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Wild-born versus captive-bred: a comparison of survival and refuge selection by translocated numbats (*Myrmecobius fasciatus*)

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ABSTRACT

Context: To re-establish a population of the threatened numbat (*Myrmecobius fasciatus*) in a newly created safe haven at Mount Gibson Wildlife Sanctuary, in the semi-arid zone of Western Australia, wild-born and captive-bred individuals of both sexes were translocated.

Aim: To compare: (1) the use of refuges by wild-born numbats pre- and post-translocation, and (2) the survival and refuge use of captive-bred numbats compared with wild-sourced numbats post-translocation.

Methods: Monitoring via radio-tracking facilitated the gathering of information on survival and behaviour of numbats pre- and post-translocation, and allowed a comparison of how different factors (e.g. captive-bred or wild-born; male or female) influenced survival and establishment in a new environment.

Key results: There were no significant differences in survival between sexes or between wild-born and captive-bred individuals. However, there were some differences in behaviour between sexes and source populations. Captive-bred numbats, regardless of sex, made greater use of tree hollows as nocturnal refuges than did their wild-born counterparts. Among wild-born numbats, there was a comparatively greater use of tree hollows and logs on the ground by males at Mount Gibson than at Scotia. The use of diurnal escape refuges did not vary between sexes or between captive-bred and wild-born individuals.

Conclusions: On the basis of the information presented here, we conclude that, in the absence of predation by mammalian predators, and with suitable release habitat, captive-bred-to-wild translocations of numbats may be as likely to succeed as are wild-to-wild translocations, at least over the first few months post-translocation.

Implications: Optimising the size and genetic diversity of the founding population by using animals from a variety of sources may not need to be heavily constrained by concerns about the ability of captive-bred numbats to adapt to and survive life in the wild.

INTRODUCTION

Species with high evolutionary distinctiveness can be particularly vulnerable to predation by exotic mammal predators such as cats (*Felis catus*) and red foxes (*Vulpes vulpes*), with extinction being a frequent outcome ([Doherty et al. 2016](#)). In Australia, terrestrial mammalian species that are within the critical weight range (between 35 and 5500 g) are considered to be at an increased risk of extinction from predation by introduced mammalian predators ([Burbidge and McKenzie 1989](#); [Johnson and Isaac 2009](#)). The numbat (*Myrmecobius fasciatus*) is an evolutionarily distinct species within the critical weight range that was once widespread across much of the southern half of Australia ([Friend 1990](#)). Numbats declined significantly from the mid-1800s onward and, by the

1980s, were extinct across most of their former range, persisting in only two locations, namely, Dryandra Woodland and Tone-Perup Nature Reserve, both in south-western Western Australia ([Friend 1990](#)). The species' decline led to it being listed as 'Endangered' on the IUCN Red List and 'Vulnerable' under the Federal Government's *Environment Protection and Biodiversity Conservation Act* 1999. Predation by introduced red foxes and cats has been identified as a primary threatening processes for numbats ([Calaby 1960](#); [Friend 1990](#)). The partial recovery of numbat populations in south-western Australia following fox control, and the success of several reintroductions into areas free of cats and foxes ([Friend and Thomas 1994, 2003](#); [Hayward et al. 2015](#)) have highlighted the significance of predation as a threatening process.

Extending the current distribution of a species by reintroduction is a common management response ([Armstrong and Seddon 2008](#)). However, reintroductions are often unsuccessful and, as such, research providing information that can increase the likelihood of success is important ([Armstrong and Seddon 2008](#)). Reintroduction to establish new populations of the numbat are listed as a 'Priority 1 action' in the Numbats Recovery Plan ([Department of Parks and Wildlife 2017](#)) and an intensive reintroduction program commenced in the mid-1990s to address the decline of the species. This program resulted in the re-establishment of four self-sustaining populations in south-western Western Australia and two in introduced predator-free fenced areas managed by the Australian Wildlife Conservancy (Yookamurra in South Australia and Scotia in New South Wales); however, six other reintroductions were not successful ([Department of Parks and Wildlife 2017](#)). The failure of some reintroductions into fox- and cat-free areas indicates that newly reintroduced individuals can be susceptible to additional threats and that the removal of cats and foxes alone will not always guarantee the success of a reintroduction ([Bester and Rusten 2009](#); [Department of Parks and Wildlife 2017](#)). Insufficient food, predation by species other than cats and foxes, poor habitat quality (i.e. absence of sufficient cover and refuges), and general naivety to dangers in their new environment (i.e. native predators) have been proposed as possible causes of failed reintroductions ([Department of Parks and Wildlife 2017](#)). Optimising the number and genetic makeup of the founders has also been identified as being critical in reintroduction programs generally ([Tracy et al. 2011](#)).

