

Habitat selection by vulnerable golden bandicoots in the arid zone

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Short title: Habitat use by golden bandicoots

1 Abstract

2 In 2010, vulnerable golden bandicoots (*Isoodon auratus*) were translocated from Barrow Island,
3 Western Australia, to a predator-free enclosure on the Matuwa Indigenous Protected Area. Golden
4 bandicoots were once widespread throughout a variety of arid and semi-arid habitats of central and
5 northern Australia. Like many small to medium-sized marsupials, the species has severely declined
6 since colonisation and has been reduced to only four remnant natural populations. Between 2010
7 and 2020 the reintroduced population of golden bandicoots on Matuwa was monitored via capture-
8 mark-recapture data collection which was used in spatially explicit capture-recapture analysis to
9 monitor their abundance over time. In 2014, we used VHF transmitters to examine the home range
10 and habitat selection of 20 golden bandicoots in the enclosure over a six-week period. We used
11 compositional analysis to compare the use of four habitat types. Golden bandicoot abundance in the
12 enclosure slowly increased between 2010 and 2014 and has since plateaued at approximately one
13 quarter of the density observed in the founding population on Barrow Island. The population may
14 have plateaued because some bandicoots escape through the fence. Golden bandicoots used
15 habitats dominated by scattered shrubland over spinifex grass more than expected given the
16 habitat's availability. Nocturnal foraging range was influenced by sex and trapping location, whereas
17 diurnal refuge habitat was consistent across sex and trapping location. Our work suggests that
18 diurnal refuge habitat may be an important factor for the success of proposed translocations of
19 golden bandicoots.

20

21 Keywords: spinifex grassland; Indigenous Protected Area; translocation; restoration; Australia;
22 marsupial

23

1 Introduction

2 Since European settlement, Australia's terrestrial mammal fauna has suffered a severe and
3 continued decline (A. A. Burbidge et al., 2009; Geyle et al., 2018) and 30 of 273 Australian endemic
4 mammal species have become extinct (Woinarski, Burbidge, & Harrison, 2015). Arid zone mammal
5 species, within the Critical Weight Range (CWR) of 35g–5.5 kg have suffered disproportionately in
6 the decline (McKenzie et al., 2007). The golden bandicoot (*Isoodon auratus*) have declined from a
7 historic range that spanned approximately 2000 km across northern Australia from central Western
8 Australia to western Queensland to four remnant natural populations in the north-west Kimberley,
9 Marchinbar Island in the Northern Territory, four islands along Kimberley coast (Gibson & McKenzie,
10 2012) and two islands along Pilbara coast (A. Burbidge & Woinarski, 2016).

11 Globally, conservation translocations are used to establish new populations to reduce the risk of
12 extinction for threatened species (IUCN/SSC, 2013). Translocations to closed systems such as
13 enclosures or islands are commonly used for conservation of fauna species that are particularly
14 susceptible to predation by introduced species such as feral cats (*Felis catus*) or wild dogs (*Canis*
15 *familiaris*) (Ringma et al., 2018). Accumulative conservation evidence, with a total of twenty-four
16 studies from around the world evaluated the effects of releasing translocated mammals into fenced
17 areas and found that the method improves the likelihood of success by increasing reproductive
18 success, survival, and body condition of the species being translocated (Littlewood et al., 2020).
19 However, fenced populations may experience issues with overpopulation and competition due to
20 restricted dispersal (Saifuddin et al., 2017; Moseby, Lollback, & Lynch, 2018); loss of predator
21 awareness (Rowell, Magrath, & Magrath, 2020); or inbreeding depression (Ottewell et al., 2014; Rick
22 et al., 2019).

23 Instances of poor persistence of species in closed systems are likely to stem from incomplete
24 knowledge of the biology and ecology of the species (Rayner et al., n.d.). Many threatened species
25 are described as data deficient either because they are cryptic and difficult to research, or their

1 populations declined before science could adequately document the ecological characteristics of the
2 species. In these situations, conservation translocations are often experimental trials that may be
3 used to test the efficacy of translocation techniques (Priddel & Carlile, 2001; Clarke, Boulton, &
4 Clarke, 2002) or identify resource requirements of the species (Stannard, Caton, & Old, 2010) and
5 suitability of the translocation site (Bester & Rusten, 2009). Successful translocations to fenced
6 enclosures subsequently provide an opportunity to research the biology and ecology of threatened
7 species in a limited but potentially diverse array of habitats present in the species original
8 distribution. Knowledge gained in these environments can provide valuable insights which may
9 benefit future translocations.

10 To date, there have been few studies on habitat selection by golden bandicoots. Previous studies
11 have occurred in sub-tropical regions of the Kimberley ($n = 8$, $t = 5$ days) (Graham, 1996) and
12 Marchinbar Island in the Northern Territory ($n = 12$, $t < 21$ days), where golden bandicoots used a
13 range of daytime shelters in a relatively stable 10-35 ha home range (Southgate et al., 1996), but
14 have used few individuals and have limited applicability to desert or rangeland habitat. Short and
15 Turner (1994) investigated the importance of habitat heterogeneity for a range of marsupial species
16 (including the golden bandicoots) on Barrow Island and concluded that the absence of introduced
17 predators and herbivores had a greater impact on the abundance and distribution of bandicoots
18 within the spinifex grassland habitat than any vegetation mosaic or disturbance characteristic.

19 In this study we examine the abundance, home range and habitat use of a translocated population
20 of golden bandicoots in an arid zone, introduced predator-free, fenced enclosure on the Matuwa
21 Indigenous Protected Area (IPA) in Western Australia (henceforth 'Matuwa'). Home-range data were
22 collected in 2014, four years after their reintroduction from Barrow Island (JA Dunlop et al., n.d.). We
23 mapped the broad vegetation categories within the enclosure using satellite imagery and ground
24 truthing and then used compositional analyses from radiotelemetry data to infer habitat selection at
25 the second and third order (Johnson, 1980). We expected bandicoots to select vegetation with an

understorey of hummock/spinifex grasses (*Triodia sp.*) for shelter and protection over open mulga (*Acacia sp.*) woodlands. Additionally, we expected home-range characteristics to differ between the sexes.

Methods

Study location

Matuwa (244,000 ha) lies in central Western Australia (-26.1986; 121.3598) and straddles the Murchison and Gascoyne Interim Biogeographic Regionalisation for Australia (IBRA) regions (Department of Agriculture Water and the Environment, 2020; Figure 1). It contains at least 20 different land systems and vegetation types such as hummock grasslands, shrublands or low woodland with mulga. This diverse habitat supports a high diversity of flora and fauna, with 480 vascular plant species and 220 vertebrate species occurring on the property (Baynes, 2006; Department of the Environment Water Heritage and the Arts, 2009; Coate, 2010; Rabosky et al., 2011; Chapman & Burrows, 2015). Matuwa has an arid climate with an average monthly diurnal temperature of 30°C in summer and 13°C in winter. The mean annual rainfall is 250mm, which primarily occurs in the summer months due to remnant tropical low-pressure systems.

The enclosure on Matuwa (26°13'S, 121°33'E), was constructed in 2009/10 (Bode et al., 2012) and encompasses approximately 1100ha of mixed habitats, including spinifex grassland (mainly *Triodia basedowii*) under acacia, and mallee eucalypt shrub overstory in the Murchison bioregion; and mulga (*Acacia aneura*) woodland over sparse to very sparse understorey of tufted grasses (*Aristida sp.*) in the Gascoyne bioregion (Figure 1 and 2).

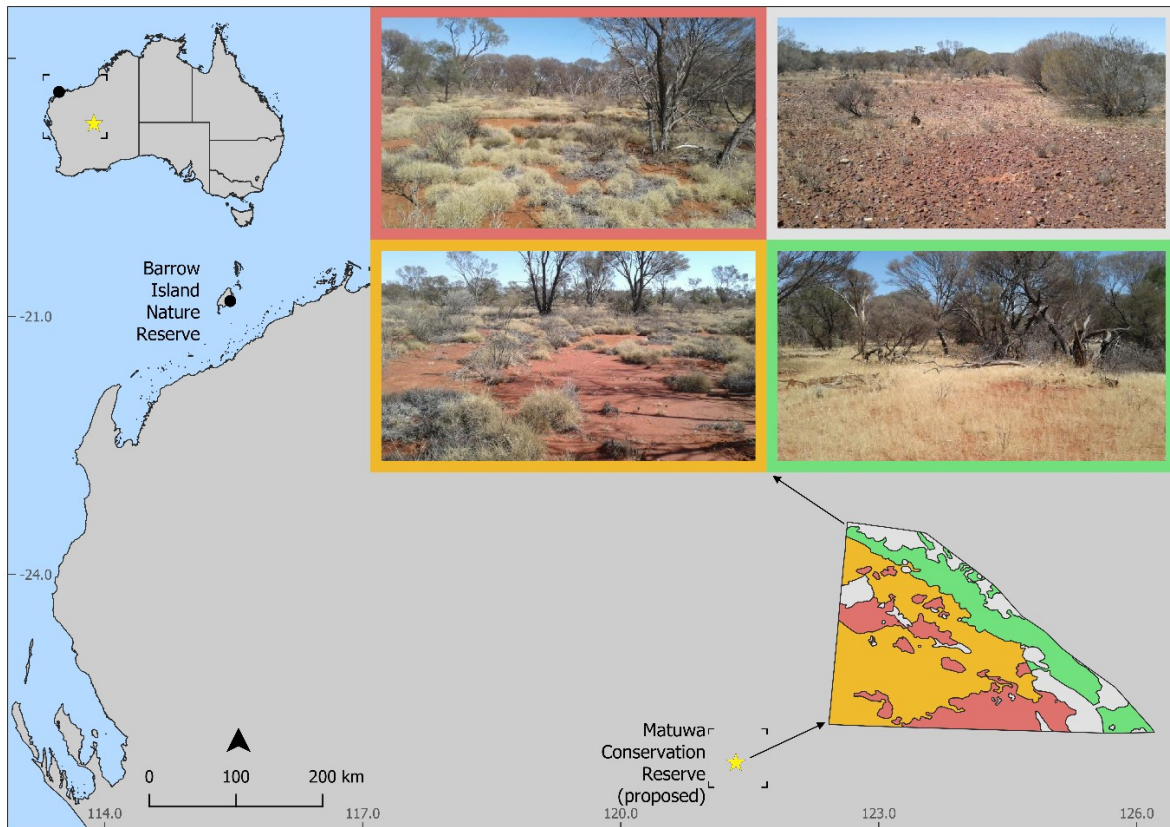


Figure 1. Map of Australia showing the location of source (Barrow Island) and translocated population (Matuwa fenced reserve enclosure), and the four broad vegetation types occurring within the enclosure.

