Dirk Hartog Island National Park Ecological Restoration Project:

Stage Two – Year One

Translocation and Monitoring Report

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Cover photo: Rufous hare-wallaby (*Lagorchestes hirsutus*) at point of release on Dirk Hartog Island. (© A. Gibson Vega/DBCA).

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Summary

The Dirk Hartog Island National Park Ecological Restoration Project (DHINPERP) or "Return to 1616" will see 12 species of mammal (ten known to be locally extinct) and one species of locally extinct bird translocated to Dirk Hartog Island (DHI) in an effort to improve their conservation status and help restore ecological processes to the island. As part of this program, a trial translocation of banded hare-wallabies (*Lagostrophus fasciatus*) and rufous hare-wallabies (*Lagorchestes hirsutus*), sourced from Bernier and Dorre Island Nature Reserve, was undertaken in August 2017 to better understand the issues associated with the capture, transport, release and monitoring of these and other species to be translocated, as well as broader challenges associated with monitoring vertebrate fauna in general on DHI.

With the success of this trial (Cowen et al., 2018), and the subsequent declaration of the eradication of feral cats (*Felis catus*) on DHI, a decision was made to proceed with a full-scale translocation of both species of hare-wallaby in 2018. A total of 90 banded hare-wallabies and 50 rufous hare-wallabies were captured and translocated in September/October 2018, again from Bernier and Dorre Islands. Radio and GPS-telemetry collars were fitted to nine and three wallabies, respectively, of each species and monitored intensively during an initial 12-week post-release period, as per the 2017 trial. Monitoring continued infrequently during summer and autumn 2019, until animals were captured in May to remove collars and conduct final health-checks. As in 2017-18, survivorship was very high, with no evidence of mortality of any radio-tracked individuals. Reproductive activity was evident in almost all female hare-wallabies encountered post-release, and recruitment appeared to be concomitantly high as well.

Building on what was learned during 2017/18, the reintroduction team has conducted further trials to help inform the future monitoring of hare-wallabies and other species. This included the use of innovative technologies such as remotely piloted aircraft (RPAs or 'drones') and analysis of DNA derived from faecal pellets.

1 Background

The vision for the ecological restoration of Dirk Hartog Island National Park (DHI) is "to create a special place with healthy vegetation and ecosystem processes that support the full suite of terrestrial native mammal species that occurred there at the time of Dirk Hartog's landing in 1616, and that this is highly valued and appreciated by the community" (DEC, 2012). Stage One of the DHINPERP commenced in 2011 and has resulted in the successful eradication of sheep (*Ovis aries*), goats (*Capra hircus*) (Heriot et al., 2019) and cats (*Felis catus*) (Johnston et al., 2019). Stage Two of the project commenced in July 2018 and focuses on the translocation and establishment of 12 species of mostly threatened native mammal, and one bird species. A strategic framework for this has been prepared to guide the implementation of this stage of the project (Morris et al., 2017).

Of the 12 mammal species to be translocated to DHI, ten are known to have previously occurred on the island. There are no confirmed sub-fossil or historical records of the banded hare-wallaby (*Lagostrophus fasciatus*) or rufous hare-wallaby (*Lagorchestes hirsutus*) on DHI, despite extant populations on Bernier and Dorre Islands, and sub-fossil records on the nearby mainland. However, given their restricted distribution, they were included in the suite of mammals to be translocated to improve their conservation status. Prior to a full-scale translocation of 50-100 of each of these species to DHI in 2018, a trial translocation was undertaken in 2017 using smaller numbers of founders to evaluate the feasibility and logistics of translocating these two species to Dirk Hartog Island. Based on the successful outcome of this trial translocation, the large-scale release planned for 2018 went ahead as planned. This report provides the results of these translocations and recommendations about future translocations of these and other species are also included.

1.1 Site description

Dirk Hartog Island is located in the Shire of Shark Bay in Western Australia at approximately -26° S and 113° E and forms part of the Shark Bay UNESCO World Heritage Area. It falls within the DBCA Parks and Wildlife Service's Shark Bay District in the Midwest Region. The island is approximately 80km long and up to 12km wide with a total area of 63,300 ha, making it the largest island in Western Australia (Figure 1). The island contains a range of terrestrial habitats, including *Acacia*-dominated shrubland communities, *Triodia*-dominated grasslands, *Thryptomene dampieri* heath, consolidated and mobile dune-systems with large areas of *Spinifex longifolius* and many small birrida clay-pans vegetated by chenopods (Beard, 1976).

The island was a pastoral lease from the 1860s to 2009, when most of it became a National Park. Some existing and additional small areas of freehold and leasehold were granted to the former lessee at this time. Maritime lighthouse facilities and areas for the purpose of recreation are also under leasehold at the north end of the island and additional areas have been classified as heritage reserves. Following 150 years of sheep and feral goat occupancy, the island's vegetation had been heavily impacted by grazing and become degraded in many parts. Since destocking commenced in

2005, vegetation cover has increased significantly over 35% of the island (Dongen et al., 2018). All sheep and feral goats have now been removed from DHI (Heriot et al., 2019) and feral cats have been eradicated from the island (an independent review in late 2018 officially confirmed successful eradication (D. Algar pers. comm.).

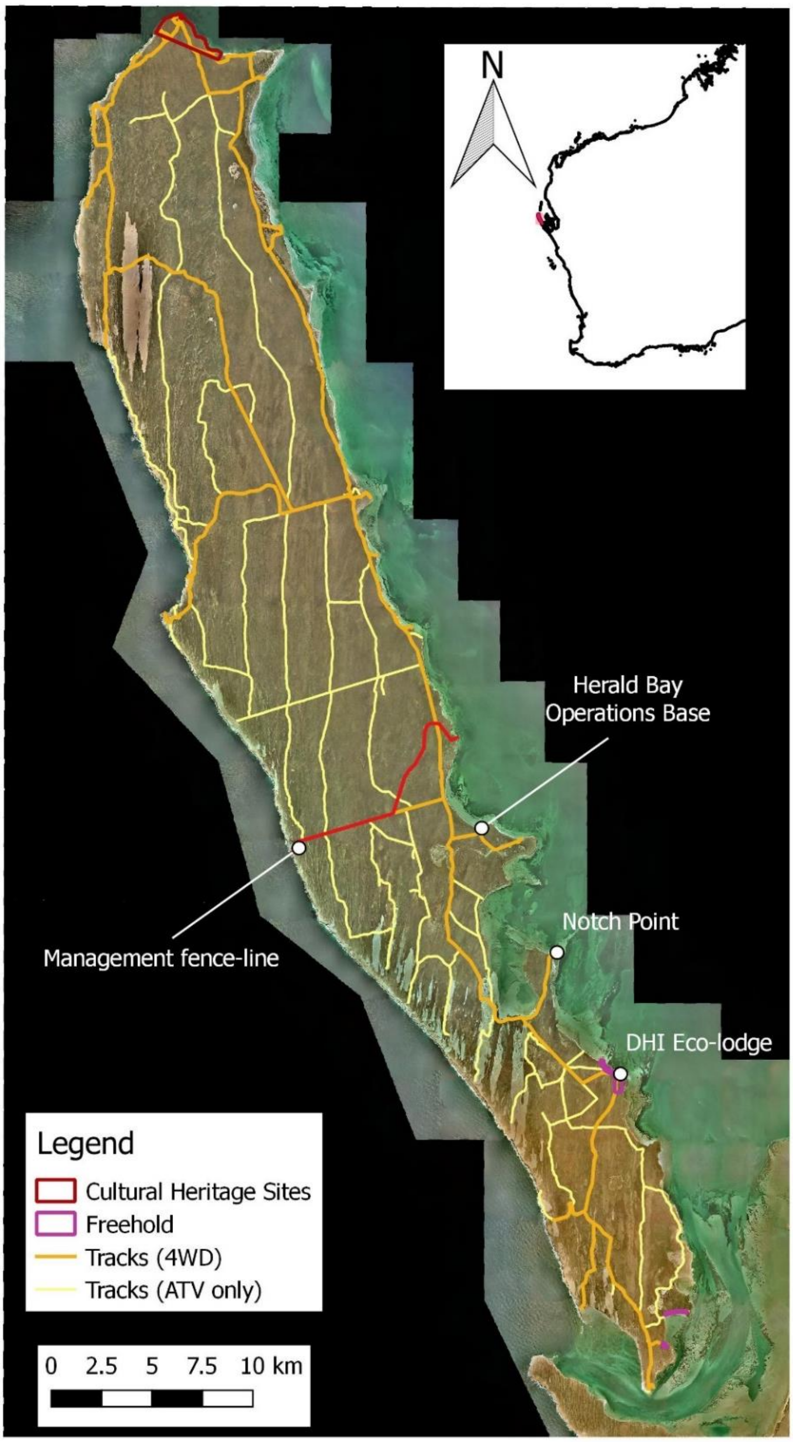

Figure 1. Map of Dirk Hartog Island, indicating important areas and 4WD and ATV track network.

1.2 Species descriptions

1.2.1 Banded hare-wallaby

The banded hare-wallaby (*Lagostrophus fasciatus*) is a small, terrestrial, macropodid marsupial and is the sole-remaining member of a now extinct lineage of ancient kangaroos (Lagostrophinae), unrelated to other hare-wallaby species (Llamas et al., 2015). Previously widespread across southern Western Australia, wild populations of banded hare-wallabies are restricted to Bernier and Dorre Islands in Shark Bay. These locations are small (~5,000ha each), isolated and vulnerable to large variations in environmental conditions, especially rainfall. Estimates of the total population size for these two islands vary from 2,000 to 9,700, with the most recent estimate at around 6,000 individuals ((Sims et al., 2019)). Additional populations have been established on Faure Island in Shark Bay and Wadderin Sanctuary near Narembeen, and a translocation program is underway at Mt Gibson Sanctuary near Wubin. Banded hare-wallabies have been introduced to Dirk Hartog Island once before, with 21 animals released between 1974 and 1978 (Prince, 1979). Failure of this translocation was largely attributed to predation by feral cats, compounded by inadequate vegetation cover caused by grazing and drought (Short et al., 1992).

The banded hare-wallaby is a nocturnal species, with bimodal peaks of activity in the first and last three hours after sunset and before sunrise. Habitat preferences on Bernier and Dorre Islands are shrubland communities, characterised by dense *Acacia* thickets. These thickets provide shelter during the day and protection from predators (Short and Turner, 1992, Short et al., 1997). Predominantly a browser (Short and Turner, 1992), the banded hare-wallaby has a broad and varied diet, feeding on a range of grasses, shrubs and other dicotyledonous plants (Richards et al., 2001). Observations in captivity suggest a preference for several *Acacia* species (*A. ligulata*, *A. ramulosa*, *A. sclerosperma*, *A. tetragonophylla* (Richards, 2012)).

The lifespan of the banded hare-wallaby is thought to be up to six years in the wild and while capable of reproduction in their first year, it is assumed that most do not breed until their second. Breeding may occur year-round, although on Bernier and Dorre, the occurrence of pouch young/lactation generally peaks in autumn (Richards et al., 2001). Young occupy the pouch for around six months and are weaned at nine (Prince and Richards, 2008). Females are monovular (Tyndale-Biscoe, 1965) and usually produce one offspring per year, although two offspring may be raised if environmental conditions are particularly favourable (Richards et al., 2001).

The sex-ratio in banded hare-wallabies appears to be biased in favour of females (Richards et al., 2001) and male territories will overlap with several females (Prince and Richards, 2008). Males and females appear to live within well-defined home ranges (Richards et al., 2001, Prince and Richards, 2008). Interactions between adult males are often aggressive, in contrast to other interactions involving females. Average home range size is estimated to be around 11ha, (Hardman, 2006) although this was calculated using data from recently translocated individuals on Peron Peninsula and may not be representative of well-established populations.

Threats to the banded hare-wallaby are chiefly from introduced predators, particularly the red fox (*Vulpes vulpes*) and feral cat (Prince and Richards, 2008, Burbidge and Woinarski, 2016). As such, reintroductions of this species are restricted to areas free of cats and foxes, as it is unlikely hare-wallabies will persist in locations where even low densities of these predators are present. The evidence for banded hare-wallabies having occurred previously on Dirk Hartog Island is largely circumstantial but compelling. Baynes (1990) found no evidence of banded hare-wallabies in subfossil deposits and, as such, the translocation of this species to Dirk Hartog Island has been considered a conservation introduction rather than a reintroduction. However, anecdotal evidence from the explorers Dampier (1699) and Peron (1803) suggests that this species may have occurred on the island (Rayner et al., 2018) and subfossil remains have also been recovered from the adjacent mainland at Edel Land and Peron Peninsula. Shortridge (1909) also acknowledged the presence of both hare-wallaby species on Dirk Hartog Island.

The banded hare-wallaby is listed as Vulnerable under IUCN and EPBC Act (1999) criteria and in Western Australia under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice (2017).

1.2.2 Rufous hare-wallaby

Like the banded, the rufous hare-wallaby (*Lagorchestes hirsutus*) is a small macropodid and is similar in size, shape and much of its behaviours. However, it is only distantly related to the banded hare-wallaby and is more closely related to modern kangaroos (Macropodinae) (Llamas et al., 2015). As with many other native marsupials, rufous hare-wallabies were formerly far more widespread than they presently are and previously occurred over much of western and central Australia. Currently, extant wild populations persist only on Bernier and Dorre Islands (subspecies *L. h. bernieri*) with their most recent population estimate at around 2000 individuals (Sims et al., 2019). Additionally, a translocated population derived from a former Tanami Desert population (*L. h.* sp. 'mala') occurs on Trimouille Island in the Montebello Islands in north-west Western Australia. Other populations of this central Australian subspecies exist inside enclosures elsewhere in Western Australia, the Northern Territory and New South Wales. A third subspecies that formerly occurred in south-western Australia (*L. h. hirsutus*) is listed as extinct.

The rufous hare-wallaby is nocturnal and generally solitary (Short and Turner 1992) with relatively small home ranges compared to those of the banded hare-wallaby (about seven hectares although this is based on data from recently translocated individuals (Hardman, 2006)). Home ranges may overlap in relation to food availability. Habitat preferences also differ between these two hare-wallaby species, with rufous preferring more open areas of *Triodia* grassland communities with scattered low dense shrubs, but often also encountered in dune systems including along coastlines. They will shelter under low shrubs or *Triodia* hummocks, digging small scrapes under vegetation. Unlike the banded, the rufous hare-wallaby is believed to be a grazer and will feed on *Triodia* spinifex (e.g. *Triodia plurinervata*) but also on more nutritious forbs and grasses (Johnson and Burbidge, 2008).

Longevity in rufous hare-wallabies has been difficult to assess in the wild (Richards et al., 2001) but it is reasonable to assume that it would be similar to banded hare-wallabies given their comparable life-history traits. Like banded hare-wallabies, rufous hare-wallabies are polyoestrus, monovular (although twinning has been reported on one occasion) and can breed year-round (Lundie-Jenkins, 1993, Richards et al., 2001). Female 'mala' are known to reproduce at 5-18 months of age with males reaching sexual maturity at 14 months. Pouch life is around five months and hence females are capable of producing up to two offspring in a year, with no apparent peak breeding season. Sex ratios in this species are usually close to parity (Richards et al., 2001).

As for the banded hare-wallaby (and many other critical weight-range mammals), the main threat to rufous hare-wallabies is introduced predators. However, some native predators, such as the wedge-tailed eagle (*Aquila audax*) will also prey on this species (Short et al., 1992, Richards et al., 2001). As with the banded hare-wallaby, Baynes (1990) found no evidence of subfossil remains of rufous hare-wallabies on DHI but again there is anecdotal evidence of their presence into the 20th Century (Shortridge, 1909). Combined with the proximity of extant populations on Bernier and Dorre Islands and the historical presence on the adjacent mainland, it seems likely that rufous hare-wallabies did occur on Dirk Hartog Island, but for the purposes of this project, the translocation of this species have been treated as a conservation introduction.

The rufous hare-wallaby is listed as Vulnerable under IUCN criteria, as is the subspecies *L. h. bernieri* under the EPBC Act (1999) and Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice (2017). *L. h.* spp. is listed as Endangered under EPBC Act (1999) and Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice (2017).

1.3 Climate and weather

Dirk Hartog Island has a semi-arid climate, characterised by winter rainfall and dry summers with a mean annual rainfall of approximately 230mm. Occasional heavy falls of rain may occur in summer and autumn, particularly when associated with cyclones moving down the west coast of Western Australia. Figure 2 shows the weather conditions that occurred on Dirk Hartog Island during 2018.

