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# Bandicoots return to Booderee: initial survival, dispersal, home range and habitat preferences of reintroduced southern brown bandicoots (eastern sub species) *Isoodon obesulus obesulus*

**Short title:** Reintroduced bandicoot survival and establishment

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**Abstract**

*Context*: Reintroductions can be an effective means of re-establishing locally extinct or declining faunal populations. However, incomplete knowledge of variables influencing survival and establishment can limit successful outcomes.

*Aim*: We examined the factors (e.g. sex, body mass, release order) influencing the survival, dispersal, home range and habitat selection of reintroduced southern brown bandicoots (*Isoodon obesulus obesulus*) into an unfenced, predator-managed environment in south-eastern Australia (Booderee National Park).

*Methods*: Over two weeks in May 2016, six female and five male bandicoots were wild caught in state forest and hard released into the park. Release locations were approximately evenly distributed between three primary vegetation types assessed as suitable habitat: heath, woodland and forest. Bandicoots were radio tracked day and night for four weeks from the initial release date.

*Key results*: No mortality was detected. Males dispersed more than twice as far as females (male $\bar{x}$ 704 m, female $\bar{x}$ 332 m), but there was no significant sex-bias in home range size. At the landscape-scale, bandicoots preferentially selected home ranges that contained heath and avoided forest. Within home ranges, heath and woodland were both favoured over forest.

*Conclusions*: Post-release dispersal is sex-biased, but more data are required to determine the influence of other predictors such as body mass and release order. Within the release area, bandicoots favoured non-forest vegetation types.

*Implications*: Our study outlines factors influencing the establishment of reintroduced bandicoots. We recommend that future bandicoot reintroductions to Booderee National Park occur within areas of heath and woodland; and that subsequent releases consider the potentially larger spatial requirements and conspecific avoidance among male bandicoots. Our findings contribute new knowledge for improving translocation methodologies of a nationally endangered medium-sized mammal.

**Keywords:** conservation biology, threatened species, radio telemetry, habitat preference, wildlife management

## Introduction

Conservation translocations are an increasingly common way of restoring species to the wild (Seddon *et al.* 2007; Seddon *et al.* 2014). The objective is usually to improve the conservation status of the target species, and / or restore natural ecosystem functions or processes (IUCN/SSC 2013; Seddon *et al.* 2014). Translocations within a species' *current* range can bolster population viability by increasing abundance (e.g. Moreno *et al.* 2004) and genetic diversity (e.g. Hedrick 1995). In contrast, reintroductions of species into their *former* ranges can re-establish locally extinct species in areas where they previously occurred (e.g. Short and Turner 2000). Both approaches, if well-designed, can provide insights into the original causes of species decline or extinction, current threats to their occurrence, and species' requirements for survival and persistence in the contemporary environment (Short *et al.* 1992; Sarrazin and Barbault 1996; Armstrong and Seddon 2008). Monitoring is key to understanding the fate of translocated individuals, the success of establishment in their new environment and, if relevant, the impacts on the source population (Short *et al.* 1992; Fischer and Lindenmayer 2000; Sheean *et al.* 2012). Yet many reintroduction programs fail to adequately monitor and evaluate against measurable objectives or report on the outcomes of the program (Fischer and Lindenmayer 2000; Sheean *et al.* 2012). This could lead to false conclusions about the success of the program, and is a missed opportunity to gain valuable information on the biology of the species and its interactions in a new environment. Initial success can be evaluated by survival and reproduction (e.g. Richards and Short 2003; Moseby *et al.* 2011). For animals, other responses such as movement and habitat selection are also useful indicators of establishment (Cook *et al.* 2010; Le Gouar *et al.* 2012). Short-term measures are not necessarily accurate predictors of longer term success (Fischer and Lindenmayer 2000; Moseby *et al.* 2011), but can act as timely triggers for management intervention or provide early insights into species' requirements.

In this study, we examine dispersal, home range and habitat use of reintroduced southern brown bandicoots (eastern subspecies; *Isoodon obesulus obesulus*) to an unfenced area in south-eastern Australia (Booderee National Park, BNP) which is poison baited to control introduced red foxes (*Vulpes vulpes*). The southern brown bandicoot (eastern subspecies) is currently listed as endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* due to threats including predation by introduced foxes and cats (*Felis catus*), habitat loss and fragmentation, and inappropriate fire regimes (Paull 1995; Short and Calaby 2001; Bilney *et al.* 2010). The subspecies was historically common across its range — the coastal fringe of New South Wales, Victoria and South Australia (Paull *et al.* 2013) — including in the Jervis Bay region, where

BNP is located (Short and Calaby 2001). It was last recorded in the region in 1919 (Ashby *et al.* 1990). Since 1999, BNP has regularly baited for foxes, with an intensification of the program commencing in 2003. During this time, fox numbers have declined, with consistently few detections of both foxes and cats, as confirmed by camera and sand plot monitoring, and reduced levels of bait take (Dexter and Murray 2009; Dexter *et al.* 2016). Detection of either introduced predator is promptly followed by targeted control. This effective management of threats provides ideal conditions in which to trial a reintroduction of southern brown bandicoots.

In this paper, we evaluate the initial success of the translocation and investigate factors influencing survivorship, post-release dispersal, home range and habitat selection of the southern brown bandicoot (eastern subspecies) to BNP. We ask 1) does sex, body mass or order-of-release influence post-release dispersal distance; 2) does home range size differ between males and females; 3) do bandicoots preferentially select for different habitat types at the landscape scale (i.e. selection of home range at the scale of the species' maximum dispersal) or within home ranges (i.e. scale of movement within observed home range)? We predicted that males, smaller (less heavy) individuals, and those released last would disperse further. This prediction was based on greater post-release dispersal among male marsupials (e.g. western barred bandicoot, *Perameles bougainville*, Richards and Short 2003) and intraspecific aggression between different sized individuals and potential territoriality of southern brown bandicoots (Heinsohn 1966; Broughton and Dickman 1991). Established male bandicoots have larger home ranges than females (Heinsohn 1966, Lobert 1990, Broughton and Dickman 1991). Thus, we predicted comparable differences among home ranges of released male and female bandicoots. Bandicoots were released into three primary habitat types assessed as equally suitable habitat; we therefore predicted that bandicoots would occupy all habitat types in proportion to their availability at the landscape-scale and within home ranges.

## Materials and methods

### *Study region*

BNP is located at the southern end of Jervis Bay on the Bherwerre Peninsula in south-eastern New South Wales, Australia (35$^{o}$ 10' S, 150$^{o}$ 40' E). The 6400 ha park is owned by the Wreck Bay Aboriginal Community Council and jointly managed with the Australian Government via a Board of Management. Prior to becoming a National Park, the region was subject to cattle grazing, local land clearing and forestry, and supported abundant introduced predator populations (Lindenmayer *et al.*

2014; DNP 2015). Minimum and maximum temperature range is 8.8 – 16.9$^{o}$ C in July to 17.2 – 25.6$^{o}$ C during January and February (BOM 2016a). The average annual rainfall of 1234 mm falls evenly throughout the year (BOM 2016b). The park geology forms the southern end of the Sydney Basin and is dominated by Permian sandstone (~260 million years old) (Cho 1995). Major wildfires occurred most recently in 2003, burning half of the park and leaving a mosaic of vegetation age classes (Lindenmayer *et al.* 2008).