Orange symbolises scattered mixed shrubland over spinifex grass, green symbolises dense mulga over tuft grass, red symbolises dense shrubland over spinifex grass, and light grey symbolises bare understorey.

Study species

Golden bandicoots are listed nationally as vulnerable under the Environment Protection and Biodiversity Conservation Act 1999 (A. Burbidge & Woinarski, 2016). Formerly widespread across Australia's arid and semi-arid zones, by 2010, golden bandicoots were restricted to Barrow and Middle islands (WA Pilbara) (Judy Dunlop & Morris, 2018), Augustus, Lachlan, Storr and Uwins islands (WA Kimberley) (Gibson & McKenzie, 2012), Marchinbar Island (NT Arnhem Land) (Southgate et al., 1996) and high-rainfall areas of the north-western Kimberley between Yampi Peninsula and Mitchell Plateau (Palmer et al., 2003).

1 Translocation

2 In 2010, as part of the Environmental Offset Conditions attempting to ameliorate the impact of the
3 Gorgon Gas Development on Barrow Island, golden bandicoots were translocated from Barrow
4 Island, Western Australia, to several new sites in Western Australia, including Hermite Island in the
5 Montebello Group, Doole Island in Exmouth Gulf, and an enclosure on Matuwa (JA Dunlop et al.,
6 n.d.; Western Australia Government, 2003). This translocation to Matuwa involved a total of 160 (78
7 female, 82 male) bandicoots transferred via car, helicopter and fixed-wing aircraft, and released
8 within 24 hours of capture (JA Dunlop, 2015). Boobies (*Bettongia lesueur*), mala (*Lagorchestes*
9 *hirsutus*), and brushtail possums (*Trichosurus vulpecula*) have also been successfully translocated
10 into the fenced enclosure (C. Lohr, 2019). Small mammal species can pass through the fence,
11 including brush-tailed mulgara (*Dasycercus blythi*), spinifex-hopping mice (*Notomys alexis*) and
12 subadult golden bandicoots.

13 Abundance estimates

14 The abundance of golden bandicoots in the fenced enclosure is monitored at least annually, through
15 capture-mark-recapture (CMR) surveys. Intervals between trapping sessions are irregular, with six
16 sessions in 2010 subsiding to annual sessions by 2015. We have analysed all data collected between
17 2010 and 2020 over a total of 24 primary trapping sessions, with a variety of trap layouts from single
18 traps spaced every 200 m along access roads to high density clusters of traps within 50 m of active
19 boodie warrens. We excluded any trapping sessions that specifically targeted boobies with trap
20 layouts that only included traps near warren entrances and provided limited opportunity for capture
21 of other species.

22 Analysis of trapping data was conducted via the open population, spatially explicit capture-recapture
23 analysis in the R package 'openCR' (Efford, 2019) with the fenced area as a closed survey mask and
24 multi-capture traps. We used the JSSAsecrD modelling framework because we were interested in
25 estimates of the abundance of bandicoots. We tested models that allowed the four parameters

1 within JSSAsecrD (σ , λ_0 , ϕ , and D) to vary among sessions (t), and models that held
2 σ and λ_0 constant whilst allowing ϕ and D to vary. We analysed data for male and
3 female bandicoots separately as well as a full combined dataset. The estimate of density (D) was
4 converted to an estimated abundance by multiplying values by the area of the mask (1120 ha).

5 Due to frequent trap interference by boodies, which diminishes our ability to accurately estimate the
6 number of golden bandicoots inside the enclosure, trap files were modified, with any traps that
7 captured a boodie being listed as inactive traps on that occasion (henceforth 'subset CMR'). We used
8 the moving.fit function within openCR to analyse blocks of five consecutive primary trapping
9 sessions. Standard error margins are derived from variation in outputs of the moving.fit function for
10 each session.

12 Habitat mapping

13 Vegetation within the enclosure was delineated using satellite imagery in conjunction with ground
14 truthing. Four broad vegetation classifications (Figure 2), and their proportions, were demarcated as
15 follows; Scattered mixed shrubland over spinifex grass (43.8% of fenced enclosure), dense shrubland
16 over spinifex grass (20.5%), dense mulga over tuft grass (19.6%) and bare understorey (16.1%).
17 Mulga overstorey species were most commonly *Acacia aneura*.

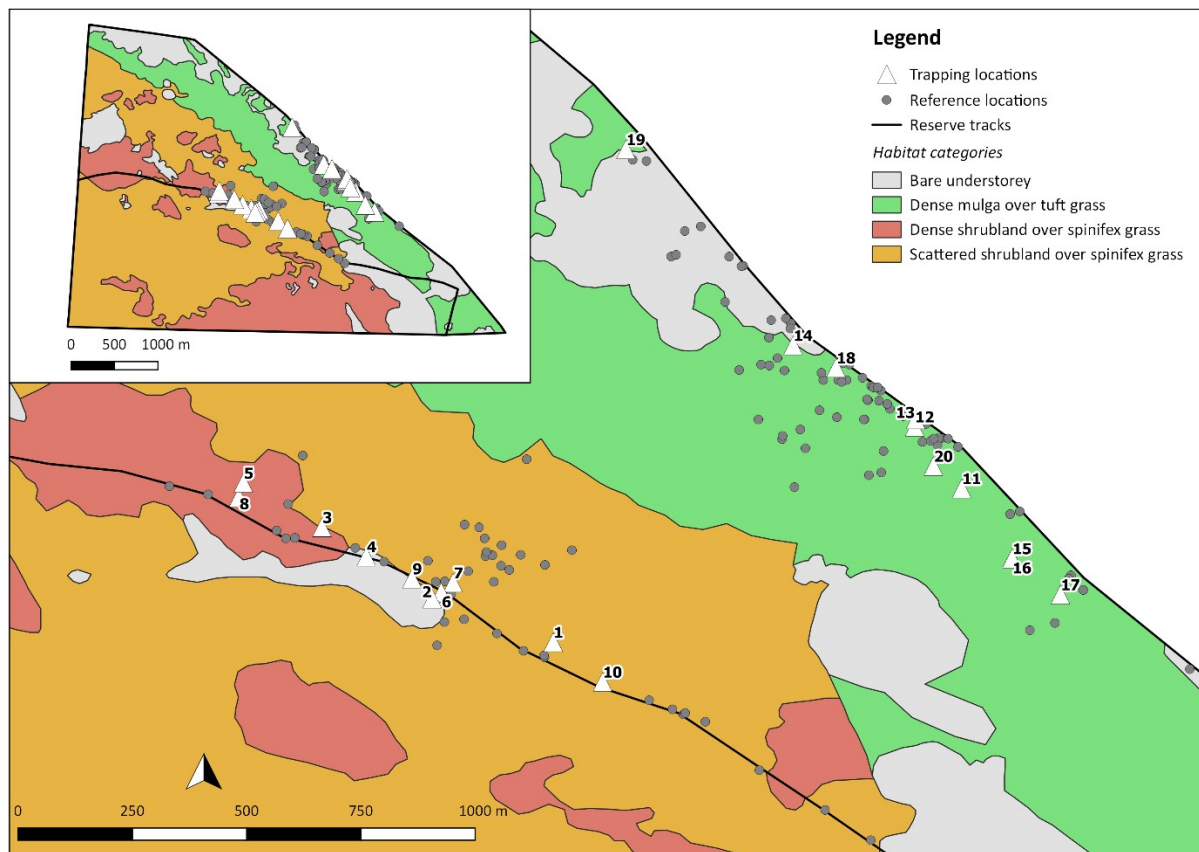


Figure 2. Habitat map of the Matuwa fenced enclosure plus numbered trap locations of the 20 golden bandicoots that were VHF tracked, and reference locations of surveyors for detecting transmitter signals.

Radiotracking

Twenty-seven golden bandicoots were trapped using small cage traps (20 cm x 20 cm x 56 cm, Sheffield Wire Co. Welshpool), with a rolled oats and peanut butter bait from the 12th to the 14th of August 2014. Trapping occurred along the central and northern track of the enclosure (Figure 2). The central and northern trapping lines were designed to capture habitat heterogeneity across the enclosure with, bare understorey or dense mulga over tuft grass dominating the northern region, and scattered shrubland over spinifex grass dominating the central region (Figure 2). Twenty adult animals (6 females and 14 males, 10 from each trap line) were fitted with Titley TX GP1-1/3N, PIC 3.0V 2-stage VHF transmitters, with 60 ppm pulse rate, 12 hr mortality switch (changing to 80 ppm), with 250 mm antenna and 60 days battery life, on an 8 mm wide soft leather collar, weighing

approximately 9 g, at their point of capture and immediately released. Radio signals were detected from transmitters using the Sirtrack Ultra receivers. Radiotracking began one day after an individual was radio-collared and released, and ended on the 22nd September, 2014 (period of 5.6 weeks). Five individuals (GB 3, 10, 14, 19, 20; Supplementary Table S2) were tracked for less than 50% of this period, with detections lost between weeks 1 to 3. Two golden bandicoots (#3 and #14) were found dead, on the 1st of September and the 28th of August, respectively, with raptor predation the suspected as cause of death.

During the day, telemetry positions of golden bandicoots were determined by homing directly to their refuge location between the hours of 12 pm and 5 pm (diurnal locations). Soil type, plant species and/or type of refuge, and vegetation characteristics of the surrounding landscape, were all recorded. During the night, three signal bearings, recorded at three different receiving locations, within five minutes of each other were used to determine an individual's location between the hours of 7 pm and 12 am (nocturnal locations). Surveyors used reference points, which were along tracks approximately 200 m apart as initial tracking locations. The reference location, bearing of the transmitter signal, and strength of the signal were all recorded. Radio collars were removed from animals from the 24th to the 27th of September 2014.

Home Range

Using LOAS software (Ecological Software Solutions, 2000), we triangulated a golden bandicoot's location from signal bearings using the Maximum Likelihood Estimator (≥ 3 bearings) or the Best Biangulation (2 bearings) as a backup method. A total of 586 groups of bearings were input into LOAS. LOAS rejected 57 of these points using *a priori* set of rules, and a further 53 were manually removed as they fell outside the boundary of the enclosure. As a result, a total of 110 radiolocations were removed from the analysis. This left 475 telemetry locations for the nocturnal period. Of these 475 locations, 282 (59%) were triangulations and 193 (41%) were biangulations. For each of the 20

bandicoots, number of telemetry positions ranged from 8 to 48, with 75% having ≥ 30 telemetry positions.