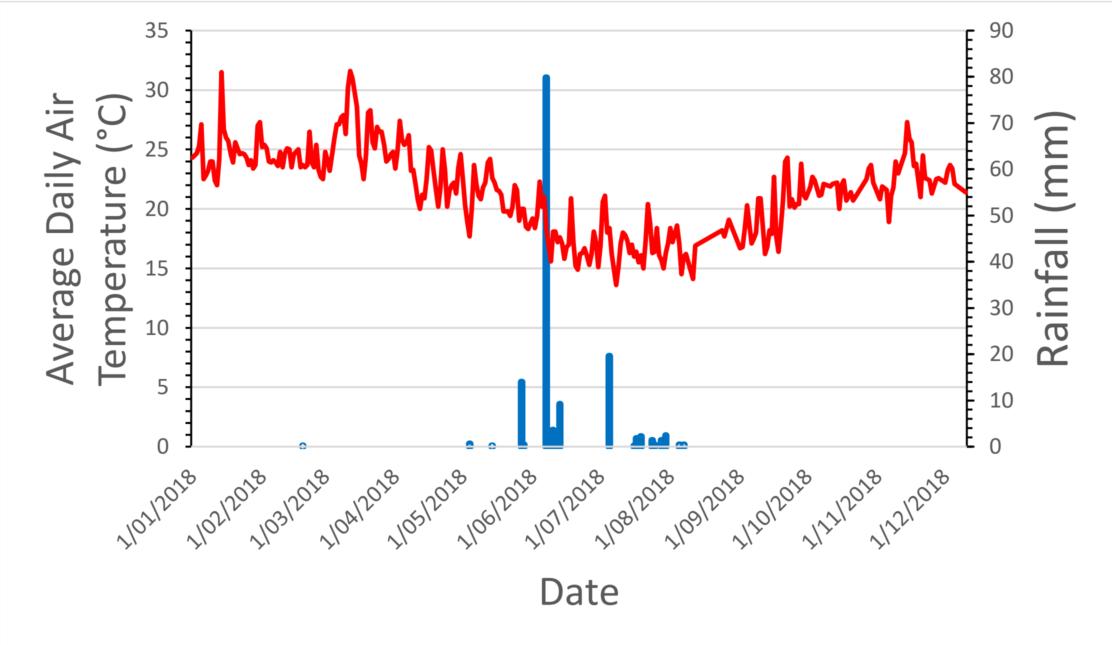

Figure 2. Total monthly rainfall (bar graph) and mean monthly temperatures (line graphs) for Dirk Hartog Island from January 2018 to December 2018.

2 Methods

2.1 Translocation Proposals

Translocation Proposals for both banded and rufous hare-wallaby translocations were prepared in May – July 2017 and approved in August 2017. An Animal Ethics application was approved for the trial translocation in August 2017 (AEC 2017/17) and the full-scale translocation in July 2018 (AEC 2018/14A).

Success criteria listed under the translocation proposals for the species were as follows:

Short-term (0 - 9 months)

1. At least 50% of the radio-collared, released hare-wallabies survive for the first four months after release.
2. Any causes of mortality are understood and ameliorated.
3. Founders have maintained or increased bodyweight, condition maintained.
4. Some evidence of successful recruitment of those that may have been larger pouch young when translocated.

(Meeting these short-term success criteria for the trial translocation in 2017 to be a trigger for proceeding with the full translocations in 2018, 2019)

Medium-term (10 - 36 months)

1. Population has established and expanded habitat is used.
2. Body weight and condition are maintained.
3. Further evidence of successful reproduction; presence of pouch young, or F1 generation (from females with large pouch young when translocated).
4. Hare-wallabies are recorded during spotlight and/or trapping monitoring sessions.

2.2 Timeline

Source population monitoring of hare-wallaby (and other mammal species) on Bernier and Dorre Islands took place in April 2018 ((Sims et al., 2019)). The translocations commenced on 15 September 2018 with the first captures of wallabies from Dorre Island followed by captures on 20, 21 and 22 September. Bernier captures took place on 23 September and 1, 2 and 3 October.

This was followed by a three-month period of intensive ground and aerial tracking of collared animals. Capture of hare-wallabies to check condition and check or replace collars occurred at the end of this intensive monitoring period, prior to less intensive aerial monitoring for the subsequent four months. Radio-collars were removed in May 2018. Figure 3 below indicates the timing of the translocations and monitoring of hare-wallabies.

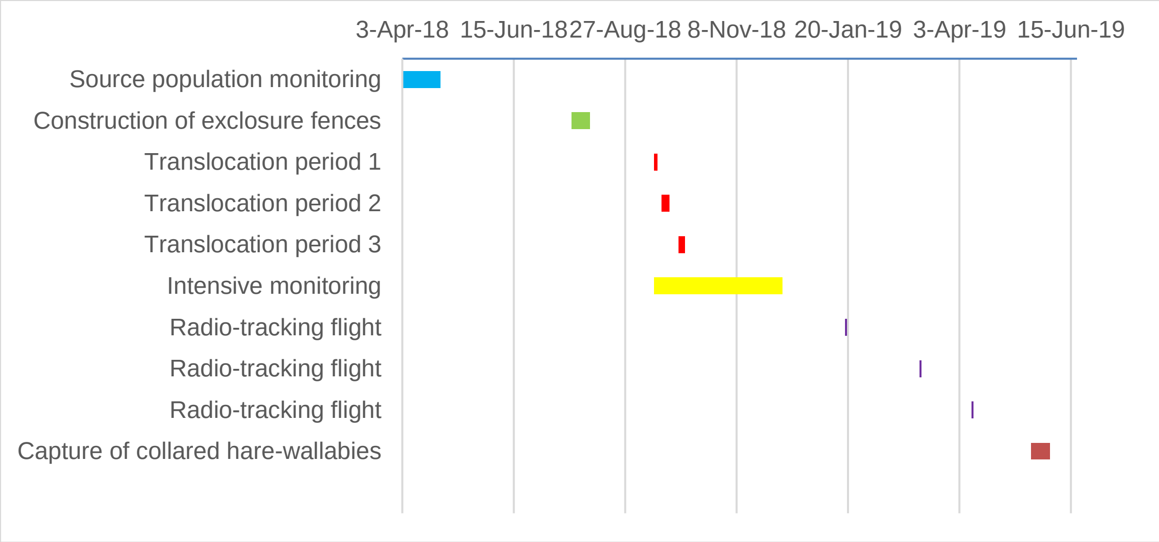

Figure 3. *Gantt chart showing timeline of outcomes from translocation between April 2018 and June 2019.*

The planned dates for translocation in 2018 were slightly later than in 2017 (29-30 August), but still designed to coincide with the sea conditions and wind strength/directions most favourable to working on the eastern side of Bernier and Dorre Islands, and when environmental temperatures were still mild enough to avoid excessive physiological stress for translocated animals. However, while the capture team experienced excellent conditions at times, the initial capture work was delayed by nearly a week due to strong winds.

2.3 Translocation site selection

Selection of translocation sites in DHI was based on ecological knowledge of the hare-wallabies on Bernier and Dorre Island (i.e. habitat suitability and condition). Proximity to a suitable basecamp for personnel to be based at up to 13 weeks was also an important consideration. Habitat suitability involved an assessment of the vegetation as both a food source and refuge for both species of hare-wallabies. Banded hare-wallabies are thought to be generalist browsers and require dense shrubs for shelter, while rufous hare-wallabies are grazers and shelter under *Triodia* hummocks. The condition of the habitat was also an important factor, given that the island's vegetation communities have been recovering from grazing pressure from the >7000 goats and sheep that were eventually removed between 2009 and 2017. Remote-sensing technology has been used to monitor the recovery of vegetation on Dirk Hartog Island since the destocking

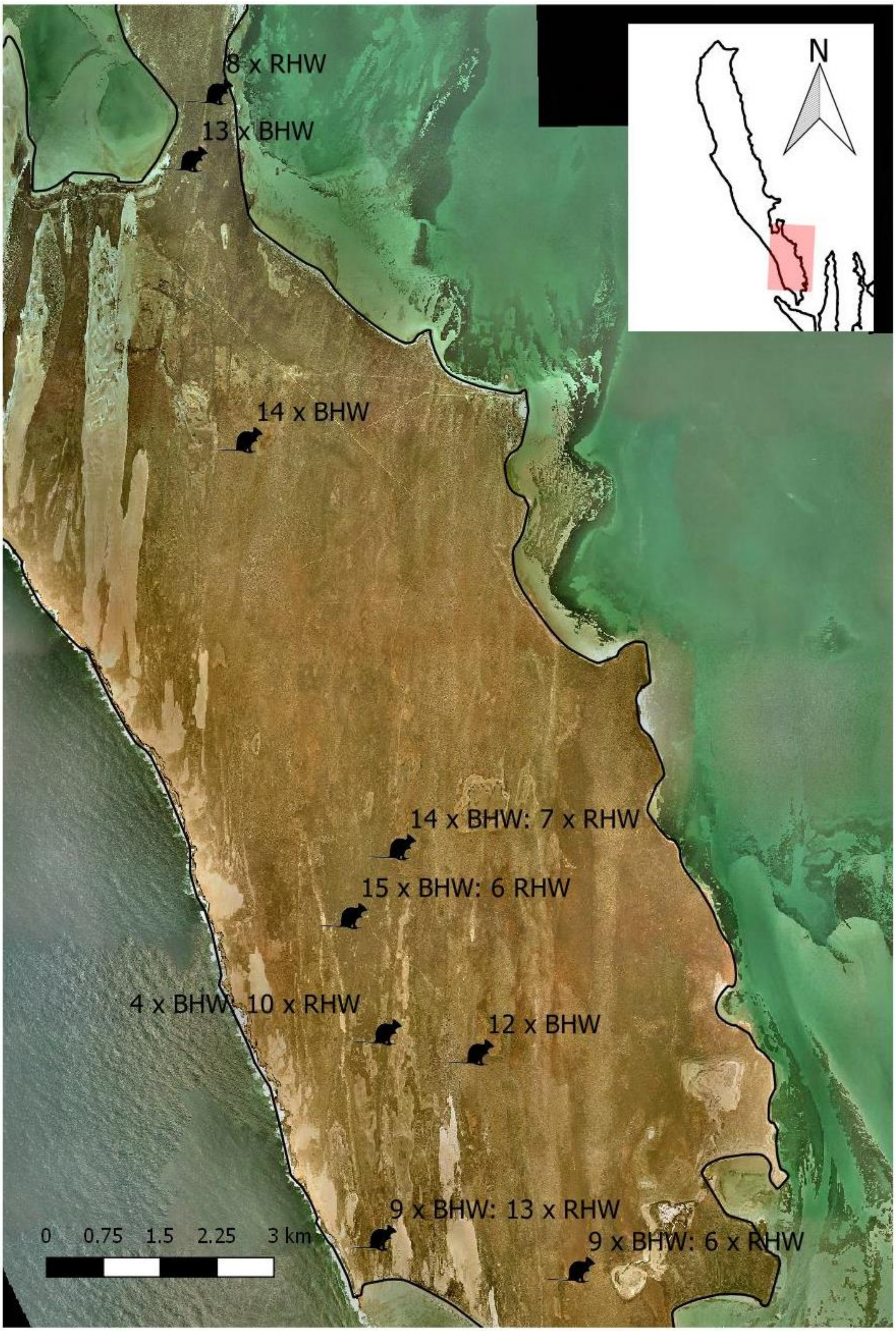

Figure 4. Map of southern end of Dirk Hartog Island indicating release sites of banded and rufous hare-wallabies and numbers release at each location.

Figure 5. Example of Triodia*-dominated community nominated as release location for rufous hare-wallabies (© S. Cowen/DBCA).*

Figure 6. Example of Acacia*-dominated community nominated as release location for banded hare-wallabies (© S. Cowen/DBCA)*

of ungulates commenced (Dongen et al., 2018). These data were used to select locations of shrublands and hummock grasslands where vegetation recovery had been greatest. In 2017 a release area was designated in the south of DHI (Cowen et al., 2018), approximately 10 km south of the Dirk Hartog Island Eco-lodge (Figure 1), which was the base for the post-release monitoring team during 2017 and 2018.

A total of nine release sites were chosen over the course of the 2018 translocation period (Figure 4) and were selected based on proximity to suitable habitat (i.e. *Triodia*-dominated communities (preferred by rufous hare-wallabies) (Figure 5) and *Acacia*-dominated communities (banded hare-wallabies) (Figure 6). Two of these were also release sites used in 2017 (Cowen et al., 2018).

2.4 Capture, transport and release

2.4.1 Capture of hare-wallabies on Bernier and Dorre Islands

Capture of founder hare-wallabies on Bernier and Dorre Islands used a standard operating procedure (DBCA SOP 9.6), employing the use of spotlights and hand-nets (Department of Biodiversity Conservation and Attractions, 2017). Techniques using live-capture traps are not appropriate for hare-wallabies as they are not readily trapped (Richards et al., 2001) and are prone to the potentially fatal disorder known as 'capture' or 'stress' myopathy, which can be induced by stressors such as trapping and handling (Paterson, 2007). Macropodids can be particularly susceptible to capture myopathy (Green-Barber et al., 2018) with rufous hare-wallabies known to be particularly vulnerable (Cole et al., 1993). Hand-netting required a team of six, with one member to locate hare-wallabies in the beam of a 35W spotlight, one to carry field-processing equipment and three to four more others with hand-nets to catch the animal. Chases were minimised to <100m to mitigate risk of capture myopathy (Paterson, 2007).

Once animals were captured, they were immediately assessed for suitability for translocation, taking into account sex, age, body condition and breeding status (i.e. presence and size of pouch young or young-at-foot). Captured animals were weighed and had Passive Integrated Transponders (PIT, Allflex ™ FDX-B Microchip, ca.11 x 3mm) inserted at the rear of the neck. To mitigate the risk of capture myopathy, all individuals selected for translocation were treated with selenium/vitamin E (0.2ml/kg), and if required, some individuals were also given Diazepam (1.0mg/kg) and/or Azaperone (2mg/kg). Selenium and Vitamin E are thought to play a role in reducing the likelihood of capture myopathy, particularly if the animal is likely to be subject to further stress. Sedation with Diazepam and Azaperone was used to maintain the animal in a calm state during transport and handling. While sedation with Diazepam only lasts a few hours, Azaperone sedation may last up to eight hours. However, the effect of Azaperone sedation is more predictable if Diazepam is administered prior. In this translocation, only rufous hare-wallabies were sedated during transport and handling, given their higher risk of capture myopathy. In the 2017 trial translocation animals were transported by boat and despite sedation, all individuals of both species suffered significant stress reactions (hypersalivation), dehydration and weight loss during transport. In 2018, a low dose of Atropine (0.04-0.05mg/kg) was administered to individuals in an effort to reduce the level of fluid and weight loss. Approximately half of the individuals were given Atropine to determine if stress levels and survival outcomes were improved by this treatment. Handling was kept to a minimum under all circumstances, since this is another stressor that may potentially exacerbate the risk of capture myopathy (Paterson, 2007).

Females with pouch young were selected for translocation only if the crown-rump length of the pouch young was ≤60mm. Females with pouch young larger than 20mm crown-rump length had their pouches secured with Fixomull® tape (BSN medical, Hamburg Germany) (as per DBCA SOP 14.1). A small number of females with dependent young-at-foot were also translocated but ensuring that the mother and joey pairs were transported and released together.

2.4.2 Transfer and holding procedure

After capture and initial processing, hare-wallabies selected for translocation were held in a black cotton bag inside a pet-pack (PP30 62 x 43 x 45 cm) and then carried to the beach and sheltered from weather inside tents until transferred off as soon as possible after first light, by Robinson R-44 helicopter (Coral Coast Helicopters) to Dirk Hartog Island. Whilst every attempt was made to minimise stress, it is impossible to eliminate all causes of stress during transport. However, the decision to use helicopter transfer in 2018, in contrast to the boat transfer used in the 2017 trial, significantly reduced the level of exposure to stressors such as motion (take off, flight and landing involved considerably less jerky movements than the significant pitch, roll and yaw of a boat in rough seas), including potential nausea associated with ‘motion sickness’, unpleasant and even toxic olfactory stimuli (diesel fumes present on boat, but not in helicopter) and duration (20-30 minutes by helicopter compared to four to five hours by boat). Noise levels were impossible to compare empirically but it is likely that engine noise between modes of transport would be comparable, but duration of exposure was considerably less with the helicopter transfer. Time in transit is linked to levels of chronic stress in translocated wildlife (Dickens et al., 2010). The negative effect of the remaining stressors inherent in translocation which could not be eliminated, was ameliorated by use of the chemical treatment methods outlined in 2.2.1. The helicopter was based on Dirk Hartog Island for the duration of the translocation program. Therefore, animal transfers commenced within 30 minutes of first light and were completed within two hours of sunrise at the latest. The maximum number of transfers completed on any one day was two, the number of flights required was determined by space available in the helicopter and the number of animals captured for translocation.

On arrival at Dirk Hartog Island, all animals were housed in a cool, quiet area in clean black cotton bags. Animals were only removed from this area during the day to be processed. During this procedure animals were reweighed and morphometric measurements were taken. Small punches of ear-tissue were taken for subsequent DNA extraction and analysis, and radio-telemetry collars fitted to twelve hare-wallabies of each species for post-release monitoring. Eighteen hare-wallabies (nine rufous; nine banded) were fitted with VHF radio collars (VHF Core (custom-built), Sirtrack, Havelock North, NZ) with a four-hour mortality sensor. In addition, six animals were fitted with telemetry collars with both VHF (four-hour mortality sensing) and GPS capabilities (Q4000ER, Telemetry Solutions, Concord, CA, USA). Ensuring close collar-fit was crucial, as significant loss of weight, resulting in loosening of the collar and subsequent entrapment of forelimbs is also a known risk of mortality for hare-wallabies (Hardman et al., 2016). Most animals were calm during processing but those that were agitated we not considered for collar-fitting. Once animals had been fully processed, they were again held in a cool, quiet area in clean black cotton bags returned to the holding area until after sunset.

