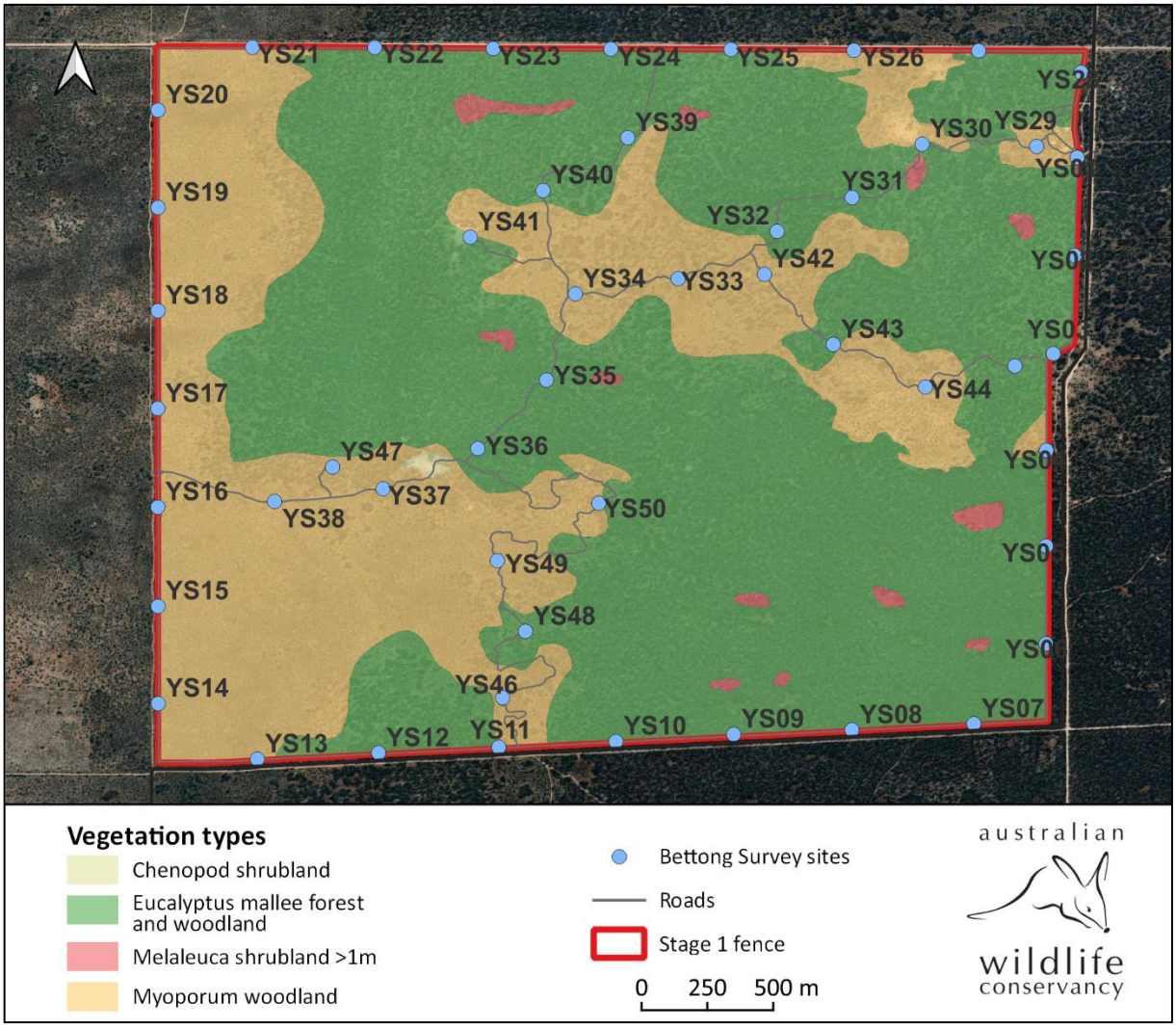

Figure 6. Location of the 50 permanent cage trapping sites used for Bettong Surveys at Yookamurra.

At each site, three standard-sized (220 x 220 x 550 mm), treadle-operated wire cage traps were deployed. Each site was opened for four nights. Cage traps were opened in the late afternoon, baited with peanut paste and rolled oat balls, checked from two hours after sunset and then closed until the following afternoon. Each captured animal was given a unique Passive Integrated Transponders (PIT) tag, processed, and then released. This survey is normally carried out in Autumn (April) only, but in 2021 a second survey was conducted in late August/ early September due to a small Brush-tailed Bettong population size estimated in the first survey.

Southern Hairy-nosed Wombat Burrow Survey

The first targeted Ecohealth survey for the Southern Hairy-nosed Wombat (*Lasiorhinus latifrons*) was carried out in Autumn 2020. To estimate population size, warrens (or potential warrens) were first identified using Google Earth at a scale of <100 m to systematically search the whole property outside Stage 1. All potential

warrens (sites) were ground-truthed in 2020 and if the site was a warren then activity was assessed. A warren was determined to be active using signs such as the presence of fresh Wombat scats or tracks. A warren was classified as inactive if there were no signs of activity at any of the warren entrances. No Southern Hairy-nosed Wombat Burrow Surveys were conducted in 2021.

Malleefowl Mound Survey

All known Malleefowl (*Leipoa ocellata*) mounds on Yookamurra were visited in October and breeding activity was assessed based on criteria outlined by the National Malleefowl Recovery Team (2016), noting features such as the mound profile, presence of leaf litter and eggshells. Disturbance to mounds by feral herbivores and predators, which threaten the Malleefowl (Harrington 1979, 1986; Wheeler and Priddel 2009), was also recorded.

Standard Trapping Survey

There are 36 Standard Trapping Sites on Yookamurra (Figure 7) stratified by location inside or outside the Stage 1 predator-free area, and by broad vegetation type. Replicates in each habitat type are located at least 500 m apart. All 36 Standard Trapping Sites are surveyed every 3–5 years, with a subset of 24 sites surveyed other years. The subset of 24 sites are representative of the two dominant broad habitat types (i.e., Eucalyptus Mallee Woodland and Forest, and Myoporum Woodland) found within Stage 1, and are generally indicative of overall species presence. Future surveys will be conducted in all 36 Standard Trapping Sites every 3–5 years, or more frequently after extreme weather.

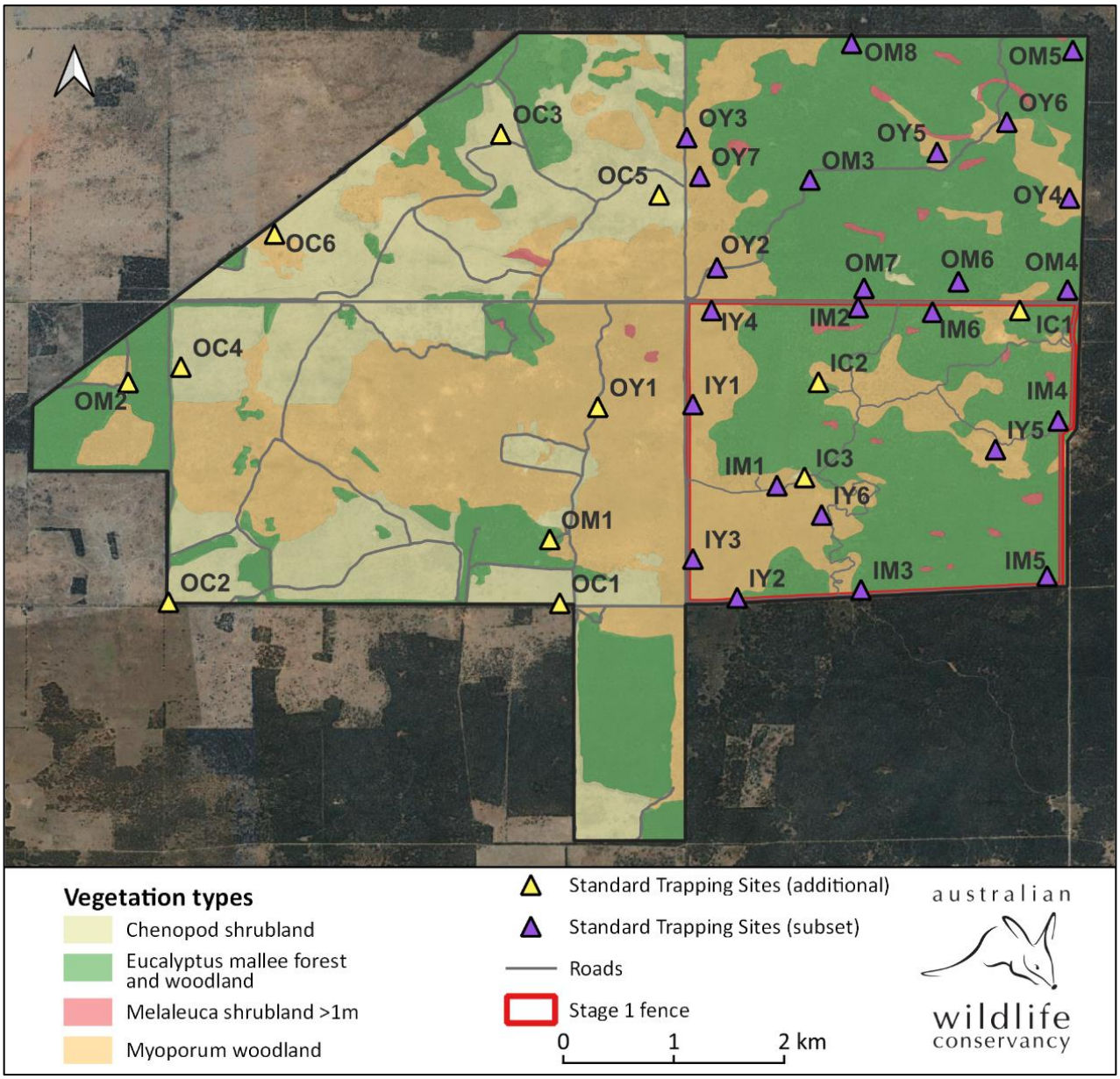

Figure 7. Location of Standard Trapping Survey, Microbat Call Survey, and Standard Bird Survey sites on Yookamurra. Sites are denoted by three characters, the first indicating location (Inside Stage 1=I, Outside Stage 1=O), the second indicating broad vegetation type (Mallee=M, Myoporum=Y, Chenopod shrubland=C), the third adding site number identification (1–7).

The Standard Trapping Survey for small terrestrial vertebrate fauna used a combination of live-trapping techniques (i.e., pitfall and funnel traps) at monitoring sites. Each survey site consisted of two back-to-back 'Y' shapes (each with three 10 m 'wings', joined at the middle) separated by about 10 m (Figure 8) which included eight pitfall and 12 funnel traps at each site. Each pair of funnel traps was covered with a sheet of air-cell insulation and nesting material was placed in the bottom of each pitfall to provide protection for trapped animals. Each trap site was operated for three nights. All traps were checked in the morning and the evening. Small mammals were identified and weighed, the sex and breeding condition was determined, and native species were measured and given a temporary mark before release. Reptiles and amphibians were identified, snout-vent length was measured, sex was determined where possible and individuals were given a temporary mark (not amphibians) before release. Surveys were carried out in Spring (October–November).