Using BIOTAS software (Ecological Software Solutions, 2000), we estimated the home ranges of animals using the 475 nocturnal radiolocations, and 228 identified refuge locations. We calculated a Minimum Convex Polygon (MCP), and the 95% fixed kernel density estimators (KDE), with least-squares cross validation, which is relatively robust to small sample sizes (Seaman & Powell, 1996; Gredzens et al., 2014). We chose to report the MCP results but exclude them from subsequent analysis due to the limitations of this method (Börger et al., 2006). Estimated home ranges were then cropped to the boundary of the enclosure. Differences in home range size between sexes, temporal periods and trapping locations were tested using an independent t-test assuming unequal variances. Additionally, due to our small sample size, we tested if the exclusion of biangulations from our dataset would produce significantly different home ranges to those calculated using both biangulations and triangulations.

Habitat selection

We examined habitat selection at two scales, second order and third order, using 95% KDE. Second-order selection is the individual's home range within their geographic range, and third-order selection is their habitat use within their home range (Johnson, 1980). We imported telemetry locations and home range extents into QGIS v3.14 and overlaid them with the habitat vegetation map to calculate proportions utilised by animals. Four vegetation categories were identified within the enclosure and used in analyses; scattered shrubland over spinifex grass, dense shrubland over spinifex grass, dense mulga over tuft grass and bare understorey (Figure 2). When a habitat type was available but not utilised, a small positive value (< 0.001) less than the smallest proportion recorded for an individual was used in place of zero (Aebischer, Robertson, & Kenward, 1993).

Second order and third order habitat selection were analysed separately for the two temporal periods (diurnal and nocturnal) and two trapping locations. A one sample t-test was performed to assess if relative habitat use was non-random (significantly different to zero). Differences in habitat preference between temporal periods, and animals trapped from the two different locations of the enclosure were tested using a t-test assuming unequal variances.

Radiotracking error

We performed a post-hoc assessment on our triangulation data to evaluate the relationship between survey parameters and triangulation covariance. Survey parameters included the minimum, maximum and average distance between receivers, the minimum, maximum and average distance between receiver and the estimated signal, and the minimum, maximum and total bearing angle of the estimated signal. We performed a linear regression using R (R Core Team, 2018), guided by AIC models in package AICcmodavg 2.2-2 (Mazerolle, 2020), to detect significant relationships between our predictor variables and triangulation covariance. Covariance values ranged from 0.02 to 1.32×10^7 . We removed 146 datapoints considered outliers to normalise our data.

Results

Abundance estimates

To estimate the abundance of golden bandicoots inside the fenced enclosure at Matuwa we ran 12 model simulations using openCR consisting of a combinations of two datasets (complete CMR or subset CMR), two model formulations ($Global = \sigma \sim t, \lambda_0 \sim t, \phi \sim t, D \sim t$; or $\phi D = \sigma \sim 1, \lambda_0 \sim 1, \phi \sim t, D \sim t$), and three groups of bandicoots (females, males, or both sexes combined).

1 In January 2010, 160 golden bandicoots were translocated from Barrow Island into the fenced
2 enclosure at Matuwa. Our results suggest that in the 10 months following the translocation the
3 number of bandicoots declined to a low of 93 (SE = 11) bandicoots in October 2010 before the
4 population became established and started to increase (Figure 3). It was not until August 2011 that
5 our estimates of abundance approach 160 bandicoots (SE = 18). The population peaked in April 2015
6 with an average estimate of 304 (SE = 66), and a maximum estimate of 393 (SE = 49).

7 In 2012 and 2015, 49 and 93 golden bandicoots were removed from the fenced enclosure and
8 translocated to unfenced areas on Matuwa (Figure 3). In the results of the *PhiD* model built using the
9 subset CMR dataset (Figure 3), the number of bandicoots removed correlates closely with the
10 change in the estimated abundance of bandicoots during surveys either side of the translocation.
11 This suggests that the more conservative *PhiD* model provides reliable estimates of bandicoot
12 abundance over time. In comparison, the *Global* models produced widely fluctuating estimates of
13 bandicoot abundance (Supplemental Information S1).

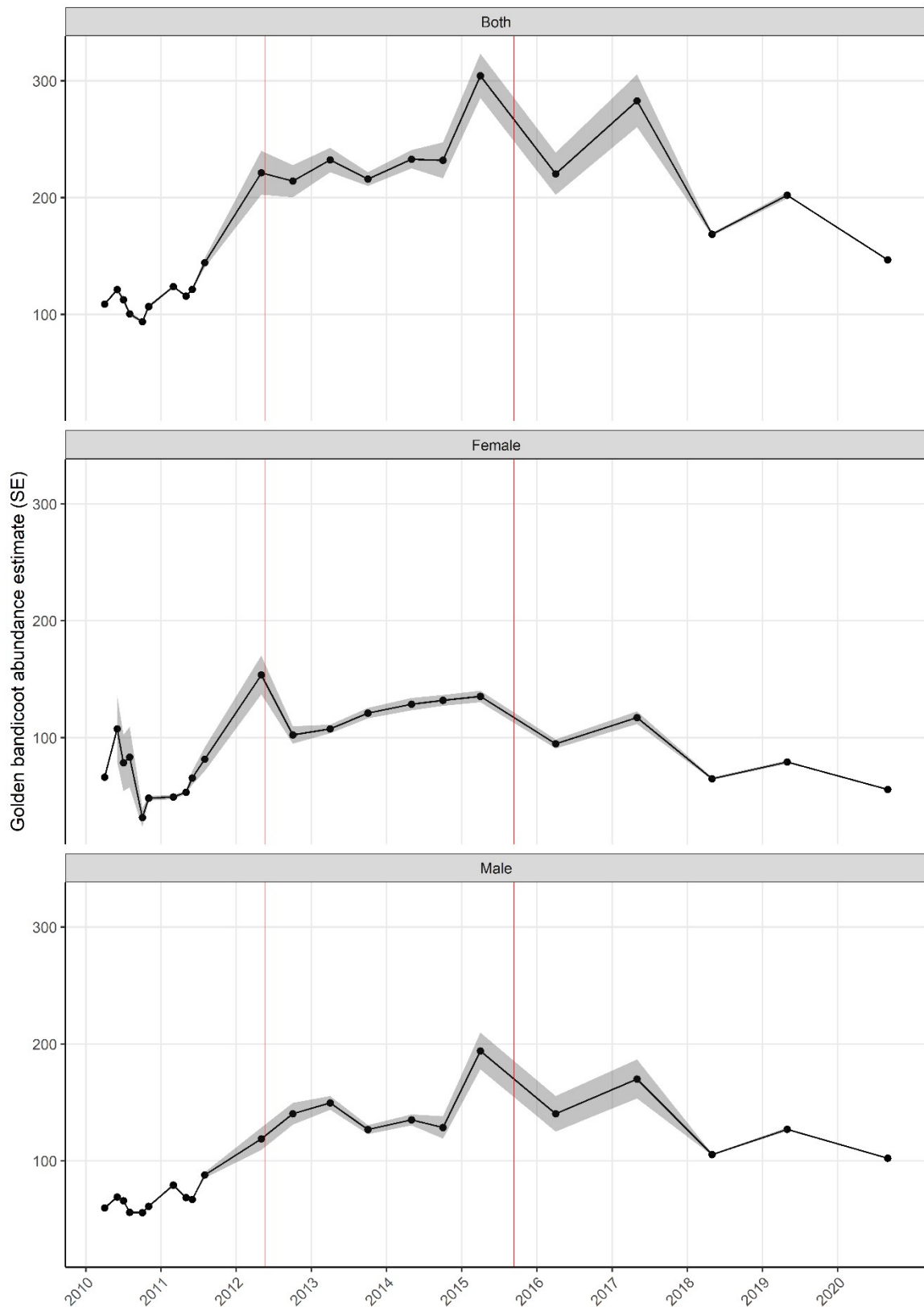
14 By May 2017, the bandicoot population inside the enclosure had recovered from the removal of 93
15 individuals 20 months earlier, returning to an average estimate of abundance of 282 golden
16 bandicoots (SE = 67). Subsequently, in 2018, the estimated abundance of golden bandicoots was
17 particularly difficult to obtain and potentially suppressed by a dramatic increase in the number of
18 boodies interfering with traps (Treloar et al., n.d.). In 2019, Matuwa recorded below average rainfall
19 with only 69.5 mm of rain in 12 months (average 262mm) that may have reduced the probability of
20 survival for some individuals. While the number of confounding variables makes it difficult to
21 confirm the precise abundance, we can conclude that the population of golden bandicoots within
22 the fenced enclosure at Matuwa is established and relatively stable with a maximum estimated
23 density of 0.35 bandicoots per hectare.

24 Removing traps that captured alternative species from the CMR dataset typically increased the
25 estimated abundance of golden bandicoots (Table 1). The estimate for female bandicoots from the

1 *Global* model increased by nearly 22%. Removing alternative species has a markedly lower impact
2 (<4%) on estimates generated by the *PhiD* model which held estimates of σ and λ_0
3 constant within each analytical window.

4 The *PhiD* models typically produced lower estimates of abundance than the *Global* model (Table 1).
5 Within simulations that used the subset CMR dataset, *PhiD* models suppressed abundance estimates
6 by 1 to 19%. Abundance estimates for female bandicoots were highly variable across model
7 formulations.

8



1
2 Figure 3: Estimates of the abundance of golden bandicoots within the fenced enclosure at Matuwa from subset
3 CMR data that excluded any traps that captured alternative species and PhiD models that held sigma and
4 lambda0 constant whilst allowing phi and D to vary. Results of other models are available in Supplementary

Information S1. Red vertical lines depict the translocation of 49 and 93 bandicoots out of the fenced enclosure onto unfenced areas of Matuwa.

Table 1: Average percent change in abundance estimates for golden bandicoots within the fenced enclosure at Matuwa when any traps that captured an alternative species were removed from the dataset (column 4) or when we switched from using the Global model ($\sigma \sim t$, $\lambda_0 \sim t$, $\phi \sim t$, $D \sim t$) to the PhiD model ($\sigma \sim 1$, $\lambda_0 \sim 1$, $\phi \sim t$, $D \sim t$).

Δ All captures →				
Sex	Model	Subset	subset CMR (%)	Δ Global → PhiD (%)
Both	Global		7.43	
Both	PhiD		4.03	
Female	Global		21.85	
Female	PhiD		-1.31	
Male	Global		8.32	
Male	PhiD		3.19	
Both		All data		1.98
Both		subset CMR		-0.49
Female		All data		-3.76
Female		subset CMR		-19.03
Male		All data		1.24
Male		subset CMR		-1.00

Home range

In total, we collected 703 telemetry positions across the 20 bandicoots within the Matuwa enclosure. The comparison between the total dataset and the dataset excluding biangulations showed that the 95% KDE did not differ significantly between the sets of data ($p = 0.50$, $p = 0.50$)

(Table 2). Less accurate biangulations did affect estimates of MCP. Therefore, the total dataset and 95% KDE estimates were used for subsequent analyses.

Table 2. Comparison of mean home range and standard error between the total dataset and the dataset excluding biangulations.

