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The Pilbara Bilby (*Macrotis lagotis*) Research Program: a review of progress (2013-2023)

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Guidelines for *'Surveys to detect the presence of bilbies, and assess the importance of habitat in WA*' were prepared by DBCA in association with Richard Southgate (Envisage Environmental) and Mike Bamford (Bamford Consulting Ecologists). These authors also developed guidelines for *'Pre-clearing searches to locate resident bilbies*' and '*Relocation of bilbies prior to vegetation clearing*' in collaboration with Glen Gaikhorst (GHD). The standardised data sheet for 2-ha sign plot surveys was developed in partnership with the World Wildlife Fund and Environs Kimberley with advice from experts including Richard Southgate. Faecal samples obtained from Kanyana Wildlife Rehabilitation Centre were used to refine faecal DNA extraction methods and conduct DNA degradation trials.

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Summary

The greater bilby (*Macrotis lagotis*; Reid, 1837), is a medium-sized, culturally significant burrowing marsupial and the sole remaining member of the Family Thylacomyidae. Once widespread across most of the Australian mainland, the range of the greater bilby has contracted by approximately 80 per cent since European settlement. Within Western Australia (WA), the Pilbara bioregion supports the north-western extent of the bilby's range and represents an important stronghold for the species. The bilby is listed as 'Vulnerable' under the WA *Biodiversity Conservation Act 2016*, the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and on the International Union for Conservation of Nature Red List of Threatened Species. The range of the bilby is believed to be contracting northwards in response to threatening processes, including predation by the introduced red fox (*Vulpes vulpes*) and feral cat (*Felis catus*), competition with and habitat degradation by introduced herbivores, inappropriate fire regimes, and habitat clearing for development.

Acknowledging that little was known about the status and ecology of the bilby in the northwest of WA, a project plan was developed in 2011 by the then Department of Environment and Conservation [now the Department of Biodiversity, Conservation and Attractions (DBCA)] to guide the implementation of priority actions for the conservation and management of the bilby in the Pilbara. In 2013, the then Department of Parks and Wildlife (now DBCA) hosted a workshop to further refine the Pilbara bilby research agenda through a facilitated process with various stakeholders. Five key areas for future research effort were identified: (1) refine survey methods, (2) improve understanding of habitat use, (3) improve understanding of the genetic structure of bilby populations, (4) improve understanding of the threat posed by introduced predators and herbivores, and (5) improve understanding of how fire regimes affect bilby conservation. Here, we summarise the progress made-to-date against each of these priorities and provide recommendations to guide future research and the ongoing conservation management of the bilby in the Pilbara.

Since the 2013 workshop, new field survey and monitoring techniques have been developed and implemented, and research undertaken by DBCA has significantly enhanced our knowledge of the status and ecology of the bilby in the Pilbara and elsewhere in WA. In summary:

- A non-invasive technique using DNA extracted from scats was developed and optimised to reliably measure bilby abundance within defined populations and can also be used to evaluate genetic structure and gene flow at the landscape scale.
- A protocol for assessing potential bilby activity and verifying bilby presence from sign was established to promote standardised, best practice occupancy survey techniques, and to assess the importance of habitat in WA.
- Guidelines for surveys to detect the presence of bilbies and assess the importance of habitat in WA were published.

- An estimate of the distribution of the bilby in the Pilbara region was generated from recent and historic records, highlighting areas of uncertain status.
- Research to better understand habitat use identified an association with substrate and vegetation types, notably *Acacia* spp. that provide important food resources in the form of root-dwelling (Cossidae) larvae.
- Preliminary dietary analysis of scats collected from 17 populations across WA (including the Pilbara) was completed, highlighting the importance of cossid moth larvae and other invertebrates in the diet of bilbies in the northwest of WA.
- The entire [greater (*M. lagotis*) and lesser (*M. leucura*)] bilby reference genome was sequenced as part of a broader collaboration. Markers for genetic identification of sex were identified for use with scat genotyping.
- Reduced representation genomic sequencing of bilby samples from WA was undertaken as part of a broader collaboration and used to develop a single nucleotide polymorphism (SNP) array for repeatable genotyping of bilby scat DNA. This approach is now being implemented in monitoring projects to identify individuals, their sex and kinship patterns and examine individual movement patterns.
- Bilby abundance is being monitored in response to a collaborative threat management and monitoring program targeting introduced predators and fire on the Coongan Pastoral Station.

1 Introduction

The greater bilby (*Macrotis lagotis*; Reid, 1837) (henceforth referred to as the bilby), is a medium-sized, nocturnal burrowing marsupial and the only remaining member of the Thylacomyidae family (Order Peramelemorphia) (Lynch, 2008). This iconic and culturally significant native Australian mammal (Abbott, 2001; DCCEEW, 2023b) is distinguished by its large rabbit-like ears, silky blue-grey fur, and long black tail with a furred white tip (Johnson, 2008). Weighing between 800-2500 g and measuring up to 550 mm in length (head and body), bilbies have strong forelimbs for digging and construct complex burrow systems for shelter (Johnson, 2008). The bilby is considered an ecosystem engineer (Fleming *et al*., 2014), with their foraging enhancing soil health and plant productivity (Chapman, 2013) and their (used/disused) burrows providing important refuge sites for other fauna (Hofstede and Dziminski, 2017). Bilbies are cryptic and generally solitary (Bradley *et al*., 2015), with reported low site fidelity (Southgate *et al*., 2007). Bilbies can be highly mobile with variable home ranges, particularly males (Bradley *et al*., 2015).

Prior to European settlement, the bilby formerly occurred over approximately 70% of the Australian mainland (Southgate, 1990), occupying various habitat types within Australia's arid and semi-arid zones (Woinarski *et al*., 2014). Like many other small to medium-sized terrestrial species, bilby populations suffered severe declines due to the direct or combined impacts of introduced non-native animals (i.e., predation and competition), landscape modification and altered fire regimes following European colonisation (Bradley *et al*., 2015; Woinarski *et al*., 2015). The bilby is now patchily distributed within less than approximately 20% of its former range (Southgate, 1990; Bradley *et al*., 2015), with the species' distribution believed to be contracting northwards in response to threatening processes (DCCEEW, 2023b). Remnant, naturally occurring populations now only persist within central and northern Western Australia (WA), the Northern Territory (NT), and an isolated area in south-western Queensland (Qld) (Bradley *et al*., 2015). Within WA, wild bilby populations are restricted to the Pilbara, Kimberley, and central desert and rangelands regions (Page, 2015; Lohr *et al*., 2021).

The Pilbara bioregion, which supports the north-western extent of the bilby's range (Dziminski *et al*., 2020c), has significant biodiversity value and is considered a centre of endemism (DPaW, 2017). The Pilbara is also of national economic significance with both mining and pastoralism operating over 70% of the region (DPaW, 2017). The range of the bilby is largely distributed across the eastern half (48%) of the Pilbara bioregion, with recent and historical records indicating the western boundary of the species' range lies roughly 50 km west of Port Headland and continues south-east of Newman (Dziminski *et al*., 2020c). Beyond the Pilbara, the species' range extends east and south-east into the Great Sandy, Little Sandy and Gibson Deserts, south in the Gascoyne, and northwards into the south-western Kimberley region (Dziminski *et al*., 2020c). In WA, two translocated populations have also been established at Matuwa Kurrara Kurrara National Park (Matuwa; formerly Lorna Glen Station) and the Australian Wildlife Conservancy's Mount Gibson Wildlife Sanctuary (NESP TRSH, 2018).

The bilby is currently classified as 'Vulnerable' under the WA *Biodiversity Conservation Act 2016* (Government of Western Australia, 2016), the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* (DCCEEW, 2023a), and on the International Union for Conservation of Nature Red List of threatened species (Burbidge and Woinarski, 2016). The bilby was also selected as one of the 21 priority mammal species in the Threatened Species Action Plan 2022-2032 (DCCEEW, 2022). Under the *EPBC Act*, the bilby is classified as a *Matter of National Environmental Significance* (MNES) by the Australian Government (DoE, 2013), thus the presence of bilbies and bilby habitat is a key environmental factor in mining and infrastructure project evaluations in northern WA (Cramer *et al*., 2017).

Key threats to the bilby in the Pilbara include predation by the introduced red fox (*Vulpes vulpes*) and feral cat (*Felis catus*); competition with introduced herbivores such as grazing livestock and the European rabbit (*Oryctolagus cuniculus*); habitat loss, fragmentation and degradation (secondary to grazing and other human-mediated activities such as land clearing, mining, infrastructure development and large scale pivot irrigation agriculture); inappropriate fire regimes; and climate change (Bradley *et al*., 2015; Cramer *et al*., 2017; DCCEEW, 2023b). Weeds [e.g., buffel grass (*Cenchrus ciliaris*); Burrows, 2019] are considered a potential indirect threat in the Pilbara due to their influence on fire patterns and competition with native plant species (Bradley *et al*., 2015; DPaW, 2017); though bilbies have been observed in areas invaded by buffel grass (M. Dziminski pers. obs.). Mortality from vehicle and/or train collisions, and the emission of artificial noise and light may also pose a threat (Gardner, 2013; BHP, 2016). Numerous road mortalities have been reported over the past decade, and the medium to long term impacts on local bilby populations are unknown (DCCEEW, 2023b). The small and fragmented nature of bilby subpopulations may reduce population resilience and genetic fitness, enhancing susceptibility to local extinction (DCCEEW, 2023b). Importantly, there are significant and complex interactions between threats (e.g., introduced predators, grazing pressure and fire; McGregor *et al*., 2014), which require further evaluation (DCCEEW, 2023b).

Until recently, knowledge regarding the status and ecology of bilbies in the north of WA was lacking, with studies limited to general and targeted survey work to establish bilby presence (Cramer *et al*., 2017). With intensifying pressure from key threats in the Pilbara, in particular the rapid growth of the mining industry over the past two decades (DPaW, 2017), a Pilbara Bilby Research Program (PBRP) was initiated by the then Department of Environment and Conservation [now the Department of Biodiversity, Conservation and Attractions (DBCA)] in 2011 (Marlow *et al*., 2011), supported by environmental offsets associated with resource development.

To seek broad collaborative agreement on a bilby research agenda in the Pilbara, the then Department of Parks and Wildlife (now DBCA) hosted a workshop in October 2013 to review existing knowledge and identify key research priorities to inform management, through a facilitated process involving scientists, environmental consultants, mining proponents and State and Federal government agencies (Cramer *et al*., 2017). As a result of the workshop five key areas or 'themes' for future research effort were identified and ranked according to priority (Cramer *et al*., 2017):

1. Refine survey methods.
2. Improve understanding of habitat use.
3. Improve understanding of the genetic structure of bilby populations.
4. Improve understanding of the threats posed by introduced predators and herbivores.
5. Improve understanding of how fire regimes affect bilby conservation.

In partnership with universities and other stakeholders, including environmental consultancies, CSIRO and traditional owners, DBCA (i.e., the Biodiversity and Conservation Science – Bilby Research Program) has been conducting bilby research focusing on the five key areas identified above.

Additionally, as part of a broader collaboration, an Interim Conservation Plan was prepared (superseding the draft recovery plan; Pavey, 2006), with input from DBCA staff, to promote an integrated approach to conservation planning and guide the implementation of recovery actions for bilby conservation across Australia (Bradley *et al*., 2015). The National Bilby Recovery Team, with membership including DBCA, was also re-established and the National Recovery Plan for the Greater Bilby was finalised in 2023 (DCCEEW, 2023b). A summary of published research and other outputs from the PBRP are provided in Appendix 1.

This review summarises the progress made by DBCA, and partners, against the five key research areas between 2013 and 2023 and provides recommendations to guide future research and the ongoing conservation management of the bilby in the Pilbara.

2 Refine survey methods

2.1 Context

The bilby is difficult to monitor in the wild given the species' cryptic and trap-shy nature (Dziminski *et al*., 2020b). Bilbies are nocturnal and generally solitary (Bradley *et al*., 2015), with reported low site fidelity and high mobility in males (Southgate *et al*., 2007), making direct observation difficult and the monitoring of individuals and populations a challenge (Cramer *et al*., 2017). Population surveys have typically relied upon the detection of bilby sign (i.e., tracks, scats, and diggings) to determine bilby presence/absence (Moseby *et al*., 2011), with repeat sampling recommended (within 1-3 months) to provide unbiased estimates of occupancy (Southgate *et al*., 2019). Burrows are not a reliable indicator of bilby presence unless accompanied by verified evidence of fresh bilby sign (Southgate *et al*., 2019). Additionally, because bilbies often use numerous burrows, and reuse and create new burrows at any time, the relationship between bilby abundance and burrows is unreliable (Lavery and Kirkpatrick, 1997; Moseby and O'Donnell, 2003), though McRae (2004) used surveys of burrows to estimate bilby population size in more open habitats in Queensland.

While remote sensor camera traps can be useful for confirming bilby presence (which normally can be immediately achieved by observation of verified sign; Southgate *et al*., 2019), bilbies do not have unique markings that can be used to identify individuals and then estimate abundance. Supplementary methods including cage traps have been used with limited success, as bilbies are reluctant to enter free-standing traps and are not reliably attracted to baits (Southgate *et al*., 1995).

At the 2013 workshop, it was recognised that there was no reliable method to adequately measure bilby abundance and the need to develop and implement an efficient, cost-effective, and unbiased population monitoring technique was identified (Cramer *et al*., 2017). The need for broad-scale remote survey techniques was also recognised.