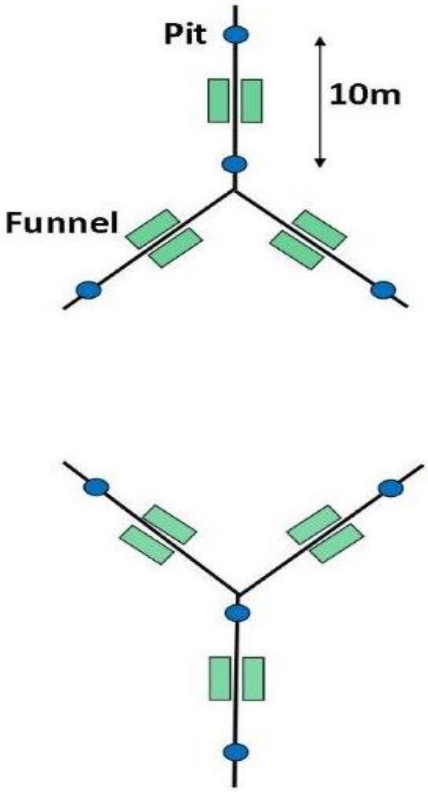

Figure 8. Schematic layout of small terrestrial vertebrate monitoring site indicating trap type and placement.

Microbat Call Survey

In 2021, the first Microbat Call Survey was conducted in conjunction with the Standard Trapping Survey, with the subset 24 of the 36 Standard Trapping Sites surveyed (12 inside Stage 1 and 12 outside Stage 1, with equal numbers in Mallee and Myoporum habitat types; Figure 7). A single AudioMoth call detector was placed at each site for three consecutive nights. The AudioMoth call detector was placed in a ziplock bag for protection from the elements and was attached to a tree within the site, above head height and facing slightly downward. AudioMoths were configured to record calls at a sample rate of 250 kHz and medium gains, for four hours from 8 pm to 12 am, based on optimisation studies undertaken before the survey (Figure 9). Future surveys will be conducted in all 36 Standard Trapping Sites every 3–5 years, or more frequently after extreme weather.

Figure 9. AudioMoths set in triplicate to determine optimal recording parameters for Yookamurra prior to the Microbat Survey (Lachlan McRae/AWC).

Calls captured by the AudioMoth were collected and analysed to identify individual microbat species using characteristic features including call frequency, duration, and shape. Only calls consisting of four or more "search pulses" (i.e., not feeding buzz pulses) were used to identify bat species (Figure 10). This was the first year the systematic Microbat Call Survey was conducted. Surveys were carried out concurrently with the Standard Trapping Survey in Spring (October–November).

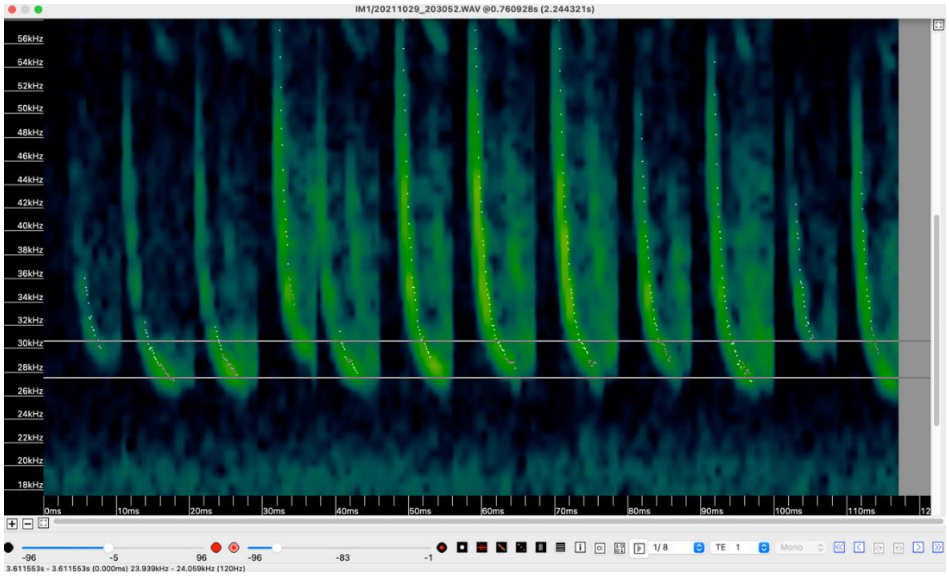

Figure 10. A compressed spectrogram of an AudioMoth audio file depicting the search pulses of a Gould's Wattled Bat (*Chalinolobus gouldii*) call.

Standard Bird Survey

Standard Bird Surveys were conducted at the 36 Standard Survey Sites (Figure 7). Surveys have been conducted annually since 2019; prior to this the Bird Surveys were opportunistic and sporadic. Surveys were carried out using the standard 20-minute, 2 ha observational survey (Loyn 1986). The observer spent 20 minutes actively searching two hectares centred on the survey site (Figure 7) identifying and recording any sightings or vocalisations. When more than one individual of the same species was noted, it was recorded only if the observer was certain that it was not an individual recorded previously. In addition to bird counts, observers noted any flowering plants within the 2 ha sites, which was used to determine the percentage of sites with at least one flowering plant. Surveys were repeated on each of three mornings. Surveys were carried out in Spring (October).

Threatened Plants Survey

Surveys of one of the threatened species of plants reintroduced to Yookamurra, Desert Phebalium, were conducted at the three reintroduction sites to assess population size in 2020 (Figure 11). At each site, every individual was counted. No Threatened Plant Surveys were carried out in 2021.

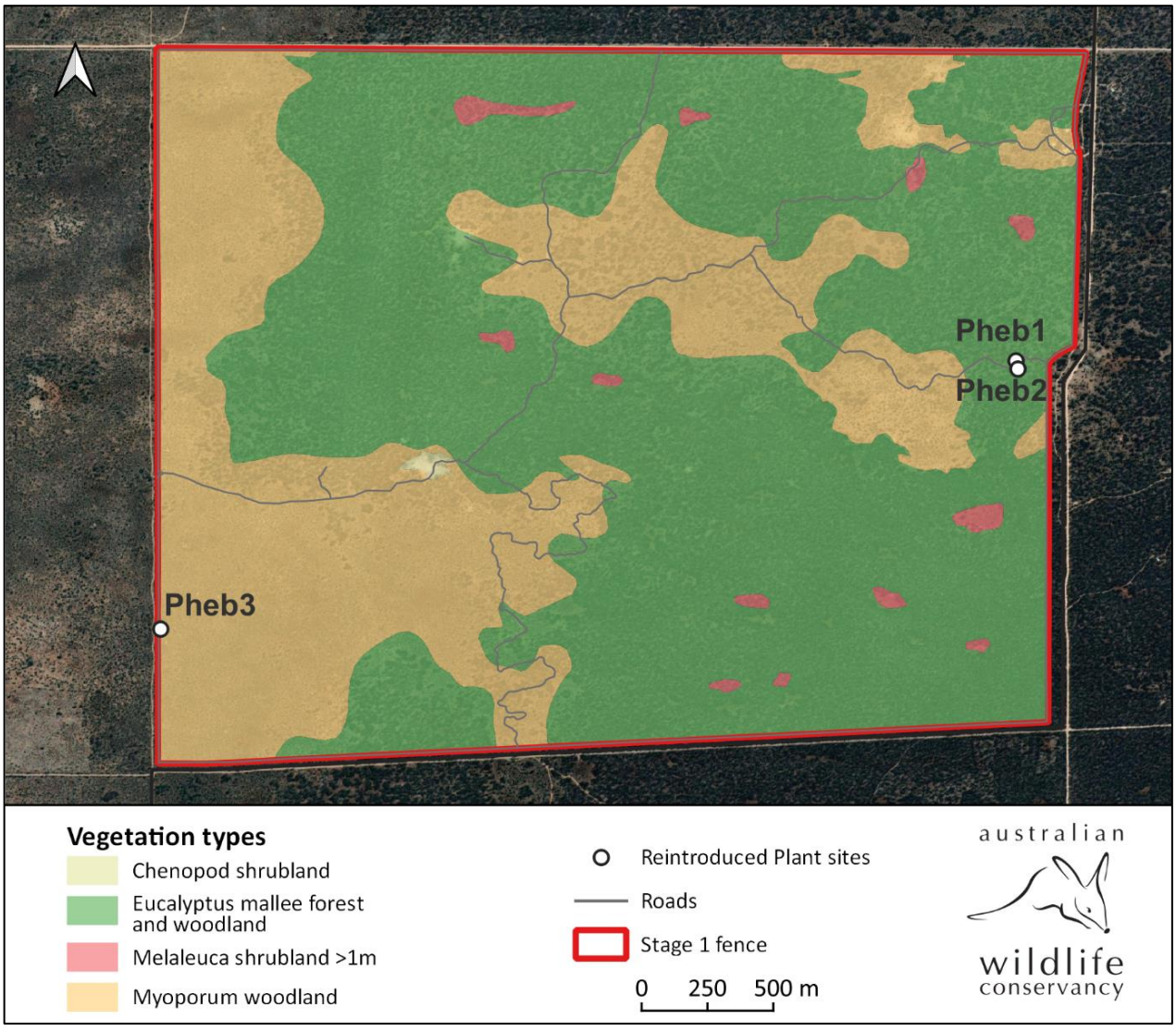

Figure 11. Location of the three sites inside Stage 1 of Yookamurra Wildlife Sanctuary used to monitor the reintroduced plant species, Desert Phebalium.

Fire

Usually, fire scar data are retrieved from Landsat or Sentinel-2 satellite imagery and on-ground knowledge of sanctuary managers, and fire scar metrics are calculated. As no fire on Yookamurra in 2021, no analysis was conducted.

Analysis methods

Most Ecohealth metrics are common across the indicators for Yookamurra. The metrics are calculated as set out in Table 5 below.

The metrics are reported for species and groups of species of a particular 'guild'. This requires that all species reported on are correctly assigned to a particular guild (or guilds) prior to undertaking these calculations. Species that are not individually reported as a unique metric are assigned to one (or more) of the following guilds: small mammals, microbats, birds (all), honeyeaters, ground active birds, reptiles (all except varanids and snakes), geckos, and/or skinks.

Table 5. Metrics and associated calculations for Yookamurra.