*Study species*

Southern brown bandicoots are sexually dimorphic, with males being larger (500 – 1500 g) than females (400 – 1000 g) (Menkhorst and Knight 2001). They occur in a variety of habitats including native forest, woodland, shrubland and heath (Menkhorst and Seebeck 1990; Claridge and Barry 2000; Paull *et al.* 2013). Dense understorey is sought for nesting and cover from predation, while foraging often occurs in more open vegetation (Stoddart and Braithwaite 1979; Haby *et al.* 2013). The species is omnivorous, opportunistically foraging on subterraneous fungal fruiting bodies, invertebrates, small vertebrates and nectar (Quin 1985; Claridge and May 1994).

*Reintroduction Program*

The reintroduction program aims to re-establish a self-sustaining population of southern brown bandicoots in BNP by translocating up to 45 wild-caught individuals over a three year period. *A priori* criteria for reintroduction success are: 1) in the first year, stable to increasing abundance of bandicoots and evidence of breeding; 2) by the second year, an increasing population and the presence of adult animals that have been born at the park, and; 3) after five years, a geographically stable or increasing population, with dispersal beyond the initial release area.

*Site selection*

Within the park, potentially suitable habitat for southern brown bandicoots was identified by Dr Andrew Claridge, an expert on the ecology of the species (Dexter *et al.* 2016; see A1 for map of habitat suitability within BNP). The release area (Fig. 1) was selected as it had suitable to good habitat with an abundance of *Xanthorrhoea* species, considered important for shelter (Haby *et al.* 2013). The area has limited vehicular traffic, which can pose a significant threat to bandicoots (Mawson 2004; Haby and Long 2005). Earlier surveys of fungi and invertebrates indicated that food sources for bandicoots are well distributed across the park (Dexter *et al.* 2011; Dexter, unpublished data). Four major vegetation types occur across the release area: heath, woodland, shrubland and forest; all contain *Xanthorrhoea* species.

[Insert Fig. 1 here]

*'Heath'* covers approximately 18% of the park and is characterised by an absence of trees (Taws 1997; Dexter *et al.* 2011). The dense, shrubby vegetation is generally < 2m in height and contains high levels of floristic diversity. *'Woodland'* covers 15% of the park; it has a low, sparse tree canopy (< 5 m) and the understorey is less dense than 'Heath' (Taws 1997). '*Shrubland*' covers approximately 10% of the park and is dominated by shrubs > 2 m in height (Taws 1997). *'Forest'* is the most extensive vegetation type at BNP (45%); it is characterised by tall to very tall trees > 10 m in height and an open-to-dense understorey (Taws 1997).

*Capture and release of bandicoots*

We sourced bandicoots from a wild population south of Eden in Forestry Corporation New South Wales (FCNSW) estate (Fig. 1). This population is approximately 300 km south of BNP and is the closest viable source population. The Eden population has been monitored seasonally at 40 sites since 2007 by FCNSW. Over the past 9 years, site occupancy has doubled and the relative abundance of bandicoots has increased; this coincides with the start in 2008 of landscape-wide predator baiting (Dexter *et al.* 2016). We minimised potentially adverse consequences of the removal of individuals from the source population by trapping broadly across three state forests (Nadgee, Timbillica and East Boyd State Forests). Southern brown bandicoot populations are capable of recovering rapidly after removal of individuals (Stoddart and Braithwaite 1979), but ongoing monitoring of the source population will further determine any impacts. Within these state forests, we set up to 140 traps at 20 – 100m apart, each night over a two-week period in May 2016. Traps were checked each morning and moved to a new location if no individuals of the target species were caught after several days. Bandicoots were caught in forest vegetation dominated by canopy tree species *Eucalyptus sieberi* and / or *E. consideniana*.

An experienced veterinary surgeon (Dr Karri Rose) examined all trapped bandicoots for their suitability for translocation; criteria included good health (e.g. absence of skin plaques indicative of bandicoot papillomatosis carcinomatosis virus type 2, Bennett *et al.* 2008), age and reproductive status (e.g. testes size in males). Body mass, and head, pes and ear length were measured. Each bandicoot received a pit tag and an ear biopsy was taken. Bandicoots were sedated with Valium (1mg / 1kg intramuscular injection), transported to BNP by road in custom-made cardboard pet transportation boxes, and released the same day of capture within 1 hour of dusk. Prior to release, bandicoots were fitted with radio transmitters (Holohil Systems, 1.9 g) mounted on the tail using *Fixomull* tape, as described by Coetsee *et al.* (2016) but without glue applied to the tail (Fig. A.2). We released bandicoots into three vegetation types roughly corresponding with their availability within the release area: heath (n = 5), woodland (n = 4), forest (n = 2). Releases occurred over a ten-day period from 17$^{th}$ to 27$^{th}$ May 2016, with 0 - 2 bandicoots released per night.

*Radio tracking*

Over a four week period from first release, we used radio tracking to monitor bandicoot survival, movement and habitat selection during day and night. After this period, bandicoots with transmitters still attached were tracked every few days until their transmitter fell off. We used Yagi antennas attached to Australis receivers (Titley Electronics, Ballina, NSW) to detect radio signals; GPSs to record locations; and compasses to record bearings. At night, locations were determined by triangulation of bearings from 2 – 4 paired observers stationed on or near roads. Observers moved to maximise the signal strength and angle of bearings for more precise triangulation. Location data for each bandicoot were collected within 15 minutes of other observers; 60% of these were within 5 minutes. Nocturnal fixes were collected between 7 pm and 12 am, typically 1 hour apart (minimum 30 minutes). Triangulation at night was required due to difficulties tracking through dense vegetation at night and to minimise interference to night-time foraging. On several occasions (< 4% of total observations), bandicoots were observed alongside roads, often foraging; these locations were also recorded. During the day, bandicoots were tracked to their exact location. Where dense vegetation precluded access to the daytime location, triangulation within an estimated 10 m of the bandicoot position was used to determine location. An ecologist experienced in radio tracking (CM) supervised and trained all observers.

We calculated triangulated positions using the Andrews estimator, with fall back options of MLE, in the program LOAS (White and Garrott 1980; ESS LLC 2010). Intersections of observations that were > 500 m were excluded, as field trials indicated that the ability of the receiver to detect an accurate signal beyond 500 m was reduced. We calculated 95% confidence ellipses and excluded locations with ellipses > 1 ha. Total percentage of fixes discarded through *a priori* set rules and subsequent error checking was 23%. The majority (80%) of remaining triangulated locations had ellipses < 0.1 ha. All triangulated positions were reviewed in ArcMap for their accuracy (ESRI 2015).