2.2 Improve methods to quantify bilby abundance

In 2014, a new population abundance monitoring technique combining scat collection and the use of molecular markers to identify individuals from DNA extracted from scats was developed and trialled at Matuwa in the Goldfields and Pardoo in the Pilbara (Dziminski and Carpenter, 2014). Briefly, this technique involves extracting DNA from georeferenced bilby scats (ideally up to 14 days old; Carpenter and Dziminski, 2017) to genotype individuals using polymorphic microsatellite loci (Moritz *et al*., 1997; Smith *et al*., 2009). Following initial field trials, the technique was fine-tuned to optimise DNA preservation, extraction and amplification (Carpenter and Dziminski, 2017). To assess the accuracy in estimating numbers of individuals within populations, this technique was calibrated in 2017 (Dziminski and Carpenter, 2018). Field sampling undertaken at Mount Gibson Wildlife Sanctuary using a known reintroduced founding population, resulted in an average genotyping success rate of 67%, which is considered high (Dziminski and Carpenter, 2017). Using spatially explicit capture-recapture (SECR) modelling, the density and number of bilbies were estimated using two models, with similar results, confirming that the abundance monitoring technique is reliable (Dziminski and Carpenter, 2017). Recent updates to the genetic methodology have included the use of single nucleotide polymorphism (SNP) markers to enable high-throughput automated sample genotyping (see Section 4.2).

This non-invasive monitoring technique can also provide information about the genetic relatedness of individuals and their relationship/connectivity with other populations (see Section 4) (Dziminski *et al*., 2020b). For example, individuals injured or killed by mining vehicles were able to be traced to their source population (M. Dziminski, pers. comm.). We now know that bilby sub-populations within the Pilbara are geographically isolated and comprise a small number of individuals (Dziminski *et al*., 2020b). Scat DNA-based abundance monitoring has since been implemented by DBCA and other agencies as a standard population monitoring technique to reliably quantify bilby abundance within the Pilbara and other regions including the Dampier Peninsula (Dziminski and van Leeuwen, 2019), La Grange (DBCA, 2018) and Fitzroy River Catchment regions (DBCA, 2021a) in the Kimberley, Kiwirrkurra in the Gibson Desert (Dziminski and Carpenter, 2019), and Matuwa in central WA (Dziminski *et al*., 2020b; Lohr *et al*., 2021). Population monitoring in the Pilbara, Kimberley and central desert regions indicates that wild bilby populations are small, comprising roughly 2-15 individuals (DBCA, 2018; Dziminski *et al*., 2020b; DBCA, 2021a). While most populations within the La Grange region are comparable in size, the Anna Plains population was unusually large, with an estimated population size of 44 individuals; the largest naturally occurring wild bilby population recorded in WA (DBCA, 2018).

Using this technique, eight wild Pilbara populations were monitored between 2013 and 2018 (Dziminski *et al*., 2020b) and monitoring is ongoing on the Coongan Pastoral Station in the vicinity of the Warralong Community (DBCA, 2023a). An information sheet outlining the abundance monitoring protocol was also produced (Dziminski and Carpenter, 2021) and the technique has been adopted and used by various environmental consultants in the Pilbara and other areas across the state.

2.3 Establish clear survey guidelines and protocols

To promote standardised and comparable best practice occupancy survey techniques, a set of interim guidelines (Appendix 2 and 3; Dziminski and Carpenter, 2017) and a protocol for assessing potential bilby activity and verifying bilby presence from sign (Southgate *et al*., 2019) were published. In 2017, a final set of best practice survey guidelines (superseding Appendix 2 and 3), compatible with techniques used nationally, were published by DBCA in association with Richard Southgate (Envisage Environmental) and Mike Bamford (Bamford Consulting Ecologists) (DBCA, 2017). The 2-ha plot method (see Moseby *et al.*, 2011) devised by Southgate *et al*. (2005) and Southgate and Moseby (2008), and subsequently modified by Dziminski and Carpenter (2017) and Southgate *et al.* (2019), has been the most efficient on-ground method for determining bilby presence/absence and occupancy without the use of aircraft (Dziminski and Carpenter, 2018).

With input from bilby experts and Indigenous ranger groups conducting surveys across Australia, a standardised mobile data app (CreativityCorp Pty Ltd) and a 2-ha sign plot datasheet (Appendix 4) were also developed by DBCA in 2017 (Dziminski and Carpenter, 2018). The standardised 2-ha sign plot technique has been broadly implemented in parts of arid and semi-arid Australia (e.g., Kimberley region; DBCA, 2021a), enabling the collection of systematically quantified and comparable data. Guidelines based on best-practice techniques used within WA and nationally were also drafted for (1) '*pre-clearing searches to locate resident bilbies*' (Box 1; Appendix 5) and (2) '*relocation of bilbies prior to vegetation clearing*' (Box 2; Appendix 5) (Dziminski and Carpenter, 2018); these protocols have since been implemented in the field by other organisations (e.g., Turpin and Riley, 2020). The data sheet and technique were recently adopted by the NESP Threatened Species Recovery Hub's Arid Zone Monitoring Project (Indigo *et al*., 2021).

2.4 Implement broad-scale survey techniques

Surveying for bilby presence typically involves searching 2-ha plots on foot for bilby sign. This method, however, is labour intensive and has some limitations within the Pilbara including:

- A reliance upon the detection of scats and diggings (specifically multiple diggings into the base of *Acacia* shrubs where root-dwelling larvae are accessed; Southgate *et al*., 2019), in preference to tracks, to provide definitive evidence of bilby presence due to harder surface substrates and the presence of leaf litter in the Pilbara (Cramer *et al*., 2017); though clear track imprints of the front and hind feet (see Moseby *et al*., 2011; Southgate *et al*., 2019) can be used individually, or in combination with scats/diggings, to confirm bilby presence (Southgate *et al*., 2019). Gait pattern alone is not sufficient to verify presence (similar to rabbits; Southgate *et al*., 2019).
- The placement of survey plots has largely been restricted to areas adjacent to roads or tracks due to access limitations on foot (Dziminski *et al*., 2020b).
- This technique only provides presence/absence data and not information about the number of individuals within populations (Dziminski *et al*., 2020b).
- Populations shift over time (e.g., DBCA, 2023a), which can be challenging for long-term population monitoring (Cramer *et al*., 2017).

To establish plot surveys in areas inaccessible by foot and to increase the number of plots surveyed per trip, DBCA incorporated the use of all-terrain vehicles (ATV) in 2015 (Dziminski and Carpenter, 2016). ATVs have since complimented standard monitoring on foot at various sites (e.g., Warralong; Dziminski *et al*., 2019). Surveying on horseback was trialled at Matuwa where bilbies were translocated (Burrows *et al*., 2012) but can be logistically challenging, requiring a quarantine period to prevent the spread of weeds via horse manure.

To implement monitoring on a much broader scale, a variety of remote sensing techniques were evaluated. The use of Remotely Piloted Aircraft (RPA: drone or unmanned aerial vehicle) fitted with real-time video imagery to detect bilby sign along a pre-plotted course were investigated (Dziminski and Carpenter, 2014). Trials using artificially constructed bilby burrows were conducted in Perth in 2014 (Dziminski and Carpenter, 2014). Subsequent field trials (to detect burrows and diggings) were undertaken at Matuwa in 2015 in recently burnt and unburnt areas where bilbies were known to be present (Dziminski and Carpenter, 2016). Burrows and diggings were readily identified in recently burnt areas, whereas only burrows were detected in unburnt areas. In 2016, trials were extended to the Pilbara, investigating the effect of altitude, camera angle and speed on the detectability of bilby sign (Dziminski *et al*., 2017). Detection of burrows was difficult as they were often obscured by vegetation, however diggings were more numerous, prominent and easier to observe, particularly at lower altitude and speed; detection was greatest around midday due to less shadows from vegetation. Battery life of the RPA currently limits the distance that can be traversed and ground-truthing of both positive and non-detections is required to determine false positive and false negative error rates (Dziminski *et al*., 2017; Southgate *et al*., 2019). While refinement of this method is ongoing, the use of RPAs may enable more efficient and cost-effective targeted surveys to be undertaken in previously inaccessible areas of the Pilbara (Dziminski *et al*., 2017). Helicopter surveys using skilled observers remains an efficient way to monitor bilby presence/absence and occupancy (Southgate *et al*., 2005).

A trial using light detection and ranging (LiDAR) showed that a 30 cm resolution was not high enough to detect burrows when flown over an area with bilby burrows at Kintyre, east of the Pilbara (M. Dziminski, pers. comm.). Higher resolution trials may be worth pursuing. Thermal imaging has been used in very open habitats such as in SW Queensland (Augusteyn *et al*., 2020), however high vegetation cover in the Pilbara may render this technique unsuitable.

Table 1 below provides a summary of recommended survey and monitoring approaches based on the learnings to date and discussed above. This information should be considered alongside the advice provided in Southgate *et al.* (2019) that implicitly discusses the use of sign-based protocols to verify bilby presence.

Table 1 Recommended survey and monitoring techniques specific to bilbies (Macrotis lagotis).

Survey type	**Recommended techniques**	**Advantages (+) and disadvantages (-)**	**References**
Bilby presence/absence	• Helicopter or drone survey with ground truthing • 2-ha sign plots (foot, vehicle or ATV)	+ Rapid assessment - No measure of population trends over time - Accuracy may be poor because of non-detection or misidentification	Southgate *et al*. (2005); Southgate and Moseby (2008); Moseby *et al*. (2011); DBCA (2017b)
Bilby occupancy	• 2-ha sign plots (4 resurveys within a season recommended) • Access on foot, ATV, vehicle or helicopter	+ Comparable data with error (trends) + Landscape scale/large areas	Southgate *et al*. (2019)

Survey type	Recommended techniques	Advantages (+) and disadvantages (-)	References
		+ Accounts for the influence of variable detection rate - Resurveys require repeat visits - Sensitive to small sample size	
Bilby abundance	• Scat DNA monitoring of discrete populations • Scat DNA survey subsampling contiguously occupied area	+ Comparable data with error (trends) + Faster detection of response of population (e.g., after management) than occupancy + DNA available for other investigations (e.g., relatedness of populations) - Fine scale - Sensitive to small sample size	Dziminski *et al*. (2020b)

2.5 Outcomes

- A non-invasive, scat DNA-based abundance monitoring technique was developed and optimised to reliably measure bilby abundance within defined populations (Dziminski *et al*., 2020b) and can also be used to evaluate genetic structure and gene flow at the landscape scale.
- Guidelines for surveys to detect the presence of bilbies and assess the importance of habitat in WA were published (DBCA, 2017).
- A protocol for assessing potential bilby activity and verifying bilby presence from sign was established (Southgate *et al*., 2019) to promote standardised best practice occupancy survey techniques.
- A standardised mobile data app and a 2-ha sign plot datasheet were developed and broadly implemented in parts of arid and semi-arid Australia, enabling the collection of systematically quantified and comparable data.
- Remotely piloted aircraft was trialled as a potential broad-scale monitoring tool in the Pilbara, though the application of this approach is currently limited by the battery life of the aircraft.

3 Improve understanding of habitat use

3.1 Context

In northern WA, bilbies inhabit a wide range of substrate and vegetation types, including residual, fluvial and sand plain landforms with typically low shrub cover of *Acacia* spp. with hummock (*Triodia* spp.) and tussock grasses (Cramer *et al*., 2017). The presence of soil substrate suitable for burrow construction is critical (Dziminski and Carpenter, 2016). Bilbies are omnivores with an opportunistic dietary strategy and exploit a wide range of food types including invertebrates and their eggs/larvae, and seeds, bulbs, roots, fungi, and fruit (Southgate, 1990; Gibson, 2001; Johnson, 2008).

In the Pilbara, local-scale studies to determine habitat use and evaluate the diet of bilbies were lacking. It was unknown whether substrate and landform type or diet composition and food availability in the Pilbara reflected habitat suitability as per the conceptual model developed by Cramer *et al*. (2017). While bilbies can respond to spatial and temporal changes in food availability (Gibson and Hume, 2004), capitalising upon rare, patchily distributed and/or seasonally abundant food items due to their high mobility and opportunistic dietary strategy (Gibson, 2001; Southgate *et al*., 2007), it was not known how bilbies respond to fluctuations in resource availability in the Pilbara (Cramer *et al*., 2017).

To determine the effect of substrate type and food availability on habitat suitability it was acknowledged that stratified and recurrent sampling between various habitat types was needed to verify bilby occupancy and site fidelity, in conjunction with analysis of faecal contents to evaluate diet (Cramer *et al*., 2017). Identifying core bilby habitat within the Pilbara is necessary to implement targeted conservation and management effort (Cramer *et al*., 2017).

3.2 Increase knowledge of the distribution of the bilby within the Pilbara

To better understand the distribution of bilbies in the Pilbara, in 2013, DBCA began collating recent and historic records of bilby presence (Dziminski and Carpenter, 2014). In 2014, an online user-contributable data entry site was developed and implemented by DBCA, accessible through NatureMap (M. Dziminski pers. comm.). The '*Pilbara Threatened Fauna Database*' enabled users to upload records (e.g., observations of bilby sign or photographs) to complement existing locational records (see Dziminski *et al*., 2020c). An information poster (Appendix 6) describing how to identify bilbies and their sign was also produced and displayed strategically across the Pilbara (e.g., at tourist information centres and mine sites) to encourage the submission of records from the public (Dziminski and Carpenter, 2014).