Indicator	Metric	Survey data sources	Description	Analysis summary/calculation
Assemblage richness	Number of species	All surveys and incidental records	A measure of intactness for the whole sanctuary	The number of species detected on the sanctuary within the last 2–5 years is compared to the number of species listed as 'confirmed', 'very likely' or 'likely' on the sanctuary species list.
Numbat	Population estimate	Numbat Survey	Estimate of total number of individuals in the population based upon strip-plot transects	(Total number of individuals seen inside the strip plot (i.e., within 9 m of the transect) during the survey / total ha surveyed) * by total Stage 1 area Confidence intervals: Student's T * Standard Error of Population Estimate (as per Silvy 2012)
Greater Bilby, Common Brushtail Possum	Population estimate	Bilby and Possum Spotlight Surveys Possum Spotlight Survey 2014 & 2016 – off-road, walking	Estimate of total number of individuals in the population based upon strip-plot transects	(Number of individuals seen inside the strip plot (i.e., within 9 m (Bilby) or 15 m (possum) of the transect) during the survey / total ha surveyed) * by total Stage 1 area Confidence intervals: Student's T * Standard Error of Population Estimate (as per Silvy 2012) (Number of individuals seen inside the strip plot (i.e., 40 m each side of transect in mallee; 80 m each side of transect in Myoporum) during the survey / total ha surveyed) * by total Stage 1 area
Burrowing Bettong, Brush-tailed Bettong	Population estimate	Bettong Survey	Estimate of total number of individuals in the population based upon live trapping	Mark-recapture was used to estimate total population size using the closed design in the software program MARK (www.phidot.org/software/mark). Population estimates were derived from models using a closed captures design with full likelihood p (capture probability) and c (recapture probability; as per White 2008). The model with the lowest Akaike's Information Criterion (AIC_c) was used. At Yookamurra, this model is consistently the one where p = c, variable over time. (i.e., the

Indicator	Metric	Survey data sources	Description	Analysis summary/calculation
				probability of an animal being caught or recaught is not constant.) From 2009 to 2020 the two bettong species were analysed within the same model, however in 2021 the small Brush-tailed Bettong population size made this impossible and so Burrowing Bettongs were modelled separately (1-species analysis) and the Brush-tailed Bettong population is therefore presented as the number of unique captures (i.e., the minimum population size).
Southern Hairy-nosed Wombat	Population estimate, activity	Southern Hairy-nosed Wombat Burrow Survey	Population estimate: estimate of total number of individuals in the population, based upon count of active burrows and burrow activity index. Activity: the percentage of burrows in use	Population estimate: the total count of active burrows was multiplied by 0.43 (Swinbourne et al. 2018) to give a conservative population estimate of the Southern Hairy-nosed Wombat Activity: (the number of active burrows / number of total burrows) * 100
Malleefowl	Number of mounds	Malleefowl Mound Survey	Number of mounds: a count of the number of mounds Activity: the percentage of mounds in use	Number of mounds: a count of the number of active mounds
Small mammals Birds (all), Honeyeaters, ground active birds Reptiles (all except varanids and snakes), geckos, skinks	Abundance	Standard Trapping Survey Microbat Call Survey Standard Bird Survey	A measure of activity; number of detections per survey (birds) or per 100 trap nights (reptiles, mammals), separated by location (inside/outside Stage 1).	Abundance (birds): average number of individuals recorded across surveys at each site, averaged across all sites Abundance (reptiles): (total number of individuals recorded/ total number of trap nights) * 100 *Guilds* Abundance (mammals/reptiles): (number of individuals recorded within the relevant guild / total number of trap nights) * 100 Abundance (bird guilds): average number of individuals recorded across surveys at each site, averaged across all sites
Microbats Birds (all) Reptiles (all)	Richness	Standard Trapping Survey Microbat Call Survey	Richness: A measure of diversity; average number of species per site, separated	Richness (microbats/reptiles): Total number of species recorded within the relevant guild / total number of sites

Indicator	Metric	Survey data sources	Description	Analysis summary/calculation
		Standard Bird Survey	by location (inside/outside Stage 1).	Richness (birds): Total number of species recorded within the guild / total number of surveys
Desert Phebalium	Population size	Threatened Plants Survey	Population size	Population size: All plants were counted at the three reintroduction sites inside Stage 1

Results

Reintroduced vertebrates

Numbat

The Numbat population has remained relatively stable over the last six years, however there was a decline observed following larger numbers in 2017 consistent with the impact of record dry conditions in 2018–2019 and potentially due to the removal of 4 individuals for translocation to Mt. Gibson (Figure 12). With improved rainfall in 2020, this trend was expected to halt. The Numbat survey in November 2021 failed due to unseasonably cold and windy conditions resulting in decreased Numbat activity, violating the assumptions of the strip-plot survey design (i.e., that Numbats will be distributed evenly through the Sanctuary). A second survey was scheduled for January 2022 during improved conditions. This survey generated a population estimate of 19 Numbats, the same as estimated in November 2020, suggesting the population decline had halted as predicted and that Numbats were stable but yet to recover from the small population decline prior to November 2020.

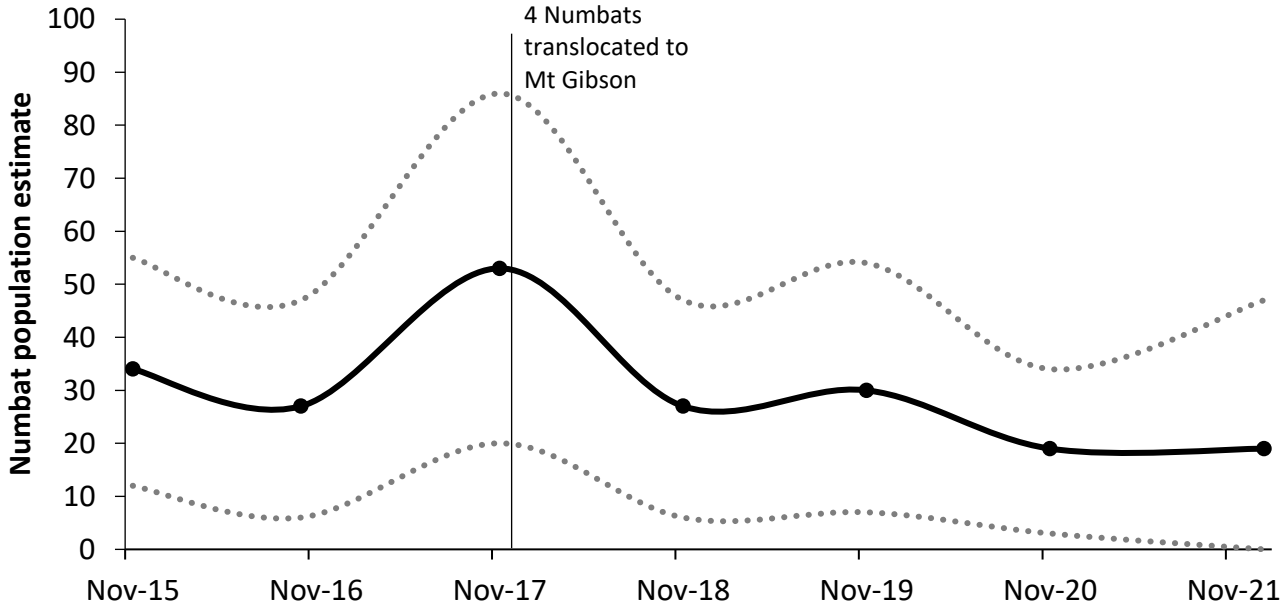

Figure 12. Numbat population estimates (± 95% CI) at Yookamurra.

Greater Bilby

Bilby population estimates are very variable within a single year. The Autumn (March) surveys are typically more successful than the Spring (September) surveys (Figure 13), due to increased Bilby activity and breeding, likely as a result of summer rains. The Bilby population declined following the record dry conditions in 2018–

19, but the population appears to have recovered in 2021 following improved rainfall and supplementation, with a population estimate of 83 in March (95% CI = 55–112 individuals; Figure 13), an increase both from the previous September survey (population estimate = 19) and the previous March survey (population estimate = 49). Fluctuations in population size are commonly reported for remnant Bilby populations in response to conditions, breeding, and season (Southgate et al. 2007). The Yookamurra population has recovered to pre-drought levels (mean population size 2014–17 = 85 individuals) with a return to average rainfall conditions.

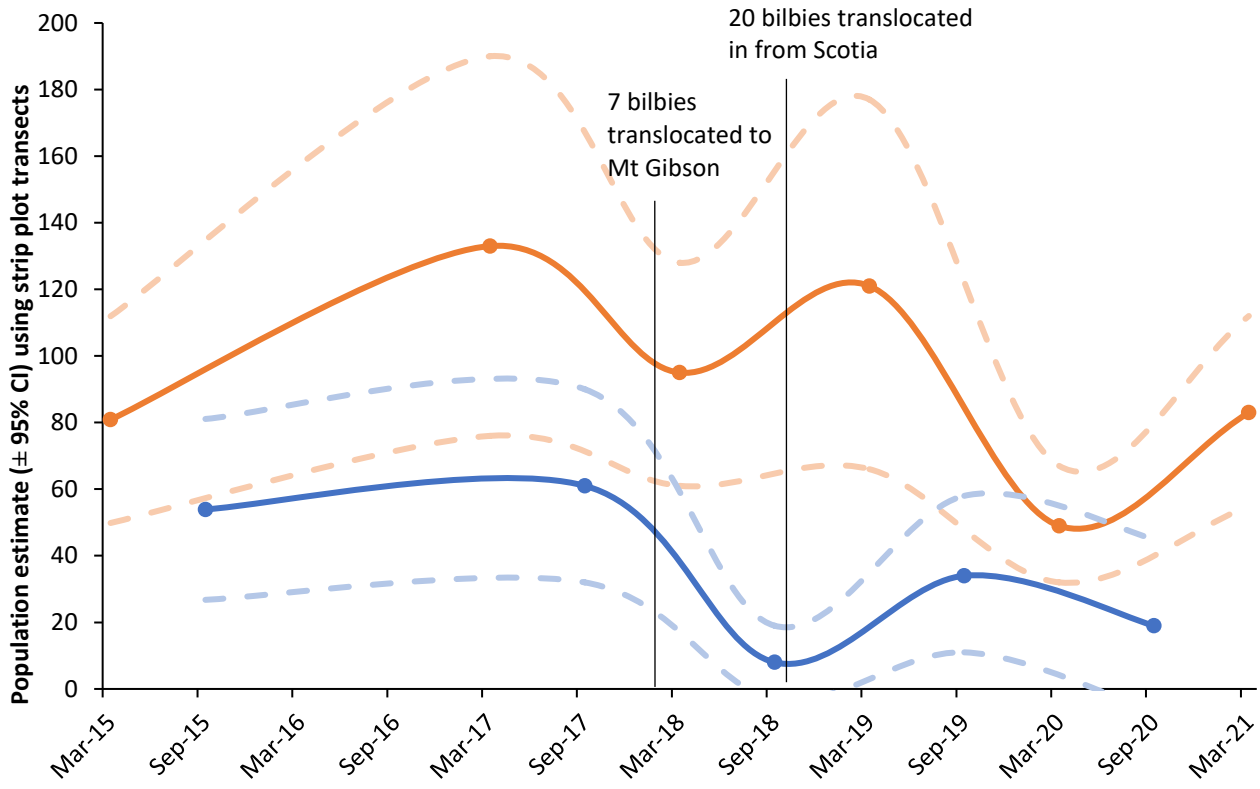

Figure 13. Bilby population estimates (± 95% CI) at Yookamurra in Autumn March (orange) and Spring September (blue) surveys.

Burrowing Bettong

The Burrowing Bettong population on Yookamurra has remained relatively stable over the last ten years with around 200–250 individuals (pre-drought (2011–17) average = 230 individuals; Figure 14). Surveys show a decline in the population from 2017–2019, coinciding with the record drought. In August 2021, the population was estimated at 193 (95% CI = 185–208), a slight increase from the previous year, and within 20% of pre-drought estimates.

