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Research Report

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# Conserving the endangered woylie (*Bettongia penicillata ogilbyi*): Establishing a semi-arid population within a fenced safe haven

Michael Smith **Michael Smith**, Georgia Volck, Nicola Palmer, Chantelle Jackson, Carly Moir, and Raquel Parker a Regional Ecologist, Senior Field Ecologist, Senior Field Ecologist, Senior Field Ecologist, Field Ecologist, and Field Ecologist, respectively, with the Australian Wildlife Conservancy (PO Box 8070 Subiaco East, Perth, WA 6008, Australia; Email:
Email Michael.Smith@australianwildlife.org).
Email Michael.Smith@australianwildlife.org

Georgia Volck

Nicola Palmer

Chantelle Jackson

Carly Moir

Raquel Parker

Bryony Palmer **Bryony Palmer** and Adele Thomasz are both former Field Ecologists with the Australian Wildlife Conservancy. Bryony is now a PhD candidate at the University of Western Australia (Ecosystem Restoration & Intervention Ecology Research Group, School of Biological Sciences, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, Australia, 6009).

Adele Thomasz **Adele Thomasz**, Formerly Field Ecologist with the Australian Wildlife Conservancy (PO Box 8070 Subiaco East, WA 6008, Austarlia; Email:
Email adelelouise@live.com)
Email adelelouise@live.com

## Summary

Measuring and monitoring population size and growth are critical to assessing the progress and ultimately the success (or failure) of a reintroduction. The Woylie (*Bettongia penicillata ogilbyi*) is one ~~of~~ Australia's threatened critical weight range mammals. To increase the species' area of occupancy, extent of occurrence, number of sub-populations and global population size, in addition to creating a source population for future reintroductions, a new population has been re-established into a safe haven located within the species' former range – Mt Gibson Wildlife Sanctuary. In this paper, we document the first 3 years of the reintroduction programme, over which time 162 individuals were translocated to Mt Gibson. Specifically, we (i) provide information on survivorship, (ii) estimate changes in critical population metrics (density, population size and distribution) and (iii) look for any major habitat preferences. Survivorship of collared animals was complete (i.e. zero mortality). The most recent population estimate was in the order of 750 individuals, reflecting strong growth in population size and density. The woylie has occupied the majority of the safe haven and is well represented in all major vegetation communities. The translocation is on track to meeting the key success criteria: a self-sustaining population of woylies with a minimum of 300 individuals.

## Keywords

population size; reintroduction; survival; Woylie


This project arose from a need to assess the success of a reintroduction programme for the Woylie.

## Implications for managers

This work provides information on the establishment of a new population of Woylies in a semi-arid setting, with an additional emphasis on describing a monitoring approach (and subsequent analysis) that can be applied to species that are commonly monitored via cage trapping.

### Introduction

To assess the success of a translocation programme, it is particularly important to monitor initial survival, population growth and the dispersal of individuals, with a view to ultimately understanding the capacity of a management area to support a particular population size (i.e. carrying capacity) and its 'normal' oscillations (i.e. Robert *et al.* 2015). For these and other reasons, population density and abundance (and underlying processes such as immigration, emigration, survival and fecundity; Royle *et al.* 2013) are considered fundamental metrics in threatened species management (Williams *et al.* 2002). Additionally, by monitoring population abundance, managers should be able to correlate change with monitored processes. Managers then have a pathway to enact management, whether it be to reduce population size of key predators or competitors, increase emigration rates, fence off areas to allow vegetation recovery, genetically supplement the population and so on. It is, therefore, also very important to identify key risk factors for monitoring (Burgman 2005; Metcalf & Wallace 2013; Smith *et al.* 2015) and to, over time, develop targets and evidence to inform a theory of management, such as a carrying capacity and limits of acceptable change (Rogers *et al.* 2013; Gell *et al.* 2016).

The Brush-tailed Bettong (*Bettongia penicillata*) is one of Australia's threatened critical weight range (CWR) mammals (Burbidge & McKenzie 1989; but see Cardillo & Bromham 2001). Once distributed across much of the continent, populations of the Brush-tailed Bettong collapsed following the introduction of the Red Fox (*Vulpes Vulpes*) and Cat (*Felis catus*; Yeatman & Groom 2012). By the 1970s, only a few populations of the Western subspecies, the Woylie (*Bettongia penicillata ogilbyi* persisted in south-western Western Australia. With a concerted management effort, primarily broad-scale control of the fox and translocations, the species was downgraded to 'low risk' (conservation dependent in 1996 (Start *et al.* 1998. However, between 1999 and 2006 the woylie declined again by c. 90% (Wayne *et al.,* 2015 and in 2008 was re-listed as 'fauna that was rare, or likely to become extinct' under the Western Australian *Wildlife Conservation Act* 1950, and as critically endangered in the IUCN Red List (Woinarski & Burbidge 2016. In 2009, it was listed as endangered under the *Environment Protection and Biodiversity Conservation Act* 1999 (Groom 2010. Clearly, developing a robust monitoring programme for every woylie population is particularly important if managers are to identify and respond to unwanted changes in population size in a timely manner.