*Survival and further observations*

Survival was determined by regular movements. If an individual’s transmitter was recorded in the same location more than three times within a 36 hour period, we sought to flush the animal. If a transmitter was dropped, we set traps in the immediate area to re-capture the individual. Traps were used successfully to re-capture individuals, with 17 re-captures of 10 individuals across 155 trap nights. Transmitters were often found in constructed nests; these observations were recorded, along with the type of habitat in which they were found. Six months after the reintroduction, we conducted targeted trapping of bandicoots over 176 trap nights to determine the number of bandicoots still in the release area, and to assess health and check for signs of breeding.

*Data analysis*

*Dispersal*

Maximum dispersal distance was calculated for each individual as the Euclidean distance between the point-of-release and its most distant telemetric location, verified by day tracking to actual location (White and Garrott 1980; Biggins *et al.* 2011). We performed t-tests with unequal variance for differences between male and female dispersal distances, and linear regressions for dispersal distance against bandicoot body mass and order of release. The latter predictor was defined as the consecutive release order (from 1 to 11). Small sample size precluded testing of interactions and limited our power to detect effects. Assumptions of normality and homogeneity of variance were met in most cases; the exception was unequal variance for associations with sex.

*Home range*

We used cumulative home range plots to determine the minimum number of fixes required to adequately describe home range area. All diurnal and nocturnal location data, including triangulated fixes and actual locations, were used. Cumulative plots revealed that the minimum number of fixes required to attain a stable home range estimate varied between 15 and 40, and that all bandicoots had an adequate numbers of fixes to reach an asymptote. Bandicoots had 28 - 84 fixes ($\bar{x}$ = 54). We calculated home ranges using 95% minimum convex polygons (MCP) using adehabitatHR (Calenge 2015). We selected MCP for home range estimation as, with small sample sizes, it produces more reliable results than probabilistic models and is appropriate for determining areas visited for analysis of habitat selection (Laver and Kelly 2008). Differences in home range size between sexes were analysed using a t-test assuming unequal variance. Assumptions of normality were met, but F tests revealed unequal variance.

*Habitat selection*

We examined habitat selection at two scales using home ranges calculated by MCP: selection of the home range location within the landscape (2$^{nd}$ order) and selection of habitat within the home range (3$^{rd}$ order) (Johnson 1980). Four broad vegetation types were included in analyses: forest, heath, shrubland and woodland. Minor vegetation types found in the park were included in area calculations but were excluded from habitat selection analyses as they were never used by bandicoots.

At the landscape-scale (defined by maximum observed dispersal distance of released bandicoots, 1003 m), we compared the composition of the observed home ranges (used, n = 11) to the composition of randomly-placed circular home ranges (available, n = 1000) equal in area to the median bandicoot home range (5.9 ha; Katnik *et al.* 2005; Squires *et al.* 2013). Available home ranges were sampled within a 1003 m radius circle, centred on the mean coordinates for locations of each bandicoot, and excluding any ocean. We calculated the proportional availability of each vegetation type in used and available home ranges, then used a resource selection function based on logistic regression to compare used to available samples (Manly *et al.* 2002; Squires *et al.* 2013). We weighted available data to used data as 0.011:1 to allow for a balanced comparison and avoid inflating statistical precision (Squires *et al.* 2013).

Within home ranges, we identified the vegetation type at each location where a bandicoot was recorded (used) and at randomly generated locations within each MCP (available). The number of randomly generated points to used points was set at 5:1 (Baasch *et al.* 2010; Sirén *et al.* 2015). Using a generalised linear mixed model (GLMM) with logit link function and individual identity as the random effect, we tested if bandicoots selectively used woodland, heath or shrubland, relative to forest (the reference level). Unless otherwise specified, analyses were conducted in R version 3.3.0 (R Core Team 2016).

## Results

### *Baseline data*

We captured 12 southern brown bandicoots from five sites in Nadgee State Forest, from a total of 1500 trap nights across three state forests (Table A.2). Eleven bandicoots (five male, six female) met our criteria for reintroduction and were translocated to BNP (see Table A1 and A2 for pre and post release observations and measurements). Males were significantly heavier than females (t-test, t = 3.43, df = 10, p = 0.006) and had longer pes (t-test, t = 3.70, df = 10, p = 0.002). There were no differences between sexes in the length of head (t-test, t = 2.17, df = 10, p = 0.066) or ear (t-test, t = 1.43, df = 10, p = 0.184).

### *Tracking and survival*

Bandicoots were tracked for an average of 32 days (range 13 – 45). Transmitters remained attached for an average of 12 days (range 3 – 22), with one to three reattachments per individual. No mortality was recorded during the four week monitoring period. One individual was monitored for 14 days (52 fixes) before losing her transmitter and, despite repeated efforts, was not re-trapped. Another individual was monitored for 13 days (28 fixes) due to being one of the last bandicoots to be released. This individual was known to have survived the tracking period as it was re-trapped six months later.

### *Dispersal*

Bandicoots dispersed on average 501 m (range = 203 – 1003 m, SD ± 273.6). Males dispersed significantly further than females (t-test, t = 2.78, df = 5, p = 0.039). The average dispersal distance of males was 704 m (± 287 SD) compared to females 331.9 m (± 90.8 SD). There were no significant associations between dispersal distance and body mass ($F_{1,9}$ =1.017, p = 0.32, $R^2$ adj. = 0.002, Fig. 2) or order of release ($F_{1,9}$ =0.122, p = 0.746, $R^2$ adj. = -0.096, Fig. 3). We did not test for interactions between predictors.

[Insert Fig. 2. and 3. here]

*Home range*

Home ranges calculated using 95% MCP were on average 9.5 ha (median = 5.9, range 0.7-30.4, SD ± 9.8, Fig. 4). Home ranges of males tended to be larger ($\bar{x}$ = 15.2 ha) than females ($\bar{x}$ = 4.6 ha) but the distance was not significant (t-test, t = 1.86, df = 4, p = 0.136).

[Insert Fig. 4. here]

*Habitat selection*

At the landscape-scale (i.e. scale of observed maximum dispersal), bandicoots selectively located their home ranges in areas with more heath (p = 0.02, Fig. 5.a), and tended to avoid forest (p = 0.06, Fig. 5.b). Shrubland and woodland habitat use was proportional to availability (p = 0.40, and p = 0.71, respectively).

[Insert Fig. 5. here]

Within their home range, bandicoots selectively used woodland (β = 0.74, SE = 0.3, p = 0.014) and heath (β = 0.79, SE = 0.3, p = 0.008) more than forest. There was no difference in selection of shrubland when compared to forest (β = 0.2, SE = 0.56, p = 0.724).