2.4.3 Release procedure

Animals were transported in pet-packs by vehicle and released after dark at designated release sites, as outlined in section 2.1. Prior to release, hare-wallabies were checked again for collar-fit and to ensure fore-limbs were not caught. Animals were observed at time of release to ensure they had not sustained any injuries during translocation, or displayed signs of incapacitation. Once this was established, staff and volunteers departed the area quickly and quietly to minimise additional disturbance to the animals.

Females with pouch young were released in their holding bags away from people and other wallabies with strings undone to allow them to depart of their own accord (‘soft-release’). Pouches were taped to ensure pouch young could not be ejected as part of a fear ‘flight’ response by the female. These bags were collected the following day to confirm that animals had departed and that pouch young had been retained.

2.5 Post-release monitoring

2.5.1 Ground radio-tracking

The primary method of post-release monitoring of hare-wallabies was regular ground tracking of radio-telemetry collars (radio-tracking). Radio-tracking allowed the location and status of radio-collared animals to be monitored remotely and data on behaviour, movement and survivorship to be obtained (Millspaugh and Marzluff, 2001). Previous radio-tracking of translocated hare-wallabies has shown that some individuals tend to remain in small areas (‘residents’), whereas others are more mobile (Hardman et al., 2016). Therefore, we anticipated that translocated hare-wallabies would vary considerably in their nightly movements, and that some animals may move considerable distances. The protocol was to ensure that hare-wallabies were not approached closely during the day to avoid flushing animals from vegetation cover, which would potentially expose them to predation by raptors, a known risk with translocations of these species (Hardman et al., 2016).

Locations of radio-tracked animals can be acquired through triangulating VHF signals by obtaining compass bearings for the strongest signal from three or more locations. In 2017, this method resulted in data with highly variable levels of position accuracy, which were not suitable to obtain robust estimates of landscape utilisation. The time required to obtain multiple fixes on individual collared wallabies also meant less time for locating ‘missing’ individuals who may not have been detected for several days.

Consequently, in 2018 confirming live/mortality detections (see below) daily for all individuals was considered a priority over acquiring triangulations. If an animal had moved to an appreciably 'new' location, then a triangulation was ideally obtained to confirm an accurate position.

To aid with the identification of collared hare-wallabies recorded on remote cameras (see 2.4.3 below), collars were marked with unique symbols in fluorescent ink (Figure 7). Symbology was based on that designed for fluorescent collar tags for quokka (*Setonix brachyurus*) to assist in the identification of individuals at night (Ealey and Dunnet, 1956).

The six GPS collars were pre-programmed on a schedule to record locations at regular intervals over time. In 2017, nine programs were used to test optimal duty schedules for the translocation, within the limitation of the battery life of the collars. Programs that balanced the number of fixes per day with the number of days the GPS was active provided the best value from the life of the collars. In 2018, the GPS schedule was divided into two active periods of 21 days at the start and end of the intensive monitoring period (30 September to 20 October and 11 November to 1 December) during which seven fixes were obtained between 1800 and 0600 at two-hourly intervals with an additional 'daytime' fix at midday. This schedule was used to investigate the hypothesis that hare-wallaby movement (and utilisation distribution) changes and declines with time post-release.

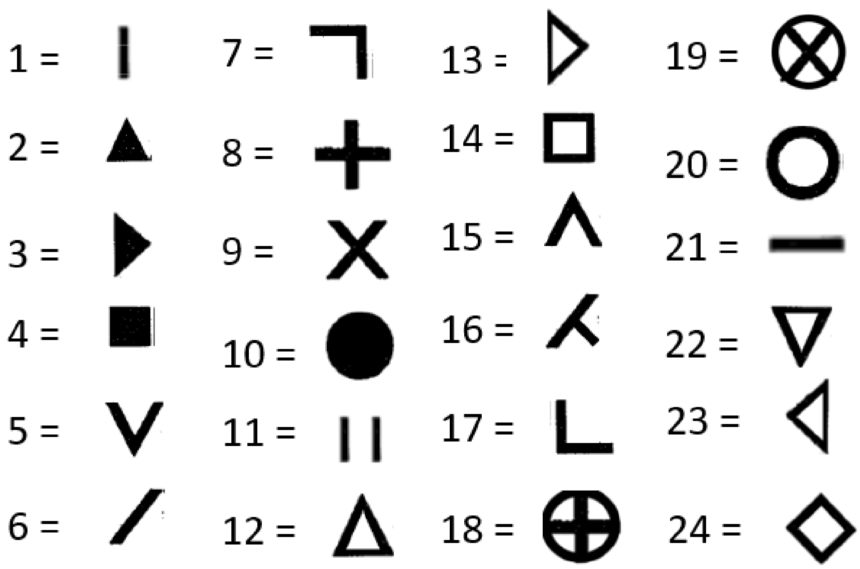

Figure 7. Symbology for unique identification marking of hare-wallaby collars (after Ealey and Dunnet (1956)).

GPS fixes were screened for accuracy and poor-quality fixes were removed based on a) no fix at all b) HDOP (horizontal dilution of precision, i.e. proximity of satellites to each other when fixes are acquired) >5.0 (as per Moen et al. (1997)) c) 2D fixes vs. 3D fixes and d) positions that were self-evidently impossible (e.g. in the sea or positions with an altitude of 1000 m etc). GPS data were used to generate 95% Minimum Convex Polygons (MCP95) and Kernel Density Estimates (KDE95) using Animove in Quantum GIS (version 3.4.7 Madeira), which provide an approximation of utilisation distribution. In addition, 'heatmaps' were created that visualize the density of fixes for each individual.

KDEs calculate a smoothed probability density function for each hare-wallaby based on the obtained locations. Generally, KDEs are considered to be accurate in estimating simulated home ranges (Seaman and Powell, 1996), even though more recent studies suggest using generalised movement trajectories approximated by Delaunay triangulation (KDE-DT) for a more accurate analysis (Downs and Horner, 2012). Through construction of the smallest possible convex polygon around all locations, MCPs describe the extent of the area occupied by the individual hare-wallabies. Both KDE and MCP are prone to overestimating utilisation distributions (e.g. Gregory (2017)).

In addition to monitoring the movements of translocated hare-wallabies, the mortality function of the radio-collars allowed monitoring of post-translocation survivorship. Understanding the causes of any mortality was crucial to mitigating risks associated with translocations, particularly predation (e.g. by raptors) and stress disorders such as capture myopathy. As such, locating and retrieving the carcass of any dead hare-wallaby within a short timeframe was extremely important, so that a comprehensive post-mortem could be carried out. Establishing the cause of death and determining if capture myopathy was implicated required adherence to appropriate protocols for collection and storage of organs for histopathological analyses. In the case of predation events, swabs of wound sites can be used for DNA analysis to establish the predator(s) involved. To this end, radio-tracking was carried out almost daily (except for one weekend during a staff changeover) from the first day after release for 12 weeks post-release (Figure 3). We aimed to locate a radio signal from each animal every day to establish if the collar was in 'live' or 'mortality' mode, as indicated by a modified signal pulse rate. If a collar was detected in mortality mode, we would locate the collar, and retrieve either the slipped collar or the carcass as quickly as possible.

An issue in 2017 was the difficulty of acquiring remote downloads from the GPS telemetry collars. This mainly related to the proximity to the collar at which a download link could be established which testing showed was approximately 15m (much less than the 200m stated in the user manual). Given the protocol above (i.e. to avoid flushing animals), downloads were not always obtained due to the difficulties in getting close enough to the animals. In May 2018, we tested a different collar by the same manufacturer (Telemetry Solutions, Concord, CA, USA) with a 'Long Distance TRX' download function and which extended the download range to over 350m.

2.5.2 Aerial radio-tracking

To monitor survivorship after the initial 12-week intensive-monitoring period (Figure 3), radio-tracking of animals wearing collars was continued at four- to six-week intervals over summer and early autumn. Detection and location of radio-telemetry collars on the ground can be potentially time-consuming as signals can be interrupted by vegetation and topography. A more efficient method of obtaining radio signals, establishing the status of the animals and determining approximate locations is through the use of aircraft. We chartered a Cessna 172 fixed-wing light aircraft (Shark Bay Aviation) and fitted telemetry antennas underneath both wings (CASA engineering order number EO TDE5788-01-R1). After initially checking for 'live' vs. 'mortality' pulse rates, collar locations were obtained by alternating between right and left antennas until the signal reaches a null (as outlined by Seddon and Maloney (2004)) and then a location was recorded using a GPS unit.

Figure 8. Phantom 4 Pro remotely piloted aircraft (RPA or 'drone') showing attachment of Telemetry Solutions remote-download base-station using cable ties (© S. Cowen/DBCA).

In addition, we tested the use of an RPA to obtain remote downloads from GPS collars. The base-station for acquiring remote downloads is light (~60g) and is designed to be attached to the skid of a Phantom series RPA (DJI, Shenzen, China) (Figure 8). This feature was advantageous, as increasing the height of the download unit improves the range and also increases proximity to the animal without approaching and potentially disturbing the animal.

In May 2019, a contractor (Debra Saunders, Wildlife Drones, Canberra, ACT) was invited to undertake a trial and training workshop using a remotely-piloted aircraft (RPA) to locate collared hare-wallabies on DHI, which if successful should significantly reduce the time required to obtain and locate signals.

2.5.3 Remote cameras

Establishing a long-term monitoring protocol for both species of hare-wallaby is a high priority for the project, since neither species has a propensity to enter live-capture traps. Remote cameras present a potentially valuable monitoring tool for species that are difficult to trap and may be relatively economical compared to other techniques such as conducting spotlighting or scat/track surveys (Bondi et al., 2010). Remote camera data have been used to model estimates of occupancy of animals in a given location with some accuracy but values for detection probability for each species must be obtained first (MacKenzie et al., 2006).

In the 2017 trial, 30 passive (unlured) remote Reconyx cameras (Hyperfire PC900, Holmen, WI, USA) were deployed on a grid for six months. The spacing of the grid was 500m apart and located in the vicinity of the release area. However, the cameras recorded so few hare-wallabies that an estimation of occupancy was not possible (Cowen et al., 2018). This low number of detections was probably due to the relatively low numbers of hare-wallabies present on the island in 2017-18 ($n \geq 23$). However, hare-wallabies were also captured on the cameras that the cat eradication team had established south of the fence to monitor for cats. Nearly all of which were placed alongside the main 4WD track or ATV tracks on a grid, spaced

Figure 9. Study area with locations of track camera-traps, marked in red if working and blue if excluded from analysis.

approximately 2km apart, which provided useful additional data.

In 2018-19, the grid of 30 cameras at 500 x 500m intervals was repeated (see Cowen et al., 2018). These cameras were deployed from 28 to 30 November 2018, serviced on 8 and 12 March and collected on 22 May 2019. As a result, as of June 2019, the analysis of these data is yet to be completed.

In addition to the 30 camera grid, 32 cameras were deployed on the grid where the cat-monitoring cameras had been set up previously, covering an area from Notch Point in the north to Cape Ransonnet in the south (Figure 9). It was hoped that enough observations would be acquired in 2018-19 to provide sufficient data for the estimation of detection probability and to inform the design of any future camera monitoring strategy. All cameras were deployed at ~15cm above the ground, using an aggressive setting, (i.e. five pictures taken per trigger and an interval of less than one second between images). A 'walk-test' was performed each time before the camera was armed to ensure the target area of the camera was correctly aligned. Two cameras were excluded from the analysis: one (N37) was removed as it became buried in sand after less than four weeks, being located adjacent to a sand-dune; the other one malfunctioned (K34) (Figure 9).

Camera images were downloaded, databased and prepared for additional analysis in CPW Photo Warehouse (Colorado Parks and Wildlife). A detection summary was exported via R into Presence 12.31 (D. MacKenzie, Proteus Research & Consulting Ltd.; https://www.mbr-pwrc.usgs.gov/software/presence.html), a software package developed to enable estimates of the proportion of area occupied by a species. Occupancy (Ψ) and detection probability (*p*) were subsequently calculated. Remote cameras that are deployed along roads, tracks or trails are not considered random sampling, as they violate the assumption of spatial independence. As such, data obtained from the camera arrays along tracks are problematic. However, in order to test the hypothesis that translocated hare-wallaby landscape utilisation changes with time after releases, it was hoped that these data may allow the detection of changes in occupancy. It was predicted that occupancy would decline with time, as hare-wallaby movements become smaller and 'home-ranges' or territories are established.

2.5.4 Hair-funnel lure trials

As discussed in 2.4.3, the number of observations of hare-wallabies obtained from the passive (unlured) camera grid in 2017-18 was too low modelling detection probability or occupancy of either species. Given this, we decided to trial active (lured) methods of detection using hair-funnels.

Hair-funnels, (tubes or –arches) have been used successfully for monitoring small mammals (Chiron et al., 2018) and are more economical and less invasive/stressful for animals than some other methods (e.g. Elliott trapping) (Garden et al., 2007). This method relies on mammals approaching a structure close enough for guard hairs to be removed by some form of adhesive (glue or tape). These 'traps' can be lured or passive, the latter usually along well-used trails used by the study species. Tissue derived from hair-collection techniques can sometimes be used for DNA analysis (Ruibal et al., 2010). This method of detection has promise for monitoring a range of both extant and translocated mammals on DHI and we were keen to learn how effective hair-funnels might be in detecting the two hare-wallaby species.

A 300 x 300m grid of 30 hair-funnels (Universal Hair Funnels, Faunatech, Bairnsdale VIC) was deployed on the Notch Point peninsula (Figure 1). Both hare-wallaby species were released in this area (Figure 4) and ongoing presence had been confirmed by the observation of tracks, a sighting of one animal at night and visitation by radio-collared animals. Locations were chosen underneath shrubs to alleviate the possible influence of wind and rain (Figure 10). Hair-funnels were fitted with adhesive wafers supplied by the manufacturer and fixed to the ground using tent-pegs. As a control, hair-funnels were deployed from 15-25 November 2018 without lures. Wafers were then collected, labelled with location, date and collector before being stored in a freezer at -20°C. A second trial was undertaken from 25 November - 5 December 2018 with new wafers and a food-based lure placed in the metal chamber at the base of the funnel (Figure 11). The chamber prevents small mammals from actually reaching the lure. The lure was made up of peanut-butter, chopped apple, molasses and honey and approximately two tablespoons were used to fill each chamber. Again, after retrieval wafers were labelled and stored at -20°C. Identification of hairs on wafers was conducted using whole mount preparations under compound microscope at Woodvale Wildlife Research Centre (Woodvale, WA). Each wafer was photographed before identification work commenced.

Figure 10. Image showing placement of hair-funnel under a tall Acacia ligulata *shrub (© L.Scheelen/DBCA)*.

Figure 11. Open hair-funnel showing base with peg-holes for attachment to ground (left), metal chamber for lures (centre) and funnel itself with fresh adhesive wafer (right) (© L. Scheelen/DBCA).

2.5.5 Faecal DNA degradation trial

Another method that shows promise as a reliable non-invasive monitoring technique involves using DNA derived from faecal pellets (scats) to genotype and identify individuals. These data can then be used with a spatially-explicit capture-recapture (SECR) modelling method of estimating of population density (Mills et al., 2000, Lukacs and Burnham, 2005). This technique has already been used in a range of mammal species (Piggott et al., 2006, Goode et al., 2014, Fuller et al., 2016, Morin et al., 2016, Woodruff et al., 2016, Dziminski and Carpenter, 2018). Here we undertook an investigation of how faecal DNA monitoring could be used for hare-wallabies, specifically focussing on the banded hare-wallaby. This study was a collaborative project with Australian Wildlife Conservancy (AWC) who are also seeking to monitor this species using this technique. It is anticipated that this approach could also be used for other species such as the rufous hare-wallaby.

One key aspect of this method is the duration after which DNA is no longer suitable for genotyping (Piggott, 2004, Panasci et al., 2011, Carpenter and Dziminski, 2017). DNA can be degraded by a range of environmental factors, including; moisture, ultra-violet rays (UV) and temperature. Consequently, a DNA degradation trial needed to be conducted initially.

Figure 12. Example of faecal DNA degradation ‘in-situ’ trial set-up, showing Plexiglas ‘A-frame’ and cage-trap with ceramic dishes containing clean, dry sand (© S. Cowen/DBCA).