Predation by introduced foxes and cats is considered an important factor in the declines of CWR mammals, including the woylie (Woinarski *et al.* 2014). One approach to manage the impacts of foxes and cats is the creation of fenced or island 'safe havens' from which introduced predators (and other unwanted species) are removed (Legge *et al.* 2018) to which predator-vulnerable species can be reintroduced. Reintroductions of the woylie to such areas have made a major contribution to securing the species, with ten populations established within island or mainland safe havens. Outside of safe havens, there are only two 'natural' populations and three translocated populations (Yeatman & Groom 2012; Woinarski *et al.* 2014).

In this study, we document the establishment and dispersal of a new population of woylies released into a 7,838 ha safe haven (Fig. 1) and report on initial survival, changes in population density and abundance, and habitat utilisation over the first 3 years post-reintroduction. In addition to providing a new source population for future translocations, the primary aim of this reintroduction was, as per IUCN guidelines (IUCN 2012), to increase the overall area of occupancy, extent of occurrence, number of sub-populations and global population size of woylies (Ruykys & Kanowski 2015). By developing a robust monitoring programme, ongoing management can proceed in an adaptive manner with a view to assessing the success of the translocation and developing an understanding of carrying capacity and its management.

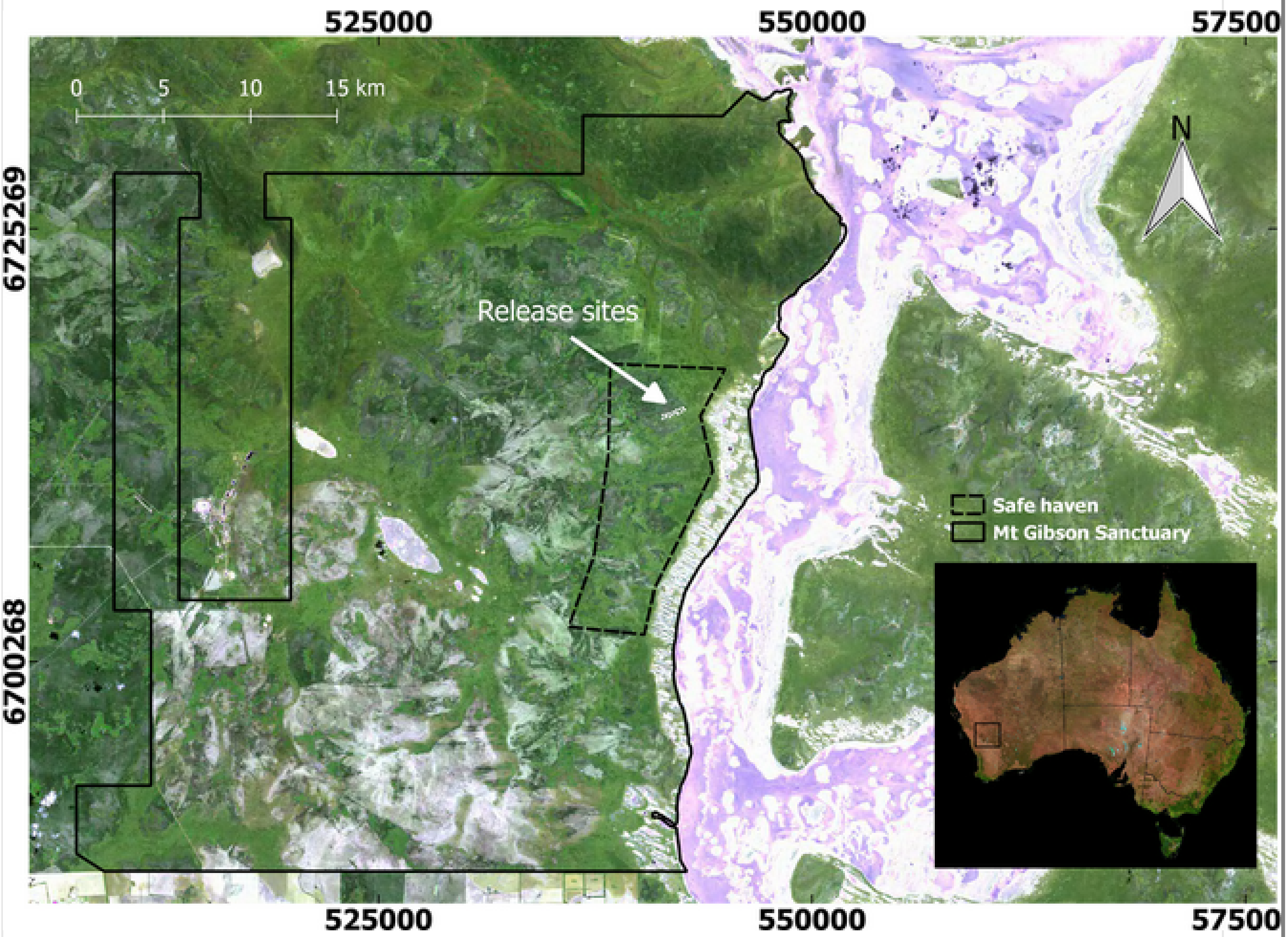


**Fig. 1** Location of the Mt Gibson Wildlife Sanctuary (solid black line) and the fenced safe haven (dashed line).

## Materials and Methods

### Translocations

Woylies were reintroduced to Mt Gibson from August 2015, with translocations being completed by July 2019. Animals were translocated from the Karakamia Wildlife Sanctuary, Perup Sanctuary, and Whiteman Park (Yeatman & Groom 2012); these source locations were selected to maximise the genetic diversity of the reintroduced population (Pacioni *et al.* 2013). A total of 162 woylies (90 males:72 females) from the three sources were translocated to Mt Gibson and released at a series of pre-determined release sites (Fig. 1). Fifty individuals were released into Mt Gibson (from Karakamia Wildlife Sanctuary) in 2015. A further nine individuals were translocated from Karakamia and 32 from Perup Sanctuary in 2016. Fifteen individuals were translocated from Whiteman Park to Mt Gibson in 2017 and a further 56 from Perup Sanctuary to Mt Gibson in 2018. Thus, only 15 individuals were translocated to Mt Gibson after the 2017 survey, but before the 2018 survey from which data are reported herein.