Dataset	Telemetry positions	95% KDE ha (SE)	MCP ha (SE)
Total data	703	18.08 (±5.66)	54.72 (±9.71)
Data with biangulations excluded	510	18.03 (±5.33)	27.22 (±4.70)

There were 228 refuge locations identified during the diurnal period, and 475 active locations identified using triangulation during the nocturnal period. Home range sizes for the nocturnal period were larger than those in the diurnal period ($p = 2.43 \times 10^{-4}$). The mean 95% KDE was 18.08 ha (±5.66) whereas mean MCP was 54.72 ha. KDE were considerably smaller than MCP due to the repeated use of diurnal refuge sites. Male bandicoots had 26% to 45% larger home ranges than females across temporal periods (Table 3), although values were not statistically significant ($p = 0.09$). When only nocturnal foraging range was analysed, males had a significantly larger home range than females ($p = 0.02$). There was no significant difference in diurnal sheltering range between sexes ($p = 0.10$).

Bandicoots trapped along the northern track (henceforth 'northern bandicoots') showed larger home ranges to bandicoots trapped along the central track (henceforth 'central bandicoots') (Table 3). Values were not statistically significant across temporal periods but approached significance when only nocturnal foraging range was analysed ($p = 0.06$). These results indicate variation in activity between sexes, and between animals trapped along the central track and the northern track, in the nocturnal foraging range but not within the diurnal sheltering range.

1 Table 3. Summary of mean home ranges for golden bandicoots calculated using MCP and fixed 95% kernel
2 density estimates in the Matuwa enclosure.

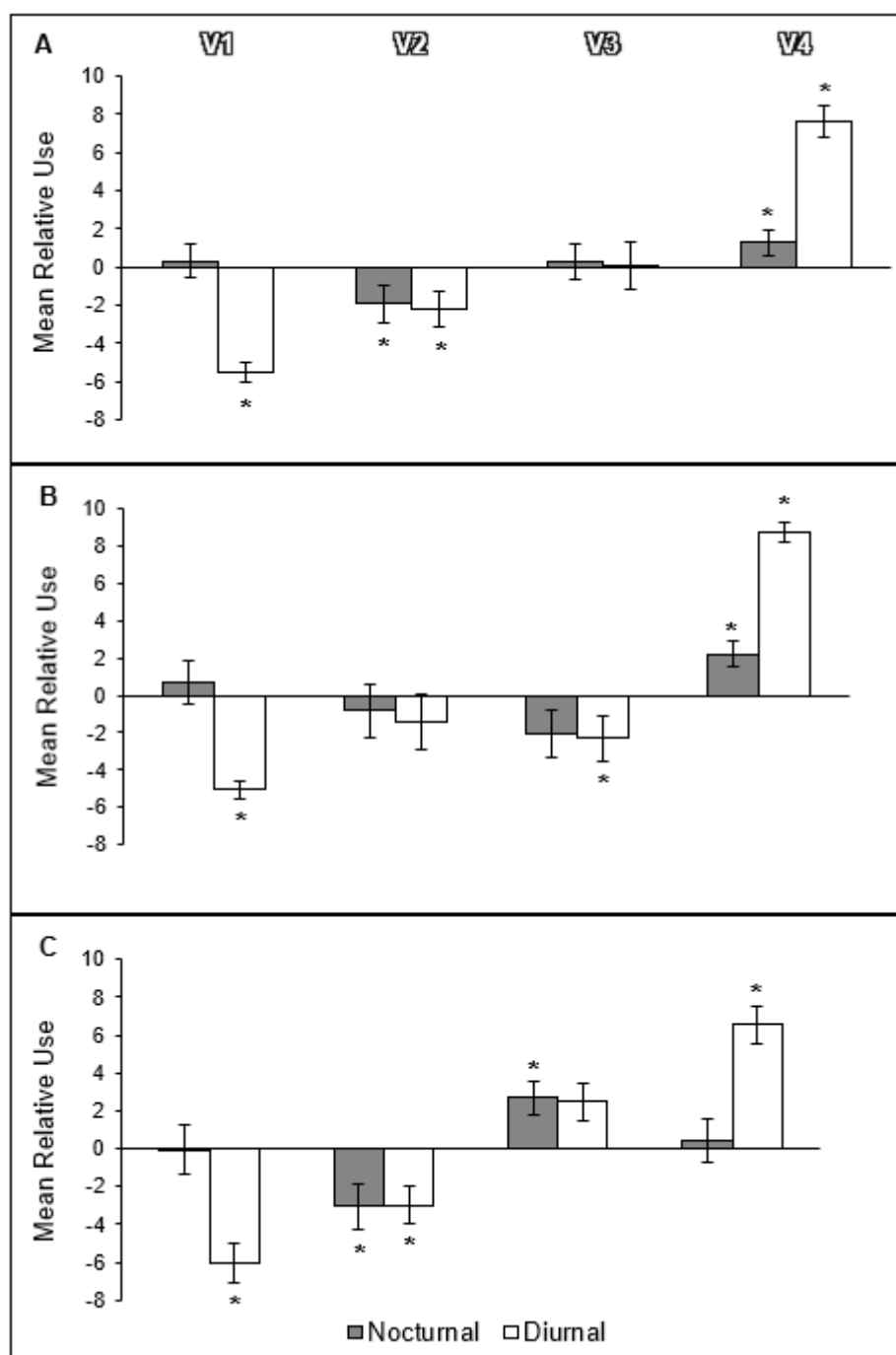
Sex	Temporal Period	n	Mean 95% KDE (ha) (SE)	MCP ha (SE)
Male	Diurnal	152	8.45 (±4.01)	3.09 (±0.65)
	Nocturnal	312	84.77 (±19.17)	46.68 (±9.02)
Subtotal		464	21.64 (±7.89)	48.64 (±8.62)
Female	Diurnal	76	2.97 (±0.45)	4.21 (±3.42)
	Nocturnal	163	34.64 (±12.28)	68.19 (±26.26)
Subtotal		239	9.77 (±2.96)	68.90 (±26.17)
Central track	Diurnal	118	5.03 (±1.06)	2.62 (±0.86)
	Nocturnal	269	46.90 (±12.05)	53.63 (±17.01)
Subtotal		387	14.08 (±2.41)	55.05 (± 16.70)
Northern track	Diurnal	110	8.79 (±5.66)	4.08 (±1.67)
	Nocturnal	206	92.56 (±25.49)	52.63 (±11.24)
Subtotal		316	22.08 (±11.23)	54.39 (±10.90)
Total		703	18.08 (±5.66)	54.72 (±9.71)

3

4 Habitat selection

5 Second-order selection by bandicoots (home range composition relative to availability within the
6 enclosure) was non-random. Bandicoots selected scattered shrubland over spinifex grassland across
7 both their diurnal refuge and nocturnal foraging home range (9.93×10^{-4}).
8 Within the home ranges of all 20 bandicoots (third-order habitat selection), scattered shrubland over
9 spinifex grass habitat was significantly selected as refuge locations within the diurnal sheltering

1 period, ($p = 7.5 \times 10^{-9}$), whereas bare understorey was significantly avoided ($p = 7.58 \times 10^{-10}$; Figure 4A1
2 and 4A2). Of the 228 refuges identified, 84% were located under a spinifex hummock. Refuge
3 locations typically had sandy soil with less than 10% overstorey cover (Table 4). During the nocturnal
4 foraging period, bandicoots also significantly selected for scattered shrubland over spinifex grass
5 habitat ($p = 0.04$). During the nocturnal and diurnal period, bandicoots showed a significant
6 avoidance of dense shrubland over spinifex (nocturnal 95% KDE $p = 0.03$, diurnal 95% KDE $p = 0.02$),
7 and used all other habitats in proportion to their availability. This trend was consistent across sexes.



1

Figure 4. Mean third-order habitat selection (using the 95% KDE) of golden bandicoots during their nocturnal and diurnal period for four habitat types; V1 - Bare understorey, V2 - Dense shrubland over spinifex grass, V3 - Dense mulga over tuft grass, V4 - Scattered shrubland over spinifex grass. Graphs A1 and A2 reflect habitat selection by all 20 bandicoots. Graphs B1 and B2 reflect the 10 bandicoots trapped along the central track of the reserve. Graphs C1 and C2 reflect the 10 bandicoots trapped along the northern track. Positive values represent habitat used more than random and negative values represent habitat used less than random. Asterisks indicate habitats selected significantly more or less than at random ($p < 0.05^*$).

Table 4: Characteristics of the total refuge sites (n=228) occupied by golden bandicoots when homing during the diurnal period. Percentages are not cumulative for soil type and vegetation overstorey as variables could co-occur.

Animal group	Soil			
	Sand (%)	Loam (%)	Clay (%)	Gravel (%)
Central (118)	77.1	39.0	17.8	0.0
Northern (110)	66.4	31.8	29.1	0.9
Total (228)	71.9	35.5	23.2	0.4
Refuge location				
	Under spinifex clump (%)	Under other grass type (%)	Burrow (adopted or self-made) (%)	Tree hollow or under fallen branches (%)
Central	92.4	4.2	0.8	2.5
Northern	73.6	4.5	5.5	16.4
Total	83.8	4.4	3.1	9.2
Location in the landscape: Veg understorey				
	Spinifex (>10% veg cover)	Other grass type (>10% veg cover)	Bare ($\leq 10\%$ veg cover) (%)	

	(%)	cover) (%)	
Central	95.8	2.5	1.7
Northern	79.1	19.1	1.8
Total	87.7	10.5	1.8
Location in the landscape: Veg overstorey			
	<i>Acacia/mulga (>10% veg cover) (%)</i>	<i>Eucalyptus/mallee (>10% veg cover) (%)</i>	<i>Minimal overstorey (≤10% veg overstorey) (%)</i>
Central	21.2	2.5	76.3
Northern	31.8	13.6	60.0
Total	26.3	7.9	68.4

Trapping location (North or Central track) was not a significant factor in explaining variation in diurnal refuge selection (Table 4), however, trapping locations did appear to influence the selection of nocturnal foraging habitat (Figure 4). Bandicoots trapped on the northern track selected for dense mulga over tuft grass habitat during the nocturnal foraging period ($p = 6.04 \times 10^{-3}$), whereas bandicoots trapped on the central track selected for scattered shrubland over spinifex grass habitat ($p = 4.96 \times 10^{-3}$). The significant avoidance of dense shrubland over spinifex seen across all twenty bandicoots was only evident among animals from the northern track when animals were analysed by their trapping location within their 95% KDE (diurnal $p = 0.02$, nocturnal $p = 0.02$). We did not perform two-way analysis with both sex and trapping location as covariates due to a low sample size of females ($n_{\text{central track females}} = 4$, $n_{\text{northern track females}} = 2$).