In October 2018, fresh scats of known age were collected while processing translocated wallabies using sterile latex gloves and replaced between animals to avoid cross-contamination. For the ‘in-situ’ trial scats from three individuals were selected based on a requirement for at least 38 individual pellets. This number was required to provide two pellets per individual for each of the seven different exposures times (0 days (control), one day, seven days, 14 days, 21 days, 30 days and 60 days) in three separate treatments (shade, part-shade and fully exposed). The method used was similar to that in Carpenter and Dziminski (2017) with pellets placed on clean, dry sand in ceramic dishes inside a closed cage under an ‘A-frame’ of UV-transmitting Plexiglas (Evonik Industries, Essen, Germany) (Figure 12). UV-transmitting material was used was to prevent excessive moisture (e.g. rain) from impacting the trial (heavy rain would almost certainly render the experiment null), whilst ensuring scats were still exposed to natural levels of UV. Ambient conditions were monitored using dataloggers (Thermodata, Eight Miles Plains, Qld) and a weather-station (Environdata, Warwick, Qld).

On completion of an exposure period, scat samples were removed (again using sterile gloves which were replaced between samples) and stored on silica gel desiccant in 50ml vials before being stored at -20°C. DNA was then extracted from the scats and quantified before being used to genotype individuals using seven microsatellite markers, specifically characterised for the banded hare-wallaby (and two developed to amplify both banded and rufous hare-wallaby DNA as positive controls) (S. McArthur pers. comm.).

A separate ‘ex-situ’ trial was also conducted to investigate the rate of DNA degradation in storage. Two pellets from an additional three animals were collected, with one pair used as a control by being stored at ambient temperature, another stored at -20°C and the last stored at -80°C before extraction. Pellet handling was conducted as per ‘in-situ’ trial above.

2.5.6 Scat and pellet collection for diet analysis

As in 2017, scats continued to be collected on an ad-hoc basis from the field for the purposes of dietary analysis. Scats were also collected from processing bags after arrival on DHI from Bernier/Dorre Islands, providing samples from those locations as well. Scats for dietary analysis were dried and stored at -20°C in either plastic vials or paper bags. These samples will form part of a comparative study of banded and rufous hare-wallaby diet, evaluating any differences in diet between species and locations. It is also intended that any seeds found in these samples will also form part of a germination study to investigate seed dispersal by hare-wallabies. As per the recommendations in the 2017-18 report (Cowen et al., 2018), a reference library of seeds and other plant specimens is being established.

Another recommendation in the 2017-18 report was to better understand the potential impact of raptor predation on hare-wallabies (and other species). This should also include the role of smaller avian predators (e.g. nankeen kestrel (*Falco cenchroides*), southern boobook (*Ninox boobook*) and eastern barn owl (*Tyto javanica*) on small mammals. In 2018, a concerted effort was made to collect raptor and owl pellets from roost and nest sites around DHI. These were dried and stored as per scat samples and then sent for dietary analysis (G. Story, Scatsabout, Majors Creek, NSW).

Scats from sand monitors (*Varanus gouldii*) were also collected. With eradication of cats from DHI complete, the sand monitor remains the largest terrestrial predator on the island and it was important to learn more about the diet of this species and to what extent small mammals contribute to their prey. Collected scats were sent to for analysis as above.

2.5.7 Monitoring of large raptors

As per recommendation eight in the 2017-18 annual report (Cowen et al., 2018), monitoring of the presence of large carnivorous raptors was undertaken in September to December 2018. The presence of raptor species was recorded by GPS (observations and/or nests). Species of main interest were the wedge-tailed eagle and white-bellied sea-eagle (*Haliaeetus leucogaster*), which are both potential predators of hare-wallabies (Short and Turner, 1992, Richards et al., 2001) and other species of medium-sized mammal. Of lesser interest were eastern osprey (*Pandion cristatus*) (an obligate piscivore), brown falcon (*Falco berigora*), whistling kite (*Haliastur sphenurus*) and spotted harrier (*Circus assimilis*) as their preferred prey does not typically include medium-sized mammals. These were recorded on an ad-hoc basis as an increase in presence and abundance may potentially relate to the absence of cats.

2.5.8 Recapture for radio-collar checking and/or removal

At the end of the 12-week intensive monitoring period (late November/early December 2018), attempts were made to recapture all radio-collared hare-wallabies to assess the collar, conduct health-checks and check for any signs of reproductive activity. Animals with GPS collars either had the collars removed or replaced with VHF only collars as the battery life of the GPS collars was expected to expire by mid-December. A second period of hare-wallaby recaptures for the purpose of collar removal took place over two weeks in May 2019, prior to the VHF collar batteries expiring. This permitted the maximum period for monitoring (especially for survivorship) using these collars. It also provided another opportunity to assess health and recruitment as well. Once captured, morphometric measurements were taken, collar-fit and body condition assessed and pouches checked for signs of reproductive activity. Collars were removed if there was any sign of significant injury (e.g. open or scabbed wounds). If the collar fit was suboptimal or there was sign of fur loss or reddening of the skin, they were adjusted.

Heath-checks included checking for presence and abundance of ectoparasites and signs of any injuries. An overall condition score was assigned using two methods. A quantitative condition index was calculated by dividing the cube root of weight (g) by long pes length (cm) (as per Caughley et al. (1988)). A qualitative estimate also used was based on the following criteria (from Chapman et al. (2015)):

1. Emaciated (very little muscle mass to touch, transverse processes of spine prominent)
2. Under weight (little flesh, able to feel transverse process of spine easily)
3. Ideal (able to (just) feel transverse processes and able to feel a ‘good’ amount of flesh between spinous processes)
4. Over-weight (only just able to feel spinous processes, unable to feel transverse processes)
5. Obese (unable to feel spinous processes, can see rolls of fat around neck and on tail)

The technique for recapture was similar to the method used to capture the founder animals on Bernier and Dorre Islands. Animals were radio-tracked during the day to determine an approximate location. The exact location was determined at night for the capture attempt itself. As above, a combination of spotlighting and hand-netting was used.

In addition, a ‘drift-fence’ was employed along with hand-netting to help reduce long pursuits of animals and increase capture success. Target animals were tracked to their daytime refuge and prior to sunset, a drift-fence was assembled in a semi-circle around the refuge. The fence was made from ‘cat netting’ mesh (Diamond Networks, Kardinya WA) and dropper-posts (Figure 8) with metal turf-pegs to hold down the base. A capture team slowly approached the refuge and either a) attempted to identify the scrape entrance and directly removed the animal from the refuge or b) flush the hare-wallaby into the fence which impeded its flight long enough to be captured either by hand or hand-net.

Thomas traps baited with Dairy-Krave© (Feed Flavors Inc., Wheeling, Illinois, USA), apples and 'kangaroo pellet' stock-feed were used to target individual animals that were difficult to catch in nets. Traps were and checked before sunrise every day and between 2000 and 2100, and set for four nights.

Figure 13. 'Drift-fence' set up, showing cat netting and metal droppers semi-encircling a hare-wallaby refuge (© D. Saunders/DBCA).

2.5.9 Post-mortem of deceased hare-wallabies

In the case of any mortalities during the intensive post-release monitoring period, it was important that a post-mortem be carried out as soon as possible to establish the probable cause of death, especially if capture myopathy was suspected.

3 Results

3.1 Capture and translocation of hare-wallabies

A total of 140 hare-wallabies (90 banded; 50 rufous) were translocated from Bernier and Dorre Islands. A total of 47 banded and 23 rufous were captured and transferred from Dorre Island between 15 and 23 September 2018 and 43 banded and 27 rufous from Bernier Island between 23 September and 4 October 2018 (Table 1). Of these, seven banded and 16 female rufous hare-wallabies had pouch young (all ≤60mm). One banded hare-wallaby was translocated with a young-at-foot weighing 825g at capture and were released together. Another juvenile banded hare-wallaby (850g) was also translocated and was released with its presumed parent.

Table 1. Capture statistics for translocation of banded and rufous hare-wallabies from Bernier and Dorre Islands to Dirk Hartog Island in Sep-Oct 2018 (NB dates reflect captures occurring before and after midnight).

		L. fasciatus			*L. hirsutus*			
Capture Date	Island	Female	Male	**Total**	Female	Male	**Total**	Island Total
15-16 Sep	Dorre	9	5	**14**	4	3	**7**	70
20-21 Sep		8	7	**15**	3	3	**6**	
21-22 Sep		5	9	**14**	0	0	**0**	
22-23 Sep		3	1	**4**	4	6	**10**	
23-24 Sep	Bernier	4	5	**9**	5	8	**13**	70
1-2 Oct		11	2	**13**	5	3	**8**	
2-3 Oct		9	3	**12**	0	0	**0**	
3-4 Oct		6	3	**9**	3	3	**6**	
	Totals	55	35	**90**	24	26	**50**	140

While every effort was made to minimise stress during the translocation, many animals exhibited some level of stress (e.g. teeth grinding, moderate to severe hypersalivation, agitation). Fifteen rufous hare-wallabies were noted as being especially stressed during processing and one banded hare-wallaby noted as ‘highly-strung’. Handling bags were generally less soaked with saliva and/or urine than in 2017, and fewer changes into fresh, dry bags were required during the course of the translocation. Four rufous hare-wallabies continued to exhibit hypersalivation during holding and handling.

On release, most hare-wallabies appeared calm and moved away, often feeding immediately on vegetation. Some animals appeared disorientated but moved away eventually. Others moved away almost immediately, in contrast to 2017 (Cowen et al., 2018), which was likely due to animals in 2018 suffering less negative effects of dehydration and sedation at the time of release.

Figure 14. Left - release of a banded hare-wallaby (© S. Cowen/DBCA); right - the release of a rufous hare-wallaby (© A. Gibson Vega/DBCA).

No mortalities of translocated hare-wallabies were recorded during the post-release period in 2018 but one unfurred ~50mm pouch young was abandoned by a 'soft-released' female rufous hare-wallaby in the holding bag. It appeared that the female had removed the Fixomull® tape prior to exiting the bag and had ejected the pouch young as it departed. When the holding bag was retrieved the morning after release, the deceased pouch young was recovered and stored at -20°C. Post-mortem was not deemed necessary as the pouch young almost certainly died of hypothermia and/or starvation and it is unlikely that an autopsy would have provided any additional information regarding cause of mortality.

3.2 Survivorship, health and recruitment

3.2.1 Survivorship

Of the 140 hare-wallabies released, 12 of each species were fitted with radio-telemetry collars and of these all were known to have survived up to the point of collar removal.

Table 2 shows the last time each animal was recorded alive. Four banded hare-wallabies and one rufous hare-wallaby were successful in removing their own collars within 17 to 35 days post-release and it was impossible to know the fate of these individuals after this time. One of the nylon nuts used to close the collar, had come undone, potentially due to the failure of the glue used to secure the nuts. Another rufous hare-wallaby had its collar removed much later (21 November 2018) when it was found that the collar was causing a sore on its neck. In total, 18 individuals (nine of each species) were known to be alive at the end of the intensive monitoring period and an aerial radio-tracking flight on 18 January 2019 found all were still alive. By 8

March 2019, two collars had come off (one banded; one rufous) and the remaining 16 were all heard again in live mode during a radio-tracking flight on 11 April 2019.

Table 2. Individual translocated hare-wallabies and the date they were last known to be alive (collar dropped by animal; † animal not recaptured in May 2019)*.

ID	Species	Sex	Release date	Last recorded alive	Days elapsed	Method
BR03	*L. hirsutus*	M	24/09/2018	24/05/2019	242	Recaptured (collar removed)
BR07	*L. hirsutus*	F	24/09/2018	24/05/2019	242	Recaptured (collar removed)
BR08	*L. hirsutus*	M	24/09/2018	17/10/2018	24	Radio-tracking (ground)*
DB17	*L. fasciatus*	F	20/09/2018	26/05/2019	248	Recaptured (collar removed)
DB19	*L. fasciatus*	M	20/09/2018	7/10/2018	17	Radio-tracking (ground)*
DB23	*L. fasciatus*	F	20/09/2018	29/05/2019	251	Radio-tracking (ground)†
DB24	*L. fasciatus*	M	20/09/2018	18/01/2019	120	Radio-tracking (aerial)*
DB26	*L. fasciatus*	M	20/09/2018	29/05/2019	251	Radio-tracking (ground)†
DB27	*L. fasciatus*	F	20/09/2018	27/05/2019	249	Recaptured (collar removed)
DB28	*L. fasciatus*	F	20/09/2018	22/05/2019	244	Recaptured (collar removed)
DB32	*L. fasciatus*	M	21/09/2018	10/10/2018	19	Radio-tracking (ground)*
DB33	*L. fasciatus*	F	21/09/2018	15/10/2018	24	Radio-tracking (ground)*
DB38	*L. fasciatus*	M	22/09/2018	27/10/2018	35	Radio-tracking (ground)*
DB40	*L. fasciatus*	F	22/09/2018	29/05/2019	249	Recaptured (collar removed)
DB41	*L. fasciatus*	M	22/09/2018	29/05/2019	249	Recaptured (collar removed)
DR09	*L. hirsutus*	M	20/09/2018	18/01/2019	120	Radio-tracking (aerial)*
DR11	*L. hirsutus*	M	21/09/2018	22/05/2019	243	Recaptured (collar removed)
DR12	*L. hirsutus*	F	21/09/2018	28/05/2019	249	Recaptured (collar removed)
DR13	*L. hirsutus*	M	21/09/2018	21/05/2019	242	Recaptured (collar removed)
DR14	*L. hirsutus*	M	22/09/2018	25/05/2019	245	Recaptured (collar removed)
DR16	*L. hirsutus*	F	22/09/2018	21/05/2019	241	Recaptured (collar removed)
DR17	*L. hirsutus*	F	22/09/2018	21/11/2018	60	Recaptured (collar removed)
DR18	*L. hirsutus*	M	22/09/2018	23/05/2019	243	Recaptured (collar removed)
DR20	*L. hirsutus*	F	23/09/2018	24/05/2019	243	Recaptured (collar removed)

Between 21 and 29 May 2019, 14 of the remaining 16 collared hare-wallabies were recaptured and their collars removed. The remaining two banded hare-wallabies, however, were unable to be captured, either by hand-nets or traps.

On 15 May 2019, Parks and Wildlife Service rangers discovered a road-kill rufous hare-wallaby on the main 4WD track ~17km north of the management fence. The carcass and associated vehicle tyre tracks were fresh (Figure 15) indicating the collision had occurred within 12-24hrs. No further details were recorded but this was the first recorded vehicle-related death of a hare-wallaby on DHI and the first record of a hare-wallaby north of the management fence. On 25 May a hole was discovered in the fence 500m west of the gate on the main 4WD track that a hare-wallaby could fit through (Figure 16).

Figure 15. Road-kill rufous hare-wallaby on main track north of management fence (15/05/2019) (© D. Fitzgerald/DBCA).

Figure 16. Image of hole in management fence, 500m west of main gate (25/05/2019) (© S. Cowen/DBCA).

3.2.2 Health

Ectoparasites (mostly ticks) were observed and collected from 34 banded hare-wallabies and 23 rufous hare-wallabies prior to release on Dirk Hartog Island but are yet to be identified. No ectoparasites were observed on subsequent recaptures of any animals.

During health-checks, weight was used as an indicator of changes in condition. Hare-wallabies were weighed at time of capture on Bernier/Dorre Islands, at time of processing on DHI and any time an individual was recaptured. Between initial capture and processing on DHI, almost all animals experienced weight loss, likely due to stress caused by the relocation to DHI. In 2017, weight loss between capture and processing (~12 hours) ranged from 2-9% (μ = -4%) in banded hare-wallabies and 8-18% (μ = -14%) in rufous hare-wallabies, the latter an alarming loss in a very short period of time (Cowen et al., 2018). In 2018 weight loss was also significant ($p < 0.001$ level, t-test for matched pairs) but while banded hare-wallabies lost between 0-15% of their body weight (μ = -5%) (Figure 17), the losses were considerably smaller for rufous hare-wallabies, varying between 0-10% of total mass (μ = -3%) (Figure 18). There was no significant difference in weight loss between animals treated with Atropine and controls ($p < 0.05$, t-test for matched pairs) in either species.