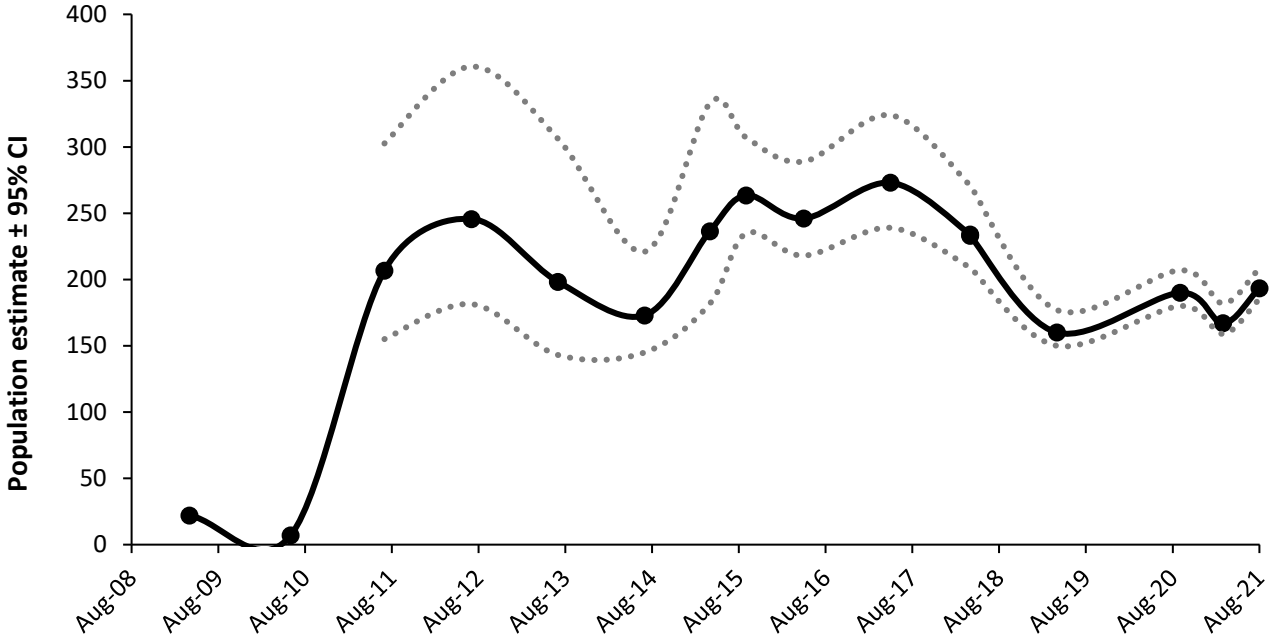

Figure 14. Burrowing Bettong population estimates (± 95% CI) at Yookamurra.

Brush-tailed Bettong

Unlike Burrowing Bettongs, the population of the Brush-tailed Bettong on Yookamurra has not recovered from a major decline incurred during the 2018–19 drought (Figure 15).

At Yookamurra, numbers of Brush-tailed Bettongs have fallen from a moderately stable long-term size of over 100 individuals (pre-drought (2010–17) average = 120 individuals; Figure 15) to a few individuals. Only 5, 12, and 10 unique individuals were caught in September 2020, March 2021, and August 2021, respectively. However, of the 10 individuals caught in August 2021, two were new (i.e., never caught in a previous survey) and two of the four captured females had pouch young, suggesting that population recruitment through breeding was still occurring despite the limited population size. Despite the addition of 26 individuals from Scotia in 2020 to supplement the Yookamurra population, it is clear that the population has not yet recovered from the drought. The continued small size renders the population vulnerable to demographic and genetic collapse, and for this reason its future is uncertain.

AWC is currently developing a plan to guide long-term management of Brush-tailed Bettongs at Yookamurra, which may involve transfer of remaining animals in the population to another site.

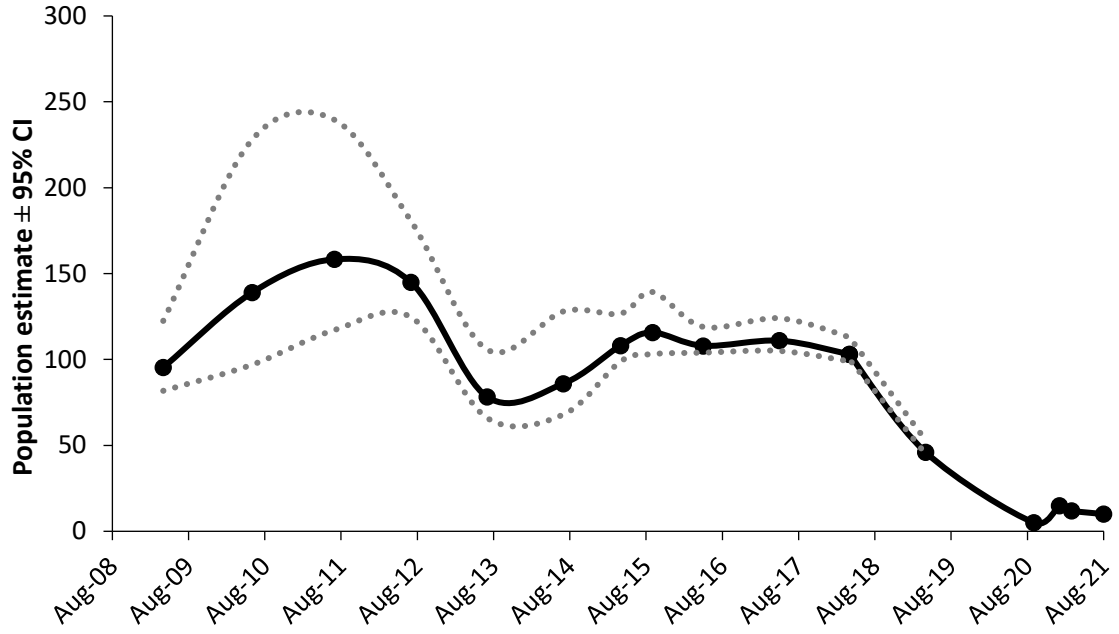

Figure 15. Brush-tailed Bettong population estimates (± 95% CI) at Yookamurra. Figures from 2008–2019 are based on capture-mark-recapture data analysed in MARK. Figures from 2020 onwards are the minimum population size at Yookamurra based on the number of unique individuals caught in the survey, as capture rate was too low to conduct a capture-mark-recapture analysis.

Key threatened and iconic vertebrates

Southern Hairy-nosed Wombat

In 2020, a total of 1,499 potential warren sites were mapped and visited, of which 1,168 were confirmed as wombat warrens, and 72% of the actual warrens were active (Figure 16). In total, there were 4,928 active burrows (each warren typically has multiple burrows), which equates to a conservative population of over 2,100 Southern Hairy-nosed Wombats on Yookamurra (a population density of 0.54 wombats/ha).

The estimate of a large number of wombats on Yookamurra is consistent with field observations, including the number of wombats observed on warrens and during opportunistic spotlighting, the extent of suitable habitat (particularly to the west of Stage 1), and the number of warrens evident in satellite imagery and old aerial photographs.

There were marked differences in the distribution of active warrens across the property, primarily driven by vegetation type. In the west block, which is dominated by chenopod shrubland, warren density was 0.31 warrens/ha and, of those, 93% of warrens were active. In contrast, in the northern block, which is dominated by large tracts of mallee, warren density was 0.05 warrens/ha and, of those, only 29% of warrens were active. The difference between the vegetation types was likely due to food availability and habitat preferences.

A total of 83 wombats were seen during the survey and none had visual evidence of mange. All but a couple of older individuals appeared in good condition.

This was the first time the survey had been conducted, providing a baseline for future years. This result is extremely encouraging given the below-average rainfall for the last three consecutive years, although Southern Hairy-nosed Wombats are known to be tolerant of drought conditions, with an extremely efficient water-use physiology (Wells 1978).

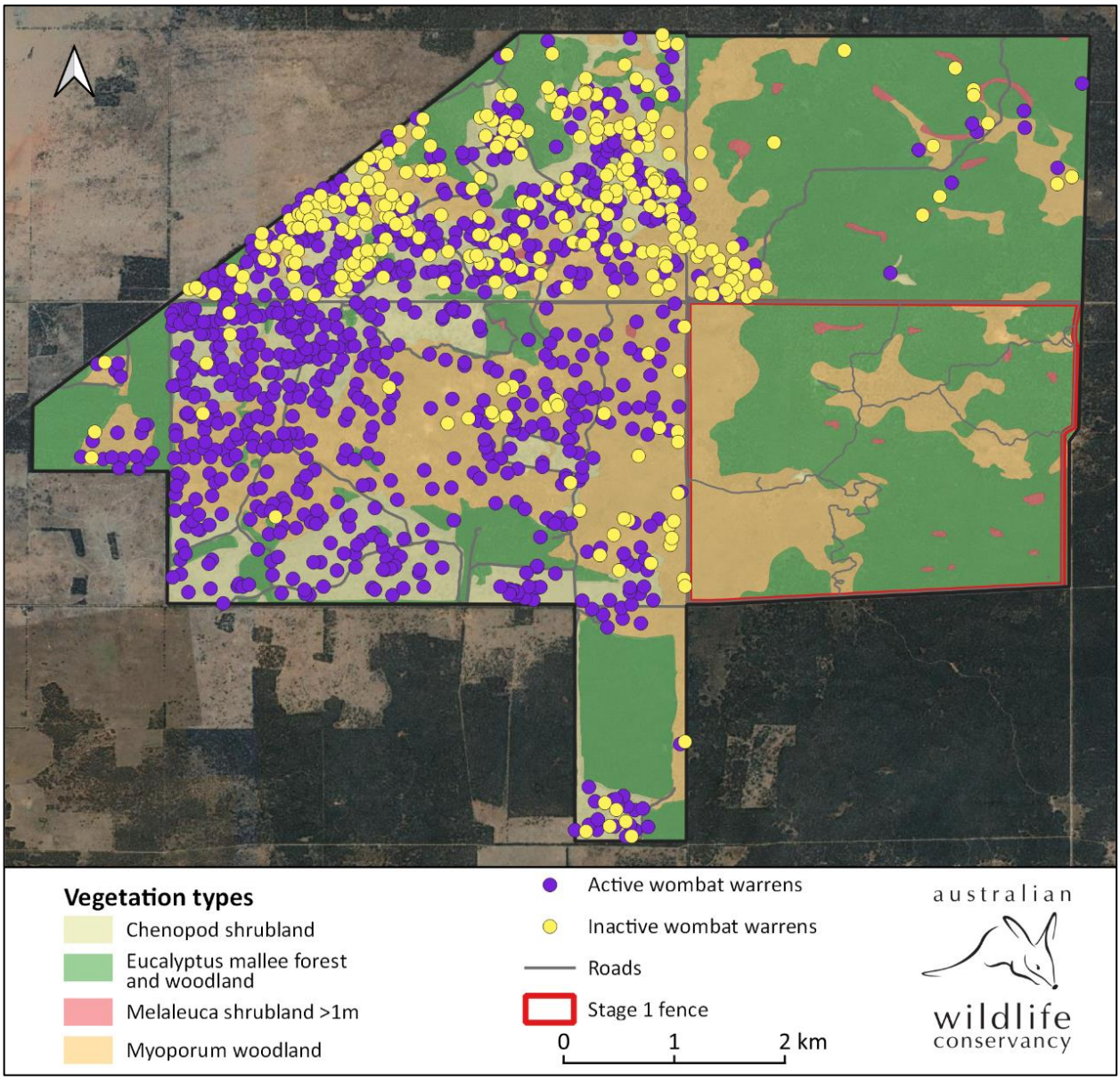

Figure 16. Location and activity status of the warrens at Yookamurra used to monitor the Southern Hairy-nosed Wombat population.

Common Brushtail Possum

In 2021, the population of Common Brushtail Possums was estimated at 193 (95% CI = 155–232), an increase from the 2020 estimate of 91 (95% CI = 60–122). A total of 110 possum sightings were recorded during the 8 nights (16 sessions) of the 2021 survey, distributed across all transects and habitat types (Figure 17).