### Release site

Mt Gibson Wildlife Sanctuary is managed by the not-for-profit organisation, the Australian Wildlife Conservancy (AWC). The property is approximately 132,500 ha and is located about 350 km north-east of Perth (Fig. 1). Mt Gibson is in a transition zone between the wetter south-west and the more arid Eremean region. It features a mix of *Acacia* shrublands, various *Eucalyptus* woodlands and *Callitris*-dominated vegetation communities. A 1.8 m high fence surrounds 7,832 ha and provides a barrier to cats and foxes and other similarly sized or larger terrestrial vertebrates. Control efforts ensured that the safe haven was free of cats, foxes and goats (*Capra aegagrus hircus*), after which a reintroduction programme for ten regionally extinct mammal species was instigated (Kanowski *et al.,* 2018). Before the second survey (October–November 2017), 71 Banded Hare-wallabies (*Lagostrophus fasciatus*), a macropod herbivore, had been translocated to Mt Gibson. Other than Banded Hare-wallabies, translocations for Numbats (*Myrmecobius fasciatus*), Greater Bilbies (*Macrotis lagotis*), Red-tailed Phascogales (*Phascogale calura*), Greater Stick-nest Rats (*Leporillus conditor*), Shark Bay bandicoots (*Perameles bougainville*) and Shark Bay Mice (*Pseudomys fieldi*) had begun. However, most of these species are not herbivores and all were considered to be in low enough numbers to not have had sufficient time to have made significant impact upon food availability or vegetation structure.

### Survival

To assess their survival, 40 individuals (14 males:26 females) translocated between September 2015 and September 2016 had radio-tracking collars (Sirtrack V5C 163E 130–260 mm or ZV6C 163D 130–260 mm) attached at release. Collars were all below 5% of the animal's body weight. Animals were tracked daily for the first 2 weeks post-release, and twice weekly for the following 2–4 weeks and then weekly until either the collars fell off or reached approximately 25% of their expected battery life, at which point animals were caught and their collars removed. Tracking involved confirming the survivorship of each individual (as determined by pulse frequency, with a doubling of the same if no movement had been detected by the collar for 10 h).

### Estimating density and population size

Woylies are easily trappable, so cage trapping is an inexpensive, well-established and potentially effective approach to measure population size. However, the species can also present a monitoring challenge with single-trap cages because individuals are particularly ‘trap happy’; this can then introduce bias to estimates of density (Royle *et al.* 2013). To reduce the bias associated with the ‘trap-happy’ nature of woylies, a spatially explicit capture–recapture (SECR) modelling approach (Efford 2016) was used to estimate population size. The SECR approach statistically accounts for biases relating to ‘trap happiness’ (Royle *et al.* 2013) and can be used to easily model spatial variation in density.