Numbats utilise burrows, hollow logs on the ground, and tree hollows not only for nesting and resting, but also as refuge sites to avoid predation ([Calaby 1960](#); [Christensen et al. 1984](#)). Of these, burrows provide the greatest insulation, having the most consistent overnight temperatures ([Cooper and Withers 2005](#)). Previous research into refuge use by numbats has investigated wild individuals ([Christensen et al. 1984](#)), captive individuals ([Cooper and Withers 2004](#)), and wild and captive individuals following translocation ([Bester and Rusten 2009](#); [Hayward et al. 2015](#)). There have been no studies comparing changes in behaviour and refuge use pre- and post-translocation, which may affect survival and the success of the translocation. Similarly, whereas some previous studies have tracked and even compared survivorship of captive-bred and wild-sourced numbats after translocation, none has compared behaviour and refuge use among animals from different sources, which may also be a determinant of translocation success. Thus, the aims of the present study were to compare (1) the use of refuges by wild-born numbats pre- and post-translocation, and (2) the survival and refuge use of captive-bred numbats compared with wild-sourced numbats post-translocation. By doing so, we provide information on behaviour and survival of individuals from different sourcing strategies. Note that we use the term 'wild-born' for animals sourced from Scotia Wildlife Sanctuary. These animals were born and matured in two 4000-ha safe havens where they are subject to the same pressures and environmental constraints as are unfenced populations, barring predation by mammalian predators; they are still exposed to avian and reptilian predation.

MATERIALS AND METHODS

Study sites

The present study was conducted across the following three sites: Perth Zoo (captive source), Scotia Wildlife Sanctuary (wild source) and Mount Gibson Wildlife Sanctuary (destination; Fig. 1). Both of the latter properties are privately owned and managed by a not-for-profit conservation organisation, the Australian Wildlife Conservancy (AWC).