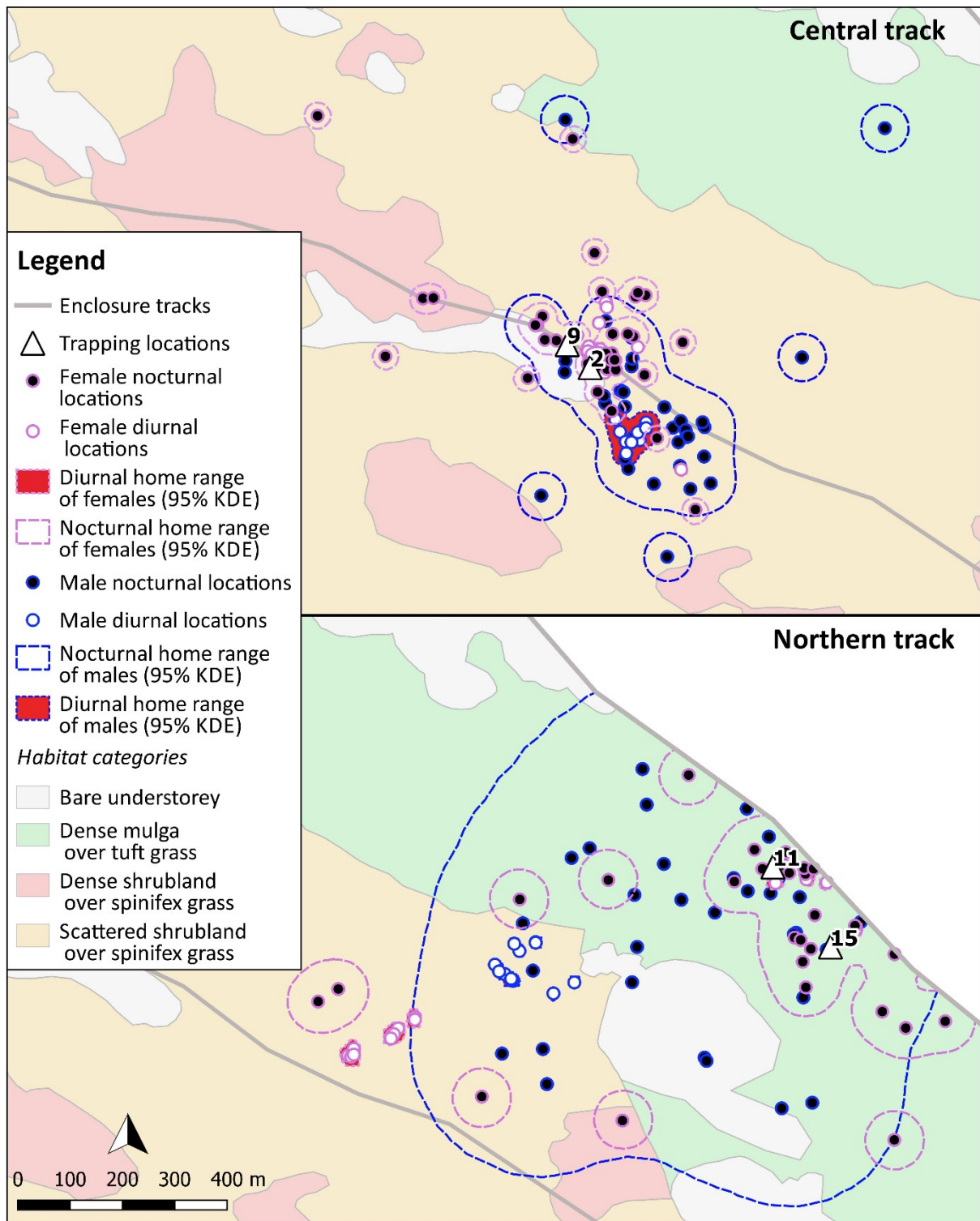


Figure 5. Radiolocations and estimated home range sizes (95% KDE) of 4 animals, a male and female from the central track (GB02 and GB09), and a male and female from the northern track (GB11 and GB15).

1 Radiotracking error

2 A significant positive relationship was found between the maximum distance between receiver
 3 locations and triangulation covariance of the estimated signal (Table 5; $p = 0.01$). As seen in Figure 6,
 4 covariance significantly increases when receivers are more than 250m apart. Reference locations
 5 were approximately 200m apart. As expected, there was a negative relationship between the
 6 distance between the receiver and the signal and the covariance but decline in signal strength was
 7 not a significant explanatory variable of covariance. It is possible that signal reflection off the
 8 enclosure fence increased signal covariance. This problem may be reduced by using ≥ 3 bearings for
 9 triangulation (Garrott et al., 1986).

10

11 *Table 5. Linear regression results for potential explanatory variables for variation in the estimated covariance*
 12 *of telemetry locations. Covariance (CoVar), MaxRDistS (Maximum distance between receiver and signal),*
 13 *MaxRDistR (Maximum distance between two receivers), TotalA (Total angle at apex of triangle created by*
 14 *signal and location of two receivers).*

Model	Adj R ²	F statistic	DF	Residual SE
(CoVar~MaxRDistS+MaxRDistR+TotalA-1)	0.58	66.44	140	486.30
Estimate				
Predictor variables	Coefficients	Std. Error	t value	Pr(> t)
MaxRDistS	-0.1492	0.2746	-0.543	0.5879
MaxRDistR	0.8828	0.3465	2.548	0.0119*
TotalA	0.3013	0.891	0.338	0.7357

15

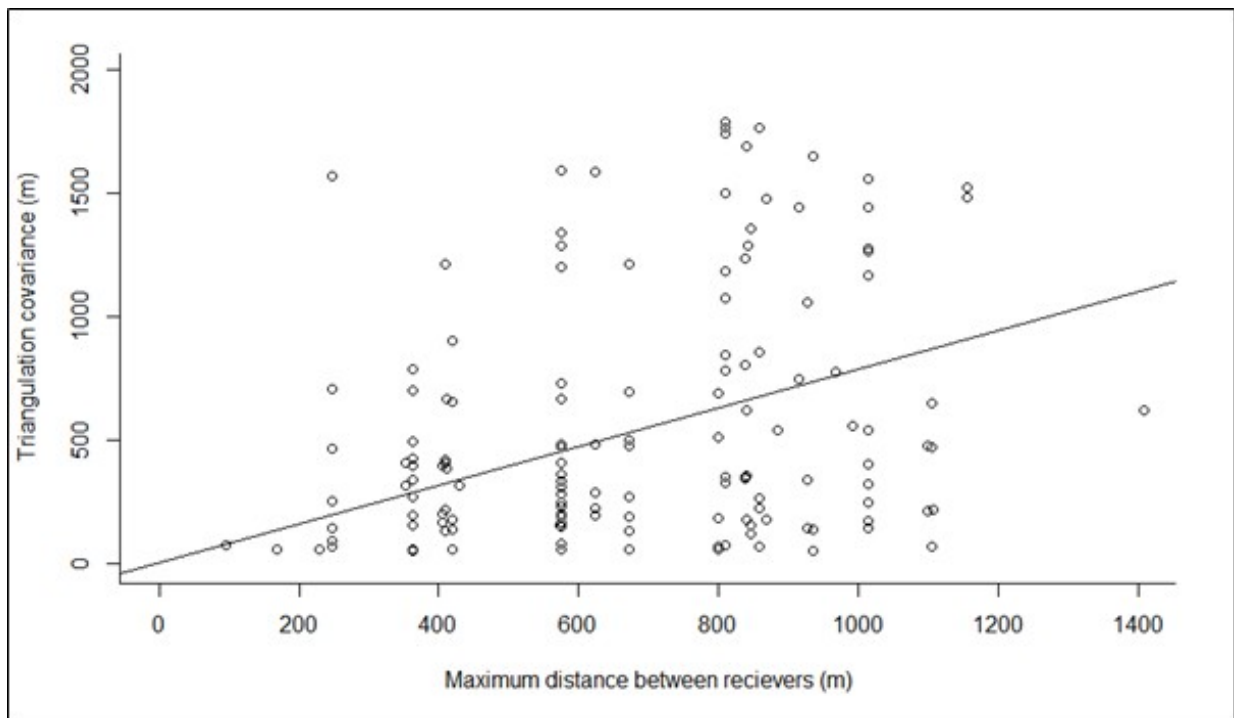


Figure 6. Response of Covariance to maximum distance maintained between receivers when radiotracking (n=143).

Discussion

Our results supported both of our hypotheses: 1) we expected golden bandicoots to select vegetation with an understorey of hummock/spinifex grasses for shelter and protection over open mulga woodlands and 2) we expected home-range characteristics to differ between the sexes.

Diurnal refuge locations occurred in scattered shrubland over spinifex significantly more than in proportion to availability both for bandicoots trapped near that habitat (central track) and bandicoots trapped in dense mulga over tuft grass. This is consistent with past radiotracking studies on golden bandicoots (Graham, 1996; Southgate et al., 1996), other bandicoot species, (Chambers & Dickman, 2002), and other small insectivorous marsupials (Bos & Carthew, 2003; Haythornthwaite, 2005).

Spinifex provides refuge from predators, insulation from temperature extremes, and a stable food resource by hosting invertebrate populations (Chambers & Dickman, 2002). Dome-forming

hummocks such as *T. basedowii* are especially insulative (Churchill, 2001) and used by three species of dunnart as shelter, *Sminthopsis psammophila*, *S. ooldea* and *S. youngsoni* (Riley, 2020). Ground temperatures in the arid zone can be extreme with records of -4.5 to 61 °C in the Western Australia Great Victoria Desert (Riley, 2020) and potentially lethal to fauna if appropriate thermally insulative shelter is not available (Kinlaw, 1999). Similar benefits are seen in other vegetation types such as grass trees where dense canopies provide shelter and insulation (Keiper & Johnson, 2004; Deborah Susan Frazer, 2005; Deborah S Frazer & Petit, 2007). Whereas, other shelter types, such as fallen logs or ring-forming spinifex species (e.g., *T. desertorum*) do not provide the same insulative properties as hummock species, but may be used during milder weather (Riley, 2020). *T. basedowii* is the dominant spinifex species in our study site.

Golden bandicoots are thought to be a polygynous species (Ottewell et al., 2014). Polygynous species have been experimentally shown to exhibit sexually diethic traits such as variation in home-range size with the promiscuous sex having the larger range (Gaulin & FitzGerald, 1988). Males of most bandicoot species have larger home-ranges (Van Dyck & Strahan, 2008). Our results also showed males to have a larger home range than females, providing further evidence that golden bandicoots are polygynous.