Walking transect surveys in 2014 estimated 202 possums within Stage 1 (Ecological Horizons Pty Ltd 2014), sufficient to allow the harvest of 80 possums from the population for a translocation to the Flinders Ranges in 2015. A follow-up survey in 2016 estimated the population at 220, indicating that the impact of the harvest on the population was negligible (Ecological Horizons Pty Ltd 2016). A decline in the population of Common Brushtail Possums from these levels was expected in 2020, given the record dry conditions in 2018–19. The 2021 results suggest the population has recovered to pre-drought levels.

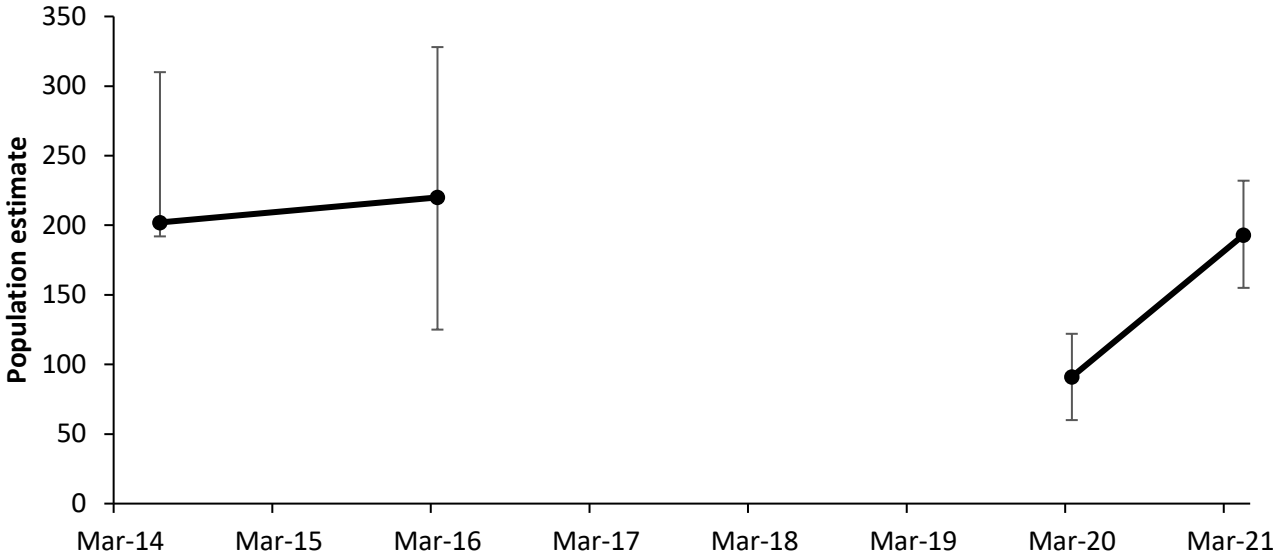

Figure 17. Number of Common Brushtail Possums estimated at Yookamurra since 2014 using walking transects (2014–16) and driving transects (2020–21). Error bars denote minimum and maximum population size estimates (2014–16) and 95% CI (2020–21).

Malleefowl

The Malleefowl is a threatened ground-active bird, susceptible to predation by feral predators. Malleefowl are difficult to detect using standard bird survey techniques. Instead, Malleefowl breeding activity can be monitored by inspection of their distinctive mounds. On Yookamurra, Malleefowl mounds have been located through ground searches, all outside Stage 1. From 2008–15, one active Malleefowl mound was known on Yookamurra; this increased to two from 2016–18. At the height of the drought, in 2019, both known mounds were inactive. In 2020, a third mound was discovered opportunistically during wombat surveys. It is possible that additional mounds exist either inside or outside Stage 1. Surveys found two of the three mounds were active in 2021, with a Malleefowl observed at one of the active mounds.

Vertebrate assemblages and surveillance species

Mammals

Assemblage richness

There are 22 native mammals (including reintroduced species) confirmed, very likely or likely to occur on Yookamurra. Of these, 17 (77%) were detected in surveys or incidentally in 2021, and 18 (82%) were detected in the last five years, including two of three confirmed small mammals, and seven of 10 confirmed or likely microbats. Overall, two small mammal, six reintroduced/iconic mammals, seven microbats, two kangaroos, and one Echidna (*Tachyglossus aculeatus*) were recorded between 2017 and 2021. The missing small mammal (Fat-tailed Dunnart *Sminthopsis crassicaudata*) was likely due to naturally small local populations and preceding dry conditions reducing available food resulting in very low detection. The Western Pygmy Possum (*Cercartetus concinnus*) was detected at Yookamurra in the last five years but not in 2021 and may be present in small numbers. Missing microbats (Large, Southern, and Little Forest Bats *Vespadelus darlingtonia, V. regulus*, and *V. vulturnus*) were likely due to small local populations and seasonal differences in behaviour missed by the timing of the Microbat Call Survey.

Small mammals

In 2021, as in 2020, only one species, the Common Dunnart (*Sminthopsis murina*), was detected during surveys. Small mammals are usually uncommon at Yookamurra and have declined following the record low rainfall 2018–19. In 2021, four individuals were caught from one species, compared to only one individual in 2020 and 2019, suggesting a small improvement in small mammal abundance (Figure 18) may have occurred following improved rainfall conditions in 2021. Common Dunnarts were caught both inside and outside Stage 1 (overall abundance 0.28 individuals per 100TN), though abundance was lower inside (0.14 individuals per 100TN) compared to outside (0.42 individuals per 100TN). In 2019, at the height of the drought, no dunnarts

were detected, and the abundance of Western Pygmy Possums was very low (1 individual from 2,160 trap nights). Western Pygmy Possums were more commonly detected prior to the drought, while the number of Common Dunnarts varied between years.

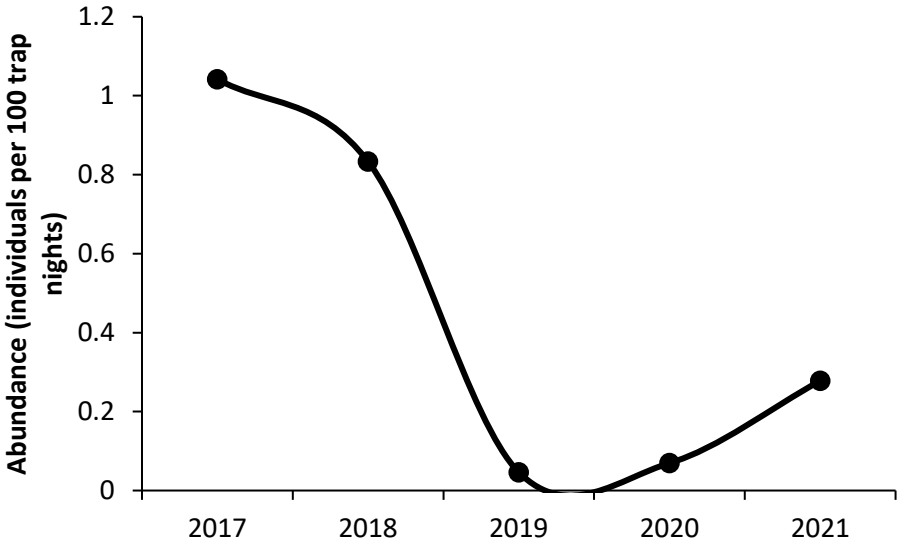

Figure 18. Abundance of small mammals at Yookamurra from 2017–2021.

Microbats

Recorders at 20 of the 24 sites detected at least one microbat call (average 132 detections ± 24 SE). Two new microbat species were confirmed in 2021: the Western Broad-nosed Bat (*Scoterepens balstoni*), and the Inland Forest Bat (*Vespadelus baverstocki*). A third new species was also detected but as there was only one call detected in one location, the bat species identity could not be considered as certain. The species was likely to be Ride's Free-tailed Bat (*Ozimops ridei*) based on characteristic call frequency and length, noting that identification confidence is medium (Appendix 1, Table A1).

Seven microbat species were identified to the species level across the 24 sites (not including the uncertain Ride's Free-tailed Bat detection), resulting in a richness of 0.29 (± 0.41 SE) species per site. Some calls could only be identified to the genus level (Appendix 1, Table A1). The most commonly detected species was the Gould's Wattled Bat (*Chalinolobus gouldii*), detected at 16 sites, whereas the Chocolate Wattled Bat (*Chalinolobus morio*) and Ride's Free-tailed Bat (yet to be confirmed) were detected at only one site each. The same number of species (six) was detected inside Stage 1 compared to outside Stage 1, with the Western Broad-nosed Bat only detected inside and the Chocolate Wattled Bat only detected outside, resulting in a richness of 0.5 species per site both inside and outside Stage 1, and an overall richness of 0.3 species per site.

Medium- and low-confidence identifications were due to a lack of call metrics specific to the region for some species, so call identification was based on call characteristics from other regions (e.g., calls from the same species in Sydney).

Birds

Assemblage richness

There are 114 native bird species confirmed to occur on Yookamurra, and a further 10 that are likely to occur based on known species ranges. Of these, 76 species (61%) were detected in 2021 and 83 species (67%) were detected in the past three years, including 10 of 19 confirmed or likely honeyeater species, and 24 of 29 confirmed ground-active bird species. Seventy-eight species were recorded during the Standard Bird and Malleefowl Surveys, and five species were observed only incidentally during the past three years. Missing species were likely due to preceding dry conditions, and many species being irregular or seasonal visitors to Yookamurra.

All birds (diurnal)

The Standard Bird Survey was conducted in October (Spring) 2021. A total of 985 individuals and 70 native species were recorded during the survey, slightly higher than in the previous year, with an average of 9.1 individuals and 4.7 species (abundance and richness, respectively) per survey in 2021. One new species was confirmed at Yookamurra in 2021: the Scarlet Robin (*Petroica boodang*).

The months preceding the bird survey were drier than average (Figure 4), but there was only a slight decrease in flowering vegetation, with 83% of sites having some form of vegetation in flower compared to 94% in 2020.

Bird abundance was higher in 2021 than 2020, but still well below results from 2015, prior to the drought (Figure 19). However, the number of species per survey (i.e., the richness) improved to 2015 levels (Figure 20), suggesting recovery is underway with higher rainfalls in 2021, even though total rainfall is still below the yearly average.