*Nest number and characteristics*

Eight bandicoots were tracked to 15 different nests (one to three nests per bandicoot). Nests were not shared. For bandicoots with multiple nests, the average distance between nests ranged from 24 to 79 m. Nine nests were located in woodland and the remainder were found in heath; of the six nests found in heath, half were found within small pockets of woodland mallee *(Eucalyptus sieberi*, *Corymbia gummifera* or *E. burgessiana*). All nests were either under the skirts of *Xanthorrhoea* species (n = 13) or under dense grass and sedge (1 bandicoot, n = 2). Nests were constructed above ground-level from a range of materials including *Xanthorrhoea* fronds, grass, leaf and other organic matter, bundled into a round nest of approximately 40 - 50 cm in size with a tunnel opening.

*Post-release observations*

Six months post-release, 7 of the 11 reintroduced bandicoots were recaptured (four female, three male; see Table A2). Each female had three to four pouch young. Their trap locations were within their estimated home range boundaries, or within 60 m of previously recorded locations, and the body weight for each animal was equal or greater than its release weight.

## Discussion

Reintroductions are an increasingly important component of threatened species conservation and restoration (Seddon *et al.* 2014). Reintroduction science has advanced greatly over the past few decades, with an increasing numbers of studies being published (Seddon *et al.* 2007). Translocations, however, remain inherently risky with many variables that contribute to the success or failure of a program (Fischer and Lindenmayer 2000). Here, we describe early findings of the reintroduction of 11 southern brown bandicoots (eastern subspecies) to an unfenced, predator-managed peninsula at BNP in May 2016. Initial survival and evidence of breeding indicated early success of the program. Our data further revealed that dispersal was influenced by sex, but not body mass or release order. Habitat selection at both the landscape-scale and within home-range scale demonstrated that bandicoots prefer certain vegetation types to others. In the remainder of this section, we discuss these results with respect to study limitations, implications for future translocations and avenues for further research.

*Survival and breeding indicate initial success*

No mortality was observed during the first four weeks after release. Due to different release times and length of transmitter attachment, bandicoots were monitored for varying periods of time (range 13 – 45 days), with one individual not relocated after 14 days of tracking. Seven of the eleven bandicoots released were still present in the release area six months post-release, and all recaptured females (67%) were carrying pouch young. Criteria for success in year one of the program were stable and or increasing numbers, along with evidence of breeding. Monitoring-to-date has shown that these criteria have been met and provides reassurance to continue with future planned translocations.

Southern brown bandicoots have been previously translocated to unfenced sites (e.g. Western Australia: Mawson 2004; Johnson 2009; Stone and Hide 2009). However, details of these translocations, their procedures and results have not been published in peer-review journals, except for summary details (e.g. Mawson 2004). This limits our understanding of the procedures and variables influencing the translocation outcome. Southern brown bandicoots have been successfully returned to the wild after a period of captivity (Cooper 2011). Other species of bandicoot within the family Peramelidae (e.g. *Isoodon auratus*, *Perameles bougainville, Perameles gunnii*) have also been translocated to fenced and unfenced areas with varying degrees of success (Richards and Short 2003; Winnard and Coulson 2008). Predation remains the biggest factor influencing bandicoot translocation success, with other variables such as suitable habitat, foraging resources, release method, source of individuals, genetic diversity and drought also contributing to outcomes (Winnard and Coulson 2008; Cook *et al.* 2010; Moseby *et al.* 2011; Ottewell *et al.* 2014).

*Dispersal*

Minimal dispersal and subsequent establishment within the release area is often the objective when establishing new faunal populations in unfenced environments (Richardson and Ewen 2016). Dispersal distances of bandicoots reintroduced at BNP (203 – 1003 m) were well within reported maximum dispersal distances of 2.5 km for the species (B. Hope pers. comm. 2009 cited in Brown and Main 2010). We investigated several factors that might influence bandicoot dispersal: sex, body mass and release order. On account of likely intraspecific aggression and territoriality (Heinsohn 1966) and generally greater dispersal among male marsupials (Richards and Short 2003), we predicted that bandicoot dispersal would be greater for males, smaller individuals and those released last. We found that males dispersed further than females, but that there was no evidence that body mass or release order affected dispersal distances. However, our study was of short duration and had limited power due to the small sample size, and so our results should be interpreted with caution.

*Is conspecific attraction or repulsion acting to influence dispersal and establishment?*

Conspecific attraction may be beneficial in anchoring new releases at the release site and thus fostering integration and genetic mixing (Richardson and Ewen 2016). However, attraction can also be an ecological trap (e.g. clustering within suboptimal habitat, Mihoub *et al.* 2009). Conversely, repulsion amongst conspecifics might drive individuals into sub-optimal habitat or beyond the intended establishment area (Clarke and Schedvin 1997). Responses to conspecifics can be driven by various factors including sex. Female bandicoots may have neutral or positive response to conspecifics, as suggested by minimal dispersal in our study. In contrast, our data and data gathered by others (Mackerras and Smith 1960; Heinsohn 1966; Stodart 1966) suggest that males have negative responses to other males. Extrinsic factors such as the presence of competitors, predation and resource availability can further influence dispersal and establishment (Le Gouar *et al.* 2012). For example, the presence of long-nosed bandicoots (*Perameles nasuta*) may influence movements, if only by avoidance (Moloney 1982). However, due to low numbers of individuals (Dexter *et al.* 2011; Dexter *et al.* unpublished data), interactions are expected to be infrequent. Understanding the importance of conspecific attraction or repulsion, and other extrinsic factors, on dispersal and establishment will help inform future translocations.

*Home range size*

Home ranges of established male southern brown bandicoots are reported as being larger than those of females (Heinsohn 1966; Broughton and Dickman 1991). Our results indicated that, for recently released bandicoots, males had larger home ranges than females. Reported home range sizes for southern brown bandicoots are variable (e.g. 2 - 7  ha, Heinsohn 1966; 1 - 3 ha, Lobert 1990; 2 - 20 ha, Sampson 1971 as cited in Haby and Long 2005) and are not easily comparable with this study due to differences in habitat type, food resource availability, bandicoot density, and methodological differences in data collection and home range calculation. Additionally, limitations in our study (small sample size, short duration) restricts interpretation of our results. Translocated animals typically hold larger home ranges than established populations (Mihoub *et al.* 2011) primarily due to the absence of conspecifics; thus over a longer time period, home ranges of reintroduced bandicoots at BNP may contract.