The range size and selection of nocturnal foraging habitat among golden bandicoots varied within our study. Central bandicoots generally remained close to their refuge with an average home-range size half that of northern bandicoots, with few long-distance foraging forays, similar to activity described for Kimberley mainland bandicoots (Graham, 1996). Northern bandicoots travelled greater distances, usually north from spinifex habitat that provided diurnal refuge towards dense mulga over tuft grass and back. Radiolocations of northern animals are sparser suggesting animals are exhibiting greater manoeuvrability and expending more energy searching for food.

Animals from the northern part of the enclosure are exhibiting a riskier foraging strategy by travelling further from their primary refuge habitat to forage in more open habitat. This foraging strategy was also seen on Marchinbar Island (Southgate et al., 1996). Greater mean daily movement

1 of individuals is associated with increased risk of mortality in other species (M. Lohr et al., 2011).

2 Open habitat is considered riskier as predators that hunt visually, such as birds of prey, can detect

3 and capture prey more readily than in dense vegetation (Brown et al., 1988; Meyer & Valone, 1999).

4 On the other hand, prey abundance and diversity can be higher in open habitat for bandicoots

5 (Scott, Hume, & Dickman, 1999), and dasyurid species (Fisher & Dickman, 1993).

6 We propose two hypotheses as to why a riskier foraging strategy is exhibited by northern animals.

7 First, scattered shrubland over spinifex grass may be a more resource rich environment than dense

8 mulga over tuft grass. Since bandicoot home-range is reportedly negatively correlated with food

9 abundance (Broughton & Dickman, 1991), northern bandicoots need to travel further than central

10 bandicoots to attain sufficient food resources. Second, a higher density of animals and associated

11 intraspecific competition and territorial behaviours may be interacting with the resource rich

12 spinifex to constrain bandicoot home-ranges (Schradin et al., 2010). Territorial behaviours, however,

13 have not been observed in closely related southern brown bandicoots (*I. fusciventer*) (Broughton &

14 Dickman, 1991; Travouillon & Phillips, 2018; Thavornkanlapachai et al., 2021).

15 Unlikely alternative hypotheses are that the energetic reward of food available in dense mulga over

16 tuft grass may outweigh the risk of predation and be encouraging bandicoots whose home-range is

17 near the ecotone between the habitats to forage widely. Or bandicoots, like many other species,

18 require a habitat mosaic to maximise foraging efficiency and increase rates of reproduction and

19 survival (Law & Dickman, 1998). Interspecific competition was deemed unlikely as the only

20 potentially competing species are brush-tailed mulgara (*Dasyurus blythi*), who forage for

21 invertebrates in topsoil (Molyneux et al., 2018; Pavey et al., 2018) while bandicoots consume

22 subfossorial invertebrates (Southgate et al., 1996).

23 Intraspecific competition and resultant emigration may also explain why the density of golden

24 bandicoots in the Matuwa enclosure is approximately one quarter of the density recorded in the

25 founder population on Barrow Island which was 1.65 to 1.72 bandicoots per hectare (Teale, 2013).

1 As in striped mice (*Rhabdomys pumilio*) (Schradin et al., 2010) high densities of animals and
2 associated intraspecific competition may limit a bandicoots' home-range and hence access to
3 resources, which may manifest as reduced bodyweight, survival or reproductive output. When
4 golden bandicoots were translocated from Barrow Island to Matuwa there was a sudden increase in
5 individuals mass by 28 to 34% for males and females respectively (Judy Dunlop, Morris, &
6 Thompson, 2012). A similar increase in mass occurred when bandicoots were translocated from the
7 Matuwa enclosure to the neighbouring open landscape (Blythman et al., 2020) suggesting the
8 translocated individuals were released from an environment with limited resources. Golden
9 bandicoots are capable of emigrating through the fenced enclosure despite the use of fine mesh
10 (40mm 'rabbit wire') and have been observed surviving on the open landscape in very low densities
11 (Blythman et al., 2020) and have appeared as prey items in dingo scats outside of the fenced area
12 (Wysong et al., 2019). If bandicoots are regularly dispersing through the fence of the enclosure, then
13 we would expect the density of the remaining population to be lower than a closed system (Barrow
14 Island) or carrying capacity.

15 We selected a conservative model (*PhiD* model on subset CMR data) to predict the density and
16 abundance of golden bandicoots in the Matuwa enclosure. The *Global* model predicted wide
17 fluctuations in bandicoot abundance over the last 10 years (Supplementary Information S1). The
18 modelling package *openCR* is a new but advanced modelling system that allows us to use spatially
19 explicit capture-recapture data analysis for open populations. All other modelling systems assume a
20 population is closed, which is frequently a fundamentally flawed assumption. Limitations of *openCR*
21 include an inability to perform goodness-of-fit tests, AIC model ranking or any adjustments for
22 overdispersion of data (Efford, 2019). This limits our ability to determine statistically if the
23 conservative model presented here is better than the *Global* model.

1 Management implications

2 Our research has demonstrated that in the central Australian arid zone golden bandicoots will use a
3 diverse array of habitat types but appear to select scattered shrubland over spinifex grass, probably
4 because of the insulative properties of hummock forming spinifex. Until further research confirms or
5 refutes our results, ideally with a larger number of female bandicoots, future translocation proposals
6 for golden bandicoots should demonstrate that their selected translocation sites contain
7 considerable quantities of hummock spinifex. Additional studies into the diet and body condition of
8 golden bandicoots as it relates to habitat selection would also be beneficial as there is some
9 suggestion that small mammal species that occupy dry habitats are dietary generalists but habitat
10 specialists (Braithwaite & Gullan, 1978). A better understanding of this relationship in the context of
11 Australian fauna could be informative in planning translocations. We also recommend that future
12 research ascertain the rate of golden bandicoot dispersal through fences as unmeasured loss of
13 animals to emigration will affect managers' interpretation of population parameters within fenced
14 enclosures.

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22 Conservation and Attractions.

23 Data Availability Statement

24 Data used in this study are available for download on Dryad (DOI to be provided on acceptance).

1

2 References

3 Aebischer, N. J., Robertson, P. A., & Kenward, R. E. (1993). Compositional analysis of habitat use
4 from animal radio-tracking data. *Ecology* **74**, 1313–1325.

5 Baynes, A. (2006). Preliminary assessment of the original mammal fauna of Lorna Glen station.
6 Perth, Western Australia: Department of Conservation and Land Management.

7 Bester, A. J., & Rusten, K. (2009). Trial translocation of the numbat (*Myrmecobius fasciatus*) into arid
8 Australia. *Aust. Mammal.* **31**, 9–16.

9 Blythman, M., Lohr, C., Sims, C., & Morris, K. (2020). Translocation of Golden Bandicoots, *Isodon*
10 *auratus barrowensis*, from a fenced enclosure to unfenced managed land on Matuwa (formally
11 Lorna Glen) September 2015: Final Report. Perth, Western Australia: Department of
12 Biodiversity Conservation and Attractions.

13 Bode, M., Brennan, K. E. C., Morris, K., Burrows, N., & Hague, N. (2012). Choosing cost-effective
14 locations for conservation fences in the local landscape. *Wildl. Res.* **39**, 192–201.

15 Börger, L., Franconi, N., De Michele, G., Gantz, A., Meschi, F., Manica, A., Lovari, S., & Coulson, T. I.
16 M. (2006). Effects of sampling regime on the mean and variance of home range size estimates.
17 *J. Anim. Ecol.* **75**, 1393–1405.

18 Bos, D. G., & Carthew, S. M. (2003). The influence of behaviour and season on habitat selection by a
19 small mammal. *Ecography (Cop.)*. **26**, 810–820.

20 Braithwaite, R., & Gullan, P. (1978). Habitat selection by small mammals in a Victorian heathland.
21 *Aust. J. Ecol.* **3**, 109–127.

22 Broughton, S. K., & Dickman, C. R. (1991). The effect of supplementary food on home range of the
23 southern brown bandicoot, *Isodon obesulus* (Marsupialia: Peramelidae). *Aust. J. Ecol.* **16**, 71–

78.

- Brown, J. S., Kotler, B. P., Smith, R. J., & Wirtz, W. O. (1988). The effects of owl predation on the foraging behavior of heteromyid rodents. *Oecologia* **76**, 408–415.
- Burbidge, A. A., McKenzie, N. L., Brennan, K. E. C., Woinarski, J. C. Z., Dickman, C. R., Baynes, A., Gordon, G., Menkhorst, P. W., & Robinson, A. C. (2009). Conservation status and biogeography of Australia's terrestrial mammals. *Aust. J. Zool.* **56**, 411–422.
- Burbidge, A., & Woinarski, J. (2016). *Isodon auratus* (errata version published in 2017). *IUCN Red List Threat. Species 2016 e.T10863A115100163*.
- Chambers, L. K., & Dickman, C. R. (2002). Habitat selection of the long-nosed bandicoot, *Perameles nasuta* (Mammalia, Peramelidae), in a patchy urban environment. *Austral Ecol.* **27**, 334–342.
- Chapman, T., & Burrows, N. (2015). Lorna Glen (Matuwa) small vertebrate fauna monitoring program 2002-2010 - preliminary analysis and review. Perth, Western Australia: Western Australia Department of Parks and Wildlife.
- Churchill, S. (2001). Survey and Ecological Study of the Sandhill Dunnart, *Sminthopsis psammophila*, at Eyre Peninsula and the Great Victoria Desert. Department for Environment and Heritage.
- Clarke, R. H., Boulton, R. L., & Clarke, M. F. (2002). Translocation of the socially complex Black-eared Miner *Manorina melanotis*: a trial using hard and soft release techniques. *Pacific Conserv. Biol.* **8**, 223–234.
- Coate, K. (2010). An annotated checklist of birds from Lorna Glen (Matuwa): A proposed conservation park on the boundary of the Murchison and Gascoyne regions of Western Australia. *West. Aust. Nat.* **27**, 127–149.
- Department of Agriculture Water and the Environment. (2020). Australia's bioregions (IBRA). *Aust. Gov.*