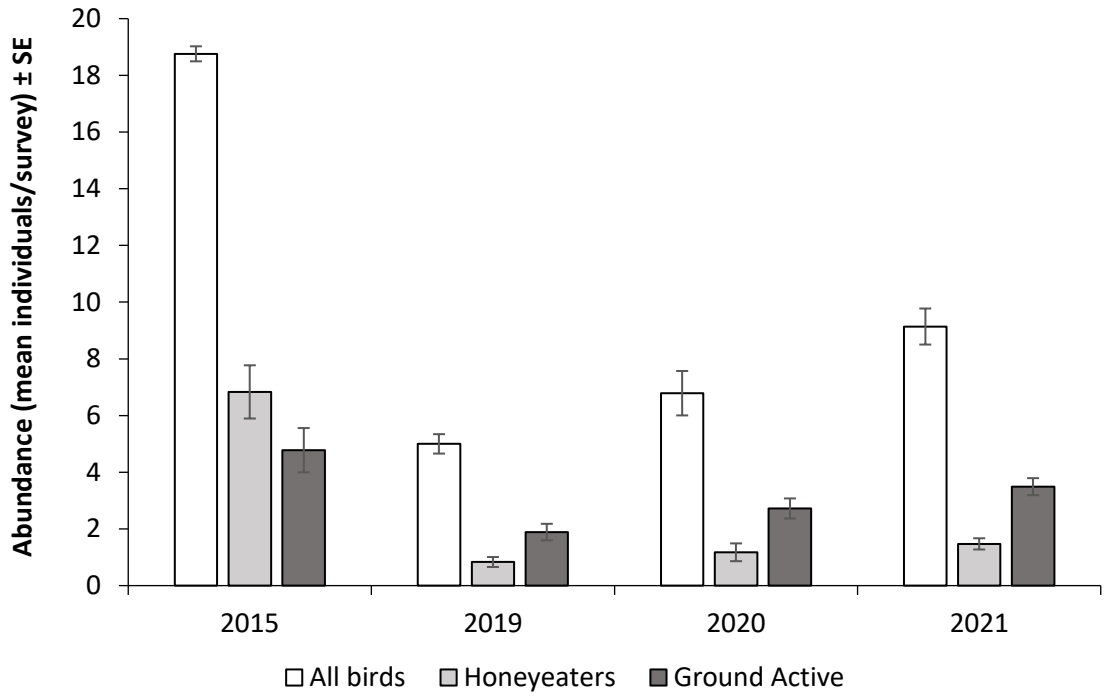

Figure 19. Bird abundance (mean number of individuals detected/survey ± SE) from 2015 (pre-drought) and 2019–2021 (years with below average rainfall) surveys for all birds, the honeyeater guild and ground active bird guild.

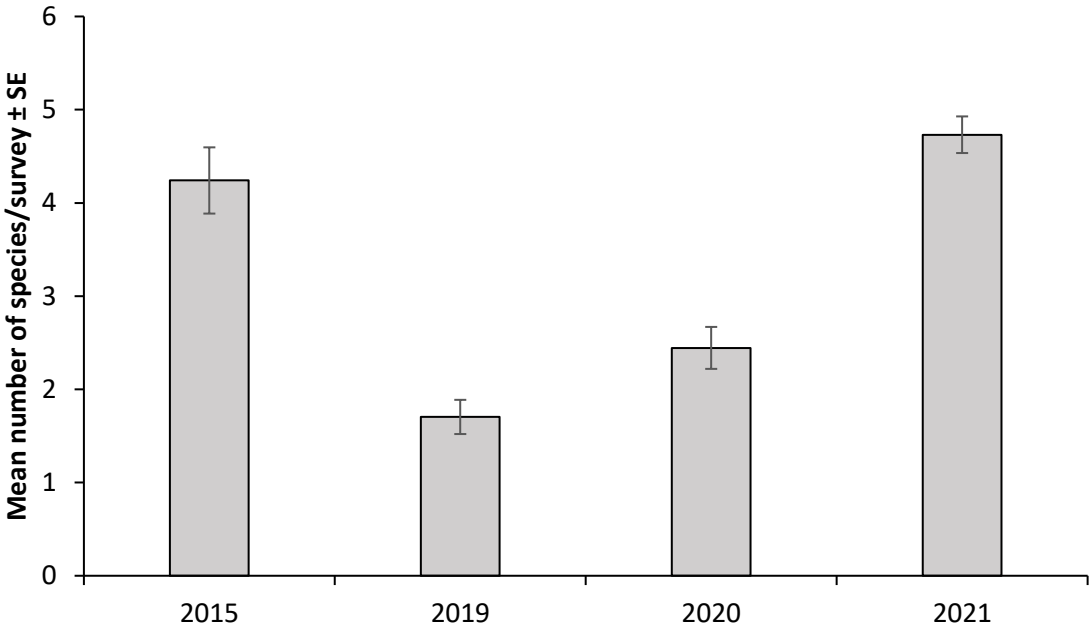

Figure 20. Bird richness (mean number of bird species/survey ± SE) from 2015 (pre-drought) and 2019–2021 (years with below average annual rainfall) surveys.

The Galah (*Eolophus roseicapilla*) was again the most frequently detected bird during the Standard Bird Survey, with 123 detections and an occupancy of 100% across the survey sites. A single Emu (*Dromaius novaehollandiae*) and two Spotted Nightjars (*Eurostopodus argus*) were also detected; species which have not been recorded during prior Standard Bird Surveys, though they are known to occur at Yookamurra. A single Pied Butcherbird (*Cracticus nigrogularis*), a species only confirmed in 2020, was also detected.

There was a slightly higher abundance of diurnal birds inside Stage 1 (9.4 species per survey) compared to outside of Stage 1 (9.0 species per survey; Figure 21), despite fewer species being detected inside compared to outside (43 species (4.6 species per site) and 66 species (4.8 species per site), respectively.

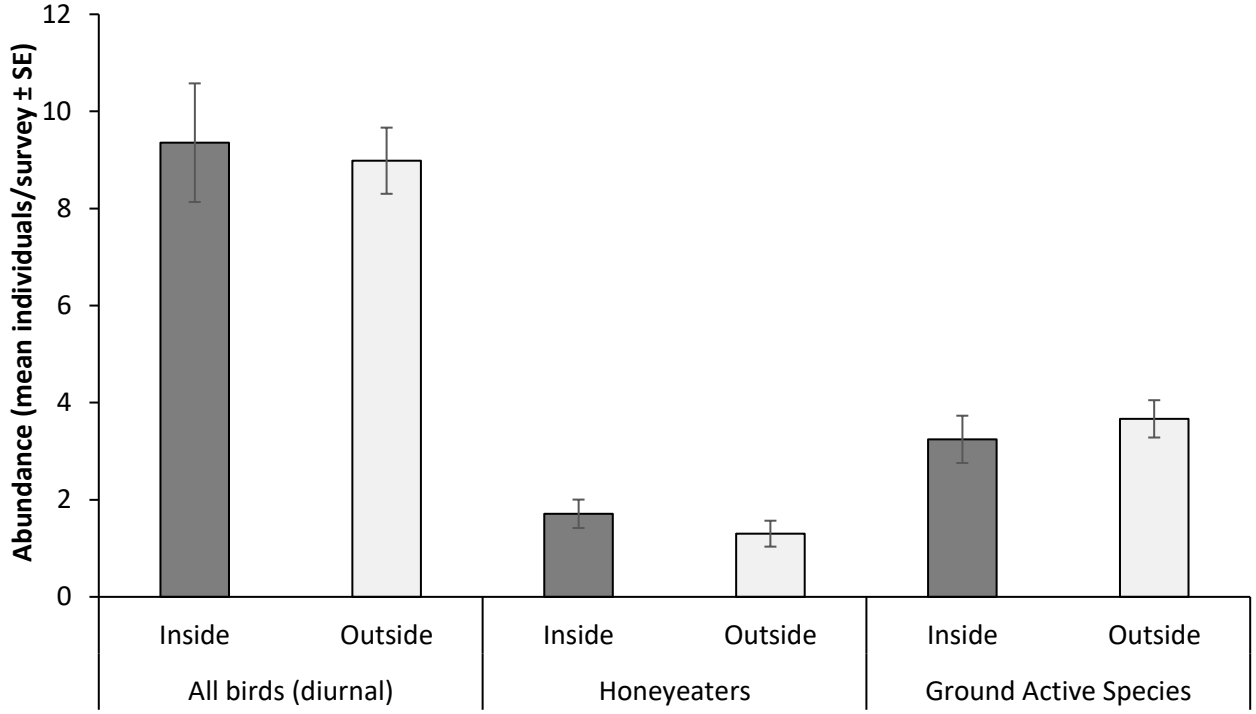

Figure 21. Bird abundance (± SE) at Yookamurra in the 2021 Standard Bird Survey, separated by location either inside (15 sites) or outside (21 sites) Stage 1.

Honeyeaters

A total of 159 honeyeaters were detected from nine species across 33 of the 36 survey sites, giving an abundance of 1.47 individuals per survey (Figure 19). There was slightly higher abundance of honeyeaters inside Stage 1 (1.7 individuals per survey) compared to outside Stage 1 (1.3 individuals per survey; Figure 21).

The most common honeyeater was the White-fronted Honeyeater (*Purnella albifrons*; 36 detections across 44% of sites), and the least common was the White-plumed Honeyeater (*Lichenostomus penicillatus*; 1 detection).

Ground-active birds

A total of 377 ground-active birds were detected from 19 species, with at least two ground-active birds detected at every survey site, giving an abundance of 3.49 individuals per survey in 2021 (Figure 19).

Two ground-active birds that have been recorded in previous surveys — the Red-rumped Parrot (*Psephotus haematonotus*) and the Shy Heathwren (*Hylacola cauta*)— were not detected during the 2021 bird survey, although the Shy Heathwren was heard opportunistically the following month.

Reptiles

Assemblage richness

There are 39 reptiles confirmed to occur on Yookamurra, and a further 26 likely to occur based on known species ranges. Of these, 22 species (34%) were detected in 2021, and 33 species (51%) were detected in the last five years, including 8 of 11 confirmed or likely gecko species, and 14 of 25 confirmed or likely skink species. Of the 33 detected species, 3 were only incidentally identified (i.e., were not detected as part of the Standard Trapping Survey). Missing species in 2021 were likely not recorded because of preceding dry conditions and low temperatures during the October survey. Species that were not detected in the last five years were likely missing due to small populations and low local abundance, combined with the cryptic nature of many native reptile species that makes them difficult to detect using traditional capture methods.

All reptiles (excluding varanids and snakes)

A total of 122 individual captures across 16 reptile species were recorded during the Standard Trapping Survey in 2021, an increase in individual captures from 2020. However, both abundance and species richness continue to be lower in 2021 compared with previous years. An average of 8.47 individuals per 100 trap nights (Figure 22; abundance) and 2.83 species per site (Figure 23; richness) were detected in 2021. These lower values in 2020 and 2021 could be due to possibly due to low rainfall preceding both surveys reducing reptile abundance and cool weather during both surveys reducing reptile activity. The Oriental Skink (*Ctenotus orientalis*) was the most frequently caught reptile species (37 individuals captured), followed by Bynoe's Prickly Gecko (*Heteronotia binoei*; 28 individuals captured).