*Habitat selection*

At the landscape-scale and within home ranges, reintroduced bandicoots at BNP bandicoots selected heath and avoided forest vegetation. They also selected woodland over forest within their home ranges. Nests were found only in heath or woodland, under species of *Xanthorrhoea*, grasses and sedges, consistent with other studies (Hope 2012; Haby *et al.* 2013). Although bandicoots occur across a range of habitats, they prefer vegetation types with a dense shrubby understorey and are especially associated with *Xanthorrhoea* species (Haby *et al.* 2013; Paull *et al.* 2013). Dense understorey vegetation provides cover from predation (Coates 2008) and *Xanthorrhoea* species often provide nesting material (Haby *et al.* 2013). All three dominant vegetation types found at BNP contain abundant *Xanthorrhoea* species, but there are differences in understorey vegetation structure. Analysis of 2012 survey data show that ground cover is higher in heath and woodland than in forest (see Table A3, Fig. A.2). In addition, Dexter *et al.* (2011) used vegetation structure data collected by Lindenmayer *et al.* (2008) at BNP to provide an index of the relative protection from predation afforded by each habitat for the long nosed bandicoot (a species with comparable dietary requirements and predation vulnerability as the southern brown bandicoot). They found that heath provided the densest understorey and thus the best protection from predators, followed by woodland then forest. Owing to behavioural differences, southern brown bandicoots may be even more vulnerable to predation than long nosed bandicoots (Hope 2012). Thus, consistent with (Dexter *et al.* 2011), forest is likely providing inferior vegetation structure for southern brown bandicoots than either heath or woodland.

## Conclusion

Understanding habitat preferences and movement patterns is useful for informing future translocations. This study provides early evidence that southern brown bandicoots can be successfully reintroduced into a predator-managed, unfenced environment, providing there is suitable habitat and the threat of predation by exotic carnivores is low. Notwithstanding limitations in our design, we recommend that future translocations of southern brown bandicoots to BNP occur in areas of heath and woodland, with abundant *Xanthorrhoea* species and shrubby understorey. We further recommend that consideration is given to the spatial needs of male bandicoots during translocation. Future work should investigate 1) how body mass (as a surrogate for age) and the presence of conspecifics interact with sex to influence dispersal, and 2) the specific habitat features that influence habitat selection by bandicoots at BNP. Ongoing monitoring will continue to reveal factors important to the establishment and persistence of southern brown bandicoots at BNP.

## Acknowledgements

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## Tables and Figures

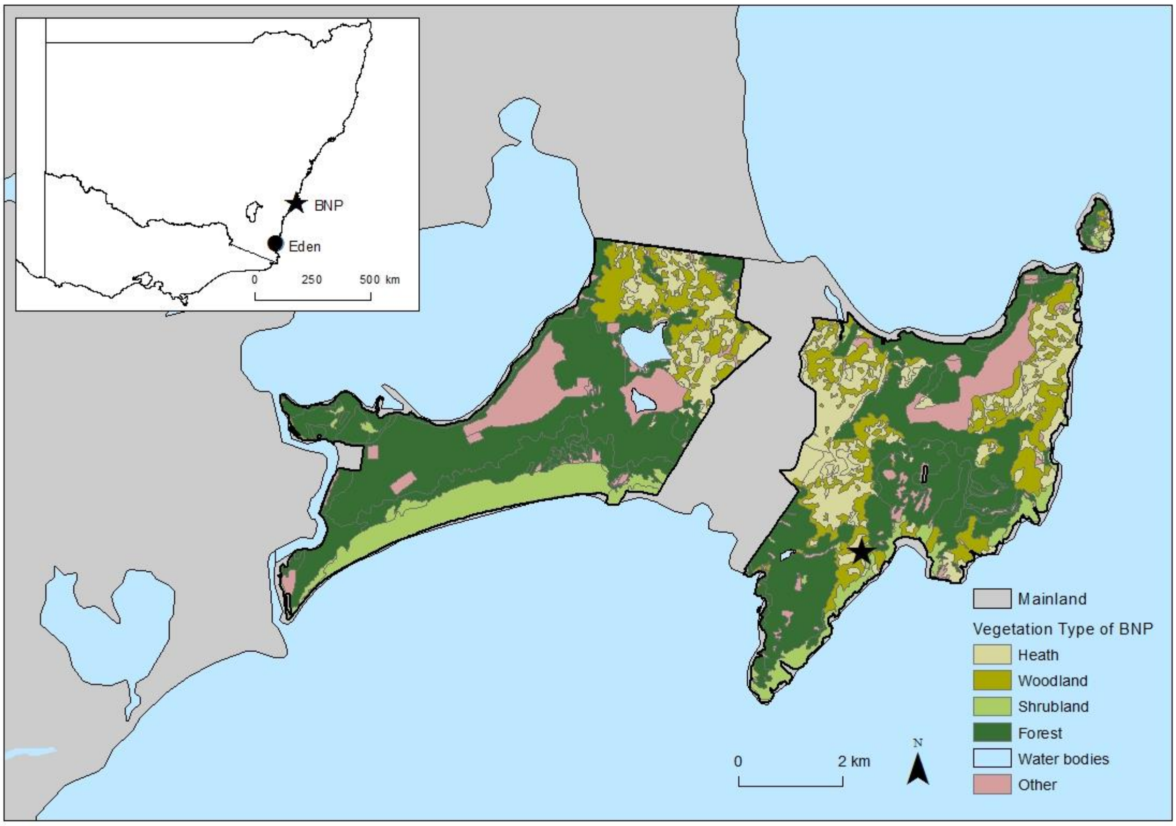


Fig. 1. Map of Booderee National Park showing the distribution of major vegetation types and the release area as indicated by the black star. Inset map of south-eastern Australia shows the location of the park (star) and capture sites near Eden, New South Wales, Australia (circle).

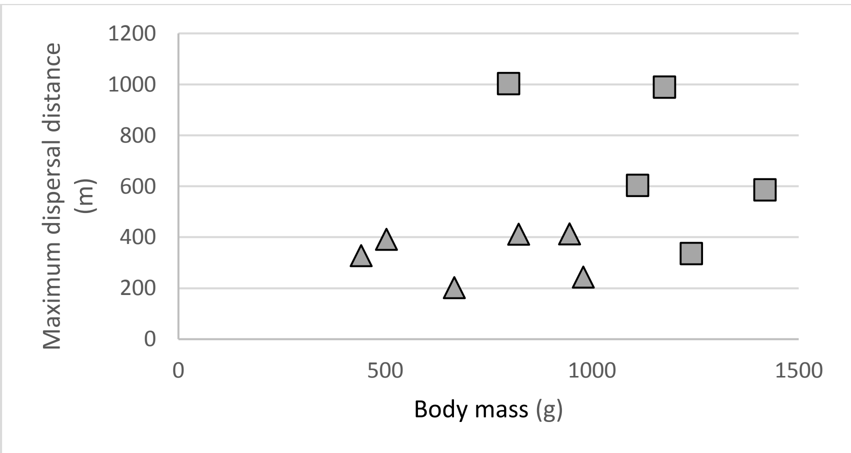


Fig. 2. Maximum dispersal distance in relation to body mass, for male (square) and female (triangle) southern brown bandicoots, Booderee National Park, Australia.