- 1 Department of the Environment Water Heritage and the Arts. (2009). Assessment of Australia's
2 Terrestrial Biodiversity 2008. Report prepared by the Biodiversity Assessment Working Group
3 of the National Land and Water Resources Audit. Canberra: Australian Government,.
- 4 Dunlop, JA. (2015). The ecology and host parasite dynamics of a fauna translocation in Australia.
5 Perth, Western Australia: PhD thesis, Murdoch University.
- 6 Dunlop, JA, Smith, A., Burbidge, A., Thomas, N., & Morris, K. (n.d.). Industry environmental offset
7 funding facilitates a large multi-species fauna translocation program. *Pacific Conserv. Biol.*
- 8 Dunlop, Judy, & Morris, K. (2018). Environmental determination of body size in mammals: Rethinking
9 'island dwarfism' in the golden bandicoot. *Austral Ecol.* **43**, 817–827.
- 10 Dunlop, Judy, Morris, K., & Thompson, A. (2012). Translocation removes island dwarfism in the
11 golden bandicoot (*Isodon auratus*).
- 12 Ecological Software Solutions. (2000). Software BIOTAS and LOAS. *Sacramento CA*.
- 13 Efford, M. (2019). openCR: open population capture-recapture. R package version 1.4.
- 14 Fisher, D. O., & Dickman, C. R. (1993). Body size-prey relationships in insectivorous marsupials: tests
15 of three hypotheses. *Ecology* **74**, 1871–1883.
- 16 Frazer, Deborah S, & Petit, S. (2007). Use of *Xanthorrhoea semiplana* (grass-trees) for refuge by
17 *Rattus fuscipes* (southern bush rat). *Wildl. Res.* **34**, 379–386.
- 18 Frazer, Deborah Susan. (2005). The Role of *Xanthorrhoea Semiplana* (grass Trees) as Refuges for
19 Small Native Vertebrates: Habitat Value, Microclimate, and Use by Animals in the Mount Lofty
20 Ranges of South Australia. University of South Australia.
- 21 Garrott, R. A., White, G. C., Bartmann, R. M., & Weybright, D. L. (1986). Reflected signal bias in
22 biotelemetry triangulation systems. *J. Wildl. Manage.* 747–752.
- 23 Gaulin, S. J. C., & FitzGerald, R. W. (1988). Home-range size as a predictor of mating systems in

- 1 *Microtus*. *J. Mammal.* **69**, 311–319.
- 2 Geyle, H. M., Woinarski, J. C. Z., Baker, G. B., Dickman, C. R., Dutson, G., Fisher, D. O., Ford, H.,
3 Holdsworth, M., Jones, M. E., Kutt, A., & others. (2018). Quantifying extinction risk and
4 forecasting the number of impending Australian bird and mammal extinctions. *Pacific Conserv.*
5 *Biol.* **24**, 157–167.
- 6 Gibson, L. A., & McKenzie, N. L. (2012). Occurrence of non-volant mammals on islands along the
7 Kimberley coast of Western Australia. *Rec. West. Aust. Museum* **81**, 15–40.
- 8 Graham, G. (1996). Golden Bandicoot: taxonomy, distribution in the Kimberley, final report.
9 Kununurra, Western Australia: Department of Conservation and Land Management.
- 10 Gredzens, C., Marsh, H., Fuentes, M. M. P. B., Limpus, C. J., Shimada, T., & Hamann, M. (2014).
11 Satellite tracking of sympatric marine megafauna can inform the biological basis for species co-
12 management. *PLoS One* **9**, e98944.
- 13 Haythornthwaite, A. S. (2005). Microhabitat use and foraging behaviour of *Sminthopsis youngsoni*
14 (Marsupialia: Dasyuridae) in arid central Australia. *Wildl. Res.* **32**, 609–615.
- 15 IUCN/SSC. (2013). Guidelines for reintroductions and other conservation translocations. Version 1.0.
16 Gland, Switzerland: IUCN Species Survival Commission.
- 17 Johnson, D. H. (1980). The comparison of usage and availability measurements for evaluating
18 resource preference. *Ecology* **61**, 65–71.
- 19 Keiper, P., & Johnson, C. N. (2004). Diet and habitat preference of the Cape York short-nosed
20 bandicoot (*Isodon obesulus peninsulae*) in north-east Queensland. *Wildl. Res.* **31**, 259–265.
- 21 Kinlaw, A. (1999). A review of burrowing by semi-fossorial vertebrates in arid environments. *J. Arid*
22 *Environ.* **41**, 127–145.
- 23 Law, B. S., & Dickman, C. R. (1998). The use of habitat mosaics by terrestrial vertebrate fauna:

1 implications for conservation and management. *Biodivers. Conserv.* **7**, 323–333.

2 Littlewood, N., Rocha, R., Smith, R., Martin, P., Lockhart, S., Schoonover, R., Wilma, E., Bladon, A.,
3 Sainsbury, K., Pimm, S., & Sutherland, W. (2020). *Terrestrial Mammal Conservation: Global*
4 Evidence for the Effects of Interventions for terrestrial mammals excluding bats and primates.
5 Synopses of Conservation Evidence Series. Cambridge, UK: University of Cambridge.

6 Lohr, C. (2019). Twelve years of rangelands restoration: reintroduction of native mammals to
7 Matuwa (ex-Lorna Glen pastoral lease): SPP 2012-024. Woodvale, WA.

8 Lohr, M., Collins, B., Williams, C., & Castelli, P. (2011). Life on the edge: northern bobwhite ecology
9 at the northern periphery of their range. *J. Wildl. Manage.* **75**, 52–60.

10 Mazerolle, M. (2020). AICcmodavg v2.3-1. *RDocumentation*.

11 McKenzie, N. L., Burbidge, A. A., Baynes, A., Brereton, R. N., Dickman, C. R., Gordon, G., Gibson, L. A.,
12 Menkhorst, P. W., Robinson, A. C., Williams, M. R., & others. (2007). Analysis of factors
13 implicated in the recent decline of Australia's mammal fauna. *J. Biogeogr.* **34**, 597–611.

14 Meyer, M. D., & Valone, T. J. (1999). Foraging under multiple costs: the importance of predation,
15 energetic, and assessment error costs to a desert forager. *Oikos* 571–579.

16 Molyneux, J., Pavey, C. R., James, A. I., & Carthew, S. M. (2018). Habitat use by the brush-tailed
17 mulgara (*Dasycercus blythi*). *Aust. J. Zool.* **65**, 335–345.

18 Moseby, K. E., Lollback, G. W., & Lynch, C. E. (2018). Too much of a good thing; successful
19 reintroduction leads to overpopulation in a threatened mammal. *Biol. Conserv.* **219**, 78–88.

20 Ottewell, K., Dunlop, J., Thomas, N., Morris, K., Coates, D., & Byrne, M. (2014). Evaluating success of
21 translocations in maintaining genetic diversity in a threatened mammal. *Biol. Conserv.* **171**,
22 209–219.

23 Palmer, C., Taylor, R., Burbidge, A., Territory, N., & Trust, N. (2003). Recovery Plan for the Golden

- 1 Bandicoot *Isodon auratus* and Golden-backed Tree-rat *Mesembriomys macrurus*, 2004-2009.
2 Darwin, NT: Northern Territory Department of Infrastructure Planning and Environment.
- 3 Pavey, C. R., Burwell, C. J., Körtner, G., & Geiser, F. (2018). Trophic ecology of marsupial predators in
4 arid Australia following reshaping of predator assemblages. *J. Mammal.* **99**, 1128–1136.
- 5 Priddel, D., & Carlile, N. (2001). A trial translocation of Gould's petrel (*Pterodroma leucoptera*
6 *leucoptera*). *Emu* **101**, 79–88.
- 7 R Core Team. (2018). The R Project for statistical computing. *R Found. Stat. Comput.*
- 8 Rabosky, D. L., Cowan, M. A., Talaba, A. L., & Lovette, I. J. (2011). Species interactions mediate
9 phylogenetic community structure in a hyperdiverse lizard assemblage from arid Australia. *Am.*
10 *Nat.* **178**, 579–595.
- 11 Rayner, K., Lohr, C., Garretson, S., & Speldewinde, P. (n.d.). Two species, one island: Retrospective
12 analysis of threatened fauna translocations with divergent outcomes. *PLoS One*.
- 13 Rick, K., Ottewell, K., Lohr, C., Thavornkanlapachai, R., Byrne, M., & Kennington, W. J. (2019).
14 Population genomics of *Bettongia lesueur*: Admixing increases genetic diversity with no
15 evidence of outbreeding depression. *Genes (Basel)*. **10**.
- 16 Riley, J. L. (2020). Spatial Ecology and Conservation Management of the Endangered Sandhill
17 Dunnart, *Sminthopsis Psammophila*. University of Bristol.
- 18 Ringma, J., Legge, S., Woinarski, J., Radford, J., Wintle, B., & Bode, M. (2018). Australia's mammal
19 fauna requires a strategic and enhanced network of predator-free havens. *Nat. Ecol. Evol.* **2**,
20 410–411.
- 21 Rowell, T. A. A. D., Magrath, M. J. L., & Magrath, R. D. (2020). Predator-awareness training in
22 terrestrial vertebrates: Progress, problems and possibilities. *Biol. Conserv.* **252**, 108740.
- 23 Saifuddin, R., Jovanoski, Z., Safuan, H., Watt, S. D., Sidhu, H. S., & Towers, I. N. (2017). Invasive

- 1 species in a confined environment: Reindeer population in the Pribilof Islands.
- 2 Schradin, C., Schmohl, G., Rödel, H. G., Schoepf, I., Treffler, S. M., Brenner, J., Bleeker, M., Schubert,
3 M., König, B., & Pillay, N. (2010). Female home range size is regulated by resource distribution
4 and intraspecific competition: a long-term field study. *Anim. Behav.* **79**, 195–203.
- 5 Scott, L. K., Hume, I. D., & Dickman, C. R. (1999). Ecology and population biology of long-nosed
6 bandicoots (*Perameles nasuta*) at North Head, Sydney Harbour National Park. *Wildl. Res.* **26**,
7 805–821.
- 8 Seaman, D. E., & Powell, R. A. (1996). An evaluation of the accuracy of kernel density estimators for
9 home range analysis. *Ecology* **77**, 2075–2085.
- 10 Short, J., & Turner, B. (1994). A test of the vegetation mosaic hypothesis: a hypothesis to explain the
11 decline and extinction of Australian mammals. *Conserv. Biol.* **8**, 439–449.
- 12 Southgate, R., Palmer, C., Adams, M., Masters, P., Triggs, B., & Woinarski, J. (1996). Population and
13 habitat characteristics of the golden bandicoot (*Isodon auratus*) on Marchinbar Island,
14 Northern Territory. *Wildl. Res.* **23**, 647–664.
- 15 Stannard, H. J., Caton, W., & Old, J. M. (2010). The diet of red-tailed phascogales in a trial
16 translocation at Alice Springs Desert Park, Northern Territory, Australia. *J. Zool.* **280**, 326–331.
- 17 Teale, R. (2013). Barrow Island bandicoot *Isodon auratus barrowensis* trial monitoring program.
18 Perth, Western Australia: Biota Environmental Sciences and Chevron Australia.
- 19 Thavornkanlapachai, R., Levy, E., Li, Y., Cooper, S. J. B., Byrne, M., & Ottewell, K. (2021).
20 Disentangling the Genetic Relationships of Three Closely Related Bandicoot Species across
21 Southern and Western Australia. *Diversity* **13**, 2.
- 22 Travouillon, K. J., & Phillips, M. J. (2018). Total evidence analysis of the phylogenetic relationships of
23 bandicoots and bilbies (Marsupialia: Peramelemorphia): reassessment of two species and

description of a new species. *Zootaxa* **4378**, 224–256.