By 2020, sufficient recent and historic bilby records (4386 in total between 1899-2019) had been compiled to enable an assessment of the distribution of the bilby in the Pilbara (Figure 1; Dziminski *et al*., 2020c). Reliably documenting their extent of occurrence enables informed and evidence-based environmental impact assessments and management decisions, and highlights areas where future targeted surveys can be undertaken to confirm the absence of the species (Dziminski *et al*., 2020c). Currently, there are few conservation reserves within the bilby's established range and most populations are located on mining tenements or pastoral land (Cramer *et al*., 2017; Dziminski *et al*., 2020c).

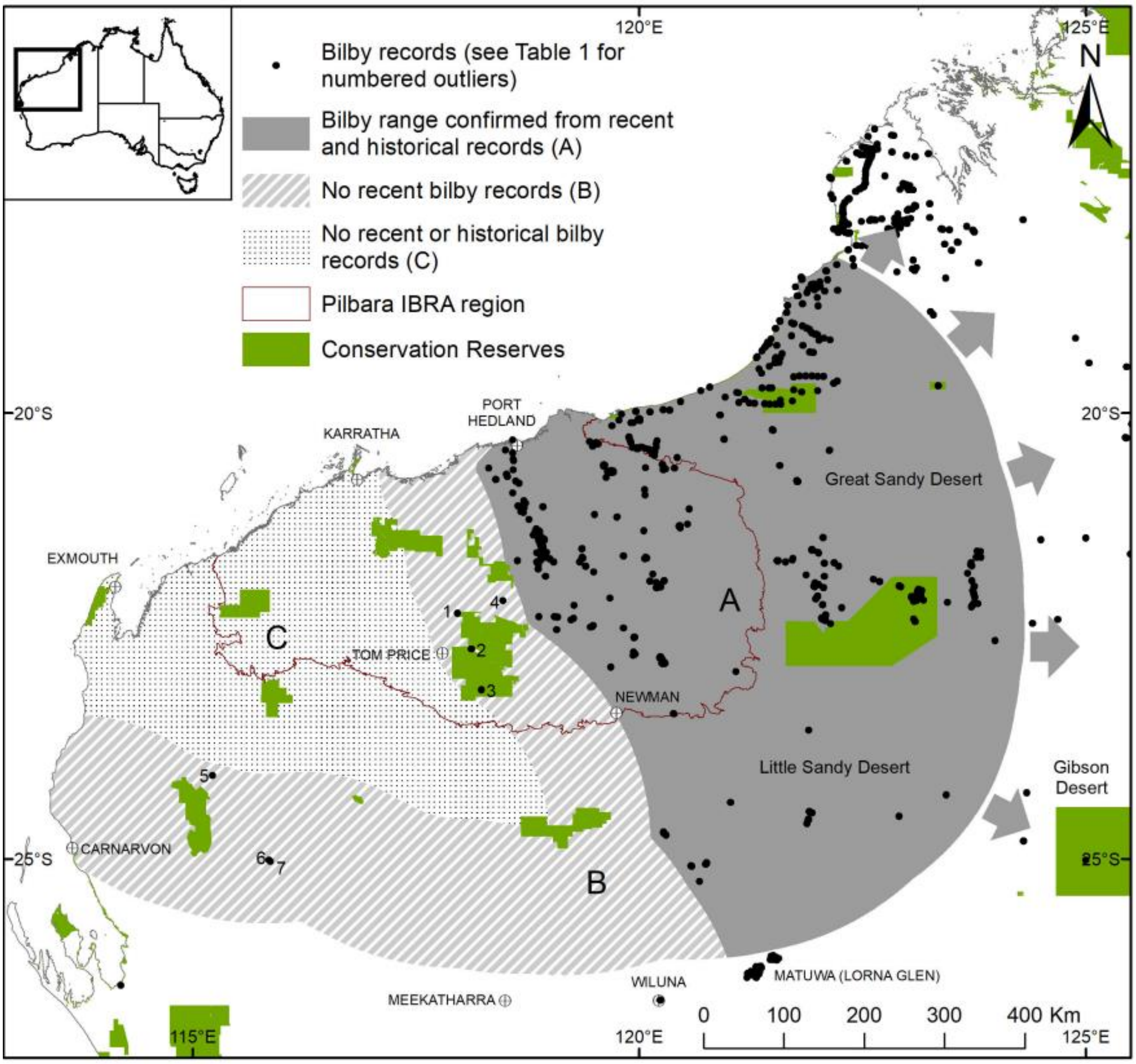

Figure 1 Range of the bilby (Macrotis lagotis) within the Pilbara region, WA (from Dziminski et al., 2020c).

3.3 Identify important resources within the Pilbara

Surveying for the presence/absence of bilbies using the 2-ha plot method in conjunction with the distributional records described above, has enabled DBCA to collect valuable ecological data and better understand the habitat requirements of the bilby in the Pilbara. A correlation between bilby presence and sand, sandy clay, or sandy gravel substrates suitable for burrowing was identified (Dziminski and Carpenter, 2016). Notably, an association with particular *Acacia* species was also found, where *Acacia* stands provide a major food resource, cossid moth larvae (grubs), from their root systems (Southgate *et al*., 2019). *Acacia bivenosa*, *A. colei*, *A. dictyophleba*, *A. melleodora*, *A. stellaticeps* and *A. trachycarpa* [including dwarf variant described in Maslin *et al*. (2010)] are all known to host root-dwelling (Cossidae) insect larvae in the Pilbara (Southgate *et al*., 2019). Associations with other plant species (e.g., *Senna notabilis*) were also identified (Southgate *et al*., 2019).

Using presence data, DBCA commenced habitat modelling in 2017 using physical habitat characteristics (i.e., topography, geology and soil properties). Preliminary results identified elevation, and soil type and depth as key predictor variables contributing to habitat suitability for the bilby (Dziminski and Carpenter, 2017). Southgate *et al*. (2019) recommended that '*residual landforms (e.g., laterite rises) and habitat types where shrubs containing root-dwelling larvae are common; loamy or sandy soils associated with palaeodrainage lines and perched drainage lines that often harbour Cyperus bulbosus; and, sand plain and dune fields*' be included (as a minimum) during stratified occupancy sampling.

Using mortality and demographic data obtained from the literature, population viability analysis (PVA) was conducted to determine the area of suitable bilby habitat (for a potential reserve) required to support a self-sustaining population of bilbies without management intervention. Results suggest that a minimum land area of about 50,000 ha is necessary to support a viable population with a low probability (< 0.1) of extinction over 100 years (Dziminski *et al*., 2012).

3.3.1 Diet

In 2021, dietary analysis of 144 scats collected from 17 populations across WA (including the Pilbara) was completed (M. Dziminski pers. comm.). Preliminary results (R. Southgate, unpubl.) confirmed cossid moth larvae were common in the diet of Pilbara bilbies, and the ratio of invertebrate to plant material was higher in Pilbara populations compared to Kimberley populations. Sampled plots were also scored for the food sources bilbies were targeting (when they could be identified).

3.4 Outcomes

- Improved understanding of the distribution of the bilby in the Pilbara.
- A greater understanding of the land area required to support a viable population of bilbies in the Pilbara.
- Improved understanding of what resources are important to bilbies within the Pilbara i.e., *Acacia* spp. that provide important food resources in the form of root-dwelling larvae.
- Preliminary analyses of the diet of bilbies confirmed the importance of cossid moth larvae.

4 Improve understanding of the genetic structure of bilby populations

4.1 Context

Given the species' trap-shy nature, and difficulty undertaking regular, population-wide sampling (Smith *et al*., 2009), knowledge regarding bilby population dynamics was limited, with information regarding the genetic structure within and between populations restricted to a handful of studies. Early research by Southgate and Adams (1994) utilised allozyme electrophoresis of blood samples to assess the taxonomic status and genetic diversity within the Qld, NT and WA sub-populations; noting that all populations were genetically similar. A subsequent more detailed evaluation incorporating mitochondrial DNA (mtDNA) and microsatellite loci sequencing from (the above) blood and (additional) tissue samples, detected the presence of two unique and divergent mtDNA lineages in the Qld population (Moritz *et al*., 1997). As such, Moritz *et al*. (1997) concluded that '*the bilby should be considered as a single evolutionary significant unit consisting of multiple management units.*' More recently however, Smith *et al*. (2009) used faecal DNA to generate population-level estimates of mtDNA and microsatellite diversity across three Qld sub-populations, revealing that the Qld population was not genetically distinct from the WA and NT populations.

As separately managing populations may increase the likelihood of extinction through demographic and genetic processes (Weeks *et al*., 2016) and natural admixture is likely to occur between the populations in the western deserts of the NT and WA (Bradley *et al*., 2015), there was support for a nation-wide management approach. To provide insurance against extinction in the wild, the need to maintain a sufficiently large, interconnected and genetically diverse bilby meta-population was identified (DCCEEW, 2023b). The development of a '*single overarching adaptive meta-population management plan, acknowledging one national genetic management unit, by 2016*' was advocated as a priority goal at the 2015 Greater Bilby Recovery Summit (Bradley *et al*., 2015). In 2016, captive populations managed by the Zoo and Aquarium Association Australasia were amalgamated and have since been managed as a single meta-population, rather than separate (WA/NT and Qld) management units (Brandies, 2021). A meta-population management plan, which acknowledges one national genetic management unit is currently being drafted (DCCEEW, 2023b).

Recognising that the genetic diversity within and between remnant populations in WA was largely unknown, the need to better understand how populations are structured genetically and mechanisms by which dispersal influences genetic structure and gene flow at the landscape scale was identified at the 2013 workshop (Cramer *et al*., 2017). While the key to maximising genetic differentiation within populations is dispersal (Dieckmann *et al*., 1999), this can be challenging for patchily distributed species inhabiting fragmented landscapes such as the Pilbara. In the absence of long-term, intensive, landscape-scale demographic studies to track individuals and determine the spatial or temporal extent of dispersal, the use of non-invasive molecular genetic techniques (i.e., genetic identification through scat or hair analyses, for example Smith *et al*., 2009), offers an alternative approach for evaluating the genetic structure of the

WA bilby population (Bradley *et al*., 2015; DPaW, 2017). To better understand and maximise the 'genetic health' of the bilby population in WA, research to enhance the preservation, extraction and amplification of faecal DNA was recommended (Cramer *et al*., 2017).

4.2 Refinement of a scat-based molecular toolkit

As discussed in Section 2.2, DBCA developed a scat-based molecular monitoring technique, capable of genotyping individuals using polymorphic microsatellite loci (Carpenter and Dziminski, 2017). This non-invasive method of obtaining DNA has the potential to enhance our understanding of bilby population dynamics within the Pilbara and across other regions of WA and Australia as a whole (Carpenter and Dziminski, 2017). More detailed analysis of the data for example, can determine how bilby populations are structured genetically, including the relatedness of individuals within a population and gene flow between populations (Dziminski *et al*., 2019).

The University of Sydney in collaboration with DBCA, have recently generated a high-quality reference genome for the greater (and lesser; *M. leucura*) bilby (Brandies, 2021; C. Hogg pers. comm.). Using representative tissue samples collected from every fenced bilby population across Australia (i.e., 18 contemporary fenced and captive sites including AWC sites, island populations and zoo/wildlife facilities), the greater bilby reference genome combined with whole genome resequencing (WGR) and reduced representation sequencing (RRS, specifically DArTseq https://www.diversityarrays.com/) data was used to characterise genome-wide diversity across the national bilby meta-population managed under the National Bilby Recovery Plan (Brandies, 2021; C. Hogg pers. comm.).

A small number of ear tissue (n = 9) and scat (n = 13) samples from wild bilby populations in the Pilbara were also analysed for comparison (Brandies, 2021). Analysis of scat samples from the Pilbara had a reduced success rate compared to tissue samples (53.5% vs 86.5%, respectively) but demonstrated that RRS data obtained from scats could provide an effective genetic monitoring tool. The Pilbara population exhibited low levels of genetic diversity relative to the managed populations (SNP H_E = 0.16) and high levels of inbreeding (F_{IS} = 0.205), though relatedness was low (0.19) (Brandies, 2021). These results likely reflect the reduced range, low density and isolated nature of bilby populations within the Pilbara (Dziminski *et al*., 2020b; 2020c), although further comparison with other wild populations would place the Pilbara population in appropriate context.

DArT sequencing data obtained from Brandies (2021) was used as the basis to develop an individual-based SNP array for repeatable genotyping of bilby scats on the MassArray automated SNP genotyping platform (R. Sun pers. comm.). This methodology is now being implemented in monitoring projects in WA (e.g., DBCA, 2023a; Moore *et al*., 2023) and the NT (H. Geyle pers. comm.) as a replacement of the microsatellite-based approach developed by Dziminski *et al*. (2020b). In collaboration with staff from DBCA, Brandies (2021) also developed a suite of sex-linked markers, which have since been included in the bilby SNP array to routinely identify individuals and their sex from scats in one assay (K. Ottewell pers. comm.).

DBCA has also developed a qPCR assay to quantitate bilby scat DNA post-extraction to improve the efficiency of scat genotyping, i.e., only samples that are shown to have sufficient DNA for analysis are sent to the SNP genotyping provider, reducing the analysis costs associated with this survey method (K. Ottewell, pers. comm.). DBCA are currently using SNP genotypes to identify individuals, their sex and kinship patterns. Individual genetic 'capture' records are entered into a georeferenced database to examine individual movement patterns through space and time. Associated kinship estimates may be used to infer dispersal of individuals and their descendants.