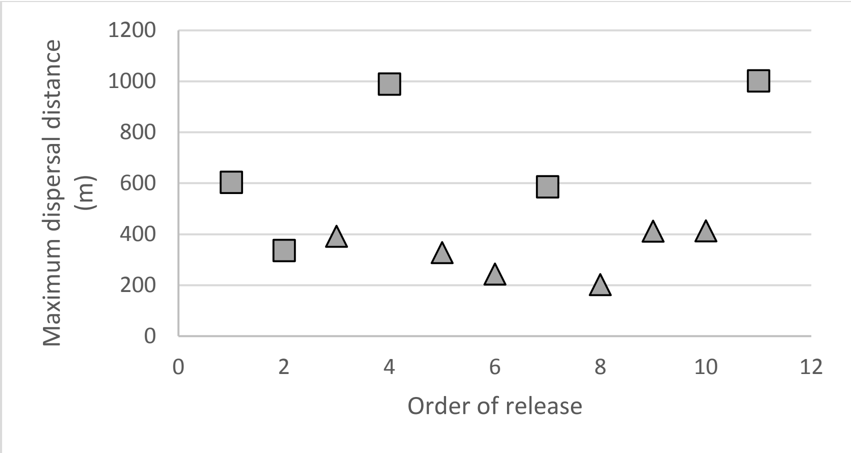


Fig. 3. Maximum dispersal distance according to order of release, for male (square) and female (triangle) southern brown bandicoots, Booderee National Park, Australia.

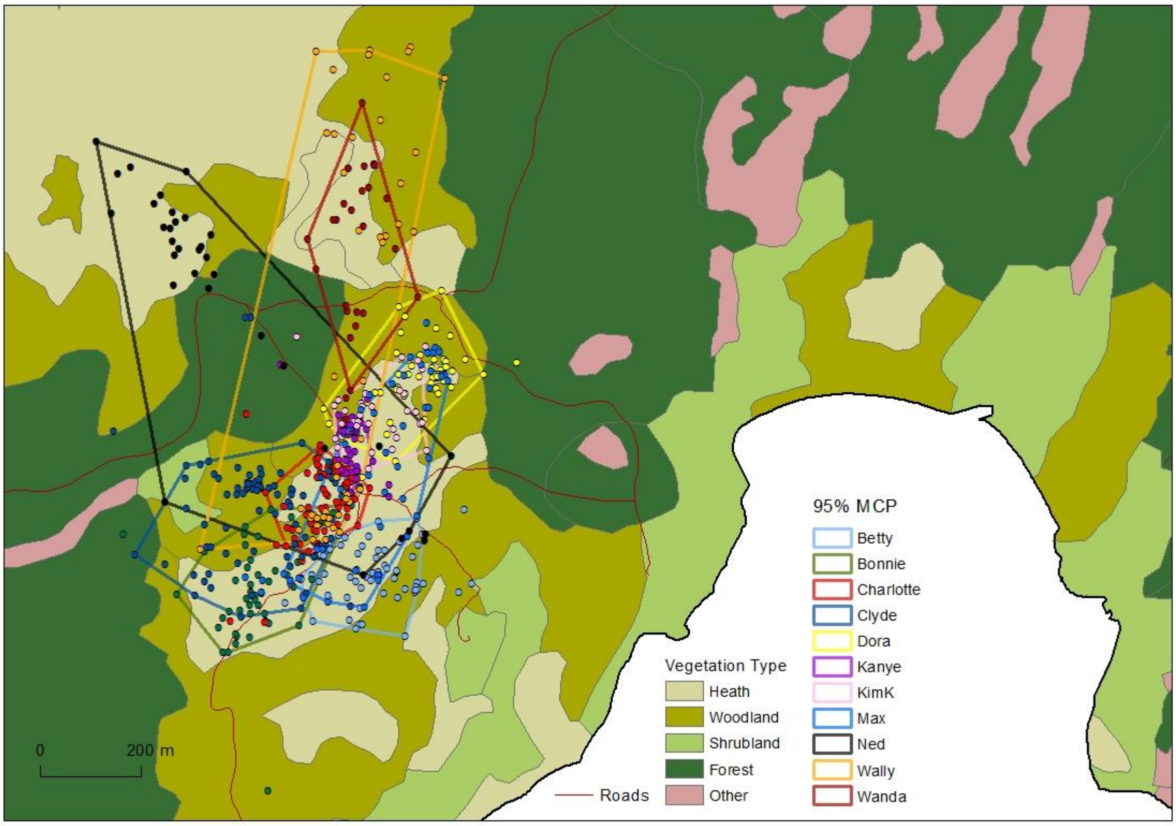


Fig. 4. Locations and home ranges mapped at 95% MCP for each southern brown bandicoot using four weeks of tracking data, Booderee National Park, Australia. Polygons represent 95% MCP and points represent location data for each bandicoot.