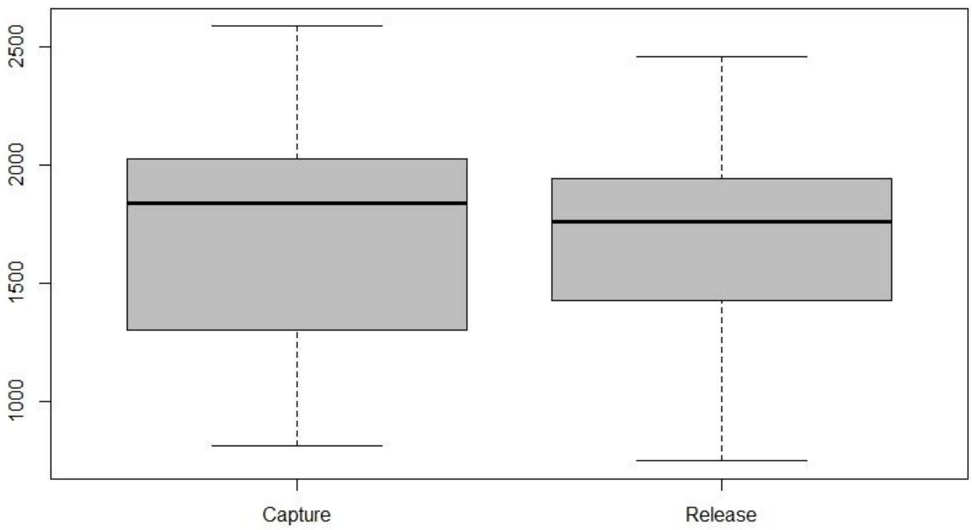

*Figure 17. Box-whisker plot of weights of **banded hare-wallabies** (n = 90) during the 12 hours between capture and processing. Black lines show median weights, error bars are maximum and minimums.*

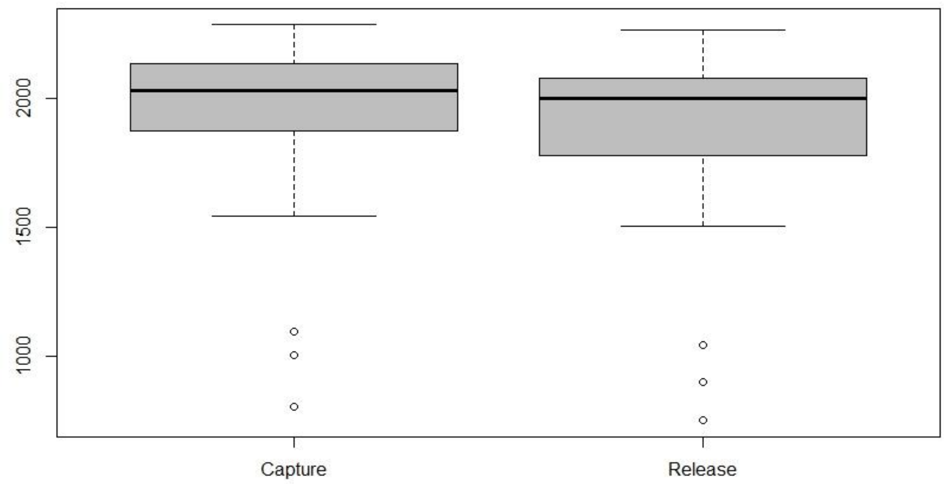

Figure 18. Box-whisker plot of weights of ***rufous hare-wallabies*** *(n = 49) during the 12 hours between capture and processing. Black lines show median weights, error bars are maximum and minimums.*

Hare-wallabies recaptured for in late November/early December, showed some variability in body weight change. In banded hare-wallabies (*n* = 7) weight change varied from +26% to -16% from the original capture weight (μ = -1%, c.f. -5% in the initial 12 hrs post-capture for the same cohort) (Figure 19). For the rufous hare-wallabies (*n* = 14) weight change varied from +1% to -16% since capture (μ = -8%, c.f. -3% post-capture for the same cohort) (Figure 20). Three of seven banded hare-wallabies had achieved or exceeded capture weight by this November/December time, while only one rufous hare-wallaby had exceeded capture weight (although two others were very close). This suggests that, while on average banded hare-wallabies gained mass soon after release, rufous hare-wallabies continued to lose weight and were slow to regain that loss.

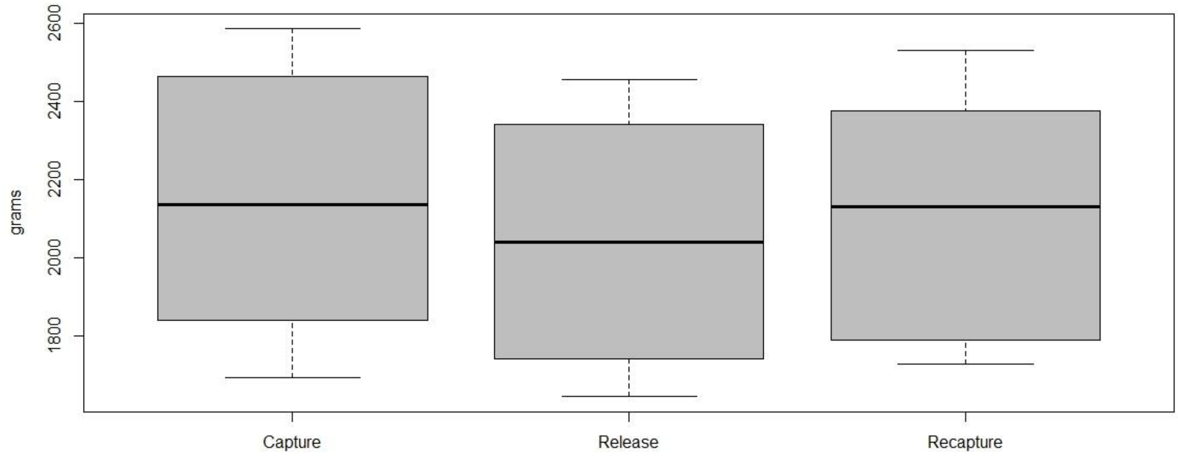

Figure 19. Box-whisker plot of weights of ***banded hare-wallabies*** *(n = 7) during the c.12 weeks between capture and recapture. Black lines show median weights, error bars are maximum and minimums (NB. Recapture weights do not include weight of collars).*

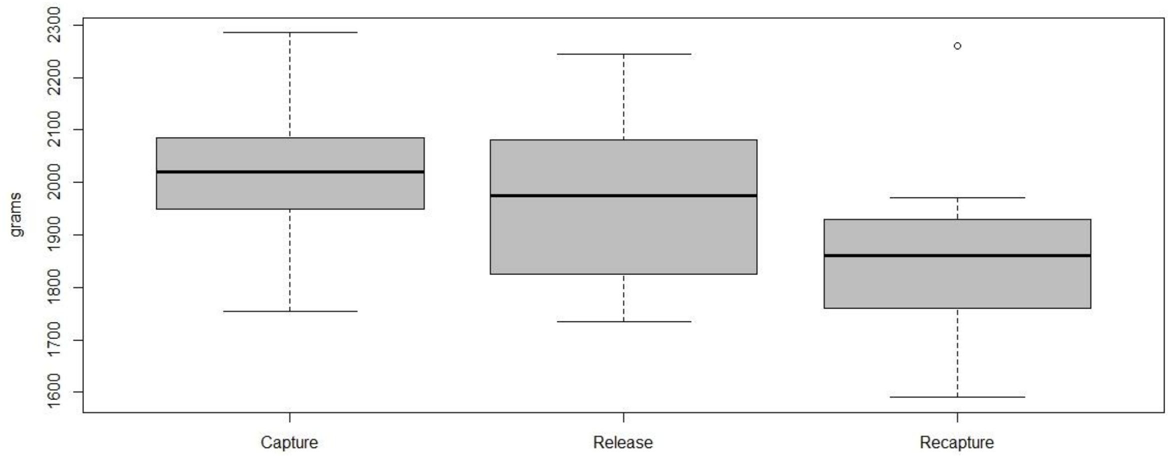

*Figure 20. Box-whisker plot of weights of **rufous hare-wallabies** (n = 14) during the c.12 weeks between capture and recapture. Black lines indicate median weights, error bars are maximum and minimums (NB. Recapture weights do not include weight of collars).*

Nine of the 14 rufous and five of the seven banded hare-wallabies recaptured in May exhibited an overall net loss of weight since capture, but weights of both species appeared to have stabilised.

Quantitative condition index values for each animal were also calculated and predictably these mirrored the patterns that were observed for body weights. At capture, median condition index scores for all individuals were 1.161 for banded hare-wallabies and 1.157 for rufous hare-wallabies. Compared to 1.187 and 1.150 respectively in 2017, banded hare-wallaby condition scores were lower, while those for rufous hare-wallabies were similar in both years. When the condition of animals recaptured in November/December were compared with that at capture, there was no significant difference in banded hare-wallaby condition index scores ($p < 0.05$, *t*-test for matched pairs, $n = 7$) but a significant reduction from a mean of 1.177 to 1.129 for rufous hare-wallabies was observed ($p < 0.001$, *t*-test for matched pairs, $n = 14$). Over the same time period, mean qualitative condition scores for these cohorts increased for banded hare-wallabies (3.79 to 3.86) but decreased for rufous hare-wallabies (3.46 to 3.27), reflecting quantitative condition scores.

Condition scores of hare-wallabies recaptured in May showed a similar pattern, with a small average reduction in condition index values for both species since last captured (0.026 for banded; 0.008 for rufous). Qualitative condition scores mostly indicated a stable or increasing trend for rufous hare-wallabies with the mean increasing from 3.46 in December to 3.75 in May. Banded hare-wallaby condition scores generally declined from 3.86 in December to 3.5 in May but these scores are still above average and the May average is based on a small sample size ($n = 5$).

3.2.3 Recruitment

Of the 16 rufous hare-wallabies translocated with pouch young, six were recaptured in November/December 2018 and, of these, five still either had pouch young or young-at-foot. One female (DR1816) showed signs of a young-at-foot (i.e. an enlarged lactating teat) but the offspring was not located during the capture (consequently, care was taken to release the mother in exactly the location she was captured). No new offspring were found in November/December, but this was not expected given that the females rufous hare-wallabies recaptured, all previously had pouch young and 50% of translocated female banded hare-wallabies (that did not have pouch young) had elongated teats, indicating they had recently weaned young in the calendar year.

In May 2019, the 10 female hare-wallabies (six rufous; four banded) that were captured had sign of reproductive activity, with the six rufous and three banded hare-wallabies having a pouch young. In addition, two young-at-foot banded hare-wallabies were sighted; one was captured and processed, despite being unable to capture the mother. Of the six female rufous hare-wallabies captured, one was a new adult female. Given her reproductive state (~60mm pouch young) this female is most likely an offspring from the 2017 translocation cohort and her pouch young represents the first known F2 individual for this species on DHI.

Of the six new offspring in 2018-19 that could be sexed, this unknown adult female was the only one of her sex; the other five pouch young were male (four rufous; one banded). In 2017-18, five young were sexed, four of which were also male (all rufous as the only female recorded was a banded).

3.3 Monitoring

3.3.1 Radio-tracking

Daily radio-tracking during the intensive 12-week monitoring period successfully obtained fixes for most animals each day. Figure 21 shows locations where fixes were obtained over this period. As in 2017, one (banded) hare-wallaby collar malfunctioned and latched in mortality mode. This meant extra effort was expended ensuring the animal was still alive, although this animal removed its collar after only 17 days. As discussed in 3.2.1, four other hare-wallabies removed their collars within 35 days of release. Almost all the remaining 19 animals retained their collars until the end of the intensive monitoring period. Figure 21 shows core areas of hare-wallaby activity.

A change in radio-tracking effort to six-weekly (approximately) aerial radio-tracking surveys proved to be very efficient method. The results of these flights are shown in Figure 21. Generally, movements of hare-wallabies by this time had stabilised and most animals were recorded in similar locations on all three occasions, except for one rufous hare-wallaby (DR13), a male that moved ~5km between January and March 2019.

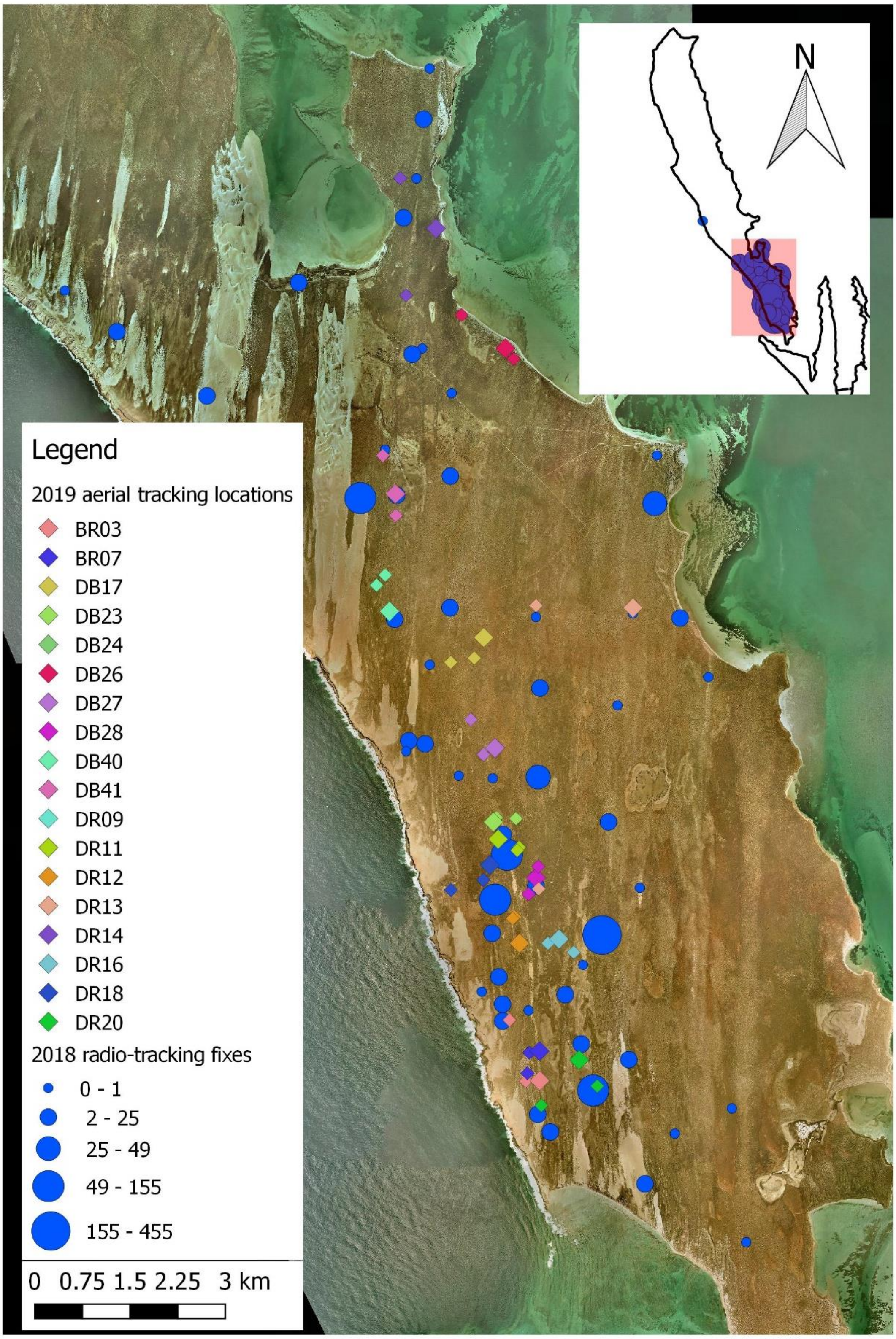

Figure 21. Map of hare-wallaby tracking locations in September-December 2018 (blue points, size indicates cumulative number of collar fixes obtained; note outlying point on overview map) and locations of 16 collared hare-wallabies acquired from aerial radio-tracking surveys in January, March and April 2019.

Analysis of data from the six GPS collars resulted in the removal of 7 to 18% of points (μ = 14%) (Table 3). This was a major improvement from 2017 when up to 50% of fixes were removed during processing.

Table 3. Screening of GPS collar fixes

Collar ID	Active period	No. of fixes before screening	No. of fixes after screening	Deleted fixes (%)
DB1824	23/09 - 01/12/2018	372	315	15.3
DB1827	22/09 - 02/12/2018	374	308	17.6
DB1828	24/09 - 01/12/2018	373	308	17.4
DR1811	22/09 - 02/12/2018	374	347	7.2
DR1812	22/09 - 01/12/2018	372	321	13.7
DR1816	3/10 - 01/12/2018	373	331	11.3

The areas of the calculated utilisation distributions (UD) are shown in Table 4. For rufous hare-wallabies, KDE areas differed widely from each other, ranging from around 16 to 101 ha (on average 46.7 ha, with a high SD of 47.3). The largest UD was occupied by one male individual. The range of MCPs was similarly wide, 8.7 to nearly 80 ha (on average 38.9 ha, SD 36.9). Having one outlier in such a small sample size is reflected in the high standard deviations. This variation is also clearly visible in the map in Figure 22. Utilization distribution estimates of the six GPS collared hare-wallabies. Based on GPS fixes from mid-September/October to December 2016.

Table 4. Utilisation distributions of collared hare-wallabies.