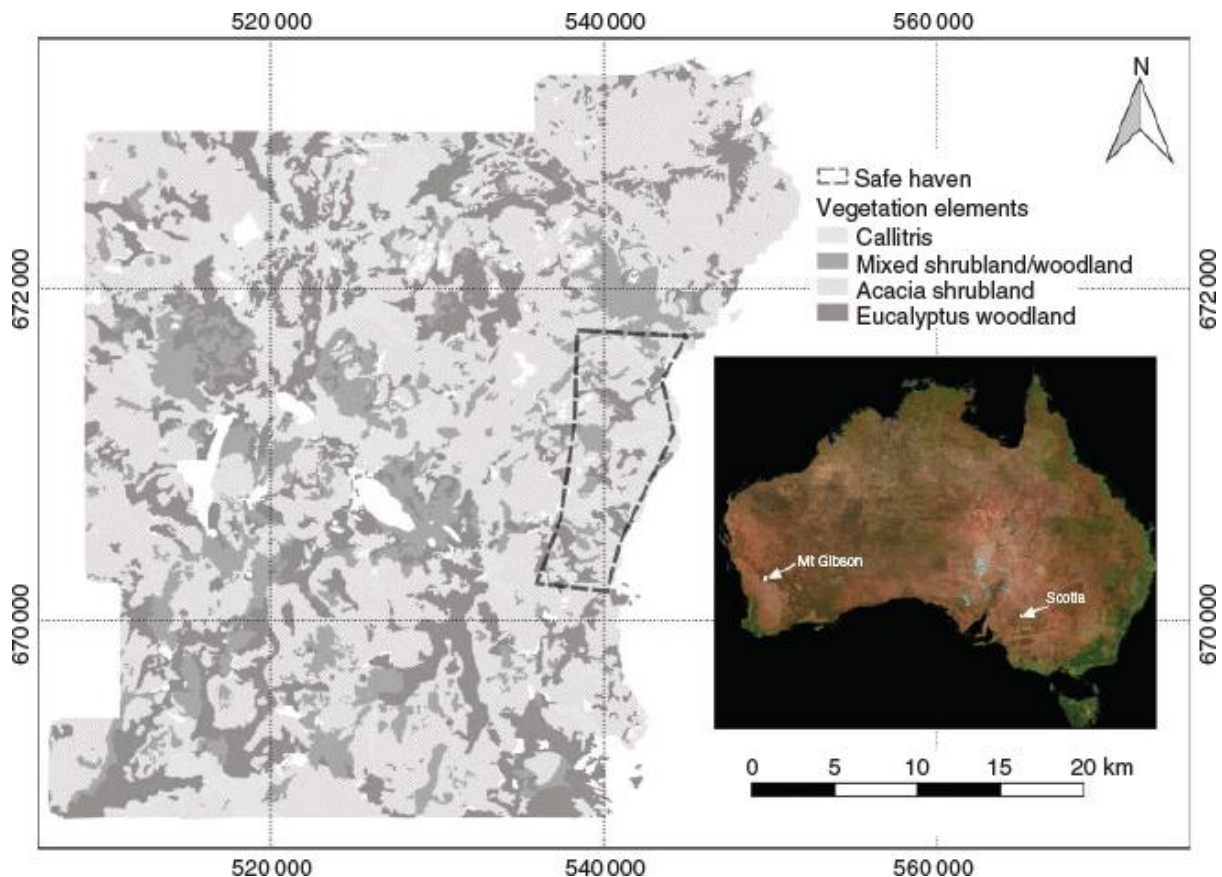


Figure 1. The location of the safe haven at Mount Gibson Wildlife Sanctuary. Inset shows the location of Mount Gibson and Scotia Wildlife sanctuaries in Australia. EPSG: 28350, GDA94/MGA zone 50.

The first source was that of Perth Zoo, which has reliably produced captive-bred numbats since 1993 (<https://perthzoo.wa.gov.au/saving-wildlife/breeding-conservation/numbat-breeding-program> accessed 16 January 2020). The colony is composed of wild-born animals and their progeny (sourced from Dryandra), and wild-born animals sourced from translocated populations. The objective of the breeding program is to provide animals for release into protected areas that are managed for a reduction of introduced predators (Power *et al.* 2009).

The second source was Scotia Wildlife Sanctuary. The property is located in far western New South Wales, on the boundary of the arid and semi-arid climatic zones. Vegetation at Scotia is dominated by mallee *Eucalyptus* spp. with a shrub or *Triodia* understorey, *Casuarina pauper* woodland or areas with a mix of woodlands and shrublands. An 8000-ha safe haven (comprising of two adjacent 4000-ha fenced areas) free of cats and foxes has been established on the property and several threatened mammal species, including the numbat, have been successfully reintroduced (Kanowski *et al.* 2018).

Mount Gibson Sanctuary is located 350 km north-east of Perth, Western Australia, and is predicted to have been formerly inhabited by numbats ([Baynes 2002](#)). It is in the semi-arid zone and located in a region characterised chiefly by a mix of salmon (*Eucalyptus salmonphloeia*) and York gum (*E. loxophleba* var. *loxophleba*) woodlands and *Acacia* shrublands. A fence was constructed around 7832 ha in 2014 and the area was declared free of cats and foxes in 2015; mammal reintroductions began in August 2015, with numbat translocations commencing in January 2016.

The present study concerns numbats that were reintroduced to Mount Gibson over four releases from two sources ([Table 1](#)). All wild-sourced numbats were adults or subadults approaching maturity, with a minimum bodyweight of 400 g. Captive-bred individuals were subadults that had been born in the year of their release. Releases were conducted in summer (December or January) as that is the season when juveniles naturally disperse from their maternal nests and establish home ranges ([Department of Parks and Wildlife 2017](#)).