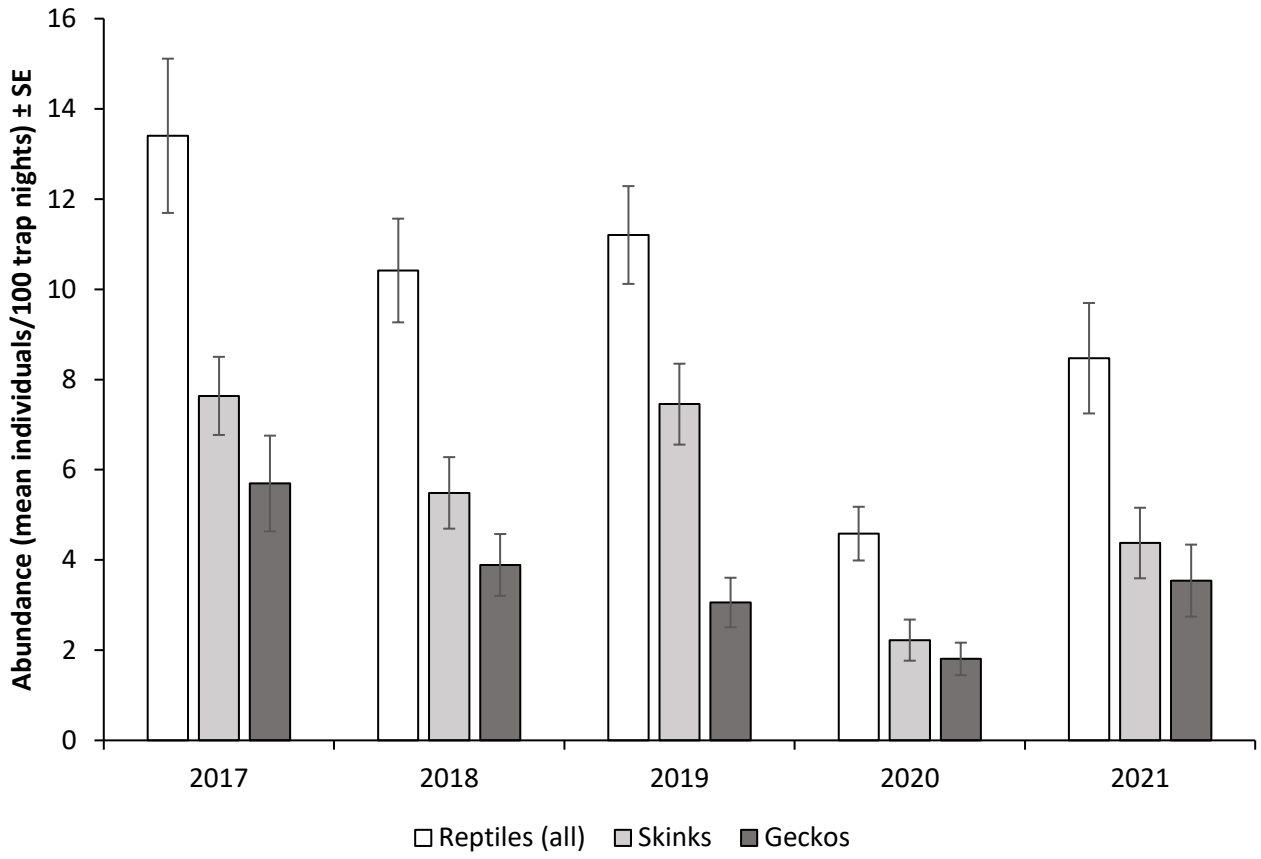

Figure 22. Reptile abundance (mean number of individuals detected/100 trap nights ± SE) for all reptiles (excluding varanids and snakes) as well as the skink and gecko guilds.

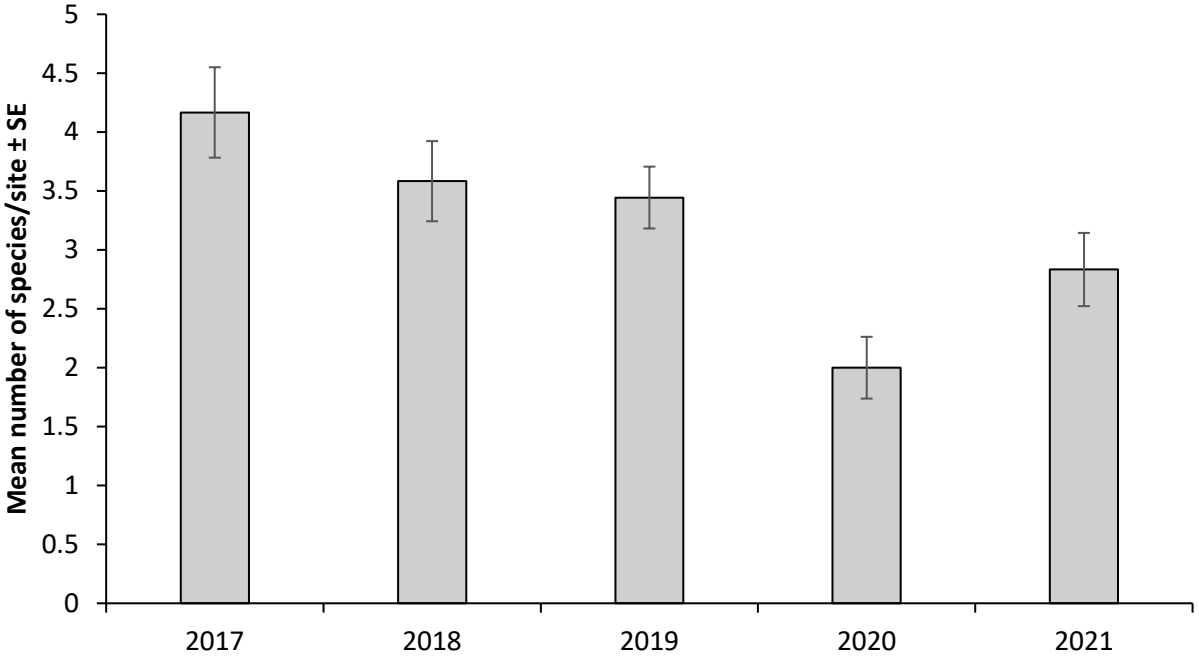

Figure 23. Reptile richness (mean number of species/site ± SE) from 2017–2021.

Reptile abundance was lower inside Stage 1 (7.4 individuals per 100TN) during the Standard Trapping Survey than outside Stage 1 (9.6 individuals per 100TN; Figure 24). Some introduced predators that consume reptiles (namely red foxes and feral cats; Woinarski et al. 2021) occur outside Stage 1, but this has not reduced the number of reptiles to below the Stage 1 abundance.

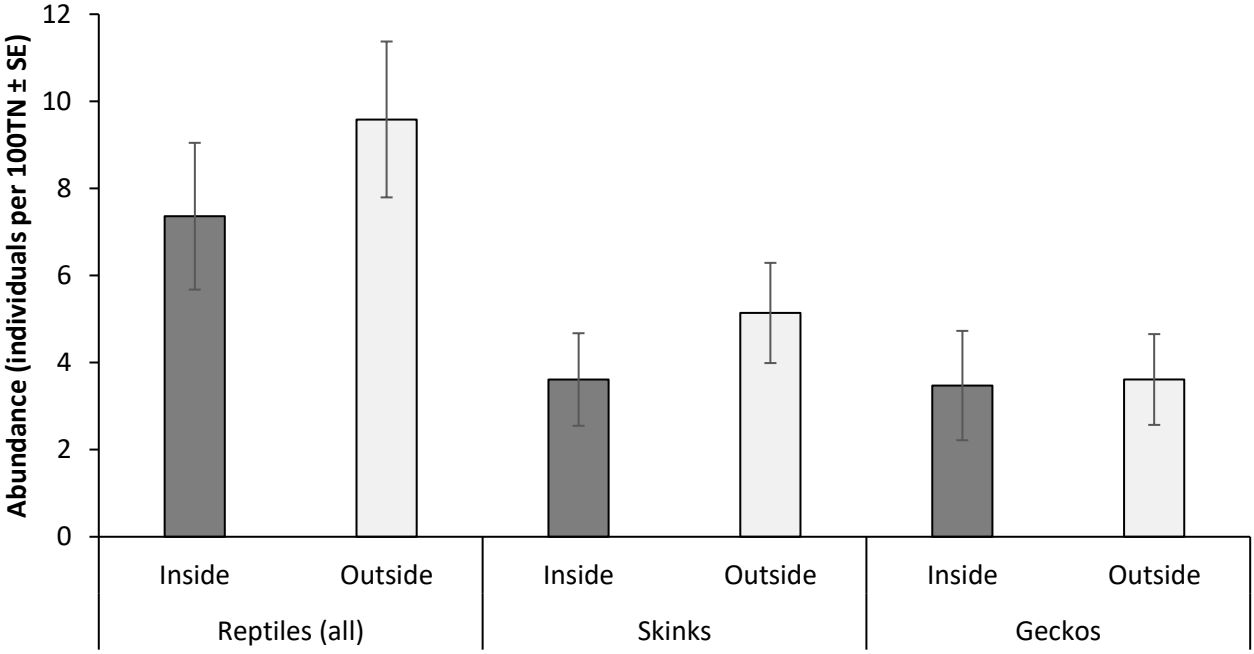

Figure 24. Reptile abundance (at Yookamurra ± SE) in the 2021 Standard Trapping Survey, separated by location either inside (12 sites) or outside (12 sites) Stage 1.

Geckos

A total of 51 individual geckos from six species were caught across 17 of the 24 sites in 2021, giving an abundance of 3.54 geckos per 100 trap nights (Figure 22). Gecko abundance was similar inside and outside Stage 1 (3.5 and 3.6 individuals per 100TN respectively; Figure 24).

The most common gecko was the Bynoe's Prickly Gecko (28 captures over 50% of the sites). The Marbled Gecko (*Christinus marmoratus*) and the South Coast Gecko (*Diplodactylus calcicolus*) were not captured in either 2020 or 2021, possibly due to low rainfall preceding both surveys reducing reptile abundance and cool weather during both surveys reducing reptile activity.

Skinks

A total of 63 individual skinks from seven species were caught across 20 of the 24 sites in 2021, giving an abundance of 4.38 skinks per 100 trap nights (Figure 22). Skink abundance was slightly lower inside Stage 1 (3.6 individuals per 100TN) than outside Stage 1 (5.1 individuals per 100TN; Figure 24). The most common skink was the Oriental Ctenotus (37 detections over 54% of the sites). Five skinks were not captured in 2020 or 2021: Ragged Snake-eyed Skink (*Cryptoblepharus pannosus*), Tree Skink (*Egernia striolata*), Broad-banded Sand-swimmer (*Eremiascincus richardsonii*), Three-toed Earless Skink (*Hemiergis decresiensis*), and Lowlands Earless Skink (*Hemiergis peronii*), possibly due to low rainfall preceding both surveys reducing reptile abundance and cool weather during both surveys reducing reptile activity.

Key threatened and iconic plants

Impacts of the severe drought on the reintroduced Desert Phebalium continued into 2020, despite the return of higher rainfall. In 2019, the number of live plants declined from 121 to 83 plants. Declines continued into 2020, despite supplementary watering, with a total of 65 individuals recorded (Figure 25).

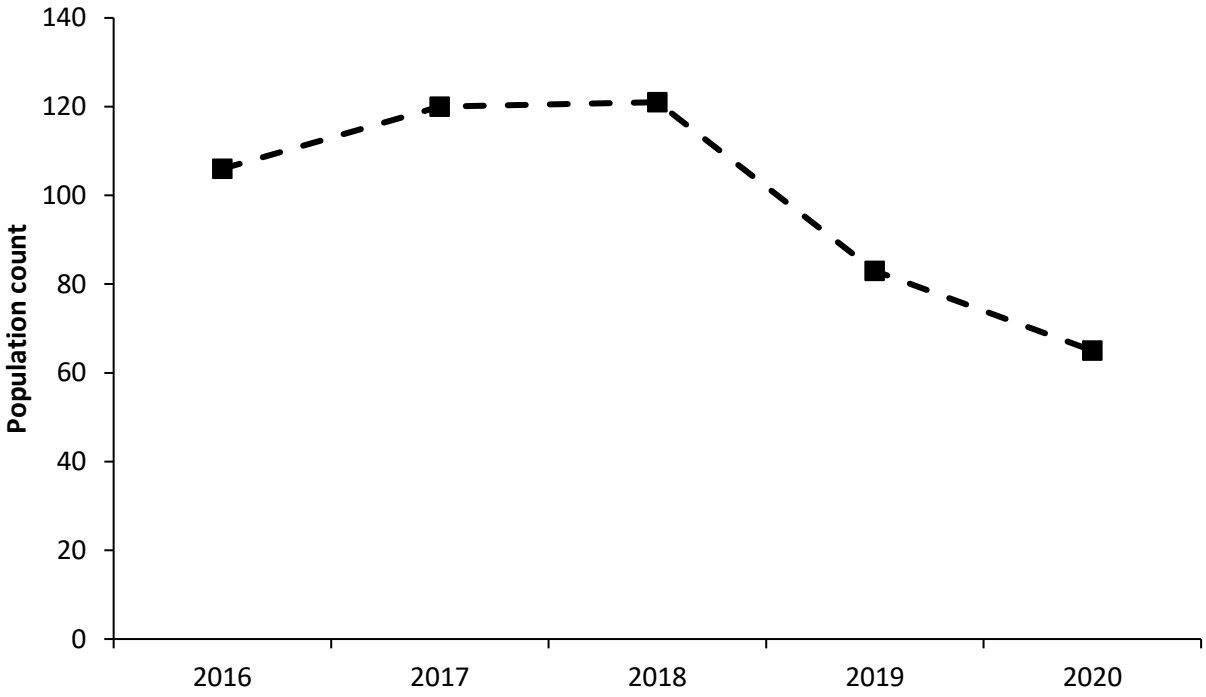

Figure 25. Population counts of the reintroduced Desert Phebalium on Yookamurra.