Collar ID	Species	Sex	Total			First period			Second period		
			No. Fixes	KDE (ha)	MCP 95% (ha)	No. Fixes	KDE (ha)	MCP 95% (ha)	No. Fixes	KDE (ha)	MCP 95% (ha)
DB1824	*L. fasciatus*	M	314	19.73	26.72	146	17.14	5.76	141	18.18	5.71
DB1827	*L. fasciatus*	F	308	22.47	117.57	143	4.13	9.04	137	17.64	5.15
DB1828	*L. fasciatus*	F	308	19.71	4.96	139	24.19	2.81	141	12.76	4.92
DR1811	*L. hirsutus*	M	347	101.09	79.97	159	129.26	32.09	158	69.59	78.87
DR1812	*L. hirsutus*	M	321	23.51	28.01	155	36.06	21.9	139	27.62	24.27
DR1816	*L. hirsutus*	F	331	15.53	8.67	152	17.55	6.85	152	12.22	4.9

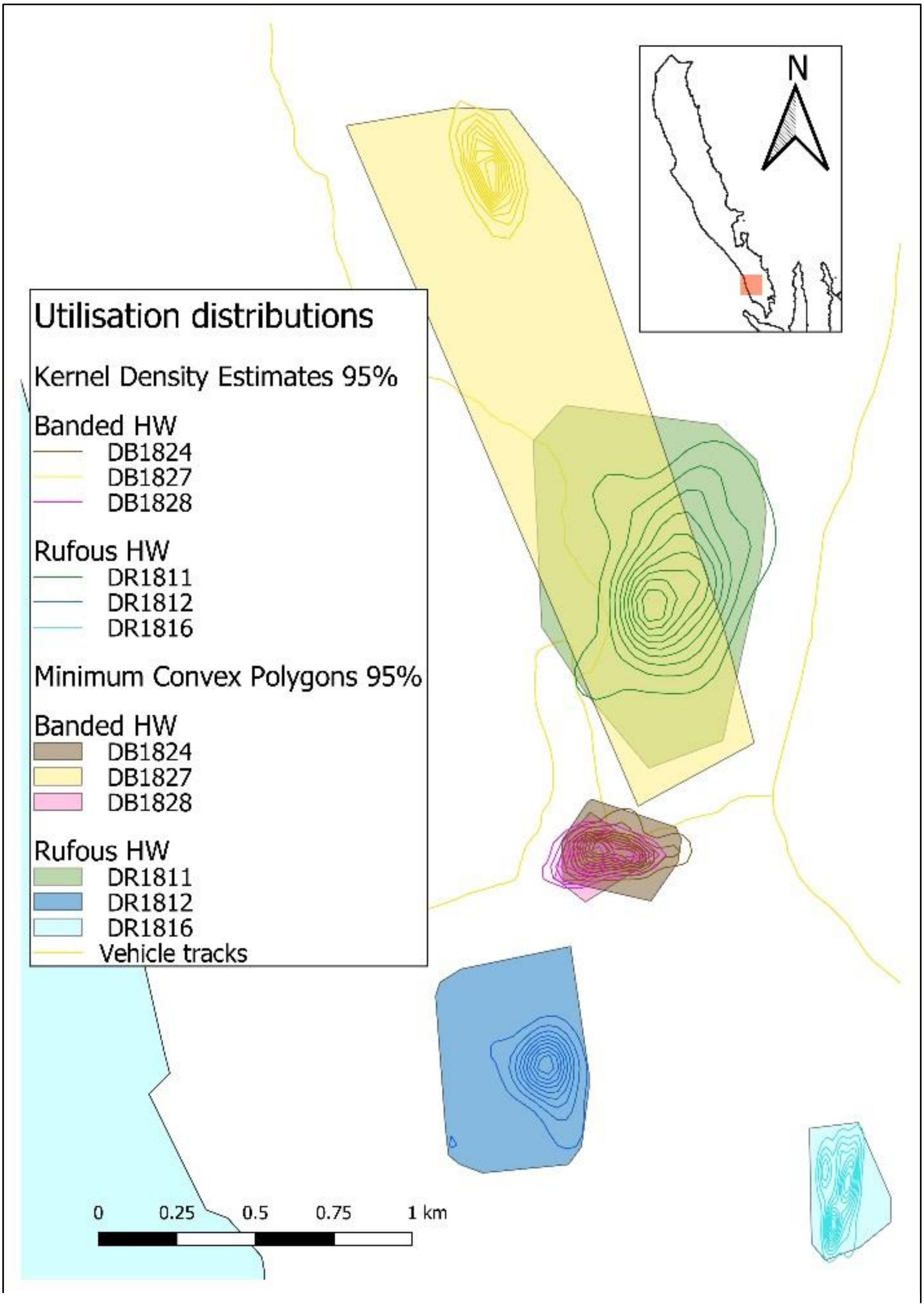

Figure 22. Utilization distribution estimates of the six GPS collared hare-wallabies. Based on GPS fixes from mid-September/October to December 2016.

Table 5. Utilisation distributions used on average, grouped by sex. The first period with eight positions taken per day lasted from 30 September until 20 October 2018 and the second one from 11 November until 1 December 2018.

	Total		**First period**		**Second period**	
	KDE (ha)	MCP95 (ha)	KDE (ha)	MCP95 (ha)	KDE (ha)	MCP95 (ha)
females	19.24	43.73	15.29	6.23	14.21	4.99
SD	3.5	64.0	10.2	3.2	3.0	0.1
males	48.11	44.90	60.82	19.92	38.46	36.28
SD	45.9	30.4	60.0	13.3	27.4	38.0

When comparing the two periods with multiple fixes per day, there is a tendency towards KDEs becoming smaller (this holds true for all rufous and one female banded, (Table 4)) while MCPs increase in three cases (two male rufous, one female banded) and decrease in the case of two other females (one rufous, one banded). This can also be seen in Figure 23.

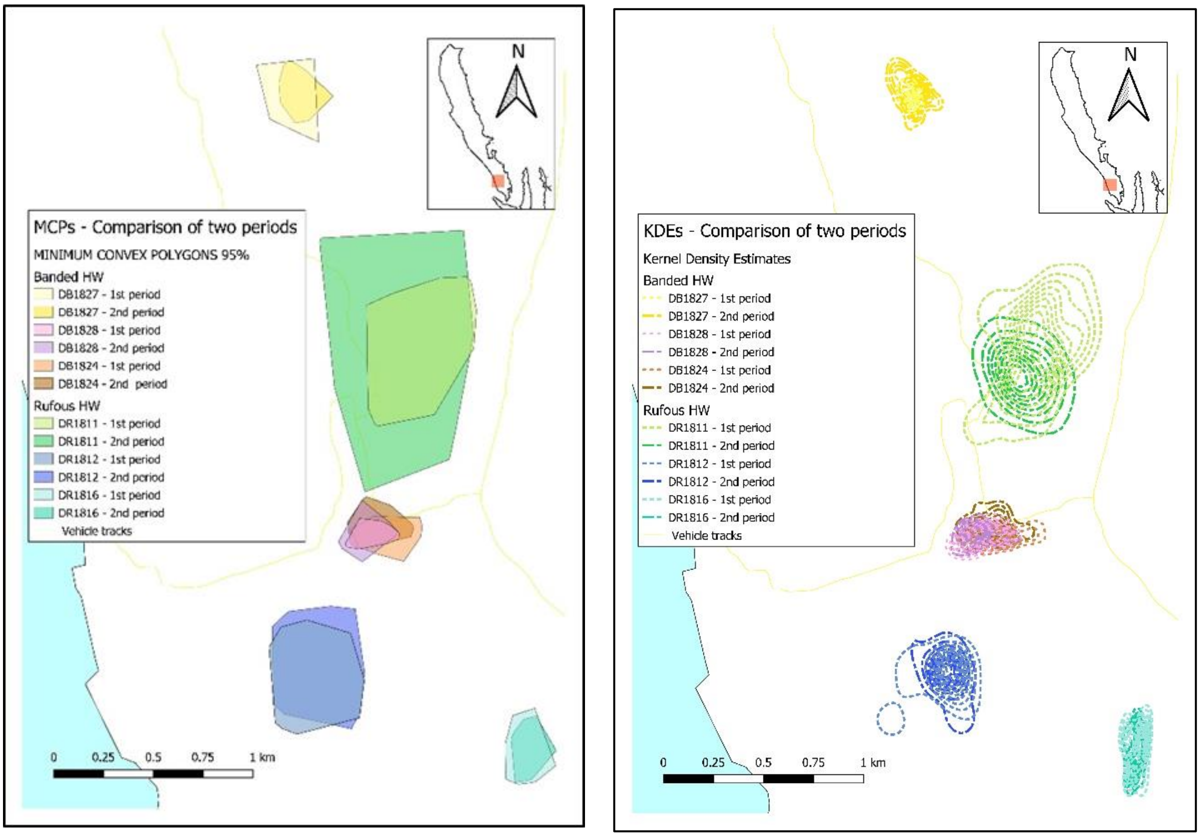

Figure 23. Maps of (a) 95% MCPs and (b) KDEs during the two periods with multiple fixes for each animal (light-coloured polygons are based on data from the first period, darker polygons from the second one).

The heatmaps show that the UDs are not used equally but that each individual has a few locations which are preferred (Figure 24). The darkest colours represent 'densest' areas where most fixes were obtained. These hotspots are the same for the two banded hare-wallabies mentioned before (DB1824 and DB1828) whose KDE and MCP polygons overlap (this could be explained by these animals being a mated pair). When comparing the two periods with multiple fixes (Figure 24), it seems that one female (DB1827) expanded the number of her preferred locations while the others mostly kept using their areas in the same way as before (DR1812 and DR1816). The male rufous DR1811 went from having several favoured locations to having only one.

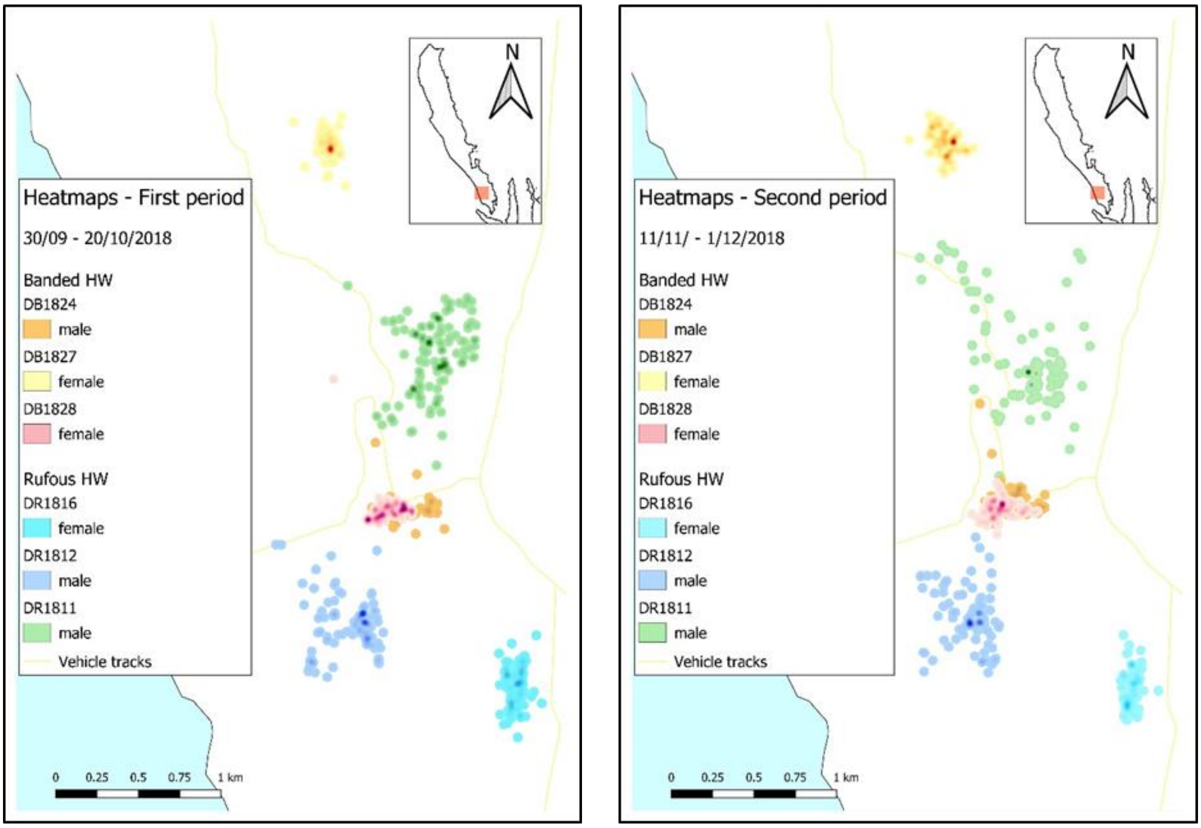

Figure 24. 'Heatmaps' showing density of fixes for collared animals in (a) the first period of multiple fixes and (b) second period. Darker colours indicate higher density of fixes.

The two periods with multiple fixes also allow an estimation of nightly distances moved. Male hare-wallabies of both species covered more than twice as much ground as their female counterparts; on average around 1.3km, compared to ~570m for females. Banded hare-wallabies only moved around 640m per night, compared to around 1.2km for rufous hare-wallabies. On average, all hare-wallabies but the single female rufous increased their distances travelled between the two periods (on average they moved 889m in the first and 996m in the second period (Table 6)). Most animals travelled only slightly further, but one female banded (DB1827) increased her movements by more than 200m, and one male rufous hare-wallaby (DR1811) moved over 2km per night in the first period and nearly 2.4km in the second one. These individuals are also the female with the largest MCP and the male with the largest KDE.

Table 6. Averaged movement distance per night for each individual.

Collar ID	Sex	Distance moved per night – 1st period (m)	Distance moved per night – 2nd period (m)	Distance moved per night – both periods averaged (m)
DB1824	M	667.4	783.1	725.3
DB1827	F	481.6	691.3	586.5
DB1828	F	605.07	638.4	621.7
DR1811	M	2066.5	2385.1	2225.8
DR1812	M	891.2	895.2	893.2
DR1816	F	621.6	583.9	602.8
mean		888.9	996.2	942.5

3.3.2 Remote cameras

From 2017 to 2019: Before and after translocation

In total, 5,401 images of hare-wallabies were recorded on the grid of 30 cameras from 31 August 2017 to 23 May 2019. However, rufous hare-wallabies were detected around five times more often than banded hare-wallabies with 333 and 60 trap-nights respectively. These detections were transformed into the form of 'presence/absence data' and then grouped into months, resulting in 21 months in total (13 months following the 2017 trial and 8 months (starting in October 2018) with the added animals from the 2018 translocation). Unfortunately, for collared individuals it was almost always impossible to identify the symbol on their collars as these were usually obscured by fur. Despite the large number of detections overall, only a small proportion of these were for banded hare-wallabies and therefore, both species were combined to provide a robust dataset for occupancy analysis.

In

Figure 25, each camera-trap location is classified according to the number of nights in which hare-wallabies were detected on them.

Several multi-season models with different parametrizations were run in Presence with models ranked from most to least supported (Table 7). There were no covariates except for time and the highest ranked model assumed detection probability to be constant. Two seasons were defined: before and after the full-scale translocation, with the first comprising 12 months and the second one, nine months.

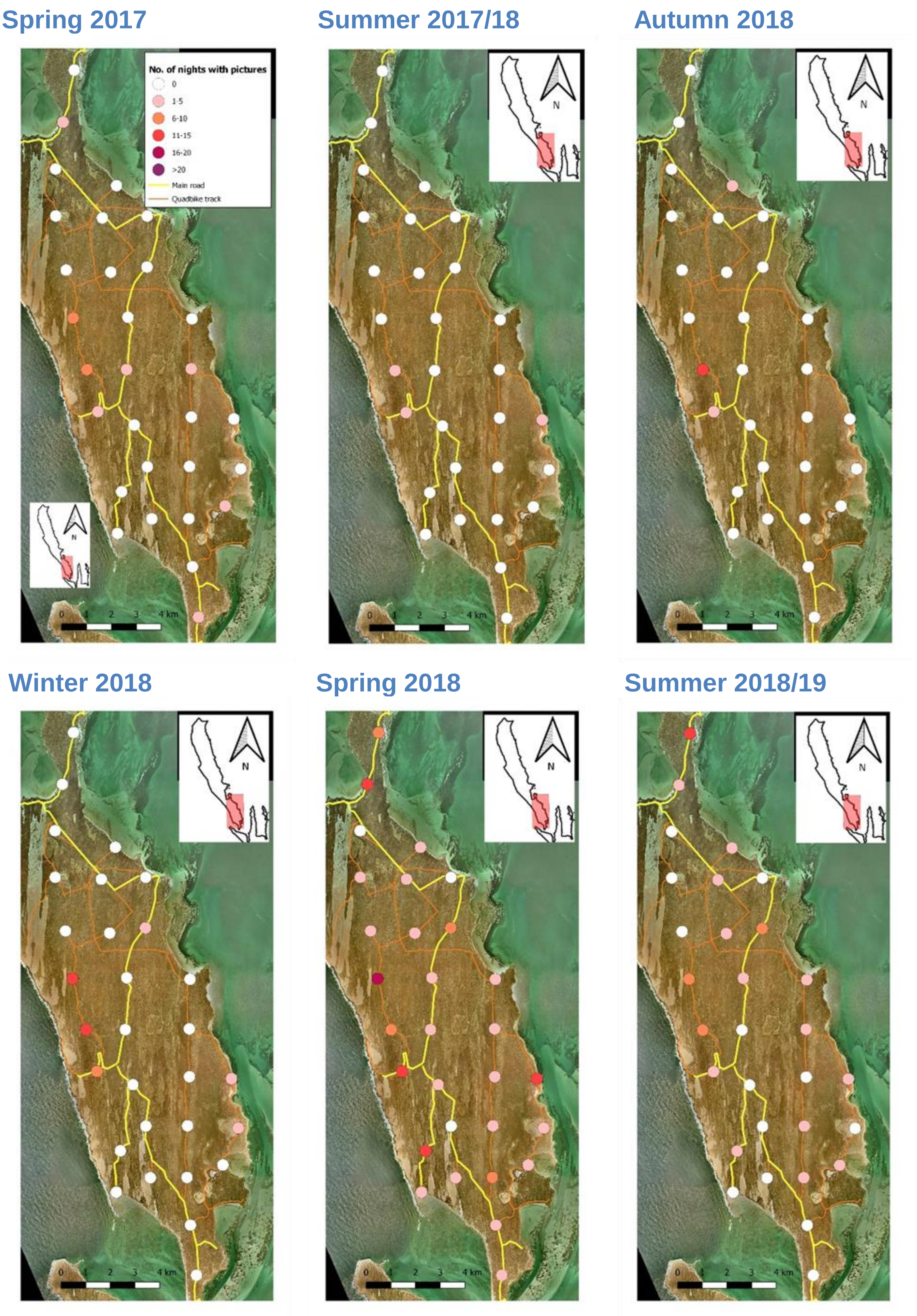

Figure 25. Distribution of hare-wallabies detected on camera from spring 2017 until summer 2018-19. (white circles, no detections of hare-wallabies were taken, green, 1-3 nights with detections, yellow 4-6, orange 7-9, bright red 10-12, and dark red 13-15 nights with detections).