Table 1. Details of translocated numbats, including number from each source population, release dates and number of individuals collared from each sex

One individual was not included in the analysis because of an insufficient number of locations

Source location	Number of numbats translocated	Date	Number of female numbats collared	Number of male numbats collared
Scotia Sanctuary	9	Jan. 2016	6	3
Scotia Sanctuary	7	Dec. 2016	5	2
Perth Zoo	14	Dec. 2016	5	9
Perth Zoo	19	Dec. 2017	4	5

Translocation process

Because numbats are not easily captured by conventional methods ([Friend and Thomas 2003](#)), animals at Scotia Sanctuary were hand caught. Diurnal drive surveys were conducted until an animal was spotted; the animal was then followed to, and extracted from, its refuge (hollow log on the ground, tree hollow, or burrow). For hollow logs on the ground and tree hollows, this was achieved by blocking all but one escape route, which was covered with a capture net. A garden hose was then inserted into one end of the refuge and puffs of air encouraged the numbat to leave the refuge by the one escape route. Animals that sought refuge in burrows were captured by covering the entrance to the burrow with a capture net and digging vertically into where the numbat was estimated to be. If the burrow contained multiple entrances, all but one were blocked off. Puffs of air blown into a hose inserted into the burrow encouraged the numbat to leave by the netted entrance.

Once captured, numbats considered eligible for translocation (i.e. those with bodyweight of >400 g, free of injury or deformity, low to moderate parasite load, among other things) were fitted with a radio-collar (Biotrack™; <http://www.biotrack.co.uk/index.php>, accessed 16 January 2020) VHF PIP3 tag and collar with an AG357 brass loop) that weighed 7 g; substantially less than 3% of an individual's bodyweight. Numbats were then released into the refuge from which they were extracted. Collared numbats were then radio-tracked regularly to nocturnal refuges until recapture for translocation. Numbats were radio-tracked to their overnight refuges for up to 6 weeks (January 2016) and up to 2 weeks (December 2016) before their translocation.

Animals from Scotia were translocated to Mount Gibson in January and December 2016. Both translocations followed the same method. The night before translocation, numbats were radio-

tracked to their refuge; they were then extracted using the same method as that of their initial capture. Captured individuals were placed into individual calico bags that were secured inside a standard pet-pack (two numbats per pet-pack [Carrier A/P model]; 61 cm (L) × 39 cm (W) × 40 cm (H)). At dawn the following morning, numbats were flown in a chartered Cessna aircraft to Mount Gibson. Numbats were released into pre-selected hollow logs just before dusk on the day of arrival.

Numbats at Perth Zoo were caught approximately 1 week before the date set for translocation by Perth Zoo staff blocking off the entrances to their burrows. They were then radio-collared and re-released to their enclosures. Monitoring over the week before translocation facilitated checking of the animals' collar fit and acceptance of the collars. On the day of translocation, animals were again trapped by blocking the burrow entrances and, this time, placed in individual calico bags. They were then secured in pet-packs (as above) and transported by automobile, the ambient conditions of which were retained in the numbat thermoneutral zone of 15–30°C ([Cooper and Withers 2002](#)). After arrival at Mount Gibson, animals were held in a quiet, darkened and cool room until late afternoon, at which time they were released into pre-selected hollow logs in the same general area as were the numbats from Scotia.

Post-translocation monitoring

A subset of translocated numbats retained collars for post-translocation monitoring, whereas all animals from Perth Zoo were collared. After their release at Mount Gibson, attempts were made to radio-track all collared numbats daily for the first 2 weeks, bi-weekly for the following 2 weeks, and then at least once fortnightly until 75% of the nominal battery life of the radio-collar had been used; at that point, attempts were made to recapture the individuals and remove their collars. The collar range and large area within which individuals were being radio-tracked meant that not all numbats were found on every session. Individuals were radio-tracked during the day to either a day retreat, flight refuge, or to where they could be seen (no refuge); they were also tracked at night to their overnight refuge(s). On each occasion, the refuge type (hollow log on the ground, tree hollow, burrow, or no retreat) was noted.