As SNP genotypes accumulate from projects in the Pilbara, and elsewhere in WA and the NT, broader analyses of the genetic relationships amongst regional populations can be undertaken (K. Ottewell pers. comm.). The bilby MassArray SNP genotyping panel was designed to be applicable across the bilby meta-population, however, is limited in the number of markers (37 loci). Population genetic analyses across the broader wild population may benefit from the use of an alternative methodology (e.g., DArTcap, Feutry *et al*., 2020; Hohwieler *et al*., 2022) that yields many more markers to detect subtle patterns of population structure. Such an analysis may benefit from inclusion of putative functional genetic markers as identified in Brandies (2021), in addition to neutral genetic markers, to better understand patterns of adaptation across the species range. Importantly, with a refined and repeatable extraction protocol and analysis method for bilby scat DNA now available, nation-wide population genetic analyses can be undertaken.

4.3 Outcomes

- Entire [greater (*M. lagotis*) and lesser (*M. leucura*)] bilby reference genome sequenced as a part of a broader collaboration.
- Identification of sex-linked markers to identify sex of unknown samples (scats and tissues).
- Identification of putatively functional genetic markers from RRS data.
- Development of a scat DNA based molecular toolkit, allowing for identification of individual bilbies and their sex.
- Establishment of a georeferenced and time-stamped database of individual bilby genetic captures to enable tracking of individuals through space and time.

5 Improve understanding of the threat posed by introduced predators and herbivores

5.1 Context

5.1.1 Introduced predators

Introduced predators and herbivores have played a principal role in the decline and extinction of Australia's terrestrial mammal fauna, including the bilby (Woinarski *et al*., 2015). Predation by the European red fox is considered the primary factor contributing to the dramatic decline of the bilby in south-western Australia during the mid-1900's (Abbott, 2001). Fox presence is negatively correlated with bilby presence (Southgate, 1990) and bilbies are at greatest risk when foxes become well established in the landscape (DCCEEW, 2023b). While there is little overlap between the current distribution of the red fox and bilby in northern WA (Bradley *et al*., 2015), foxes occur throughout the western deserts (Cramer *et al*., 2017), and they are present in the Fitzroy and Ord Valleys of the Kimberley in low numbers (King and Smith 1985). Foxes were detected at three bilby sites in the Fitzroy River catchment in 2020, confirming their continued presence in the north of WA (DBCA, 2021a). Within the Pilbara, foxes are largely restricted to the coastal fringe and hinterland plains but extend further inland along major drainage lines (King and Smith, 1985; DPaW, 2017; Turpin and Riley, 2020). A fox was detected, for example, in the sandplain habitat in the vicinity of the Warralong Community west of the Coongan River (~70 km inland) (DBCA, 2021b). Foxes have also been seen at Nullagine and Marble Bar.

Feral cats co-occur with and prey on bilbies (McRae, 2004; Bradley *et al*., 2015). Feral cat predation can limit or extirpate local bilby populations (Woinarski *et al*., 2014), but it does appear that bilbies are resilient to some level of feral cat presence (DBCA, 2021a). Feral cats are widespread across the Pilbara with CSIRO modelling indicating that without management intervention, 25% of conservation significant species, including the bilby, may be functionally lost from the region within 20 years (Carwardine *et al*., 2014). As juvenile bilbies are likely to be targeted in preference to adults, recruitment may be negatively impacted (DBCA, 2021a).

The threat from other predators in the Pilbara, including dingoes (*Canis familiaris*) is unknown. As the distribution of dingoes and bilbies has overlapped for thousands of years, dingoes are considered a naturalised predator (Dawson, 2017). Bilbies have been shown to exhibit antipredator behaviour towards dingoes (Steindler *et al*., 2018). While the interaction between bilbies, dingoes and other predators requires further evaluation, there is evidence to suggest that dingoes predate and competitively exclude cats and foxes (Southgate *et al*., 2007; Kennedy *et al*., 2012; Letnic *et al*., 2012). While there was no evidence that occupancy of dingoes influenced bilby occupancy in the Fitzroy River catchment, feral cat occupancy tended to decrease with increasing dingo occupancy (DBCA, 2021a). Areas where bilbies are present in the Pilbara (non-rocky habitat) have also been found to have high feral cat occupancy (DBCA, 2021b), comparable to other areas where bilbies are present in the Kimberley (DBCA, 2021a).

5.1.2 Introduced herbivores

Introduced herbivores (especially grazing livestock and the European rabbit) compete for resources with bilbies, degrade habitat and elevate predator densities (Bradley *et al*., 2015; Woinarski *et al*., 2015). Erosion, compaction, and de-vegetation of native habitat decreases the availability of food resources and burrow sites, while the establishment of artificial water points to support pastoralism and industry development, fragment bilby populations, enable predator expansion, and support higher introduced herbivore (and predator) numbers (McRae, 2004; Bradley *et al*., 2015). The current distribution of the bilby across Australia is associated with low or absent stock/pastoralism and rabbits (Bradley *et al*., 2015). In the Pilbara, undisturbed habitat is scarce as over 60% is now pastoral land (primarily commercial cattle grazing) (DPaW, 2017).

Morton (1990) proposed that the decline of medium-sized arid fauna, such as the bilby, could be attributed to their reliance on more productive substrate types which also attract introduced herbivores (i.e., the competitive refuge hypothesis). Although Southgate *et al*. (2007) found no relationship between substrate type, and the activity of introduced herbivores and bilby prevalence in the Tanami Desert. An examination of the patterns of contraction of the bilby in the NT post-1975 (McDonald *et al*., 2015) indicated bilbies were less likely to occur on land with a history of cattle grazing or with high rabbit densities. DBCA (2021a) reported a clear negative relationship between bilby and cattle occupancy in the Fitzroy River catchment in the Kimberley. Southgate (1990) also found bilby occurrence correlated with a low abundance of livestock.

5.2 Threat monitoring and management

At the time of the 2013 workshop, the impact of introduced predators and herbivores on bilbies in the Pilbara was poorly understood. To better understand the threats posed by feral cats and foxes, and inform effective introduced predator management, the need for manipulative, landscape-scale experiments in different habitat types and under various environmental conditions, and in the presence of dingoes, was identified (Cramer *et al*., 2017).

In 2014, a bilby population was detected on the Coongan Pastoral Station by DBCA staff and Warralong community members (DBCA, 2021b). With ongoing evidence of bilby presence at this site (i.e., the Coongan colony) and an additional northern colony detected in 2018 (i.e., the River colony; Dziminski *et al*., 2019), a project to monitor and manage threats to this bilby population (i.e., Warralong population) was initiated in 2018 in collaboration with Roy Hill, CSIRO, Greening Australia, and the Warralong community (DBCA, 2021b). A fauna occupancy monitoring program was implemented to determine the effectiveness of predator and fire management to benefit bilbies. A ~10,000 ha Bilby Land Management Area (BLMA) was established on the Coongan Pastoral Station (referred to as Warralong; Burrows, 2019).

Research to determine the occupancy of feral predators and other fauna using 2-ha plot surveys and remote cameras was conducted before planned introduced predator and fire management began in 2019. Bilby abundance monitoring had already been conducted in 2016 and 2018 at the Coongan colony and in 2018 at the River colony

(Dziminski *et al*., 2019; 2020a). In 2019, feral cat occupancy was high [measured at 0.79 (±0.19 SE) from sign plots and 0.92 (±0.07 SE) from remote cameras] and a single fox was identified (DBCA, 2021b). Due to the COVID19 Pandemic, cameras were not deployed in 2020 (Greening Australia, 2022) and feral predator management did not commence as planned. During fauna monitoring in 2021, only the River colony was found (DBCA, 2022). Feral cat occupancy remained high (0.80 from sign plots and 0.85 from cameras) and no foxes were detected (Greening Australia, 2022). Feral cat occupancy was higher within the Warralong BLMA when compared to the outside (Greening Australia, 2022). Similarly high feral cat occupancy rates have been reported during occupancy monitoring using remote cameras at other sites in northern WA [e.g., 0.8 (± 0.1 SE; across all sites combined) on the Dampier Peninsula; DBCA, 2021a].

Eradicat® baits were aerially deployed within the BLMA in June 2022 (DBCA, 2023a). Follow-up surveys to estimate feral cat occupancy and bilby abundance were carried out between September and November 2022 (DBCA, 2023a). Preliminary results indicate *Eradicat*® baiting did not have a significant effect on feral cat occupancy (measured using camera trap and sign plot data) or the feral cat detection rate (DBCA, 2023b). Bilby abundance (determined using scat genotyping and SECR) could not be estimated for the River colony due to the low number (n = 6) of successfully genotyped scat samples. An abundance estimate of five individuals (range 2-12 from n = 24 genotyped scat samples) was derived for the Coongan colony (located again in 2022), indicating that the population had increased by one individual since 2019 (DBCA, 2023a).

As part of the fauna occupancy monitoring program at Warralong, introduced herbivores were monitored using remote cameras and sign plots (DBCA, 2021b). Cattle (*Bos taurus*) occupancy derived from remote cameras was very high [0.94 (±0.05 SE) to 1], with up to 100% occupancy within and outside the BLMA. Sign plot occupancy was also high [0.73 (±0.09 SE) to 1]. Occupancy of horses (*Equus ferus*) and camels (*Camelus dromedarius*) was lower; donkeys (*Equus asinus*) were only identified on plots (DBCA, 2021b).

5.3 Outcomes

- A threat management program targeting introduced predators and fire has been initiated on the Coongan Pastoral Station (Warralong) to benefit the local bilby population under an adaptive management framework.
- Aerial application of *Eradicat*® baiting commenced at Warralong to manage feral cats (also targets foxes).
- A bilby abundance monitoring program has been established at Warralong to measure management effectiveness, concurrent with occupancy monitoring of introduced predators and herbivores.
- The local Indigenous community at Warralong have been engaged in bilby monitoring.

6 Improve understanding of how fire regimes affect bilby conservation

6.1 Context

The loss of Aboriginal burning practices since European colonisation resulting in frequent, large and high intensity fires has likely contributed to the decline of small to medium-sized mammal populations in northern Australia (Lawes *et al*., 2015; Santos *et al*., 2022). Within the Pilbara, many plant species are adapted to fire, requiring fire as part of their life cycle (DPaW, 2017), however altered fire regimes in conjunction with other landscape-scale changes (e.g., pastoralism; Woinarski *et al*., 2011) has increased the risk of wildfires burning vast areas of habitat. In addition to the direct impacts on wildlife, reduced vegetation cover post-burn can reduce food availability and enhance predation pressure. Feral cats for example, have shown a preference for sites recently subject to intense fire in the north of WA (McGregor *et al*., 2014), travelling large distances to hunt (McGregor *et al*., 2016).

Bilbies are known to inhabit areas of various fire age stages including recently burnt and long-unburnt vegetation (Southgate, 1990). In the Tanami Desert, bilbies have been associated with recently burnt areas, probably due to the availability of fire-promoted food plants (Southgate *et al*., 2007). In the Pilbara, evidence of bilby foraging activity (i.e., scratchings and diggings) was detected in areas of limited vegetation cover, six months after fire (Thompson and Thompson, 2008). Habitat suitability may depend on the effects of individual fire events and the quantitative impact of fire frequency (Cramer *et al*., 2017). Unmanaged fire is believed to have caused the local extinction of two Pilbara bilby populations at Pardoo and McPhee Creek (Dziminski *et al*., 2020b). In both cases, large-scale, hot fires destroyed the majority of suitable bilby habitat, and it was postulated that limited food resources and increased predation risk post-fire lead to the extirpation of these populations (Dziminski *et al*., 2020b).

Given the small size and geographical isolation of bilby populations within the Pilbara, they are highly vulnerable to the impacts of fire (Dziminski *et al.,* 2020b). Lack of fire may also reduce habitat suitability, with high density vegetation becoming largely impenetrable to bilbies (Bradley *et al*., 2015). Prioritising fire management to mitigate the risk of large-scale intensive wildfires and promote fire age heterogeneity is therefore a vital component of managing habitat for bilbies and preventing further loss of populations. Smaller, more frequent fires that create a mosaic of fuel ages, in conjunction with strategic firebreaks are recommended to increase habitat and resource diversity for bilbies (Southgate and Carthew, 2006).

Limited fire research in relation to bilbies has been conducted in the Pilbara. While the presence of food-producing plant species is important, knowledge of how contemporary burning regimes impact these resources is lacking and the point at which the prevalence and persistence of the bilby is impacted by a fire mosaic is unknown (Cramer *et al*., 2017). Specifically, the need to improve understanding of how particular fire regimes impact habitat suitability and food production for the bilby in the Pilbara was identified, in combination with the interactive effects of predation by introduced predators and total grazing pressure (Cramer *et al*., 2017). Consideration should also be given as to how climate change is likely to impact prescribed burning practices within the Pilbara in the future.

6.2 Fire management at known bilby sites

In 2017, a fire management plan was developed and implemented with the support of Millennium Minerals to protect the Nullagine bilby population from large, hot wildfires. Controlled burning of 27.5 ha was carried out, and mineral earth fire breaks and grading tracks were created to protect known bilby habitat (Dziminski and Carpenter, 2018). While future management aimed to create a fire mosaic within the protected area and conduct introduced predator control, no further management was implemented at this site (M. Dziminski pers. comm.).