Table 7. Results of Presence models with different assumptions showing Akaike Information Criterion values.

Model	AIC	deltaAIC	AIC wgt	Model Like	no.Par.	-2*LogLike
psi(season),eps(),p(season)	578.93	0.00	0.3853	1.0000	24	530.93
psi(site),eps(),p(season)	578.93	0.00	0.3853	1.0000	24	530.93
psi(site),gamma(season),p(season)	580.97	2.04	0.1389	0.3606	24	532.97
psi(season),gamma(),p(site)	585.45	6.52	0.0148	0.0384	5	575.45
psi(season),gamma(),p(season)	585.45	6.52	0.0148	0.0384	5	575.45
psi(season),gamma(site),p(site)	585.45	6.52	0.0148	0.0384	5	575.45
psi(.),gam(.),eps=1-gam,p()	586.67	7.74	0.0080	0.0209	3	580.67
psi,gamma(season),eps(),p()	586.87	7.94	0.0073	0.0189	4	578.87
psi(season),eps(site),p()	586.87	7.94	0.0073	0.0189	4	578.87
psi(site),eps(),p()	586.87	7.94	0.0073	0.0189	4	578.87
psi,gamma(),eps(),p()	586.87	7.94	0.0073	0.0189	4	578.87
psi(season),eps(),p()	586.87	7.94	0.0073	0.0189	4	578.87
psi(site),gamma(season),p(site)	591.24	12.31	0.0008	0.0021	24	543.24
psi(season),gamma(season),p(season)	591.24	12.31	0.0008	0.0021	24	543.24
psi(),gamma(season),p()	607.14	28.21	0.0000	0.0000	3	601.14
psi(),eps(),p()	607.14	28.21	0.0000	0.0000	3	601.14
psi(),gamma(),p()	607.14	28.21	0.0000	0.0000	3	601.14
psi(),gamma(time),p()	607.14	28.21	0.0000	0.0000	3	601.14
psi(season),gamma(),p()	612.99	34.06	0.0000	0.0000	4	604.99

Based on the top-ranked model, the occupancy probability (ψ) of hare-wallabies was 0.409 (SE 0.09) during the first season and 0.935 (SE 0.05) after the full-scale translocation. Colonisation probability γ (the probability of the hare-wallabies colonising a sampling unit between the two seasons) was 0.89 (SE 0.08) and the extinction probability ε (the probability of the animals becoming extinct locally between two seasons) was 0.00 (SE 0.00). The detection probability p was 0.26 (SE 0.11). The growth rate λ (rate of change in occupancy) was 2.29 (SE 0.50).

After the translocation: Spring and Summer 2018/19

A multi-season model following the 2018 translocation reveals a change in occupancy. The three months after the start of the translocation in spring 2018 were divided into five seasons of three weeks. The estimates for ψ show an increasing trend since the translocation (Table 8). Detection probability was 0.463 (SE 0.05).

The rate of colonisation was 40% after the full-scale translocation (γ = 0.406, SE 0.11), rising to 71% (γ = 0.711, SE 0.17) between the second and third seasons. Between the third and fourth seasons, it is still at nearly 40% (γ = 0.396, SE 0.23), falling to 0% from the fourth to the fifth season (γ = 0.000, SE 0.00). The rate of growth in occupancy was very high after the translocation (λ = 10.623, SE 10.49) but fell to 1.72 (SE 0.47) after the second season. It decreased to 0.89 (SE 0.13) between third and fourth season and 0.74 (SE 0.07) between fourth and fifth season.

Table 8. Occupancy estimates of hare-wallabies for post-release period spring 2018.

Three-week periods during spring 2018	26 Aug - 15 Sep	16 Sep - 6 Oct	7 Oct - 27 Oct	28 Oct - 17 Nov	18 Nov - 17 Nov
Estimates of ψ	**0.0394**	**0.4188**	**0.7222**	**0.6423**	**0.4734**
Standard error	0.0388	0.1033	0.1053	0.0796	0.0975

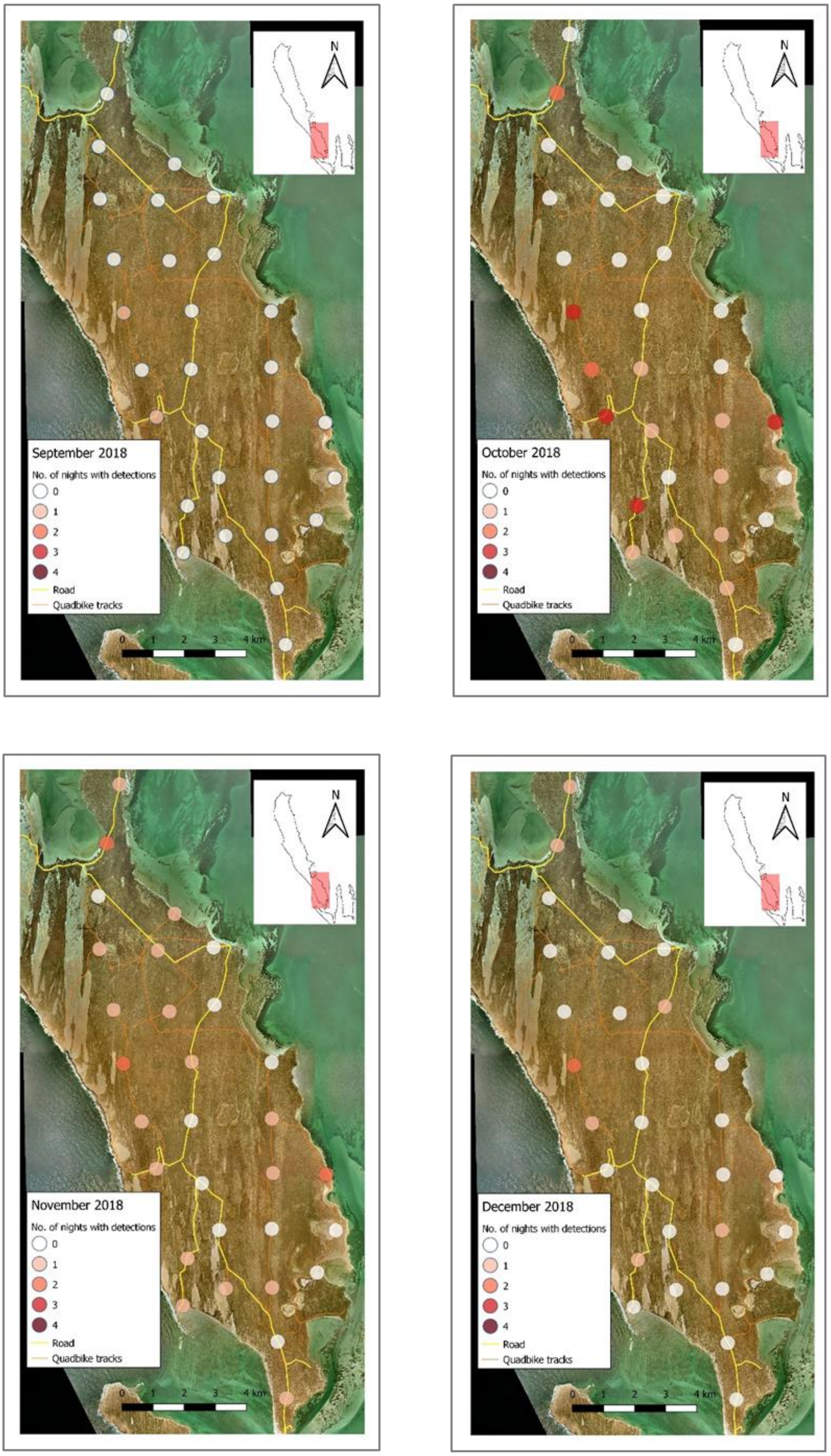

Figure 26. Distribution of hare-wallabies over four months after translocation in September 2018 (from left to right and top to bottom).

Following the first release of 24 wallabies in the 2017 trial, detections were predictably few. During spring, hare-wallabies were mostly detected close to the release areas around the Blowholes track (

Figure 25). From summer 2017/18 up until the full-scale translocation, detections were all found on cameras around the Blowholes track area. Following the 2018 translocation, detections became widespread, covering nearly the entire southern part of the island, with hotspots on Notch Point, the Blowholes track and in the area north of Long Tom Bay on the eastern coast. The first four months after release are shown in Figure 26. Hotspots of detections were highest in October and November 2018. In December 2018, fewer cameras detected hare-wallabies.

The images collected from the 30 500x500m camera grid are yet to be analysed.

3.3.3 Hair-funnels and camera lure trials

Passive hair-funnels recorded mammals in just two locations. One was identified as a house mouse (*Mus musculus*), the other was unable to be identified. The lured hair-funnels were more successful, with house mouse recorded at 16 sites, sandy inland mouse (*Pseudomys hermannsburgensis*) recorded at two sites and unknown mammals recorded at three sites. No hare-wallabies were recorded using passive or lured funnels. Vertebrate by-catch included four reptiles on the passive funnels (*Ctenotus fallens*, *Lerista elegans* and two unknown) and one on lured funnels (*Lerista praepedita*).

3.3.4 Faecal DNA degradation trial

Preliminary results from extractions of DNA from scats suggest that successful amplification of the nine primer sets can be achieved from scats 21 days old or less, similar to that found by Carpenter and Dziminski (2017). However, the full results of these analyses are not yet complete.

It is anticipated that should these results be confirmed, a trial faecal DNA survey for banded hare-wallabies will take place on DHI in spring 2019, with the aim of developing a robust monitoring protocol that can produce abundance estimates and help identify trends. A similar array of microsatellite markers will be developed for rufous hare-wallabies in 2019-20, and a similar degradation trial run in spring 2020.

3.3.5 Scat and pellet collection for diet analysis

Scats collected for dietary analysis from both species of hare-wallabies will be analysed in 2019-20, using manual identification of seeds and eDNA analysis of other faecal material.

A total of 699 raptor and owl pellets and 25 sand monitor scats were collected and analysed for prey items. The majority (n = 660) of pellets were from nankeen kestrels and Figure 27 shows the frequency of different prey items for this species. Primary prey items in terms of frequency appeared to be skinks (Scincidae) (92%) and ants (87%), with other invertebrates (<1-39%), dragons (Agamidae) (30%) and rodents spp. (2-25%) less frequent. Surprisingly, there were three pellets with material identified as chuditch (*Dasyurus geoffroii*), which is believed to be locally extinct on

DHI (although a small number were released on Peron Peninsula on the adjacent mainland in 2011). It is unlikely nankeen kestrels will prey on the 1-2kg chuditch and rarely feed on carrion (Olsen et al., 2016). Unfortunately, these specimens were disposed of by Scatsabout before DHINPERP staff had a chance to query this. Other species for which pellets were collected were white-bellied sea-eagle (*n* = 6), eastern osprey (*n* = 3) and eastern barn owl (*n* = 1). There was no evidence of mammal predation in white-bellied sea-eagle pellets but ash-grey mouse (*Pseudomys albocinereus*) and sandy inland mouse were detected in the single owl pellet and house mouse was detected in three of the four osprey pellets.

The main prey item in the sand monitor scats were beetles and cockroaches (76% of scats) with centipedes and grasshoppers considerably less frequent (24%) (Figure 28). Small mammals only occurred in 20% of scats, with 12% of those being house mouse.

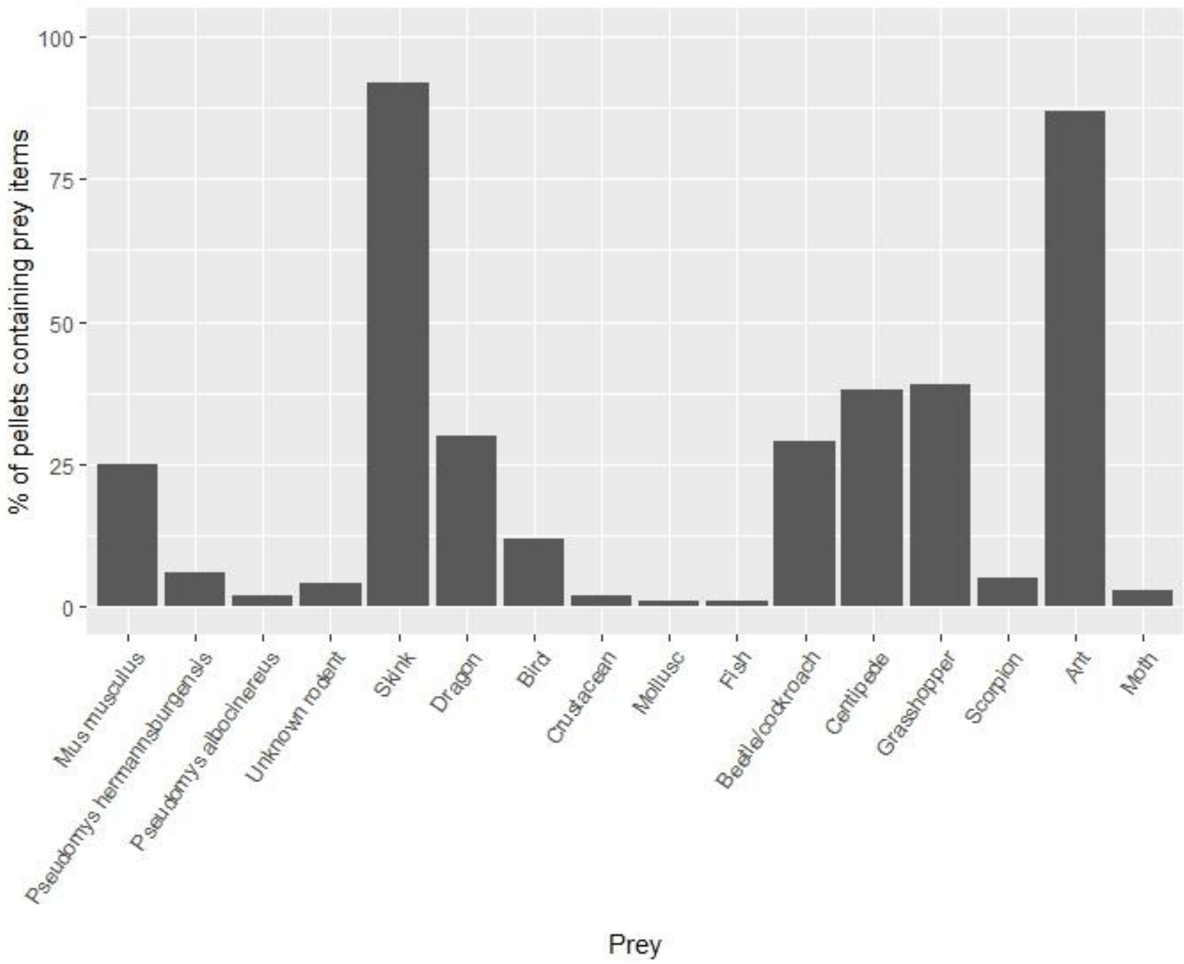

Figure 27. Chart of frequency of prey items found in nankeen kestrel (Falco cenchroides) pellets (n = 660) on Dirk Hartog Island.