Trapping was conducted over a period of nine days in July 2017 and July 2018, respectively. In each trapping session, two (2017) and four (2018) wire-mesh cage traps (20 cm × 20 cm × 56 cm) were placed at 40 sites in the northern third of the safe haven for three trap nights (Fig. S1). The cages were then moved to 40 sites in the centre of the safe haven for the subsequent three trap nights and, finally, to the southern end of the safe haven for the last three trap nights (Fig. S1). Sites were located by first creating a 50 m buffer around the vehicle tracks within the safe haven and then randomly assigning 120 points within the buffered area. This approach was taken: (i) to allow sampling across the entire safe haven (as we expected considerable spatial heterogeneity in density) and (ii) as it was critical for staff and animal welfare that cages could be quickly and effectively checked and cleared. Within each site, the two or four cages were positioned within 10 m of each other. Each trap was weighted down, half-covered with a hessian bag and baited with universal bait (peanut butter and rolled oats). Traps were set between 16:00 and 18:30 AWST each evening (i.e. just prior to sunset). Traps were cleared twice per night in 2017 and once per night in 2018. All traps were finally cleared, and all animals were processed. Animals were scanned and microchipped when necessary and had their sex, age, reproductive status, weight, pes length and general condition measured. Animals were released, by approximately 08:00 AWST. When required, a microchip was inserted (following Department of Biodiversity, Conservation, & Attractions 2017). A combination of Avid, Biomark and Trovan microchips had been used at the source sites but, on recapture at Mt Gibson, only Trovan 9-mm microchips were used.

The technique of having multiple traps per site and checking traps twice per night in 2017, or having four traps per site in 2018 (but single-trap clearing), ensured that open traps generally remained available to woylies for the entire trap night and thus reduced the effects of the species' trap happiness. Given the different sampling approach employed, each year's trapping results were analysed separately.

The SECR approach is designed to estimate density and alleviate the issues with the definition of effective trapping area that are associated with more standard mark–recapture approaches (Efford & Fewster 2013; Royle *et al.* 2013). Although these are not major issues here because the study area is defined by the safe haven fence, the approach allowed us to readily model spatial variation in density, an explicit goal of the monitoring. In particular, SECR models the spatial distribution of latent individual activity centres and distant-dependent detection (Efford & Fewster 2013). The approach is essentially spatial in nature and is based on the premise that each individual animal is increasingly detectable with its proximity to its activity centre (Efford & Fewster 2013; Royle *et al.* 2013).

The use of SECR techniques with single-catch traps has the potential to introduce additional bias to estimates of population size; this is because the approach assumes all traps are always available to individuals of the target species over the sampling period (Royle *et al.* 2013). Although this is clearly not the case for single-catch traps, some initial research has found that ‘reasonable’ population size estimates can nevertheless be made for some species (Distiller & Borchers 2015). Including multiple traps at each site and/or checking traps twice per night (i.e. effectively mimicking multiple catch cages), allowed an improvement in capacity of the SECR approach to estimate woylie population size.

Package SPACECAP (Gopalaswamy *et al.* 2012), initiated through R software (R Core Team 2013), was used to analyse the data. SPACECAP is a simple but robust R package developed for SECR analysis by Gopalaswamy *et al.* (2012) that performs the Bayesian data augmented models that were originally developed by Royle *et al.* (2009). Gopalaswamy *et al.* (2012) provide a detailed description of SPACECAP, its use and its statistical underpinnings. The package uses a hierarchical model that incorporates an observation and a state process (Royle *et al.* 2009). The state process models density and individual activity centres, where the location of an individual ($i$) is defined by $s_i$ ~ Uniform (S). $s_i$ (1, 2,..,N) represents individual animal activity centres that are distributed randomly over region S. As described by Gopalaswamy *et al.* (2012), SPACECAP incorporates binary observations ($y_{ijk}$) collected from multiple individuals ($i$) at multiple sites ($j$) across multiple repeated visits ($k$). $y_{ijk}$ ~ Bernoulli($p_{ijk}$), where $p_{ijk}$ is the probability of detecting individual $i$ at site $j$ on visit $k$. Also, SPACECAP uses the complementary log–log link transformation (cloglog($p_{ijk}$) = $\beta_0$), where $\beta_0$ is the inverse of the cloglog transformation:

$$p_{i,j,k} = 1 - e^{-e^{\beta_0}}$$

Under a Poisson model, $p_{ijk}$ is the probability that individual $i$ is captured by a trap at site $j$ on visit $k$ (Royle *et al.* 2009). SPACECAP allows the modelling of (i) the probability of capture up to ($\beta_0$) and after ($\beta_1$) first capture of individual $i$ at site $j$; and (ii) change in the effect of distance between an individual's activity centre and site location ($\beta_2$). SPACECAP employs either a half-normal or a negative exponential link function (Royle *et al.* 2009) and improper uniform priors. Positive parameters are Uniform(0,∞), and others are Uniform(−∞,∞).

SPACECAP requires the provision of a data file with potential home range centres, trap deployment details, animal capture details and the area that is associated with each potential home range centre pixel. A trap response, spatial or non-spatial model, and either a half-normal or negative exponential detection function (Gopalaswamy *et al.* 2012) can be chosen. Finally, as the analysis is a Bayesian data augmented model (Royle *et al.* 2013), the user must enter the number of MCMC iterations, the burn-in period, the thinning rate and the augmentation level (Gopalaswamy *et al.* 2012). Models with different detection functions and home range spacing (25, 50 and 100 m) were run to assess their impact on the estimated population size. Note that 25 m is equivalent to 0.000625 km$^2$, 50 to 0.0025 km$^2$ and 100 to 0.01 km$^2$.