Similarly, to protect the BLMA at Warralong from large wildfires, the establishment of a firebreak was recommended (Burrows, 2019; Dziminski *et al*., 2019). In 2019, fire breaks were established using a grader with some burning conducted around the BLMA perimeter (H. Moore pers. comm.). As specified in the fire management plan for the Warralong Bilby Offset Project area (Burrows, 2019), buffer burning of the BLMA perimeter was a key fire management strategy. The establishment of firebreaks surrounding managed populations prevents large wildfires destroying habitat and food resources (Wright and Clark, 2007) and facilitating predator access (McGregor *et al*., 2014). To produce fire age heterogeneity and potentially improve habitat and resource diversity for bilbies (Southgate and Carthew, 2006; 2007) ground-based (hand) patch mosaic burning under prescribed conditions was also advised (Burrows, 2019; Dziminski *et al*., 2019). A study on the Dampier Peninsula in the Kimberley investigating the multiscale impacts of fire attributes on bilbies indicated that fire frequency and extent of unburnt habitat (> 3 years) are important factors in predicting the presence of bilbies, with bilbies avoiding habitats with a limited proportion of unburnt habitat at a range of scales and areas experiencing more frequent fire (H. Moore pers. comm.).

6.3 Outcomes

- Fire management has commenced within the BLMA at Warralong to mitigate the risk of large-scale intensive wildfires under an adaptive management framework.

7 Future research directions

To improve knowledge and enhance the conservation management of the bilby in the Pilbara, we propose a revised set of research priorities for the bilby (Table 2) based on our review of existing knowledge and progress made-to-date (Sections 2-6). Research priorities are ranked as high, medium or low, however a structured decision-making process (e.g., Pritchard *et al*., 2022) would help to prioritise research topics within these groupings.

Table 2 Research priorities for the bilby (Macrotis lagotis) in the Pilbara, ranked high, medium or low.

Priority	Research topic	Objective	Outcome
High	Survey and monitoring – baseline occupancy survey of the Pilbara	A baseline occupancy survey of bilbies in the Pilbara is lacking. Conduct a large-scale survey to compare bilby occupancy with other regions where this approach has been undertaken (e.g., Fitzroy River catchment) and establish a baseline to compare occupancy in the future. Selection of sites should include areas where there is a high level of uncertainty of bilby presence (e.g., zone B in Figure 1; Dziminski *et al*., 2020c).	Estimates of bilby occupancy in the Pilbara will help to inform conservation planning including environmental impact assessments.
High	Survey and monitoring – establishment of long-term monitoring sites	Based on the occupancy survey above, and previously monitored populations, establish long-term monitoring at selected populations, and resurvey at regular intervals, to better understand population trends and changes in distribution over time. Concurrent monitoring of introduced herbivores and predators, and habitat condition, would also enable the identification of potential factors influencing changes in bilby abundance and distribution.	Improved understanding of long-term population trends of the bilby in the Pilbara to identify changes in conservation status, the potential cumulative effects of developments, and effectiveness of threat mitigation.
High	Habitat requirements – undertake habitat suitability modelling to identify important habitat	Using both historical information and data collected from the occupancy survey above, produce a habitat suitability model to identify important bilby habitat. Combined with genetic data, population connectivity (gene flow) and genetic diversity hotspots across	Identification of areas important for targeted conservation management to support bilbies in the Pilbara.

Priority	Research topic	Objective	Outcome
		the Pilbara could also be examined (e.g., Shaw *et al*., 2023).	
High	Habitat requirements – association of key food resources and fire	Identify the association of root-dwelling invertebrate larvae favoured by bilbies with their host *Acacia* (or other) spp. and the relationship between these plant species and fire (e.g., re-seeders/re-sprouters), including interactions with other flammable vegetation (e.g., *Spinifex,* buffel grass). This could also include other attributes such as rainfall.	Fire management strategies that promote food resources for bilbies and maintain/promote suitable habitat.
High	Threat mitigation – threat interactions and their management	Better understand how multiple interacting threats influence bilby populations (e.g., introduced predators, grazing pressure and fire) by using established survey and monitoring protocols and a network of paired managed and unmanaged bilby populations.	Effective integrated threat management to better protect bilbies.
High	Habitat requirements – influence of spatial and temporal fire attributes on bilby habitat	Using existing information on the distribution of the bilby across the Pilbara, combined with satellite-derived spatially explicit fire data, investigate the influence of multi-scale fire attributes on bilby presence. This could be further refined following the baseline occupancy survey that would also include data on introduced predator and herbivore occupancy.	Fire management strategies that promote/protect bilby habitat.
Medium	Threat mitigation – resilience of bilbies to feral cat density/activity thresholds	Interrogate the survey and monitoring data to determine the density threshold of feral cats below which bilbies can persist to inform targeted feral cat management.	Identification of a feral cat management strategy that facilitates the persistence of sustainable bilby populations.
Medium	Threat mitigation – cumulative impacts of mining	Better understand the cumulative impacts of mining on bilby populations and habitat connectivity.	Improved understanding of the influence of mining

Priority	Research topic	Objective	Outcome
		Identify potential barriers to gene flow such as railway lines and roads.	disturbance and strategies to mitigate these.
Medium	Population dynamics – understanding population shifts	Develop and test a long-term satellite tag and attachment system to enable long-term tracking (6+ months) of individual bilbies, to better understand what triggers populations to shift location across the landscape. Validate the use of scat DNA to track individuals/descendants as a complementary approach.	Management strategies that enhance population connectivity.
Medium	Population structure – understand genetic diversity and gene flow in the Pilbara relative to other wild populations	Continue to refine sequencing techniques based on scat DNA (e.g., DArTcap) to understand the broader genetic structure of wild populations.	Accurate measurement of population genetic parameters to inform management.
Low	Threat mitigation – influence of invasive buffel grass on habitat suitability	The interaction of introduced buffel grass, grazing and wildfire has been identified as a potential threat to bilbies by hindering or altering fire management. Research to improve knowledge on the complex interactions between buffel grass, fire and introduced herbivores will help to inform threat mitigation.	Threat mitigation strategies effective for management of buffel grass to ensure suitability of bilby habitat is maintained.
Low	Survey and monitoring – continue to investigate broadscale survey techniques	Continue trialling, development and optimisation of aerial survey techniques including RPA, and if technology develops and becomes more cost effective reinvestigate very high-resolution LiDAR over large areas to detects burrows and diggings. Evaluate trade-offs between accuracy, efficiency and cost-effectiveness per area covered of new technology compared to plot and/or transect-based methods.	Improvement in survey extent including previously inaccessible areas of the Pilbara to better understand bilby distribution.

Priority	Research topic	Objective	Outcome
Low	Habitat requirements – trial eDNA approaches to further evaluate diet using scats	Develop (or refine existing) DNA barcode libraries of potential dietary items and match DNA extracted from scats to provide a more comprehensive understanding of dietary requirements (e.g., Dawson *et al*., 2021).	Provision of a comprehensive understanding of bilby diet and habitat requirements.
Low	Threat mitigation – influence of climate change	Undertake a climate change vulnerability assessment (e.g., Foden and Young, 2016) for the bilby that considers interactions with threats (e.g., distribution and abundance of) introduced predators).	Improved understanding of the influence of climate change on bilby populations in the Pilbara to inform adaptation strategies.

8 Threat management for bilbies in the Pilbara

Threat management may be implemented at a local or regional level and prioritised based on factors such as ecological cost-effectiveness (e.g., Carwardine *et al*., 2019). Using a structured elicitation approach, Carwardine *et al*. (2014) prioritised threat management for Pilbara species of conservation significance including the bilby. Seventeen management strategies were agreed upon and prioritised based on their estimated average expected benefits, average costs and cost-effectiveness. Feral ungulate and domestic herbivore management, fire management, and feral cat management (including combined management strategies) ranked highest. In the absence of management intervention, the bilby was one of 13 species at high risk of being lost from the region over the next 20 years.

The Pilbara Conservation Strategy (DPaW, 2017) describes a landscape-scale approach to biodiversity conservation across the region and provides strategic direction for on-ground management actions to enhance conservation outcomes in partnership with State and Commonwealth governments, mining industry, traditional owners, natural resource management groups, pastoralists, local government, non-government organisations, community groups and research institutions. While landscape-scale threat management may be desirable, this is not always achievable, with on-ground actions often tailored to suit local conditions, resources and capacity, which may vary over time (DCCEEW, 2023b). Management on a smaller scale (no less than ~10,000 ha), focusing on local bilby populations and/or key habitat, is also beneficial, and cumulatively over time and space, may eventually result in a landscape-scale program (DBCA, 2021a).

Based on current knowledge of the bilby and associated threats, we provide a number of options to guide management that are most likely to benefit and facilitate the persistence of bilbies in the Pilbara (Table 3). These options closely align with the proposed on-ground strategies listed in the National Bilby Recovery Plan (DCCEEW, 2023b) and for other bilby populations in WA that face similar threats (e.g., Dziminski and van Leeuwen, 2019; DBCA, 2021a).

Table 3 Threat management options for the bilby (Macrotis lagotis) in the Pilbara.

Threat	**Population-scale actions** (i.e., applied to an area ~10,000 ha surrounding the population)	**Landscape-scale actions**
Introduced predators	Implement localised, strategic aerial and/or ground baiting using *Eradicat*® in managed populations and surrounding buffer zones, in conjunction with supplementary methods such as trapping (e.g., Lohr and Algar, 2020) and shooting (CoA, 2015). Consider trialling Felixer™ feral cat grooming traps, which show potential as an effective complementary tool for	Implement annual, strategic aerial *Eradicat*® baiting (Algar and Burrows, 2004; Algar *et al*., 2013; Doherty and Algar, 2015; Comer *et al*., 2020). The bilby has benefited from large-scale introduced predator management using baits and supplementary control methods elsewhere in WA (e.g., Matuwa, Lohr and Algar, 2020; Lohr *et al*., 2021).

Threat	**Population-scale actions** (i.e., applied to an area ~10,000 ha surrounding the population)	**Landscape-scale actions**
	targeted feral cat control (Dunlop *et al*., 2020; Moseby *et al*., 2020).	*Eradicat*® baiting (and wild dog baiting operations on pastoral lands) will also opportunistically target foxes.
Inappropriate fire regimes	Implement localised, ground-based (hand) patch mosaic burning in and around managed populations and establish firebreaks around managed areas (Burrows, 2019) to prevent large wildfires destroying habitat and food resources (Wright and Clark, 2007) and facilitating predator access (McGregor *et al*., 2014; McGregor *et al*., 2016). The fire management plan developed for the Warralong BLMA (Burrows, 2019) can be used as a template to be applied to other bilby populations in the Pilbara.	Implement adaptive fire management across selected large areas of the Pilbara with suitable bilby habitat (DBCA, 2021a).
Introduced herbivores	Opportunistic ground culling of feral herbivores and unmanaged livestock (DBCA, 2021a). Negotiate the closure of artificial water points within managed bilby populations (DBCA, 2021a). Exclude introduced herbivores from large areas of bilby habitat using livestock fencing (DBCA, 2021a).	Consider aerial culling of feral herbivores and unmanaged livestock over large areas of suitable bilby habitat (DBCA, 2021a). Consider fencing large areas to exclude livestock (DBCA, 2021a).
Land clearing	Avoid clearing habitat near key bilby populations (DBCA, 2021a).	To reduce the impacts of land clearing, conserve large tracts of connected suitable habitat to support wild bilby populations (DBCA, 2021a). Create formal conservation reserves within the established range of the bilby (DBCA, 2021a).
Threat interactions	Introduced predators and fire: Implement localised fire management (as above) and concurrent targeted ground *Eradicat*® baiting and trapping/shooting at managed sites and surrounding buffer zones (DBCA, 2021a).	Implement fire management across selected large areas of the Pilbara with suitable bilby habitat, with concurrent aerial *Eradicat*® baiting and targeted trapping/shooting (DBCA, 2021a).
Loss of genetic diversity	Consider genetic supplementation of populations (e.g., translocations) with low levels of genetic diversity.	Promote habitat integrity and connectivity to facilitate dispersal and enhance gene flow across the Pilbara. Establish and maintain a bilby meta-population that preserves genetic diversity and evolutionary potential (DCCEEW, 2023b).

Threat	**Population-scale actions** (i.e., applied to an area ~10,000 ha surrounding the population)	**Landscape-scale actions**
Mining associated infrastructure and disturbance	Avoid clearing habitat near key bilby populations where possible (DBCA, 2021a). Consider wide culverts/underpasses under railway lines and roads in the proximity of bilby populations. Introduce dusk to dawn speed limits near bilby populations.	Consider the cumulative impacts of mining operations in areas of bilby habitat e.g., habitat surrounding salt lakes where there is increasing development of mineral sand, rare earth and lithium mining.
Weeds	Targeted management of buffel grass and habitat restoration.	
Road mortality	Limit the construction and upgrading of roads in areas where there are bilbies. Introduce dusk to dawn speed limits near bilby populations. Consider wide culverts/underpasses under roads in the proximity of bilby populations.	
Population decline	Reintroduce free ranging bilbies, and the beneficial ecosystem services they provide, to areas where they were locally extirpated, without the need of high-cost predator exclusion fencing (e.g., replicate the success of Matuwa, Dziminski *et al*., 2020c; Lohr *et al*., 2021). This would require management of introduced predators and herbivores, and fire as above.	