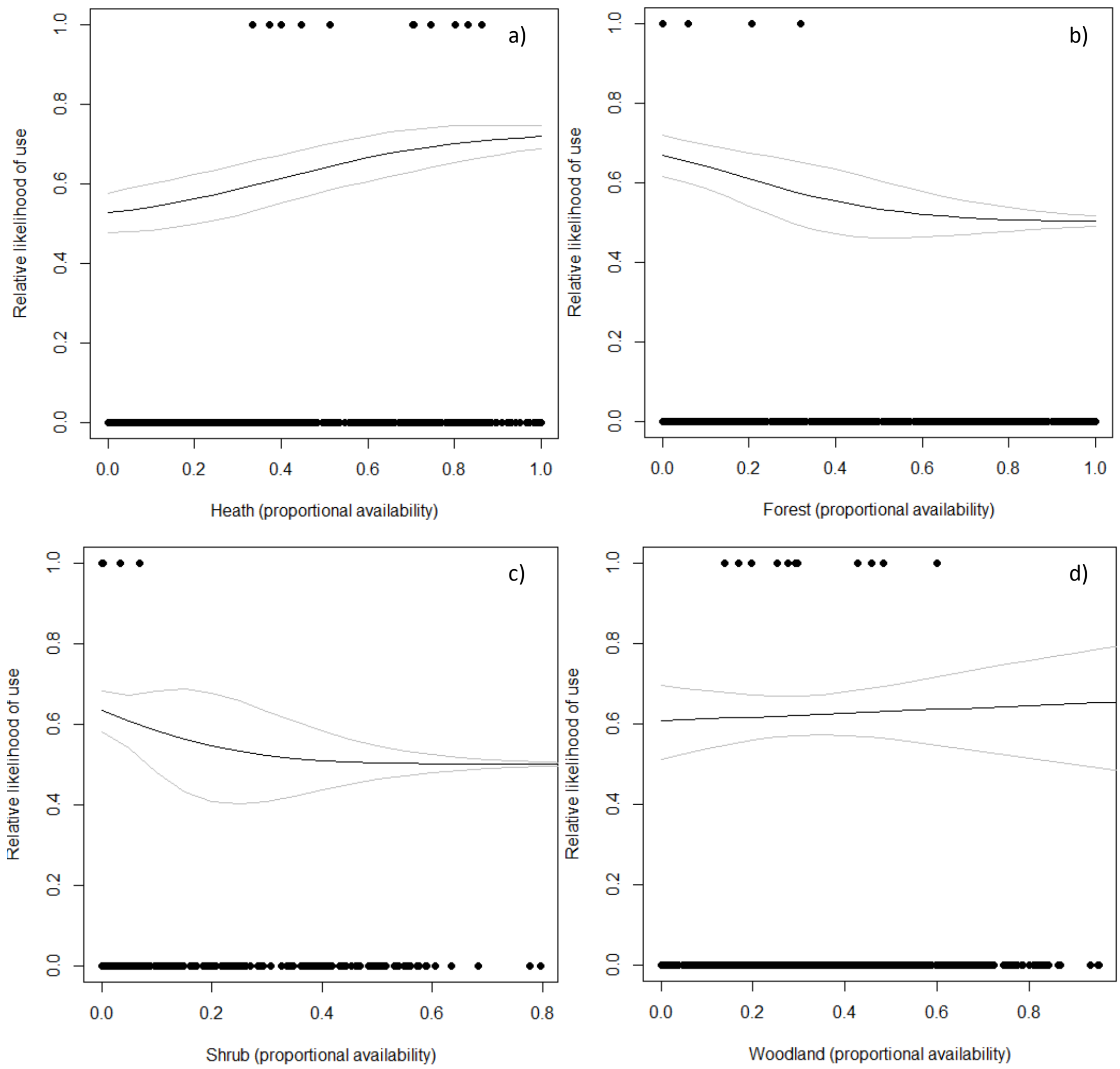


Fig. 5. Predicted resource selection functions for southern brown bandicoot home ranges at the landscape-scale for a) heath; b) forest; c) shrubland; and d) woodland, in Booderee National Park, Australia. Black lines are predictions of use from logistic regression, with 95% confidence intervals shown by the grey lines. Habitat availability in used home ranges (n = 11) is indicated by black dots with a relative likelihood of 1. Habitat availability in available samples (n = 1000) is indicated by black dots with a relative likelihood of 0.

**Supplementary Material**

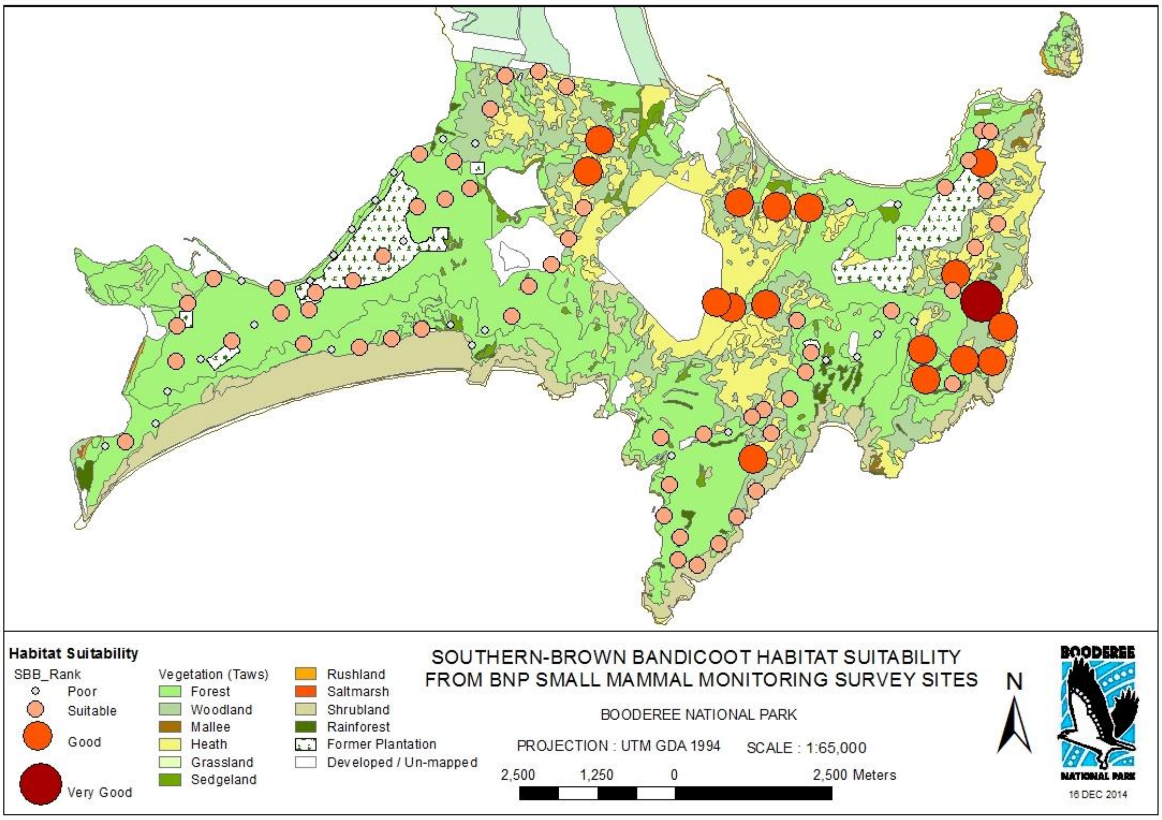


Fig. A.1. Habitat suitability scores for southern brown bandicoots throughout Booderee National Park (BNP).