N(S) (the population size) is an estimate of the number of activity centres located within S. Density is calculated as D = N(S)/||S||. ||S|| is the state-space area. $\lambda_0$ is the expected encounter rate of an individual [$i$,$j$,$k$] with an activity centre exactly at the site. $\sigma$ (or 1/$\beta_2$) can be interpreted as a mean ‘range’ parameter that is scaled according to Borchers and Efford (2008).

SPACECAP automatically generates outputs that allow assessment of the model; these include a Bayesian *P*-value (Gopalaswamy *et al.* 2012 provide details relating to the generation of the Bayesian *P*-value) that should be around 0.5 for an adequate model fit. To evaluate convergence, SPACECAP provides the Geweke's diagnostic (Geweke 1992) and a *z*-score of the diagnostic. Absolute *z* scores <−1.6 or >1.6 indicate a lack of convergence. The mean ‘range parameter’ estimate can be thought of as an estimate of the average amount of movement around each activity centre, such that animals that move further away from their activity centres will have a larger mean range parameter estimate (Gopalaswamy *et al.* 2012).

## Results

### Translocations

No mortality occurred during the translocation process, nor whilst individuals were wearing radio-tracking collars.

### Trapping

In 2017, 121 woylies (75 males:46 females) were captured and the maximum distance an individual moved between capture sites was 7.3 km. All models performed well and converged (Table S1). For all models, there was significant indication of a positive trap response by woylies (95% credibility intervals did not include zero), as reflected in the increased detectability of an individual after its first capture (Table S1). The density and population size estimates from each model were similar, regardless of pixel density; however, the negative exponential detection function consistently produced slightly smaller estimates (Fig. 2).

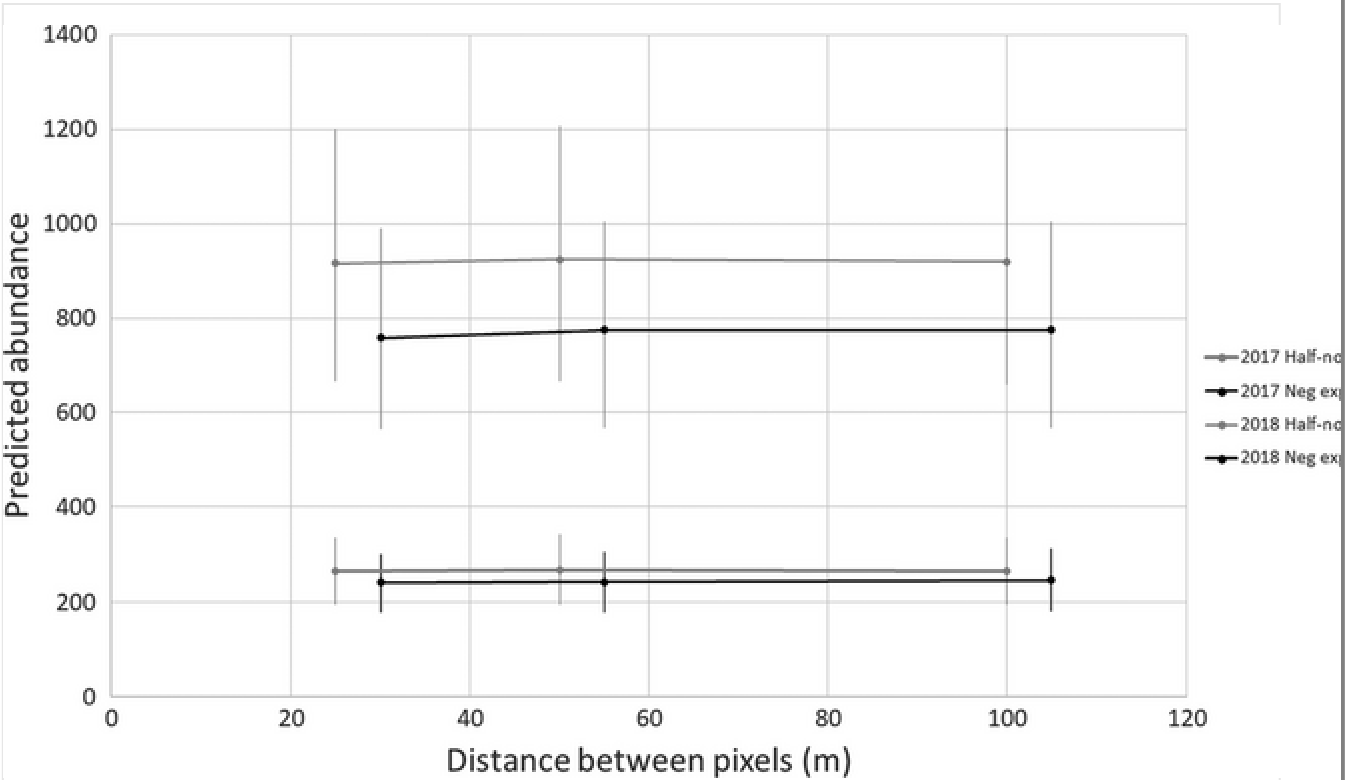


**Fig. 2** Estimate of woylie population size at Mt Gibson in 2017 and 2018 for different pixel densities and detection functions. Vertical lines indicate 95% credibility intervals. Note that, for ease of interpretation, pixel densities have been jittered and reported in metres between each pixel. A distance of 25 equals a pixel density of 0.000625 $km^2$; 50 equals a pixel density of 0.0025 $km^2$; and 25 equals a pixel density of 0.001 $km^2$.