9 Conclusions

Ecological knowledge of the bilby in the Pilbara, and elsewhere in WA, has been improved as a result of the Pilbara Bilby Research Program and associated collaborations. Given the difficulty of monitoring this species, there has been a clear focus on improving survey and monitoring techniques for bilbies which have evolved with genomic and analytical advances. A particular highlight is the development of a scat DNA based molecular toolkit, allowing for identification of individual bilbies, and their sex, and the establishment of a georeferenced and time-stamped database of individual bilby genetic captures to enable tracking of individuals through space and time.

We now have clear guidance on effective and efficient survey and monitoring practices, which if used consistently, can provide comparative information on population trends across the bilby's distribution. Survey information to date has also allowed for a better understanding of the conservation status and distribution of the bilby in the Pilbara; sub-populations are geographically isolated and comprise a small number of individuals. Further work on genetic structure will be useful in relation to understanding connectivity between these populations. We also have an improved understanding of what resources are important to bilbies in the Pilbara, such as *Acacia* spp. that harbor important food resources in the form of root-dwelling larvae. However, how fire influences this important resource remains uncertain.

Effective management of introduced predators, particularly feral cats, and foxes where they are most prevalent, is likely to be crucial for the persistence of bilbies in the Pilbara. Strategic feral cat management using a combination of control options (e.g., targeted ground and aerial baiting, trapping) is likely to provide the most benefit, as demonstrated at Matuwa, where bilbies were successfully reintroduced. Another area requiring investigation is understanding how multiple interacting threats influence bilby populations, particularly the synergistic threats of introduced predators, fire, and herbivore grazing. The adaptive management and monitoring approach at Warralong (Coongan Pastoral Station) where both fire and introduced predators are being managed is likely to provide insight into the effectiveness of controlling multiple threats. The addition of other bilby populations where a similar approach is applied will also improve our understanding of how to effectively mitigate interacting threats to enhance bilby persistence.

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Appendices

Appendix 1 Outputs of the Pilbara Bilby Research Program (2013-2023)

Journal articles

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Appendix 2 Interim guidelines for occupancy surveys of bilbies (superseded by DBCA, 2017)

Department of Parks and Wildlife

Interim guidelines for occupancy surveys of bilbies across large areas in Western Australia

Version 1 – 8 May 2017

Background

This document provides interim guidelines for surveys of the threatened greater bilby (*Macrotis lagotis*) to detect the presence or absence of bilbies across large areas at the landscape scale. This bilby survey protocol addresses the targeted search requirement for conservation significant fauna as recommended for the reconnaissance survey component of a Level 1 survey in the *Technical Guide for Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment*.

Protocol

Detecting bilbies

Bilbies are cryptic and not easily observed or trapped. The most efficient and reliable technique to detect whether bilbies are present at, or have used, an area is the observation of sign by trained and experienced observers. Only the presence of scats, clear tracks (hind foot imprints: narrow with indistinct side toes and the front foot: three parallel toe marks), and/or multiple diggings into the base of plants to access root dwelling larvae (RDL) can be used to confirm current presence and use of a site by bilbies. Unclear tracks (gait pattern alone), burrows, and diggings in the open, can be used to flag potential bilby activity or potential past presence, but not to verify current presence with certainty.

Caution is required in using unclear tracks, burrows and diggings in the open to ascribe presence as other species can be responsible for such sign. A range of other species produce similar diggings (e.g. varanid lizards, echidnas) and gait pattern (e.g. rabbits, quolls) to that of the bilby. Bilbies sometimes also use previously constructed burrows without a distinctive sand apron and other species can rework long inactive bilby burrows.

Juvenile bilbies can be identified from the size of scats and tracks indicating that recruitment is occurring in the population. A standardised protocol to achieve validation of sign as summarised above will soon be available. Trained and experienced observers must have previous experience in tracking and detecting bilby sign, and/or be trained to an appropriate standard. Traditional owners, ranger groups and experienced wildlife ecologists are likely to have these skills..

Surveying for bilby sign

A number of techniques have been applied to survey for sign of wild bilbies. These have included the use of transects to monitor the incursion of bilby tracks along a prepared surface or to detect activity and burrows along a fixed width, and plot-based approaches to detect a range of sign. The transect methods generally result in a poor return on effort, and have limited practicality in application across large survey areas. In comparison, the 2 ha plot sign-based monitoring protocol has been applied broadly, is currently used widely across the arid and semi-arid areas of Australia and is therefore the recommended method.

2 ha sign plot technique

Originally developed from larger plots, the 2 ha area survey protocol has been refined over the last two decades. It provides a standardised repeatable technique to systematically record the use of a site by bilbies based on validated sign by experienced observers. The advantages of this technique are that it provides quantified and comparable data and surveys can readily be repeated to estimate occupancy and detectability. Open source software for the analysis of occupancy data is available. Standardised data sheets and App templates for recording data captured during sign plots surveys can be requested from Parks and Wildlife.

The 2 ha plot allows for a practical 200 m × 100 m area to be sampled in approximately 25 minutes by an observer. This technique is also used to record important habitat information and capture observations of the sign of other species (e.g. invasive predators, herbivores and livestock) that may affect bilby occupancy. Single sampling of a series of plots provides an estimate of frequency of occurrence, which is a description of the surveyors' ability to *find* the species in the landscape, not where the species *is* in the landscape.

In order to address issues with the variability of this monitoring method in detecting all sign or all individuals within a sampled area, resampling of sites recommended to allow the probability of the area being occupied

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and the detectability of sign to be estimated. Surveys should be repeated within 1-4 months to account for imperfect detection and assess error.

Placement and stratification of sign plots

Sign plots should not only be placed near access tracks but should also be located more broadly across the survey area. Suitable bilby habitat should be identified and although survey effort can be focussed on habitat types that are known to support bilbies, other habitat types in a project area should also be included in the survey program. Quad bikes/ATVs, horseback, 4WD vehicles across country, helicopters and walking have been used to access areas away from tracks. Movement to and between plots also provides the opportunity for supplementary transect searches.

To achieve sampling independence, plots need to be spaced further apart than the foraging range of an individual bilby. Plots spaced more than 4 km apart would meet the assumption of sample independence (bilby movement is commonly 2-3 km for males and 0.5-2 km for females between burrows per night). If present, stratification should include: residual landforms and habitat types where shrubs containing RDL are common; loamy or sandy soils associated with drainage lines; and, sand plain and dune fields; and fire ages varying between recent (1-2 years), medium (3-10 years) and old (>10 years).

Remote cameras

The detection of scats, clear tracks and diggings at the base of plants for RDL alleviates the need to use remote cameras to confirm bilby presence. Determining whether bilbies are present can be achieved more rapidly and cost effectively by simply observing the sign described above than deploying cameras on active burrows. However, remote cameras may be useful in detecting and confirming the presence of bilbies where their signs are not clear, or over the longer term, when deployed in grids in a similar method in which they are currently being used for detecting the occupancy of introduced predators.

Aerial Survey

Aerial survey using helicopters has proved efficient and cost effective in detecting bilbies. Digging and burrow activity can be readily detected along transects flown at a height of approximately 20 m and at 40 knots. Fixed wing aircraft have been used in very open and very sparsely vegetated habitat in SW QLD to detect burrows. A proportion of the putative bilby sign detected needs to be confirmed with ground-truthing to determine false-positive error. In addition, a series of sites under the flight path, particularly in key favoured habitats such as laterite and sandy rises and drainage lines, needs to be examined to determine false negative error.

The efficacy of remotely piloted aircraft (RPA) is being investigated and will likely become a useful survey technology. Calibration by ground-truthing will need to accompany RPA surveys to enable assessment of false positive and negative error.

Appendix 3 Interim guidelines for surveys to detect the presence or absence of bilbies (superseded by DBCA, 2017)

Department of Parks and Wildlife

Interim guidelines for surveys to detect the presence or absence of bilbies, and assess the importance of habitat within small impact areas in Western Australia

Version 1 – 8 May 2017

Background

This document provides interim guidelines for detecting the current or recent presence of bilbies, and assessing the importance of the habitat proposed to be cleared, specifically within small areas. The purpose of such survey is to inform impact assessment procedures associated with native vegetation clearing permits in potential bilby habitat. This bilby survey protocol addresses the targeted search requirement for conservation significant fauna as recommended for the reconnaissance survey component of a Level 1 survey in the *Technical Guide for Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment*.

Protocol

Detecting bilbies

Bilbies are cryptic and not easily observed or trapped. The most efficient and reliable technique to detect whether bilbies are present at, or have used an area, is the observation of sign by trained and experienced observers. Only the presence of scats, clear tracks (hind foot imprints: narrow with indistinct side toes and the front foot: three parallel toe marks), and/or multiple diggings into the base of plants to access root dwelling larvae (RDL) can be used to confirm current presence and use of a site by bilbies. Unclear tracks (gait pattern alone), burrows, and diggings in the open, can be used to flag potential bilby activity or potential past presence, but not to verify current presence with certainty. Caution is required in using unclear tracks, burrows and diggings in the open to ascribe presence as other species can be responsible for such sign. A range of other species produce similar diggings (e.g. varanid lizards, echidnas) and gait pattern (e.g. rabbits, quolls) to that of the bilby; bilbies sometimes also use previously constructed burrows without a distinctive sand apron and other species can rework long inactive bilby burrows. Juvenile bilbies can be identified from the size of scats and tracks indicating the population is a source and recruitment is occurring. A standardised protocol to achieve validation of sign as summarised above will soon be available. Trained and experienced observers must have previous experience in tracking and detecting bilby sign, and/or be trained to an appropriate standard. Traditional owners, ranger groups and experienced wildlife ecologists are likely to have these skills.

Surveying for bilby sign and asserting absence

Because bilbies are sparsely distributed across large areas, and populations can move across the landscape, single surveys of small areas can be unlikely to detect bilby presence. This does not mean that bilbies never use the habitat within that area or never will, and the area may be important bilby habitat. Furthermore, if bilbies are present nearby then it is more likely it may have been, or will become important habitat. To increase confidence in asserting absence, surveys need to occur both within the area proposed to be impacted and a buffer zone around this impact area. Buffer zones account for the propensity of bilbies to emigrate and colonise adjacent habitat, and provide regional context of the consequences of clearing habitat.

Surveying the impact area

A number of techniques can be applied to survey for sign of bilbies within small areas where impacts are proposed to occur. These include:

- 2 ha sign plot technique
- transect searches
- a combination of the above
- traversing the entire impact area if small enough.

A range of transect types and different size plots may be adequate to detect bilby sign within the survey area, however the recommendation is to default to the technique that is most compatible and comparable with that used in regional surveys and surveys of the buffer zone. Furthermore, it can be impractical to use transects or entirely traverse larger areas. The standardized 2 ha sign plot technique provides systematically quantified and comparable data and is currently applied broadly. Details of the technique are included in Parks and

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Wildlife's *Interim guidelines for occupancy surveys of bilbies across large areas in Western Australia*. Standardised data sheets and App templates for recording data captured during sign plots surveys can be requested from Parks and Wildlife.

Bilby movement is commonly 2-3 km for males and 0.5-2 km for females between burrows per night and this information can be used in planning the placement of plots in the layout of surveys. Across larger areas and buffer zones, 2 ha sign plots should be spaced more than 4 km apart to ensure independence and increase efficiency by limiting resampling within a single bilby movement range during a survey event. Within smaller survey areas (< c. 1600 ha), independence is not required and plots can be placed more densely, particularly if increasing the confidence of asserting absence is the goal. The number of plots depends on the size and shape of the survey area. For small areas a density of 2-4 plots per 100 ha, or alternatively less plots with supplementary transect searches, can be manageable and sufficient to confidently assert absence. As impact areas become larger, plot spacing can increase up to the 4 km spacing, and supplementary transect searches can be applied between plots to provide increased confidence of asserting absence, if required. As plot spacing increases, plot locations need to include habitat known to be favoured by the bilby including laterite and sandy rises, drainage lines and recently burnt habitat (within the last 1-3 years).

Surveying the buffer zone

The size of a buffer zone can be based upon the known movement range of bilbies. An 8-10 km buffer from the perimeter of the impact area will provide a measure of the presence or absence of bilbies within two home ranges. The buffer zone survey provides information regarding the likelihood of bilbies being in the vicinity of the area proposed to be impacted and can be used to assess the importance of habitat to be cleared. For example, if there is no bilby sign within the proposed impact area but there is sign nearby within the buffer, and the proposed impact area includes similar habitat, then it is considered more significant as potential past or future bilby habitat. Plot spacing should be based on the size of the buffer zone using the same considerations outlined above.

Additional techniques

It should not be necessary to verify bilby presence with remote camera imagery when scats, clear tracks and diggings at the base of plants for RDL are present at a site. Remote cameras may be useful in detecting and confirming the presence of bilbies in habitats where their sign is not easily detected, or to determine whether an area is being used over the long term. Methods of traversing transects and accessing plots are discussed in *Interim guidelines for occupancy surveys of bilbies across large areas in Western Australia*, together with the use of remotely piloted aircraft (RPA) which may have potential in the survey of small impact areas.