Threat indicators

Fire

In 2021, no fires occurred on Yookamurra, resulting in 0% of the property burnt. No wildfire has occurred in Yookamurra Stage 1 since government records began in 1931, in line with ongoing conservation of the critical mallee habitat.

Discussion

The survey results reported here show that many wildlife on Yookamurra continue to be adversely affected by the record drought experienced in 2018–19, though some species and guilds are showing signs of recovery and others have recovered to pre-drought levels. Only one of the four species of reintroduced mammals (the Bilby) is near pre-drought population levels; a second species (the Burrowing Bettong) is recovering towards those levels, while the other two species (Numbat, Brush-tailed Bettong) have yet to recover, and are at concerningly (Numbat) or alarmingly (Brush-tailed Bettong) low numbers. The supplemented population of Common Brushtail Possum population increased in 2021 from the 2020 population estimate, and this is also possibly due to improved rainfall in 2021. All assemblages (mammals, birds, and reptiles) improved in abundance, occupancy, and richness in 2021 compared to 2020 levels, also likely because of the improved rainfall conditions. The population of the reintroduced threatened plant Desert Phebalium declined through the drought and was still low when surveyed last in 2020 so we are yet to discover if it is on its way to recovery. Further improvements are likely to occur for all taxa with continued improved rainfall at Yookamurra.

Positive statuses for the Yookamurra populations of two key threatened species was observed: the Southern Hairy-nosed Wombat and the Malleefowl. The Southern Hairy-nosed Wombat burrows were surveyed for the first time on Yookamurra in 2020, so it is uncertain whether low rainfall has impacted the population; however, the estimated population size was large, demonstrating that Yookamurra provides an important refuge for this regionally significant species. Malleefowl activity remained stable, with two of three Malleefowl mounds active in 2020 found to be active again in 2021. Malleefowl are considered vulnerable both federally and in South Australia. Habitat on Yookamurra is likely marginal for this species, and the small but stable population is expected.

The recent surveys have identified species new to the sanctuary. Three native vertebrate species were recorded for the first time at Yookamurra in 2021, including two microbats: the Western Broad-nosed Bat and the Inland Forest Bat, and a passerine: the Scarlet Robin. Microbats were systematically surveyed for the first time in 2021, resulting in seven species being detected using acoustic monitors, including two new species for Yookamurra.

Interestingly, the difference in abundance of small vertebrates inside compared with outside the Stage 1 fence was mixed. There were a few indicators that had a larger density outside of the Stage 1 fence (i.e., the Common Dunnart showed a much higher abundance and Skinks showed a slightly higher abundance outside the fence), the remainder of indicators (i.e., Birds, including Ground-dwelling Birds and Honeyeaters; and Geckos) the response was not strong. This result is in line with recent research that demonstrated a mixed response to the predator-free fence from small vertebrates with many taxa being found at larger densities outside of the fenced areas (Roshier et al. 2020). This is potentially due to predation by or competition with reintroduced mammals inside Stage 1 or ongoing effects of the low rainfall during 2018–19, which continues to impact species detections.

No fires occurred on Yookamurra in 2021, in line with our ongoing commitment to protect the critically important old-growth mallee habitat inside Stage 1 and elsewhere on Yookamurra.

Acknowledgments

AWC acknowledges the Nganguraku people from the Ngarrindjeri Nation as the Traditional Custodians of the country on which Yookamurra resides. We also acknowledge their continuing connection to land, culture, and community. We pay our respects to Nganguraku people from the Ngarrindjeri Nation Elders past, present, and emerging.

AWC's Ecohealth Program is only possible because of the generosity of AWC's supporters.

For their assistance in conducting Ecohealth surveys at Yookamurra in 2021, we particularly thank our amazing volunteers, and intern Lachlan McRae.

References

Berry L, Holland G, Anson J, Pierson J, Kanowski J (2021) *Bridled Nailtail Wallaby: Population management plan Scotia Sanctuary*. Australian Wildlife Conservancy, Perth.

Bester AJ, Rusten K (2009) Trial translocation of the numbat (*Myrmecobius fasciatus*) into arid Australia. *Australian Mammalogy* 31, 9–16.

Biosecurity SA (2021) Controlling declared weeds in SA. https://pir.sa.gov.au/biosecurity/weeds/controlling-weeds. Accessed 13/08/2021.

Clarke PA (1996) Aboriginal culture and the riverine environment. In: *Natural history of the Riverland and Murraylands* (Ed JT Jennings) pp. 142–161. Royal Society of South Australia, Adelaide.

Clarke MF, Kelly LT, Avitabile SC, Benshemesh J, Callister KE, Driscoll DA et al. (2021) Fire and its interactions with other drivers shape a distinctive, semi-arid 'Mallee' ecosystem. *Frontiers in Ecology and Evolution* 9, 647557.

Ecological Horizons Pty Ltd (2014) *Possum Survey at Yookamurra Sanctuary.* Report to Australian Wildlife Conservancy, Perth.

Ecological Horizons Pty Ltd (2016) *Possum Survey at Yookamurra Sanctuary.* Report to Australian Wildlife Conservancy, Perth.

Flannery TF (1994) *The Future Eaters: An Ecological History of the Australasian Lands and People*. Reed Books, Sydney.

Foulkes JN, Gillen JS (2000) *A Biological Survey of the Murray Mallee South Australia*. Biological Survey and Research, Department for Environment and Heritage and Geographic Analysis and Research Unit, Department for Transport, Urban Planning and the Arts.

Gammage B (2011) *The Biggest Estate on Earth: How Aborigines Made Australia.* Allen & Unwin, Australia.

Harrington G (1979) The effects of feral goats and sheep on the shrub populations in a semi-arid woodland. *The Rangeland Journal* 1, 334–345.

Harrington G (1986) Herbivore diet in a semi-arid *Eucalyptus populnea* woodland. 2. Feral goats. *Australian Journal of Experimental Agriculture* 26, 423–429.

Kanowski J, Joseph L, Kavanagh R, Fleming A (2018) Designing a monitoring framework for Australian Wildlife Conservancy, a national conservation organisation. In: *Monitoring Threatened Species and Ecological Communities* (Eds S Legge, DB Lindenmayer, NM Robinson, BC Scheele, DM Southwell, BA Wintle) pp 241–253. CSIRO, Melbourne.

Loyn R (1986) The 20 minute search: A simple method for counting forest birds. *Corella* 10, 58–60.

National Malleefowl Recovery Team (2016) National Malleefowl Monitoring Manual: Edition: 2016-1.

Power V, Lambert C, Matson P (2009) Reproduction of the numbat (*Myrmecobius fasciatus*): observations from a captive breeding program. *Australian Mammalogy* 31, 25–30.

Roshier D, Carter A, L'Hotellier F, Bellchambers K, Riessen N, Kemp L (2014) Interim Report on Survey Programs in SE Australia. Australian Wildlife Conservancy, Perth.

Roshier D., Hotellier F, Carter A, Kemp L, Potts J, Hayward M, Legge S. (2020) Long-term benefits and short-term costs: small vertebrate responses to predator exclusion and native mammal reintroductions in south-western New South Wales, Australia. *Wildlife Research* 47, 570–579.

Rule S, Brook BW, Haberle SG, Turney CSM, Kershaw AP, Johnson CN (2012) The aftermath of megafaunal extinction: ecosystem transformation in Pleistocene Australia. *Science* 335, 1483–1486.

Silvy NJ (2012) *The Wildlife Techniques Manual. Volume 1: Research. 7th ed.* The Johns Hopkins University Press, Baltimore.

South Australian Museum, National Folk Province Feasibility Study Steering Committee, Pretty GL (1977) *Ngaiawang folk province: preliminary inventory of the cultural landscape / [National Folk Province Feasibility Study Steering Committee]*. Anthropology and Archaeology Branch, South Australian Museum, Adelaide.

Southgate R, Paltridge R, Masters P, Carthew S (2007) Bilby distribution and fire: a test of alternative models of habitat suitability in the Tanami Desert, Australia. *Ecography* 30, 759–776.

Swinbourne M, Taggart D, Ostendorf B (2018) A Comparison between Video and Still Imagery as a Methodology to Determine Southern Hairy-Nosed Wombat (*Lasiorhinus latifrons*) Burrow Occupancy Rates. *Animals* 8, 186.

Tindale NB (1974) *Aboriginal Tribes of Australia : Their Terrain, Environmental Controls, Distribution, Limits and Proper Names*. Australian National University Press, Canberra.

Wells RT (1978) Thermoregulation and Activity Rhythms in the Hairy-Nosed Wombat, *Lasiorhinus latifvons* (Owen), (Vombatidae). *Australian Journal of Zoology* 26, 639–651.

Wheeler R, Priddel D (2009) The impact of introduced predators on two threatened prey species: A case study from western New South Wales. *Ecological Management & Restoration* 10, S117–S123.

White GC (2008) Closed population estimation models and their extensions in Program MARK. *Environmental and Ecological Statistics* 15, 89–99.

Woinarski JCZ, Stobo-Wilson AM, Crawford HM, Dawson SJ, Dickman CR, Doherty TS et al. (2021) Compounding and complementary carnivores: Australian bird species eaten by the introduced European red fox *Vulpes vulpes* and domestic cat *Felis catus*. *Bird Conservation International*, 1–17.

Appendices

Appendix 1

Table A1. Identification confidence of the species detected on Yookamurra in 2021. Calls that were identified only to the genus level are indicated with *.

Common name	Scientific name	Occupancy (%)
White-striped Free-tail Bat	*Austronomus australis*	58
Gould's Wattled Bat	*Chalinolobus gouldii*	67
Chocolate Wattled Bat	*Chalinolobus morio*	4
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	42
Southern Free-tailed Bat	*Ozimops planiceps*	46
Ride's Free-tailed Bat	*Ozimops ridei*	4
Free-tailed Bat*	*Ozimops planiceps/ridei*	4
Western Broad-nosed Bat	*Scotorepens balstoni*	8
Inland Forest Bat	*Vespadelus baverstocki*	50
Forest bat*	*Vespadelus baverstocki/regulus/vulturnus*	50

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