Statistical analysis

The analysis addressed the following four specific questions: (1) was there any difference in survival between wild-born numbats and captive-bred individuals; (2) was there any change in the type of nocturnal refuge selected by wild-born individuals pre- and post-translocation; (3) was there a difference in the type of nocturnal refuge selected by wild-born and captive-bred individuals post-translocation; and (4) was there any difference between wild-born and captive-bred individuals in their selection of diurnal escape refuges? All statistical analyses were performed within the R software environment (R Core Team 2013).

For Question 1, 'censored' survival data were analysed with a parametric survival regression (with exponential distribution) by using the R package 'survival' (Therneau 2015). Three predictor variables were incorporated, namely, captive-bred (or not), female (or not), and their interaction. Survival (in days) was calculated as the time between release at Mount Gibson and the individual's death or last known-to-be-alive location. Censored individuals were those that either had their collar removed or, subsequently, disappeared and did not have their collar removed. A series of models with different assumed y -variable distributions (exponential, log normal, and Rayleigh) were compared with Akaike information criterion (AIC; Burnham and Anderson 2002) to identify the most appropriate model(s).

Statistical analyses for Questions 2–4 were performed using the 'rjags' package (Plummer 2017). Repeat measures (within-subject design) multinomial generalised linear models were applied

following Kruschke (2015). This modelling approach was chosen because the refuge choice is a nominal dependent variable (consisting of a choice between ‘tree hollow’, ‘hollow log on the ground’, or ‘burrow’ for nocturnal preferences, and the addition of ‘no refuge’ for diurnal preferences), for which each individual was measured on multiple, but varying numbers of, occasions. A modelling approach appropriate to analyses with a small number of ‘question’-relevant predictors, as described by Royle et al. (2013), was applied (i.e. we did not use any model-selection procedures as they are not necessary for this approach). For each question, a random-intercept model was used, where it was assumed that the random intercept for each individual came from a normal distribution centred on the population average intercept. Thus, a predictor that accounts for the repeat measures of individuals was included, along with the two fixed predictors that relate to the questions of interest, as follows: Mount Gibson (‘1’ or Scotia ‘0’) and female (‘1’ or male ‘0’) for Question 2; and, for Questions 3 and 4, captive-bred (‘1’ or wild born ‘0’) and female (or male). Interaction terms for the fixed predictors were also included. For Questions 2–4, the model structure used was as follows (in the formatting appropriate for rjags):

```
for (i in 1:nrows) {
  Refuge[i] ~dcat(explambda[1:ncat, i])
  for (r in 1:ncat) {
    explambda[r,i] <- exp(alpha[r] + beta.1[r] *
      Fixed_Predictor.1 [i] + beta.2[r] * Fixed_Predictor.2 [i] + beta.3[r] * Fixed_Predictor.1 [i] * Fixed_Predictor.2
      [i] + beta.4[Nominal_Predictor[r,i]])
```

Vague or uninformative normal priors were set for each parameter, referenced to the ‘burrow’ category:

```
alpha[1] <- 0
beta.1[1] <- 0
beta.2[1] <- 0
beta.3[1] <- 0
for(i in 1:nind){beta.4[1,i] <- 0}
for (r in 2:ncat) {
  alpha[r] ~dnorm(0, 1/20^2)
  beta.1[r]~dnorm(0, 1/20^2)
  beta.2[r]~dnorm(0, 1/20^2)
  beta.3[r]~dnorm(0, 1/20^2)
  For (i in 1:nind){beta.4[r,i]~dnorm(0,1/20^2)}}}
```

Burrows were used as the reference state. Standard model-checking procedures were followed (Kruschke 2015); these included running models on repeated occasions to confirm consistency in the parameter estimates, and checking levels of autocorrelation and chain convergence by graphical examination of multiple chains. Mean α and β parameter estimates are reported for each model, along with 95% Bayesian credible intervals (CI). Where CI do not include zero, one can infer a

'significant' difference. Otherwise, as the mean parameter estimate moves further away from zero and the CI progressively approaches the non-inclusion of zero, the relationship can be considered increasingly important.