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Appendix 4 2-ha sign plot datasheet for occupancy surveys

Department of **Biodiversity, Conservation and Attractions**

GOVERNMENT OF WESTERN AUSTRALIA

2HA SIGN PLOT DATASHEET v1.4

FOR OCCUPANCY SURVEYS

1. RECORD LOCATION AT THE START

Site Name/Location/Plot ID____

GPS:Lat/Easting______________________Long/Northing______________________ Date ______/______/_____

Ranger group ____________________________________Time started___________Time finished___________

Team members____

2. TEAM SPLIT UP EVENLY AND WALK A 2HA AREA FOR APPROXIMATELY 20 MINUTES
(Approximately 200m x 100m area)

3. INSPECT 100M OF THE ROAD FOR SIGN (ensure to tick "on road" for this sign)

4. RECORD ANIMAL DATA (tick boxes in table below ✓)

5. RECORD AGE OF SIGNS AT END OF WALKING 2 HA PLOT (1,2 or 3 in last column below)

Age of Sign: 1. Fresh 1-2 days old 2. Older, 3 days to 1 week 3. In hard mud/substrate or >1week

Species (add if not listed) All species prelisted	Tracks	Scats	Burrow	Digging	Digging into roots of plants	Tracks or sign on road	Other (eg sighting, remains, nest, resting place etc – add)	Juveniles present?	Age of most recent sign (1,2,3)
Bilby									
Bandicoot									
Bettong									
Dingo									
Echidna									
Euro									
Hopping mouse									
Kangaroo Red									
Kangaroo unknown									
Kangaroo W Grey									
Large rat									
Marsupial mole									
Mouse / Small Rodent / Dunnart									
Mulgara/Ampurta									
Possum									
Quoll									
Wallaby Agile									
Wallaby Hare									
Wallaby - Northern Nailtail									
Wallaby - Spectacled Hare									
Wallaby - unknown									
Lizard - Blue tongue									
Lizard - Goanna large									
Lizard - Goanna small									
Lizard - Great Desert Skink									
Lizard - Medium									
Lizard - Small									
Lizard - Thorny devil									
Sand slider (Lerista)									
Snake - other									
Snake - Python									
Bird - Curlew									

Department of **Biodiversity, Conservation and Attractions**

2HA SIGN PLOT DATASHEET v1.4
FOR OCCUPANCY SURVEYS

Species (add if not listed) All species prelisted	Tracks	Scats	Burrow	Digging	Digging into roots of plants	Tracks or sign on road	Other (eg sighting, remains, nest, resting place etc – add)	Juveniles present?	Age of most recent sign (1,2,3)
Bird - Emu									
Bird - Hopping									
Bird - Quail									
Bird - Turkey (Bustard)									
Bird - Walking									
Insect									
Other									
Cat									
Camel									
Cow									
Donkey									
Fox									
Goat									
Horse									
Pig									
Rabbit									

6. WHEN FINISHED WALKING RECORD THE FOLLOWING

Plot type
☐ Random ☐ Targeted at habitat ☐ Known location of target species

Plot sequence
☐ First time ☐ Repeat survey ☐ Unknown

Landform type
☐ Drainage line ☐ Dune or dunes ☐ Other (type in below)
☐ Salt lake system ☐ Hill or higher area ____________________
☐ Plain (flat low ground)

Soil type (substrate)
☐ Sand ☐ Soil/clay ☐ Gravel

Vegetation structure
☐ Shrubland ☐ Open woodland ☐ Dense woodland ☐ Open grassland

Vegetation thickness
☐ Open (easy to walk through) ☐ Thick (very hard to walk through)

If there are bilby diggings into roots what plants are they? ____

What percentage of the plot is suitable for tracking (eg sand or dirt)**?**
☐ To ¼ (0-25%) ☐ To ½ (25-50%) ☐ To ¾ (50-75%) ☐ Up to all (75-100%)

Department of **Biodiversity, Conservation and Attractions**

GOVERNMENT OF WESTERN AUSTRALIA

2HA SIGN PLOT DATASHEET v1.4
FOR OCCUPANCY SURVEYS

How big are the majority of the sand patches?

☐ less than 1m in width ☐ 1-3 m in width ☐ more than 3 m in width ☐ No sand patches

Shadow (look at own shadow

☐ Distinct shadow ☐ Slight shadow ☐ No shadow

Time since rain that would clear animal tracks (enter number) ☐ Days ☐ Weeks ☐ Months

Time since strong wind that would clear animal tracks (enter number) ☐ Days ☐ Weeks ☐ Months

Time since burnt (if known)

☐ <1 month ☐ <1 year ☐ >1 year

Photos of habitat taken? Y / N (if yes –list photo file names) ____

____

____

[OPTIONAL] If bilby burrows are found GPS the location of each one:

GPS Location (lat, long)	Any notes - location (e.g under log or tree), sensor camera number if placed

Any other comment/ notes:

Please submit datasheets to:
Department of Biodiversity, Conservation and Attractions - threatenedfauna@dbca.wa.gov.au, Woodvale Wildlife Research Centre, Bilby Research, Locked Bag 104 Bentley Delivery Centre WA 6983. (08) 9405 5105

Acknowledgements: WWF and Environs Kimberley assisted in producing the initial version of this template.

Appendix 5 Guidelines for pre-clearing searches to locate resident bilbies and relocation of bilbies prior to vegetation clearing

Box 1. Guidelines for pre-clearing searches to locate resident bilbies

Version 2 – September 2018

Scope

Where targeted surveys or other information indicate that bilbies (*Macrotis lagotis*) are likely to occur in a development footprint (vegetation clearing area and may include any additional disturbance areas), avoidance, displacement or relocation, and management are likely to be required.

This document provides guidelines aimed at locating bilbies (generally occupied burrows) in development footprints so that the animals can either be avoided, displaced or relocated to prevent mortality. Search design may need to be adapted to the habitat types present, and the size and shape of the project area and in response to the targeted search results (refer to the *Guidelines for Surveys to Detect the Presence of Bilbies, and Assess the Importance of Habitat in Western Australia* (DBCA 2017).

Pre-clearing searches, also referred to as clearance surveys, are required to be conducted in accordance with conditions of the development or clearing approval, an approved fauna management or relocation plan, and a licence to take fauna (which includes fauna disturbance). Other licenses or permits may be required.

These guidelines only apply to the on-ground searches to locate bilbies *in situ* to avoid direct impact and mortality.

Protocol

Bilbies are cryptic and not easily observed or trapped. The most efficient and reliable technique to detect whether bilbies are present is the observation of sign by trained and experienced observers. A range of sign may be present, including scats, tracks, burrows and diggings.

Pre-clearing guidelines are very different in intent from targeted surveys as they aim to locate bilbies in impact areas (i.e. the disturbance footprint) as close as possible to the time of clearing. Bilbies are often sparsely distributed across large areas, and populations can move across the landscape, so a search to locate bilbies must be undertaken a close as possible to the clearing activity, at the most no longer than 2 weeks prior to commencement of vegetation clearing. Bilbies can move into an area within a short period therefore it is also recommended to have an experienced fauna spotter and a plan to manage situations that arise during clearing operations.

Graduated levels of intensity are recommended for these searches, effectively progressing from coarse to very fine scale searching in order to locate burrows:

- The initial approach is traversing transects in order to locate areas with bilby activity/sign. Transects must be spaced close enough together to ensure that bilby sign between transects will not be missed. This spacing will depend on visibility, for example, transects in recently burnt low open spinifex would be further apart than transects in thick Acacia shrubland which would need to be much closer together. Distance selected should be justified based on visibility and terrain at each site. These transects can generally be restricted to the area to be cleared or disturbed, unless the approval conditions specify otherwise.
- If evidence of bilbies is found during these initial transects, undertake more intensive searches where transects spacing ensures visibility of all ground between adjacent transects. Exact distances between transects depend on vegetation and terrain but are in the order of 20m spacing. The aim is to locate recent foraging sign, fresh tracks and scats. Even more intensive searches may be necessary to locate all occupied burrows.
- Once a burrow is located, clearly mark and record the location

A single bilby may have up to 18 burrows within its home range and can create new burrows or rework old burrows at any time. Not all burrows are occupied and the same burrows may not be occupied on successive nights. All burrows therefore need to be located, and then need to be examined for signs of occupancy. This can often be informed by fresh tracks and recent excavation, and the use of remote cameras is highly recommended. Many other animals use bilby burrows, so a burrow with fresh activity that does not show distinct bilby sign (ie clear bilby tracks or scats) may contain other animals rather than a bilby. This would need to be confirmed with remote cameras. Remote cameras need be located at burrow entrances for a minimum of three nights to confirm burrow use or if a bilby is not present in a burrow. A disturbed bilby could stay in a burrow for 24 hours. Careful consideration needs to be given to the positioning and angle of the camera. Consideration needs to be given to the brand and quality of cameras (many cheaper ones are unreliable) and the settings of the camera trigger. This information should be included in reporting. Because remote cameras are not always reliable and not always triggered, two cameras positioned at different angles could be used to ensure high confidence of burrow occupancy or vacancy.

Once occupied burrows are found, the pre-developed fauna management or relocation plan will dictate how to reduce, avoid or mitigate the direct impact to individuals (*Guidelines for relocation of billies prior to vegetation clearing are under development*). This may include relocation by displacement or trapping (capture and release), and these decisions are informed by surrounding land use, adjacent habitat quality, ability to undertake further monitoring, etc. The fauna management plan must be developed in consultation with DBCA and endorsed prior to pre-clearing searches.

Important Principles

- Extensive searches are required to avoid, displace or relocate, and manage resident bilbies prior to clearing.
- The aim of these searches is to locate bilbies in impact areas (i.e. the disturbance footprint) as close as possible to the time of clearing.
- These surveys should be undertaken as close as possible to the clearing activity, preferably less than 2 weeks.
- Search intensity needs to progress from coarse to very fine searching in order to locate burrows.
- All burrows located need to be monitored to determine activity.
- Once occupied burrows are identified, undertake the actions set out in a pre-developed and endorsed fauna management plan, developed in consultation with DBCA.

Acknowledgements

These guidelines were prepared by DBCA with major contributions from Martin Dziminski, Amy Mutton, Kim Onton, Manda Page and Tracy Sonneman.

Box 2. Guidelines for relocation of bilbies prior to vegetation clearing

Version 1 – September 2018

Scope

The greater bilby (*Macrotis lagotis*) is a threatened species that may need to be relocated from a development footprint (i.e. vegetation clearing area including additional disturbance areas) to prevent mortality. This guideline recommends actions to be undertaken and incorporated in planning documents for the relocation of bilbies. These actions should be planned and implemented under the supervision of a suitably qualified and experienced zoologist/ecologist.

Pre-clearing surveys for bilby burrows within a development footprint must first be conducted as outlined in *Guidelines for pre-clearing searches to locate resident bilbies* (Department of Biodiversity, Conservation and Attractions 2018) to identify burrows and assess their occupancy before relocation options are considered.

The first approach to relocation is displacement where the animal is encouraged to move out of the footprint area on its own accord. This is the preferred course of action as it minimises direct trapping and handling of bilbies and reflects the behaviour of bilbies to use multiple burrows within their home range and their ability to rapidly excavate new burrows. The appropriateness and likely success of displacement will depend on the quality of the surrounding habitat and the long-term retention of adjacent vegetation. Displacement can only be used if the surrounding habitat is, and will remain, viable in the long term. Trapping and physical relocation should be only undertaken under circumstances where displacement has not been successful before clearing occurs, or if adjacent habitat is inviable.

NOTE: Ensure all applicable licenses, permits and approvals are in place prior to undertaking these activities. These recommended protocols should be incorporated into an approved Fauna Management Plan.

Protocol

The following sequence of events is recommended for bilby relocation:

- pre-clearance surveys to locate burrows,
- determine occupancy of burrows,
- fauna relocation;
  - by displacement – encouraging fauna to abandon burrows,
  - by capture and release,
- conduct vegetation clearing with a fauna spotter present,
- monitor displaced or relocated fauna activity after disturbance and mitigate threats.

Each stage should be consecutive, or concurrent where appropriate. Timing and surveillance are important to ensure that relocated fauna have no or limited opportunity to return to the impact area prior to disturbance.

Pre-clearing searches

Pre-clearing searches must be undertaken immediately before clearing, no more than two weeks prior to the clearing activity, and in accordance with *Guidelines for pre-clearing searches to locate resident bilbies* (Department of Biodiversity, Conservation and Attractions 2018). Searches need to consider the time required to undertake any necessary fauna displacement or relocation but also limit the time available for fauna to move into the area between searches and clearing. A minimum of a week (3 nights for displacement, 4 nights for trapping) should be devoted to relocation if potentially occupied burrows are identified.

Determining burrow occupancy

The occupancy of each burrow that is located during pre-clearing searches needs to be determined. A single bilby may have up to 18 burrows within its home range and can create new burrows or rework old burrows at any time. Not all burrows are occupied and the same burrows may not be occupied on successive nights. All burrows therefore need to be located, and then need to be examined for signs of occupancy immediately before clearing.

Many other animals use bilby burrows, so a burrow with fresh activity that does not show distinct bilby sign (i.e. clear bilby tracks or scats) may contain animals other than a bilby. If there is any evidence that a burrow is potentially occupied, and the animal cannot be confirmed as a bilby, the protocols for 'occupied burrow' should be followed under the precautionary principle.

Unoccupied burrow

A burrow may only be considered unoccupied if:

- it has begun to collapse and no longer has a round entrance or cavity and would not enable a bilby to enter without additional digging, and there is no evidence that other vertebrates are making use of the burrow, or
- it has vegetation in the entrance and cob webs across the entrance and there is no evidence that any vertebrates are making use of the burrow.