In 2018, 253 woylies (165 males:88 females) were captured and the maximum distance an individual moved between capture sites was 14.6 km, with mean movement of 2.25 km (SD = 3.32 km). All models converged (Table S1) well but the Bayesian *P*-values for the models with a half-normal detection function indicated a poor fit. The population and density estimates were consistent across pixel densities for each detection function. As with 2017, the negative exponential models predicted a smaller population size than did the half-normal models. Given the models with the negative exponential detection function had better fit in 2018, we report on the models with a negative exponential function and a 25-m grid spacing (or 0.000625 $km^2$ pixel area). Of note, in 2018, 47 individuals were recaptured (from 2017), all of which were male.

The population estimate from 2017 was 241 animals (95% CI: 180–300), with an average density of 3.09 woylies/$km^2$ (95% CI: 2.34–3.88). The population estimate from 2018 was 758 (95% CI: 566–989), with an average density of 9.95 woylies/$km^2$ (95% CI: 7.35–12.94; Fig. 3). The mean range parameter decreased from 721.8 (95% CI: 642.2–799.6) in 2017 to 621.5 (95% CI: 543.3–676.7) in 2018, indicating that individual activity areas decreased over time.

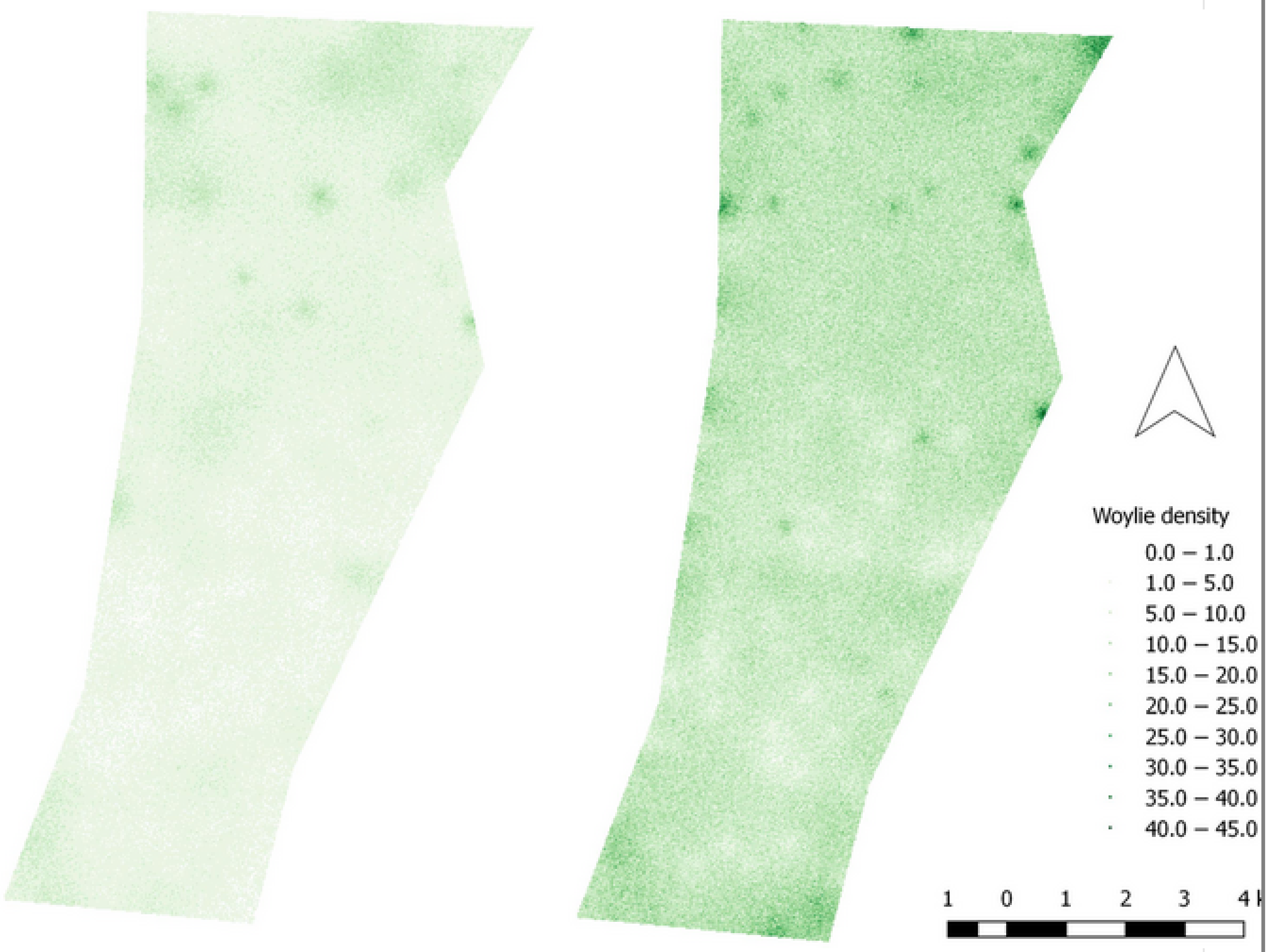


**Fig. 3** Map of predicted woylie density in the Mt Gibson safe haven in 2017 and 2018, based on models that included a trapping response covariate, a negative exponential detection function and 0.000625 $km^2$ (25-m spacing) pixel density. Density is the predicted number of individuals per square kilometre.

In 2017, mean predicted pixel density estimates across the various habitat types (Fig. S2) were reasonably similar, but slightly higher in mallee, saltbush and York Gum woodland habitats (Fig. 4). Saltbush habitats are geographically limited, with the only patch occurring in the northeas~~ter~~n area, where woylies were also in high densities in 2017. By 2018, mean predicted pixel density estimates across the various habitat types were similar, with the exception of the saltbush habitat, which maintained its comparatively high mean density (Fig. 4).

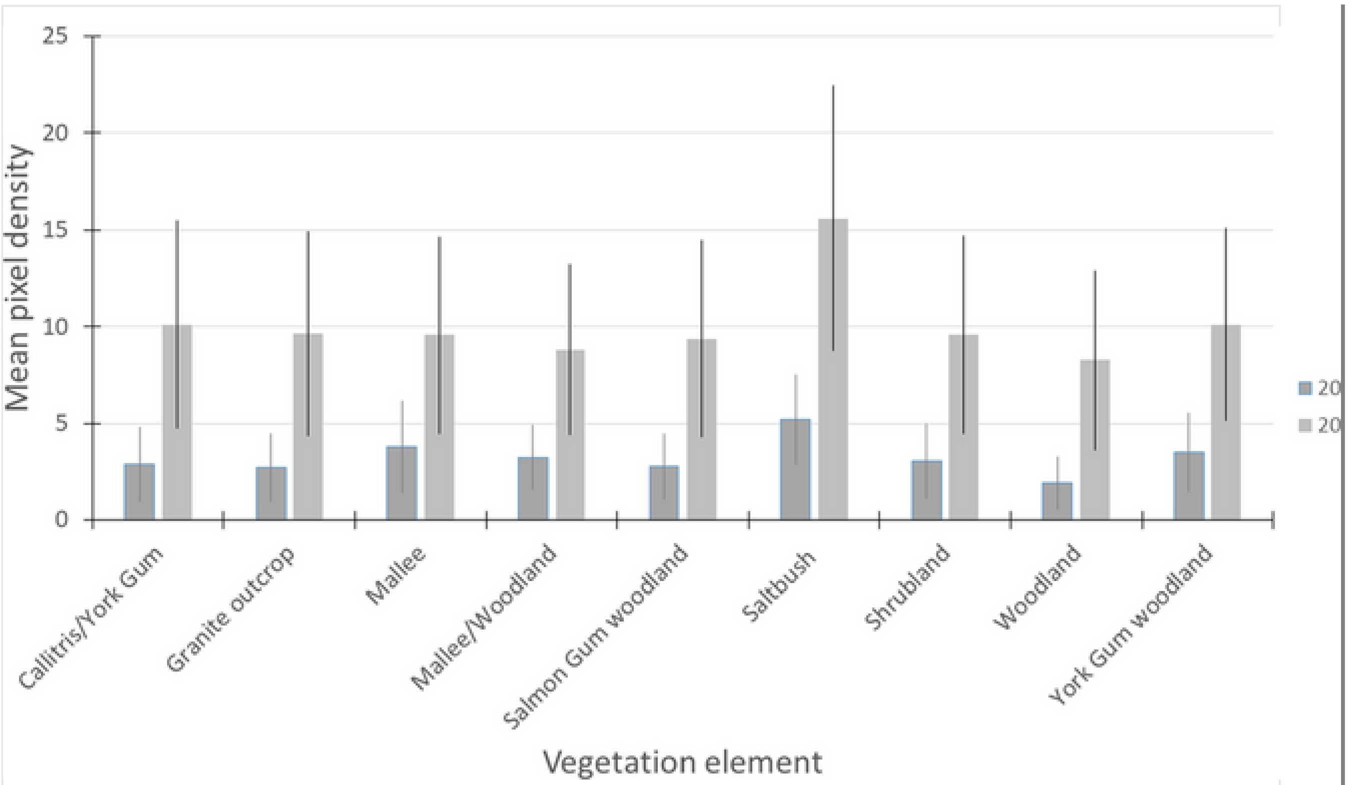


**Fig. 4** Mean predicted pixel density for each habitat type within the safe haven in 2017 and 2018. Vertical lines indicate ± standard deviation.