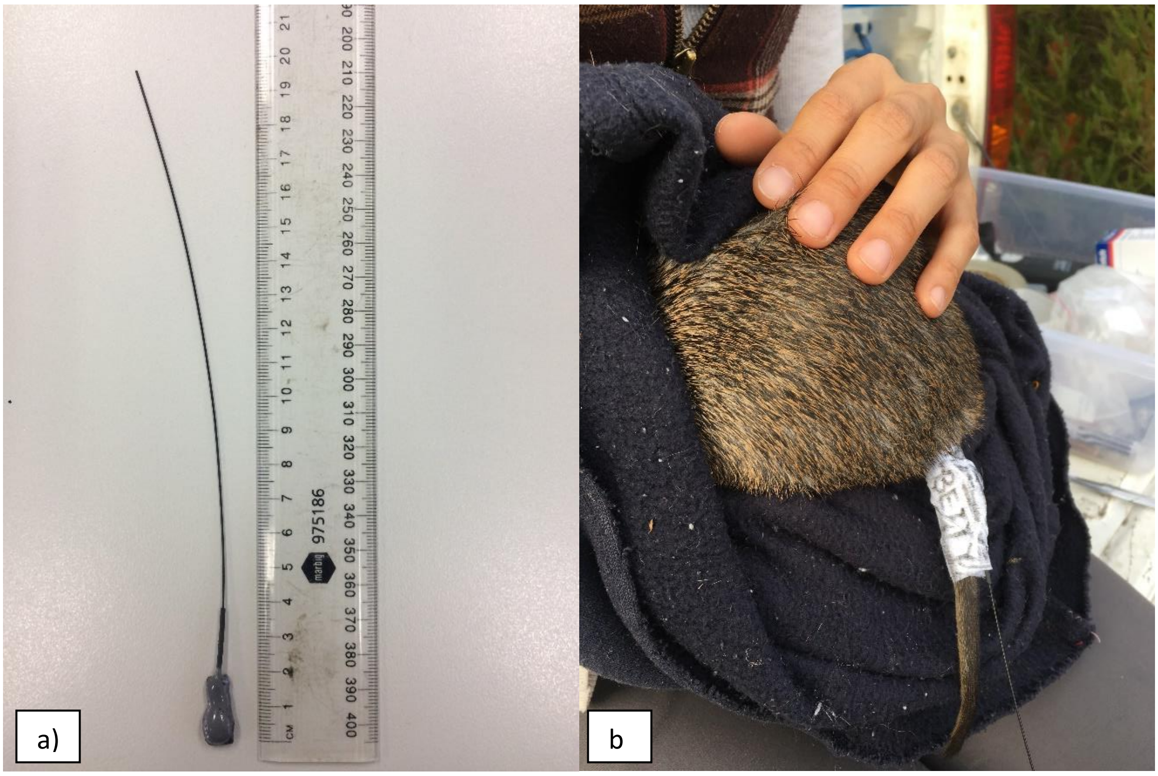


Fig. A.2. Photos of a) radio transmitter and b) transmitter attached to the tail of a bandicoot using 5 cm *Fixomull* stretch tape. Radio transmitter specifications are Holohil Systems BD-2, 1.9 g, 20 x 9 x 6.6 mm, 180 mm whip antennae, 151-152 MHz, 10 week battery life, and no mortality signal.

Table A.1. Baseline average measurements of male and female reintroduced bandicoots, with standard deviation.

| Sex | Number | Weight (g) | Head length (mm) | Pes length (mm) | Ear length (mm) |
|---|---|---|---|---|---|
| Male | 5 | 1221.8 (271.5) | 87.7 (9.4) | 62.8 (2.8) | 33.8 (1.5) |
| Female | 6 | 726.7 (226.1) | 77.7 (6.4) | 56.6 (3.0) | 31.8 (3.0) |

Table A.2. Summary of release variables, dispersal, home range, nests and post-release observations (six months) for reintroduced Southern Brown Bandicoots. Source locations are Nadgee State Forest (NSF), Timbillica State Forest (TSF) and East Boyd State Forest (EBSF). Release vegetation types are forest (F), heath (H) and woodland (W). PY = Pouch Young.

| Name | Source location | Sex | Pre-release weight (g) | Release order | Release vegetation | Dispersal distance (m) | Home range size (ha) [no. of locations] | No. of recorded nests | Post-release weight (g) | Post -release breeding |
|---|---|---|---|---|---|---|---|---|---|---|
| Clyde | NSF | Male | 1110 | 1 | F | 604.1 | 10.1 [82] | 2 | n/a | n/a |
| Kanye | NSF | Male | 1240 | 2 | F | 336.5 | 0.7 [53] | 1 | 1130 | n/a |
| Dora | NSF | Female | 503 | 3 | W | 391.9 | 5.9 [52] | n/a | n/a | n/a |
| Wally | NSF | Male | 1175 | 4 | H | 989.6 | 26.4 [51] | 2 | 1210 | n/a |
| Charlotte | NSF | Female | 442 | 5 | H | 327.6 | 2.6 [84] | 1 | n/a | n/a |
| Betty | NSF | Female | 979 | 6 | H | 243.5 | 4.2 [63] | 3 | 960 | 3 PY |
| Max | NSF | Male | 1418 | 7 | W | 587.1 | 8.5 [52] | n/a | 1460 | n/a |
| KimK | NSF | Female | 667 | 8 | W | 202.7 | 2.9 [39] | 1 | 750 | 4 PY |
| Wanda | NSF | Female | 823 | 9 | W | 412 | 6.3 [28] | n/a | 830 | 3 PY |
| Bonnie | NSF | Female | 946 | 10 | H | 413.5 | 5.9 [54] | 3 | 890 | 3 PY |
| Ned | NSF | Male | 798 | 11 | H | 1002.9 | 30.4 [34] | 2 | n/a | n/a |

Table A.3. Tests of differences in percentage ground cover of the major vegetation types at the release area, Booderee National Park.

| | t | p | df |
|---|---|---|---|
| Heath vs forest | 9.48 | < 0.001 | 115 |
| Woodland vs forest | 5.41 | < 0.001 | 122 |
| Woodland vs heath | 3.9 | < 0.001 | 82 |

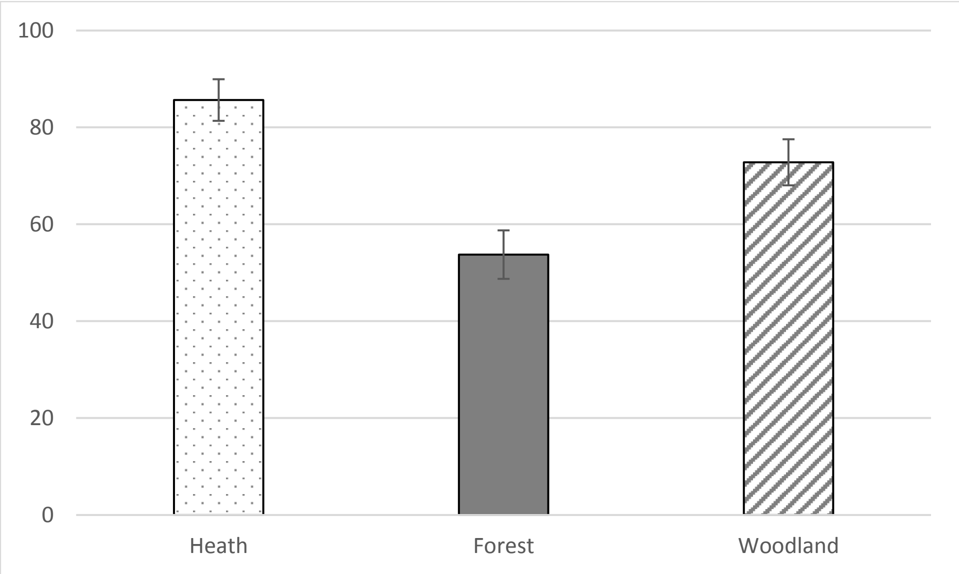


Fig. A.2. Percentage ground cover of heath, forest and woodland at the release area, Booderee National Park. Error bars are 95% confidence intervals.