Treloar, S., Lohr, C., Hopkins, A., & Davis, R. (n.d.). Rapid population expansion of Boodie (Burrowing Bettong, *Bettongia lesueur*) creates potential for resource competition with Mala (Rufous Hare-wallaby, *Lagorchestes hirsutus*). *Ecol. Manag. Restor.*

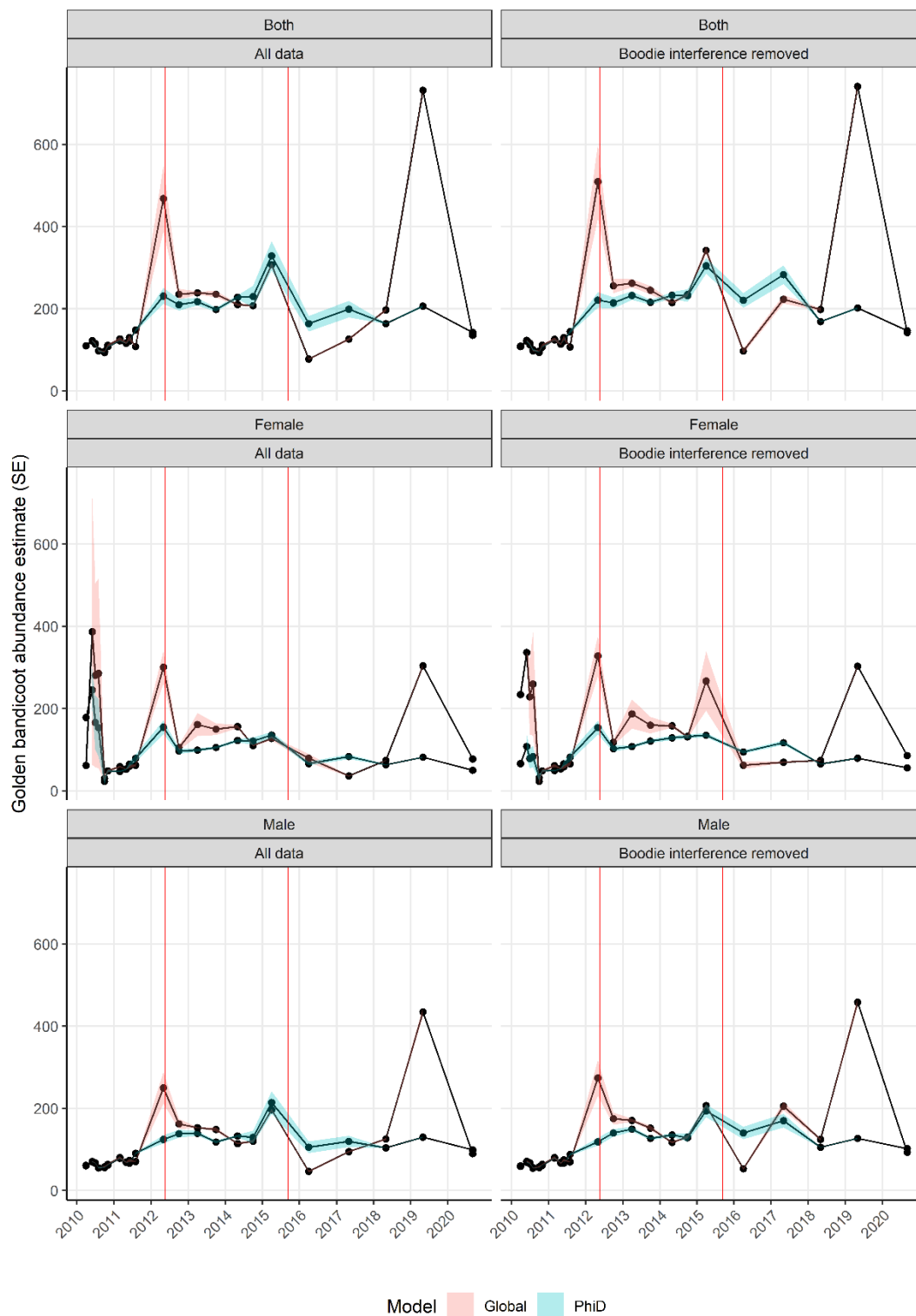
Van Dyck, S., & Strahan, R. (2008). The mammals of Australia. third ed. Sydney, Australia: Reed New Holland.

Western Australia Government. Barrow Island Act 2003 (2003). Perth, Western Australia: Western Australia Government.

Woinarski, J. C. Z., Burbidge, A. A., & Harrison, P. L. (2015). Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. *Proc. Natl. Acad. Sci.* **112**, 4531–4540.

Wysong, M. L., Tulloch, A. I. T., Valentine, L. E., Hobbs, R. J., Morris, K., & Ritchie, E. G. (2019). The truth about cats and dogs: assessment of apex-and mesopredator diets improves with reduced observer uncertainty. *J. Mammal.* **100**, 410–422.

1 Supplementary Information



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Figure S1: Average abundance estimates for golden bandicoots in the fenced enclosure at Matuwa generated by global models ($\sigma \sim t$, $\lambda_0 \sim t$, $\phi \sim t$, $D \sim t$) and PhiD models ($\sigma \sim 1$, $\lambda_0 \sim 1$, $\phi \sim t$, $D \sim t$) in the R package 'openCR' for all golden bandicoots, female bandicoots and males. Models in the left column estimated using all capture data whereas models in the right column are estimated from a subset of capture data that excludes any traps that captured alternative species.

Table S1: AIC model ranking for the four best models that explain variation in signal covariance (CoVar) given variation in MaxRDistS (Maximum distance between receiver and signal), MaxRDistR (Maximum distance between two receivers), and TotalA (Total angle at apex of triangle created by signal and location of two receivers). Models used were; CoVar~MaxRDistS+MaxRDistR-1 (m1), CoVar~MaxRDistS+MaxRDistR+TotalA (m2), CoVar~MaxRDistR-1 (m3), CoVar~MaxRDistS+MaxRDistR+TotalA-1 (m4).

Model	Adj R ²	F statistic	DF	Residual SE	K	AICc	$\Delta AICc$	Model likelihood	AICc weight	Log likelihood
m1	0.09	5.68	139	476.20	5	2175.60	0.00	1.00	0.57	-1082.58
m2	0.58	199.90	142	484.50	2	2177.26	1.66	0.44	0.25	-1086.59
m3	0.58	100.20	141	484.80	3	2178.51	2.91	0.23	0.13	-1086.17
m4	0.58	66.44	140	486.30	4	2180.51	4.91	0.09	0.05	-1086.11

1 Table S2. Summary information for the 20 golden bandicoots that were radio-tracked within the Matuwa fenced enclosure.

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangula tions (≥ 3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
GB01	M	Diurnal		13						6.26	6.21
		Nocturnal		34	16	1275.70	18	3	1	27.95	66.56
		Total	37	47						26.10	66.56
GB02	M	Diurnal		12						2.47	0.22
		Nocturnal		36	17	375.94	19	2	1	15.71	38.10
		Total	39	48						8.12	38.10
GB03	M	Diurnal		5						11.71	2.47

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangula tions (≥ 3 bearings)	Biangu lations	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
GB04	M	Nocturnal		13	10	11242.81	3	0	0	112.75	26.65
		Total	19	19						3.04	26.65
		Diurnal		13						2.70	0.48
GB05	F	Nocturnal		32	19	1589.42	26	4	0	44.37	16.86
		Total	39	45						15.24	16.86
		Diurnal		14						3.73	0.86
GB05	F	Nocturnal		29	16	36542.10	13	4	1	93.51	195.21

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangula tions (≥3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
		Total	39	43						16.38	195.21
GB06	F	Diurnal		16						2.63	0.48
		Nocturnal		33	16	502.14	17	3	0	22.79	19.36
		Total	39	49						7.61	19.36
GB07	M	Diurnal		13						7.51	6.91
		Nocturnal		24	15	958.35	9	3	0	24.69	13.45
		Total	39	37						19.95	27.63

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangu lations (≥ 3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
GB08	M	Diurnal		16						6.03	4.33
		Nocturnal		24	13	51071.03	11	7	2	94.29	61.45
		Total	39	40						17.80	61.45
GB09	F	Diurnal		15						2.21	1.59
		Nocturnal		37	25	348.77	12	1	0	11.36	31.43
		Total	39	52						5.43	31.43
GB10	F	Diurnal		1						-	-
		Nocturnal		7	4	1421.09	3	2	0	21.59	67.27

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangula tions (≥ 3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
		Total	5	8						21.13	67.27
GB11	M	Diurnal		14						2.36	0.85
		Nocturnal		31	19	1234.13	12	2	8	66.70	31.33
		Total	37	45						8.23	31.84
GB12	M	Diurnal		15						1.69	1.60
		Nocturnal		19	15	202.99	4	4	1	26.39	26.23
		Total	39	34						3.09	29.72

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangu lations (≥ 3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
GB13	F	Diurnal		12						1.97	0.26
		Nocturnal		28	16	11509.60	12	4	7	37.88	46.76
		Total	36	40						3.35	46.76
GB14	M	Diurnal		4						3.99	1.83
		Nocturnal		11	7	3774.62	4	1	0	108.34	50.55
		Total	14	16						113.36	51.93
GB15	F	Diurnal		18						4.32	17.86
		Nocturnal		29	18	3924.24	11	3	11	20.69	49.09

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangula tions (≥ 3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
		Total	38	47						4.69	53.40
GB16	M	Diurnal		14						3.66	5.90
		Nocturnal		27	19	25880.06	8	6	8	159.43	128.01
		Total	37	41						11.90	128.01
GB17	M	Diurnal		14						4.85	6.21
		Nocturnal		27	18	3803.94	9	4	7	25.44	55.47
		Total	37	41						6.73	55.47

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangu lations (≥ 3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
GB18	M	Diurnal		12						3.27	3.61
		Nocturnal		24	13	1209.28	11	2	4	79.82	98.79
		Total	37	36						12.08	98.79
GB19	M	Diurnal		4						2.15	0.33
		Nocturnal		5	3	13074.79	2	1	2	279.89	30.54
		Total	14	9						3.37	35.63
GB20	M	Diurnal		3						59.68	2.39
		Nocturnal		5	3	963.67	2	0	0	120.98	9.58

Individual	Sex	Survey period	Tracking period (days)	Telemetry positions	Triangu lations	Mean co variance (m) of triangula tions (≥ 3 bearings)	Biangula tions	No. of triangulations and biangulations considered errors and removed by LOAS	No. of locations manually removed by falling outside the enclosure	Fixed 95% KDE (ha)	MCP (ha)
		Total	5	8						53.95	12.36
Summary		Total locations		703	282	Mean: 8422.74 (± 2599.7 1)	193	56	53		

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