RESULTS

Comparison of survival between wild-born and captive-bred numbats at Mount Gibson

Survival of translocated numbats was high, with only 4 of the 38 collared individuals known to have died over the course of the study (one wild-born male, one captive-bred female, and two captive-bred males). Of those found deceased, one had been subject to predation by a raptor, whereas the cause of death could not be established in the other three individuals; there were no signs of predation, trauma or collar-related issues and too much time had elapsed for a full necropsy to be performed. Twenty-seven individuals were alive when they had their collars removed and seven individuals were alive at their last detection, but were never again detected. The model with the log-normal distribution had the lowest AIC estimate and thus was used. The exponential ($\Delta\text{AIC} = 0.65$) and log-logistic ($\Delta\text{AIC} = 0.77$) models were within two units of the log-normal model, but produced similar results. Consistent with the high survival rates, at the significance level of $P = 0.05$, there were no significant differences in survival between males and females ($\beta[\text{female}] = 14.46$; $z < 0.00$; $P = 1.00$) or between captive-bred and wild-born numbats ($\beta[\text{captive-bred}] = 0.71$; $z = -0.30$; $P = -0.76$). There was also no significant interaction effect between sex and birth place ($\beta[\text{interaction}] = -17.21$; $z < 0.00$; $P = 1.00$).

Comparison of nocturnal refuge selection by wild-born numbats pre- and post-translocation

The analysis indicates that, in general,

1. tree hollows and logs on the ground were used more at Mount Gibson than at Scotia (95% CI did not include zero; [Fig. 2](#)), but,
2. there were strong interactions between sex and sanctuary (95% CI did not include zero; [Fig. 2](#)). In particular, males used tree hollows and logs on the ground more frequently at Mount Gibson than they did at Scotia ([Fig. 2](#)).

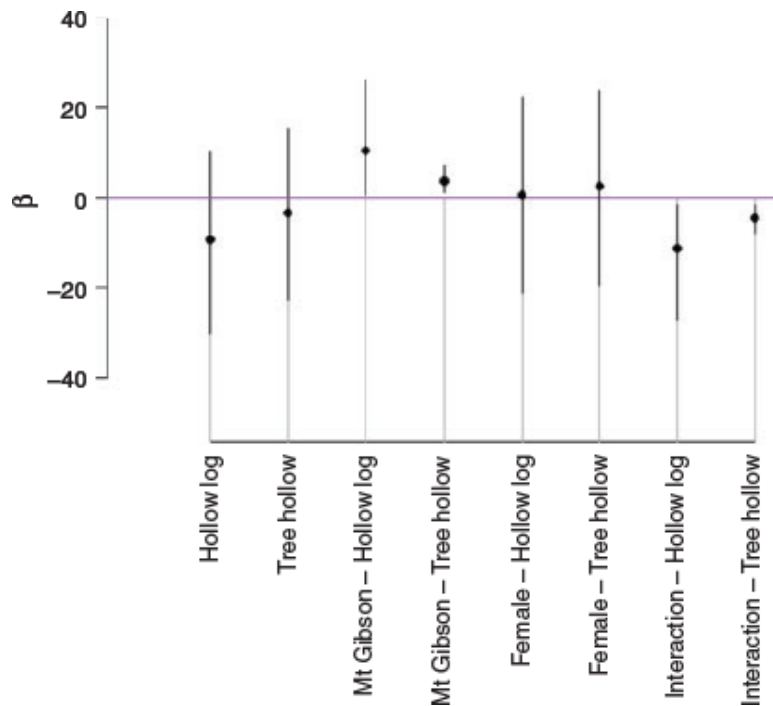


Figure 2. Posterior mean estimates of β (black dot) for each fixed predictor, inferring the relationships between nocturnal refuge choice by female and male numbats at Mount Gibson and Scotia sanctuaries. Where the 95% credible intervals (CI) do not include '0', the relationship can be thought of as statistically significant. The closer the posterior mean is to zero and the more the 95% CI includes zero, the more equivocal the estimate. The width of the 95% CI also provides an estimate of the power of the model to make inferences about the parameters. The horizontal line is included to facilitate comparisons with '0'.