## Discussion

In addition to creating a new population for future reintroductions, the primary aim of the reintroduction of woylies to Mt Gibson was to increase the overall area of occupancy, extent of occurrence, number of sub-populations and global population size of the species (Ruykys & Kanowski 2015). A new population has now been established at Mt Gibson that is growing in size and spreading across the available area. Although the translocation is still in its early phase in terms of a typical reintroduction time frame (i.e. it may take decades to ensure a viable and genetically diverse population has been established), the key long-term success criterion for Mt Gibson is that by 2021 there will be a population of woylies with a minimum of 300 individuals (Ruykys & Kanowski 2015). This criterion is well on its way to being met.

At this stage, it is uncertain just how large the population at Mt Gibson will be or how much it will oscillate over time. Understanding population size and its variability with a view to quantifying and managing a viable carrying capacity is a critical goal of any translocation (Robert *et al.* 2015). The long absence of woylies from Mt Gibson or similar environments makes it challenging to develop a management regime based on a target density range; however, the concurrent monitoring of woylie density and other system elements and processes will provide an evidence base on which to evaluate the impacts of woylie population size on their habitat. Collection of these data, and understanding of the processes driving change in this system, should eventually facilitate adoption of a mature theory of management for the woylie population at Mt Gibson (e.g. Van Wilgen *et al.* 1998).

Based on the results reported here, we can see that woylies can occupy the majority of the safe haven and, given a reduction in the mean range parameter, individual activity areas appear to be decreasing with population size (as has been shown for other macropods; Viggers & Hearn 2005). Thus, it will be particularly important to identify, monitor and, where possible, manage key threatening processes, including those that relate to the possibility of over-population (e.g. see Linley *et al.* 2017). As a first step to managing threatening processes, AWC ecologists conducted a structured expert-based risk assessment for the Mt Gibson safe haven in 2016 (unpublished), following the approach of Smith *et al.* (2015) and Smith *et al.* (2019). The risk assessment identified several direct risk factors and their associated system process for monitoring. Disease and the availability of food were believed to be particularly important risk factors for woylies. Should over-population of woylies occur, food availability may decrease and disease outbreaks may become more likely (e.g. Herman 1969). Additionally, with over-population of one of the reintroduced grazing species, the safe haven's vegetation elements might be negatively impacted, with possible cascading effects for many different faunal elements, including woylies, via changes to the availability of habitat and food (e.g. Ripple & Beschta 2012). Regularly measuring woylie population size will allow AWC to monitor the species' density and distribution.

In terms of the monitoring of woylies, we found the approach of having more traps per site, but with a single check, to be more manageable (as opposed to multiple checks per night). The male-biased inter-annual recapture rates and sex ratio may indicate that there is a male bias in the population. Alternatively, it is also possible that, using this approach, males are more trappable than females (note that a similar approach used at Karakamia typically results in a slightly female-biased sex ratio, AWC unpublished data; 2020). If the latter is correct, then population size will have been underestimated and further work may be required to address that issue. If the former is correct, the male bias may eventually dissipate, the population may be male-biased and will remain so, and/or further research to determine the cause of the bias may be warranted.

## Conclusion

AWC has established a population of the endangered woylie within Mt Gibson Wildlife Sanctuary's safe haven. Reintroduced individuals had high survivorship and, given the increases in population size, have clearly recruited into the population. The species now also occupies most of the safe haven and, as such, the site is on track to becoming an extra insurance population. The population also increases the species' overall extent of occurrence, number of sub-populations and global population size. By developing a robust monitoring approach, ongoing assessment of population size can occur in conjunction with monitored change in vegetation structure and composition along with other key system elements and risk factors. We also note that, given the changes in range parameter, inferences about home range size and habitat use made from shorter-term radio-tracking studies should be viewed with suitable caution. Finally, by adapting a standard single-catch cage trapping method and applying the SECR modelling approach, we were able to generate estimates of the population size (and associated uncertainty) of a species that is known to be ‘trap happy’. We suggest that this approach could be trialled on other populations of woylies and on other species that present similar challenges. By using a simple-to-use R software package, we feel that the approach can be easily adopted by people and organisations that lack significant statistical expertise, but with confidence that the outputs can be checked and assessed appropriately.

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### Conflict of Interest

There are no conflicts of interest to declare.

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| LotteryWest | 1082 |
| Perth Zoo | Perth Zoo Wildlife Conservation Action Program |


# Supplementary Material

Figure S1. Map showing location of trapping sites, grouped into the three trapping phases.

Table S1. Paramater estimates from the various models to estimate population size and density of woylies.

Figure S2. Major vegetation types within the Mt Gibson fenced area.

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