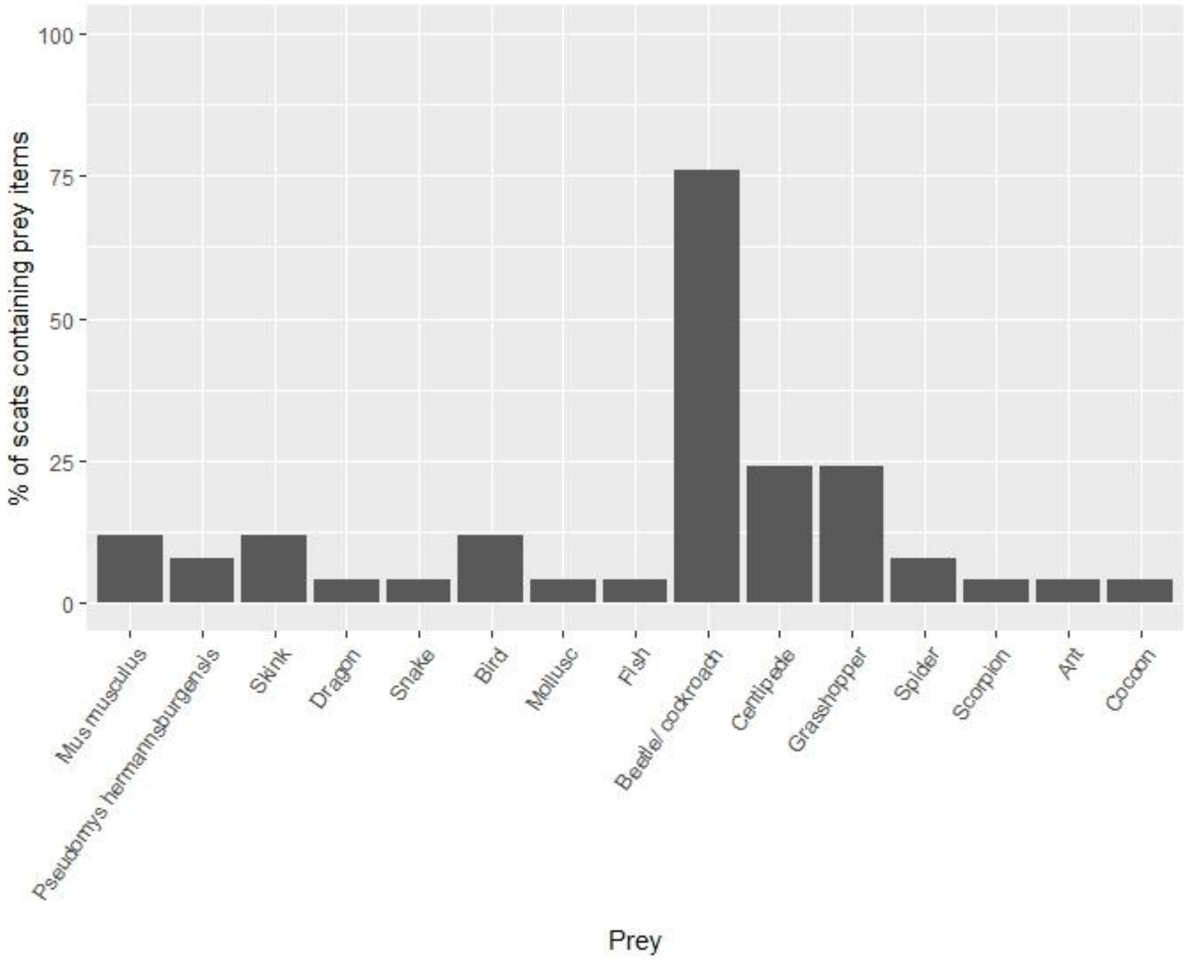

Figure 28. Chart of frequency of prey items found in sand monitor (Varanus gouldii) scats (n = 25) on Dirk Hartog Island.

3.3.6 Monitoring of large raptors

There were 17 locations where large raptors were recorded between September 2018 and March 2019 on DHI (Figure 29) and of these, eight were of eastern osprey. There were five locations where wedge-tailed eagles were recorded, mostly in the southern third of the island, in the vicinity of the hare-wallaby release sites. However, this was also the area where the monitoring team spent most time. White-bellied sea-eagles were recorded at four locations, all along the east coast of the island, including one nest site (the northern-most location) where two chicks were present in September 2018 only one was still alive in November in a presumed case of siblicide (the carcass of the second chick was present in the nest).

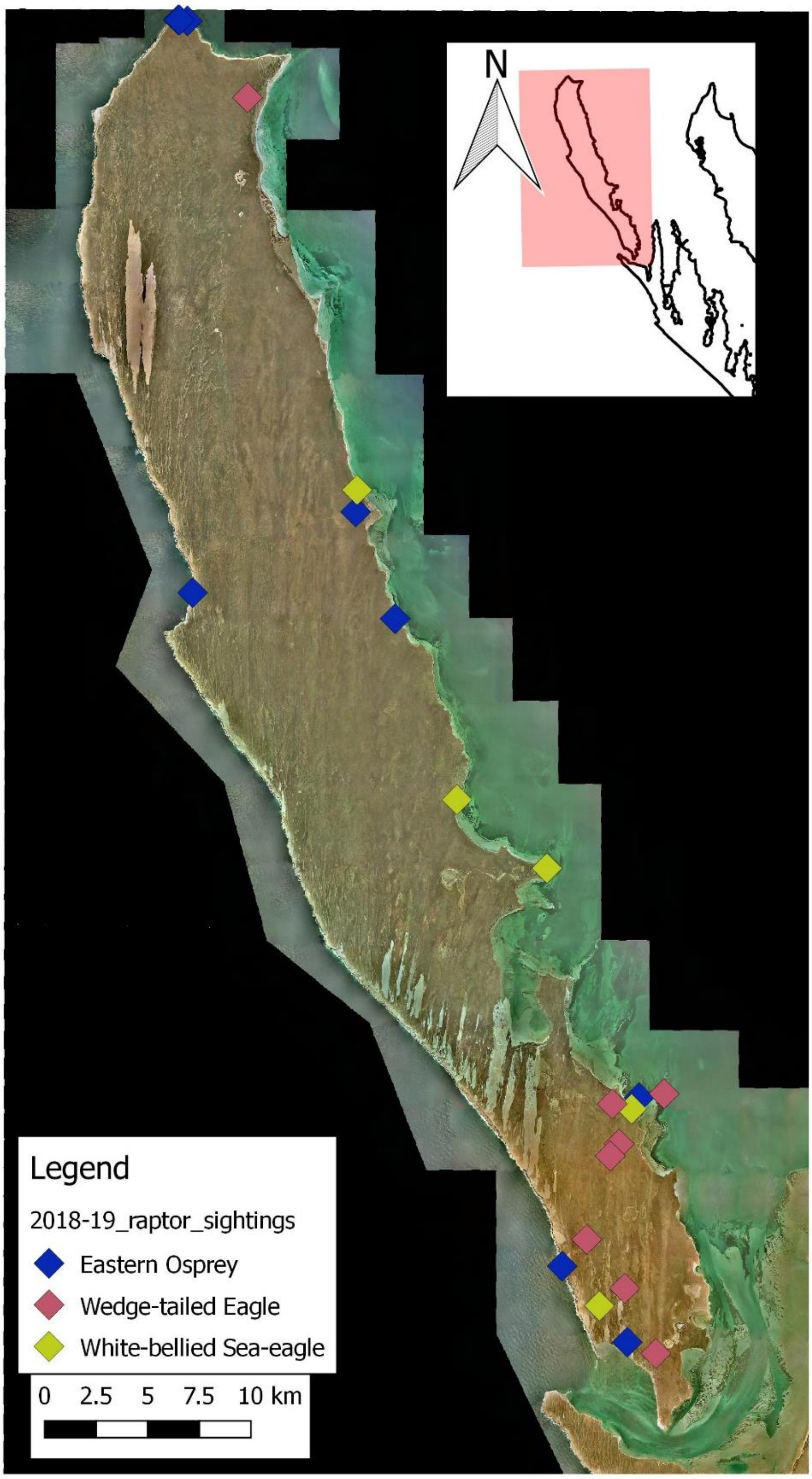

Figure 29. Map of locations of large raptor sightings on Dirk Hartog Island between September 2018 and March 2019.

4 Discussion

4.1 Translocation outcomes

The 2018 translocation of banded and rufous hare-wallabies to Dirk Hartog Island was the first full-scale release of native species as part of the Dirk Hartog Island National Park Ecological Restoration Project ('Return to 1616').

All short-term success criteria (one to four) were met in 2018-19 and three (one to three) out of four medium-term criteria were also met. Survivorship was 100% for radio-collared hare-wallabies with the only mortality during the release period a rufous hare-wallaby pouch young that was abandoned by its mother in the 'soft-release' holding bag (despite the pouch being taped). No mortalities or incidents as a result of predator interactions were recorded in 2018 despite large raptors, including wedge-tailed eagles, being occasionally sighted over the release area. This outcome may have been due in part to vigilance for the presence of raptors and a concerted effort not to disturb hare-wallabies during the day. While we expect that predation is likely to increase in response to an increase in mammal abundance over the course of the translocation program, continued efforts to keep predation to minimum will be necessary to facilitate the successful establishment of hare-wallabies on DHI.

In contrast to 2017, weight loss in the first 12 hours after capture for rufous hare-wallabies was substantially less in 2018. Weight loss for banded hare-wallabies was more-or-less unchanged but the losses in 2017 were not as dramatic in this species as for the rufous. While the rufous hare-wallabies were treated with Atropine to try and mitigate the loss of fluids, it is likely that the shorter transit time by helicopter (as opposed to vessel) was a major factor in the reducing the level of stress, and hence the smaller weight loss in 2018. Whilst there was some ongoing weight loss after release, qualitative condition scores indicated most animals were still at average or above-average condition.

Recruitment on DHI was facilitated by the seven banded and 16 rufous hare-wallabies translocated with pouch young, and one or possibly two, banded hare-wallabies with young-at-foot. Eleven new dependent offspring were also recorded in May 2019, although it is likely there were many more. All females captured in May were in reproductive condition and even the one individual without pouch young showed evidence of having recently weaned a joey. Another interesting observation was that of the 11 offspring of known gender in 2017-2019, only two were female Putatively, this result potentially follows the Trivers-Willard hypothesis, which states that natural selection should favour the adjustment of sex ratios according to resource availability, i.e. as resources decline, females should produce more offspring of the sex that is less costly to produce (Trivers and Willard, 1973). Conversely, when resources are more abundant females should produce more offspring that are likely to benefit from their mother's good condition, which are (in many cases) males. This relationship has been observed for at least other two species of Macropodiform marsupial: the tammar wallaby (*Macropus eugenii*) (Sunnucks and Taylor, 1997) and bridled nailtail wallaby (*Onychogalea fraenata*) (Fisher, 1999). However, it is probably too early to accurately assess whether the observed sex-ratio in offspring is indicative of a bias due to maternal condition, or rather relates to sampling error.

Overall, given the high rate of survivorship, maintenance of condition and clear evidence of reproduction, this translocation (combined with the 2017 trial) appears to have been highly successful so far.

4.2 Monitoring outcomes

As in 2017, monitoring by radio-tracking proved to be an effective method of establishing the daily status of individual hare-wallabies. Most animals were located each day which meant that had any mortalities occurred, these could have been investigated rapidly to determine cause. Furthermore, it helped to develop a better understanding of the variation in post-translocation movement of hare-wallabies in the landscape, with some animals remaining close to their release area and others travelling large distances before settling down in discrete locations.

The GPS collars served their purpose for monitoring survival and movements of the hare-wallabies, and the use of a drone to obtain remote downloads of data from proved worthwhile. The locations obtained from the new model GPS collars were more reliable and accurate than in the 2017 trial and fewer fixes were excluded from the analysis. The six GPS-collared hare-wallabies stayed close to their release sites with only one female banded hare-wallaby moving around 1.5km northward before settling. This indicates that the release areas selected provide suitable habitat and resources for both species. In contrast to the 2017 trial, there was not such a clear separation between species in terms of landscape use. Rufous hare-wallabies did establish their territories in areas dominated by *Triodia plurinervata*, as in the trial (Cowen et al. 2018), but so did some banded hare-wallabies. A high-resolution vegetation map could help to elucidate any differences in habitat use and the planned comparative dietary study will help to determine the degree of dietary overlap.

The results also show a wide variation in the size of UDs. This is partly due to the small sample size. While the large variation in Minimum Convex Polygons confounded trends, Kernel Density Estimates generally became smaller over time indicating that the animals eventually settled down in their new landscape and established territories. Males moved further than females and rufous hare-wallabies further than banded hare-wallabies. On average, KDEs of females were also smaller than those of the males but were generally around 20ha for both species (excluding an outlier, a male rufous). The overlapping of a single male territory with those of several females, as described by Prince and Richards (2008), was evidenced in the two banded hare-wallabies who even shared the same favoured spots. When compared to the VHF-collared animals, whose signals sometimes indicated long distances travelled over the course of a few days, the six GPS-collared hare-wallabies moved considerably less.

The results of the occupancy analysis as well as the camera-trap detection maps show (predictably) that rate of occupancy increased post the full-scale translocation of 140 hare-wallabies. Camera-trap data from grids orientated along tracks indicated that hare-wallabies often use existing roads to travel at night. Their tracks were also regularly observed on ATV bike tracks and the main 4WD track. The high colonisation rate and low extinction rate estimates reflect the gradual expansion over the study area; after an initial quiet period, the hare-wallabies started to explore new habitat. Camera detections eventually became less frequent over time, which probably indicates animals becoming established in their territories or home-ranges. This aligns with the results from the radio-tracking. It also shows the extent of distances moved by hare-wallabies. While camera-traps are unlikely to be useful in terms of estimating population size, cameras on roads provide a low maintenance option to monitor the distribution of hare-wallabies over large areas and can indicate changes in occupancy.

A trial of the use of hair-funnels proved unsuccessful. It might be that either the design of the funnels is unsuitable for hare-wallabies, or that the chosen bait is not attractive to them. For other species, especially rodents, the lured funnels proved to be a relatively easy way to verify presence, and therefore has potential to detect smaller mammal species intended for future translocation to the island, e.g. desert mouse (*Pseudomys desertor*), Shark Bay mouse (*P. fieldi*), heath mouse (*P. shortridgei*) and dibbler (*Parantechinus apicalis*).

While there were occasional observations of large raptors on the island in 2018-19, there was no apparent spatial or temporal pattern, except that white-bellied sea-eagles were mainly observed around the coastline of the island. Anecdotally, a juvenile wedge-tailed eagle has taken up residence at the southern end of the island and makes daily forays to prey on seabirds (e.g. crested tern *Thalasseus bergii*). There is still no evidence of raptor predation on hare-wallabies but this is expected to change as numbers on DHI increase.

4.3 Recommendations

Based on the results of the 2018 translocation of hare-wallabies, the following recommendations are made:

1. The considerable reduction in transit time and sensory stressors by using a helicopter rather than a marine vessel for transfers from Bernier/Dorre Islands is believed to have been an important factor in minimising stress-related weight loss experienced (in rufous hare-wallabies in particular). Furthermore, as there was no evidence of issues related to capture/stress myopathy, future translocations of hare-wallabies and other species, should utilise the fastest and least disruptive form of transport to minimise acute and chronic stress.

2. Treatment of hare-wallabies with Atropine appeared to have minimal effect. However, as it did not appear to have any negative side-effects, it should still be considered an option for mitigating the issue of weight-loss due to stress.

3. While the decision not to attempt to triangulate all collared individuals on a regular basis resulted in increased efficiency, a large proportion of time was still apportioned to daily radio-tracking. The use of drones to undertake radio-

tracking has great promise in further improving efficiency, and accurately locating animals, and further trials are recommended.

4. GPS telemetry collars proved to be an important source of information on landscape use and movement by translocated hare-wallabies. The collars used in 2018-19 proved to have much better remote download capabilities and more accurate fixes. However, GPS collar technology is currently of limited use for longer term studies due to their short battery life and other methods of monitoring landscape utilisation should also be considered.

5. Monitoring of hare-wallabies using remote cameras on tracks proved useful to establish movements and changes in occupancy. This grid will continue to be maintained for this purpose. However, given that at least one hare-wallaby has been found north of the management fence, consideration should be given to expanding the camera grid beyond its current limits (south of Notch Point).

6. Evidence from cameras and GPS collars has shown that both species of hare-wallaby occur in the same habitats. A dietary study looking at potential niche partitioning of these species is planned for 2019-20 and the role of these species in dispersal of seeds (native and weed species) should also be considered.

7. Although no predation by large raptors was recorded, as the population sizes of hare-wallabies increase, the likelihood of predation will also rise. Raptors may also change their behaviour to target areas where hare-wallabies are present. Therefore, monitoring wedge-tailed eagles and white-bellied sea-eagles should be continued.

8. In 2018, signs warning members of the public to slow down for hare-wallabies, particularly between dusk and dawn, were erected south of the management fence. However, the incidence of a road-kill north of the management fence indicates that similar signage should also be established in the northern half of DHI (possibly of other translocated species).

9. The discovery of a gap in the management fence, through which hare-wallabies can move, means that this fence is no longer impermeable. A decision needs to be made regarding either maintaining the fence to continue to manage reintroduced populations, leaving it in its semi-permeable state, or removing the structure entirely.

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