Comparison between captive-bred and wild-born numbats in use of nocturnal refuges at Mount Gibson

The analysis indicates that, in general,

1. wild-born and captive-bred numbats made greater use of burrows than hollow logs (95% CI included zero; [Fig. 3](#)), and,
2. captive-bred individuals made greater use of tree hollows than did the wild-born individuals (95% CI included zero; [Fig. 3](#)).

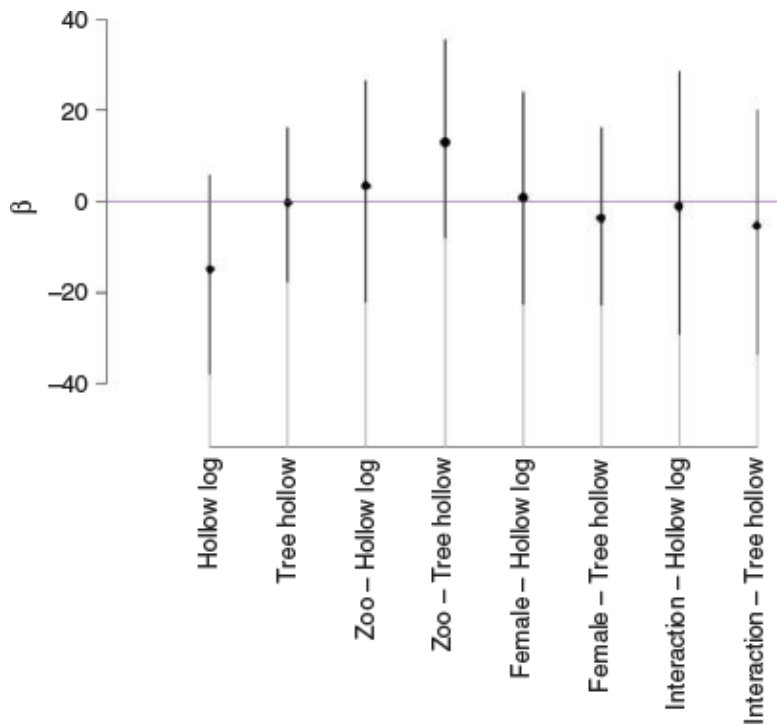


Figure 3. Posterior mean estimates of β (black dot) for each fixed factor, inferring the relationships between nocturnal refuge choice by female and male numbats that were captive-bred or wild-sourced. See [Fig. 2](#) caption for more information on interpreting the graph.

Comparison between captive-bred and wild-born numbats in use of diurnal refuges at Mount Gibson

There were no detectable differences in the type of refuge used as a diurnal escape refuge between captive-bred and wild-born numbats ([Fig. 4](#)).

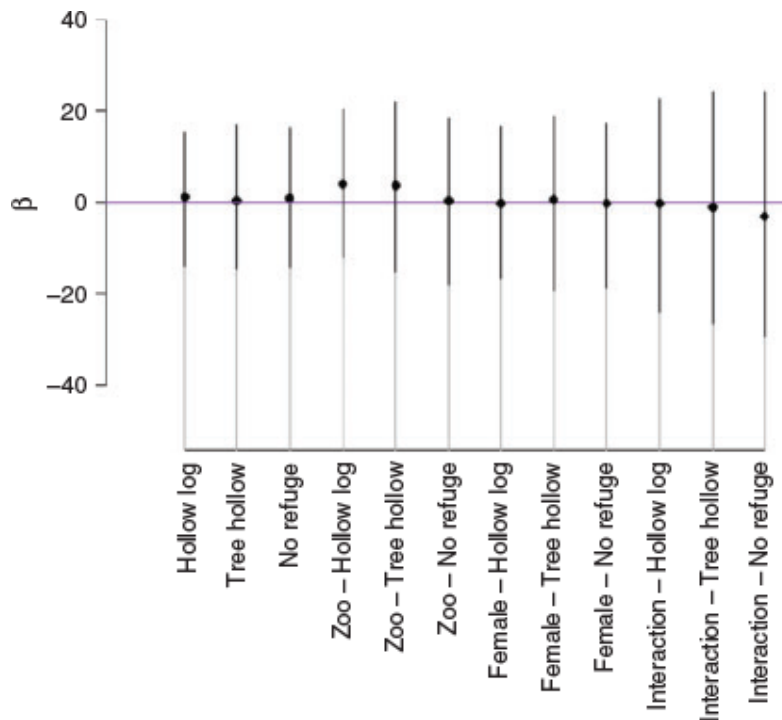


Figure 4. Posterior mean estimates of β (black dot) for each fixed factor, inferring the relationships between diurnal refuge choice by female and male numbats that were captive-bred or wild-sourced. See [Fig. 2](#) caption for more information on interpreting the graph.

DISCUSSION

In the present research, translocated numbats had a high survivorship, with the only known mortalities being those of captive-bred individuals (both sexes) and a wild-born male (noting the unknown fate of seven individuals). Wild-born male numbats made greater use of hollow logs and tree hollows as nocturnal refuges post-translocation than did wild-born females; furthermore, captive-bred numbats made more use of tree hollows as nocturnal refuges than did their wild-born counterparts. Comparable and high survivorship and similar escape refuge choices made by the wild-born and captive-bred numbats suggests that any possible confounding effects associated with release date were minimal to non-existent. As such, we also consider any potential confounding effects of release date relating to refuge choice also likely to be minimal. Importantly, the availability and spatial distribution of refuge types will have varied from Scotia to Mount Gibson (as they would between any two places and over time) and they are likely to be the major cause of any observed changes in behaviour. However, the key point of these results is that numbats that were translocated to a similar habitat were able to adapt to their new surroundings such that they mostly survived, at least for a reasonable period of time post-translocation. Additional research to determine the significance of any interactions between refuge availability and use, and survival, may be of general value to be able to better predict translocation success. This may be particularly important where the translocation site has a markedly different environment with regards to refuge type and availability.

Historical reintroductions of numbats have had mixed success, with some reintroductions failing several years after the first release of animals ([Department of Parks and Wildlife 2017](#)). Of the failed reintroductions, two were in safe havens and, as a result, factors other than predation by cats and foxes must be responsible. For example, a trial translocation to Karakamia Wildlife Sanctuary in

Western Australia failed, likely owing to the fact that the release was of a small number of animals ($N = 6$) into an area that was almost certainly too small (~260 ha) to maintain a viable population. The other unsuccessful translocation was that of Arid Recovery in South Australia; however, this was also only a trial translocation that comprised a small number of individuals ($N = 5$). Predation by native species was considered the key factor behind this failure ([Moseby *et al.* 2011](#)). For Mount Gibson, the high survival rate of numbats indicates that predation by native animals has not been a significant risk factor. Consequently, our results, along with those of successful translocations into larger safe havens (i.e. Scotia and Yookamurra wildlife sanctuaries; [Hayward *et al.* 2015](#); [Department of Parks and Wildlife 2017](#)) suggest that native avian and reptilian predation may not be a significant issue if, in addition to having suitable habitat (food and refuges), the number of founders (e.g. [Cremona *et al.* 2017](#)) and the amount of available habitat (in terms of area) are sufficient.

The fact that the captive-bred numbats made use of all types of recorded refuges indicates that their rearing environment did not substantially restrict their ability to find suitable resting and escape sites post-translocation; this, in turn, suggests that their rearing environment was suitable (at least for release to areas free of introduced predators). At Perth Zoo, numbats were provided with above- and below-ground nest boxes and most individuals demonstrated an ability to burrow (C. Lambert, pers. comm., 2019). They were provided with elevated climbing branches (not hollows) for activity and enrichment, but not elevated boxes that would replicate a tree hollow (C. Lambert, pers. comm., 2019); elevated boxes could be considered for additional enrichment for captivity.

A key recovery goal for the numbat is to 'ensure genetic health and diversity is maintained' ([Department of Parks and Wildlife 2017](#), p. 4). The results reported here indicate that numbats from either wild or captive populations could be used for translocations that aim to supplement a population's genetic diversity, at least for translocations into areas free of introduced predators. Our study suggests that captive-bred individuals released into safe havens can have reasonable survival, meaning that individuals with a desired pedigree could be bred and released. Additionally, assuming that a reasonable number of individuals with the desired genetic diversity can be released, the negative impacts of stochastic events on the transmission of genetic information may be able to be minimised.

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