In these circumstances, no further monitoring is required and the inactive burrow should be 'exposed' by using a shovel to dig it out to 1 m thus making it unsuitable for use by any vertebrates but enabling any remaining fauna to escape for at least one night before clearing activities commence. It should then be filled in to prevent fauna moving into the burrow before, during or after disturbance activities. Further inspection is recommended to ensure the burrow is not re-excavated and occupied.

If an unoccupied burrow is found in the vicinity, but outside of the development footprint, it should be left undisturbed as a potential refuge for fauna displaced from within the impact area.

Potentially occupied burrow: Monitoring

Monitoring of a burrow needs to be conducted if:

- the burrow is open (i.e. round entrance and depth characteristics adequate to house a bilby), with or without a sand apron, and/or
- fresh bilby sign is present at site.

Evidence of activity is the best way to assess burrow use or burrow vacancy and all monitoring techniques must be applied for a minimum of three nights and photographic records must be kept demonstrating the method and the number of nights of monitoring.

Monitoring using remote cameras is highly recommended. Remote cameras need be located at all burrow entrances for a minimum of three nights Camera type, settings and positioning should be selected to increase the likelihood of triggers by fauna. This information should be included in the fauna management plan and reporting. Careful consideration needs to be given to the positioning and angle of the cameras. Two cameras positioned at different angles will increase the confidence of determining burrow occupancy or vacancy.

If it is impossible for remote cameras to be used then all of the methods below should be used in combination:

- Signs: fresh scat, tracks and diggings at a bilby burrow may indicate recent use. Smoothing the burrow entrance to create a sand-pad and checking each morning for tracks may assist in detecting activity. Evidence needs to be fresh and clear, and observed by an appropriately experienced and skilled person to confirm occupancy by bilby, as other fauna species are known to use bilby burrows.
- Physically blocking entrance: very loosely block the entrance with small sticks or clumps of grass and check the location of the blockage each morning to assist in determining activity.
- Burrowscope: a burrowscope may be used to observe any fauna within the burrow. This method is the least reliable as effectiveness will be dependent on the length of the scope, and the burrow size and construction including the presence branching tunnels or blockages., and backfilling of tunnels.

If there is no evidence of fauna activity for at least three nights, then the burrow can be classed as unoccupied and actions described above undertaken immediately.

Occupied burrow: Displacement

If a burrow is determined to be occupied or remains potentially occupied or unknown following monitoring, then the following techniques for fauna displacement should be applied. However, displacement is only appropriate if there is suitable adjacent habitat that will remain undisturbed and where threats to the bilby are managed. Displacement can only be used if the adjacent habitat is, and will remain, viable in the long term.

The displacement approach reflects the behaviour of bilbies to use multiple burrows within their home range and their ability to rapidly excavate new burrows, and is considered to be less-stressful, and more effective than a capture and release method.

1. Remote cameras previously installed to determine occupancy or potential occupancy should remain *in-situ* to continue monitoring fauna activity and confirm that fauna have left the burrow. Remote cameras, or other effective monitoring techniques must be deployed and remain *in-situ* during the displacement process. Successful displacement will likely take several days and nights to achieve and must be confirmed with evidence (see #3).

2. Some disturbance (i.e. partial excavation) of all burrow entrances within the development footprint may help make the burrows unattractive to the fauna and they may vacate the burrow and leave the impact area. Ensure that such disturbance does not prevent fauna from exiting the burrow. If abandonment of a burrow occurs and is confirmed (see #3), it is considered as displacement.

3. Time and date stamped images of fauna exiting a burrow and not returning, together with a lack of fresh sign (tracks on a sand-pad at the entrance), must be gathered to confirm successful displacement has occurred. Because remote cameras are not always reliable and not always triggered, two cameras positioned at different angles should be used to ensure high confidence of burrow occupancy or vacancy.

4. Once fauna displacement from a burrow has been confirmed, the burrow must be filled in immediately to prevent fauna moving in before, during or after vegetation clearing. The burrow should be carefully excavated by hand to verify that displacement has occurred. Ongoing surveillance is recommended (see #6).

5. Following displacement it is possible that new burrows will be created within the development footprint. A method of ongoing surveillance of the development area must therefore be incorporated into the program. Observations of fresh tracks and diggings may be followed to assist with this surveillance.

6. An animal may persist in using even a partly excavated or collapsed burrow, or try to re-excavate a burrow. Therefore, all burrows should continue to be monitored to ensure recolonisation does not occur up until clearing is undertaken.

7. If there is no confirmation that fauna have left an occupied or potentially occupied burrow, monitoring should continue for at least three nights until displacement is certain or capture and release is used.

In extreme circumstances, clearing up to the burrow, but no closer than 10m, can be used to help disturb and encourage displacement however a bilby is more likely to dig deeper and remain in the burrow than escape. In these circumstances clearing must be in a progressive manner from one direction, towards the closest adjacent intact vegetation. Surveillance and confirmation of displacement is still required (see # 3) and all further clearing must cease until displacement is confirmed.

Occupied burrow: Capture and Release

In instances where displacement of an occupied burrow has not been successful before clearing is scheduled to begin, or where there is not suitable adjacent habitat, capture and release may be appropriate. Bilbies can be difficult to trap and displacement is the preferred relocation method as it may create less stress on the animals than trapping. Capture and release should only be undertaken by personnel with appropriate skills and experience, licences, permits and approvals.

It is important that capture and release is conducted in accordance with the department's standard operating procedures (SOP) available at https://www.dpaw.wa.gov.au/plants-and-animals/96-monitoring/standards/99-standard-operating-procedures. In particular, the following SOPs are relevant:

- *Cage traps for live capture of terrestrial vertebrates*
- *Animal handling and restraint using soft containment*
- *Hand capture of wildlife*
- *Hand restraint of wildlife*
- *Transport and temporary holding of wildlife*
- *Care of evicted pouch young.*

Where capture and release is appropriate, the following information, techniques and protocols must be planned and documented prior to undertaking any activity, and may be required as part of the licensing process. Release sites must be identified and confirmed prior to any trapping commencing. It may be a requirement to document the location, quality of habitat and occupancy at release sites.

Trapping using free standing baited traps has not proved successful on wild bilbies. Instead, traps need to be placed in burrow entrances (burrow traps) or yard traps installed. Burrow traps take less time to install than yard traps but yard traps are particularly useful when:

- it is not feasible to fit a trap neatly into a burrow entrance (e.g. large termite mound),
- there are multiple entrances or pop-holes,
- there is evidence that the burrow may contain multiple individuals (e.g. mother and young), or
- a bilby has set off a burrow trap but was not captured.

Burrow traps

Cage traps with internal-opening doors (spring closing) are required. Hessian should cover the top and sides of the trap but not the end to enable a bilby to see out and also not the base. The sides of the burrow need to be carefully dug out using a small shovel to enable the trap to fit snugly inside the burrow, and deep enough so the treadle is just inside the burrow entrance (McGregor and Moseby 2014). Bait is unnecessary and is a detriment to the operation. Having no hessian on the base enables sand to bed between and obscure the wire mesh. However, the treadle needs to remain free and protected from sand build up from below. The treadle can be camouflaged by spraying water over the treadle, and then sprinkling sand on top to affix.

Yard traps

A yard is built around a potentially active burrow using 3-4 m panels of 25x25 mm square mesh (or finer), 900 mm tall with a hinged 300-400 mm footing (Southgate *et al.* 1995). The hinged footing can be attached with ring fasteners. A rod through ring fasteners attached to the end of each panels can be used to join additional panels. The panels need to encircle the burrow leaving about 1 m or more from the entrance. The footing needs to face inward toward the burrow entrance and can be cut to enable overlap and panels to curve around the burrow. The footing should be flat with the ground and covered with sand. Internally opening (spring closing) cage traps should be set inside the yard trap against the side of a panel and the wire mesh on the base obscured with sand. The top and sides of the traps should be covered with hessian but absent from the end. The yard traps should be free standing if relatively small radius. The panels of large radius traps may need support with attachment to external star pickets.

Trapping period

Traps need to be checked at sunrise each morning. A burrow trap that has been sprung by a bilby or another animal and not captured needs to be removed and replaced with a yard trap around the burrow.

A potentially active burrow should not be trapped using a burrow, yard or combination for more than for more than three consecutive nights. A burrow should then be fully excavated carefully (refer to appendix 1). Burrows should be excavated after trapping to confirm that all animals have been captured, then collapsed to avoid re-excavation of the burrow. Collapsed burrows should continue to be inspected to ensure re-excavation and recolonisation does not occur up until clearing is undertaken.

Handling protocols

All interactions with animals captured during this relocation program will be humane and ethical. It is essential that the animal handler/s is experienced in working with Greater Bilby to ensure the relocation program present limited risks to the animals. The length of time spent handling animals will be restricted as much as possible. Animals should be safely removed from traps and temporarily held following SOPs.

With the use of burrow traps and yard traps the likelihood of females ejecting pouch young is significantly reduced. However when removing animals from traps always check there are no ejected pouch young in or around the trap. Re-insert any ejected pouch young, tape and release together, following SOP.

Young-at-foot spend two weeks in a burrow before being left by their mother to become independent and at this stage are unlikely to survive if relocated. Such animals should be placed with a pre-determined licenced wildlife rehabilitator with experience with bilbies and the Department notified within 24 hours. If a lactating female is captured, hold the mother until burrow excavation is completed to attempt to retrieve the young and reunite (as per SOP).

All individuals captured should receive a general health check and sex determined. Check if females are lactating and retain until burrows are excavated to retrieve and reunite young with the mother. DNA samples may be required under a licence (refer to SOP), and temporary marking using non-toxic markers will enable individual identification of future camera images (refer to SOP).

Transport and release

Animals should be released at the pre-selected release site as soon as possible. If release cannot be undertaken immediately (early morning) store animals in dark, well ventilated, quiet and cool areas (less than 20°C) in soft containment bags within petpacks. Animals should not be held for more than 14 hours. Transport protocols must follow SOPs.

Release sites must be identified and confirmed prior to any trapping commencing. It may be a requirement to document the location, quality of habitat and occupancy at release sites. Individuals should be moved further than 5 km away from the capture site to reduce the chance return to the operational area and to sites with existing evidence of bilbies. Habitat should be as similar as possible similar to the capture site

If possible locate a dis-used bilby burrow at the site for release. If a suitable burrow cannot be found an artificial burrow should be constructed. Artificial burrows are a pre-dug burrow oriented at approximately 30 degrees to a minimum depth of one metre. The roof of the hole is lined with a half cut PVC pipe (35-45 mm diameter) and the floor remains earth. Multiple burrows are recommended at the release site. Animals can be released directly into the entrance of the artificial burrow.

If releasing early morning, a yard trap can be constructed around the intended release burrow (dis-used or artificial) prior to release to contain the bilby in the event the bilby finds the burrow unsuitable and decides to re-emerge during day light. Individuals should be released during day light and encouraged to enter a burrow and remain there. The yard trap should be removed at dusk.

Monitoring relocated bilbies

Little is known about the response of wild bilbies following release so post release monitoring is recommended with the objective to determine whether the relocated bilby emerges in good health from the burrow, if the animal remains at the release site and to assess whether other individuals are present. Four days of monitoring using remote cameras set on burrows is recommended. Monitoring with more intensive methods like tracking require considerably more planning, resources, skills and approvals.

During vegetation clearing

If clearing is scheduled to commence and the displacement or relocation of fauna from occupied or potentially occupied burrows cannot be confirmed, clearing in the immediate area should be postponed and effort to relocation continued. If this is impossible, the burrow must be clearly marked, and clearing undertaken from one direction progressively toward the area containing the burrow. Before reaching the marked burrow, it must be carefully excavated by hand (appendix 1) as described above, to ensure animals are not buried and killed during clearing operations. This is an absolute last resort and only undertaken after all other methods above have been completed for a minimum of a week and clearing cannot be postponed.

Further, the following is recommended during clearing activities.

- A walk-through of the clearing area should be conducted immediately prior to clearing (either the day before or day clearing begins), to inspect previously filled burrows and ensure that no fauna has recolonised burrows, and no new burrows have been constructed.
- Clearing should commence at a maximum distance from any retained burrow and progressively work towards it and be conducted in a direction that allows fauna to move out of the impact area into adjacent vegetation that is not proposed to be cleared.
- A fauna spotter should be present during the clearing activities to observe any fauna leaving other refuge areas. The spotter can guide machinery operators to prevent fauna harm, injury or mortality.

It should be noted that fauna moving across cleared areas are exposed to a high risk of predation, therefore displacement during clearing operations is not appropriate and allowing at least a week to relocated animals prior to the commencement of clearing must be incorporated in to planning.

After vegetation clearing

After clearing the following points should be considered.

- Any remote cameras installed at burrows during the clearance surveys outside of the clearing area, within additional disturbance areas, or at release sites and/or buffer zones, should remain *in-situ* during the fauna displacement and clearing activities to monitor fauna movement. These burrows are potential refuge sites for fauna displaced from the impact area. Activity should be recorded.
- Secondary signs observed opportunistically within the area surrounding the development footprint should be recorded.
- The cleared area should be inspected periodically to determine if bilbies have recolonised the area, as bilbies often prefer loose and recently excavated soil to construct new burrows.
- Minimise areas of loose soil and soil piles, especially beside vehicle tracks, to discourage bilbies from constructing new burrows.
- If more than two weeks lapse between the fauna displacement and the clearing, or clearing stages, or after clearing and other activities commencing (i.e. construction), then additional pre-clearing searches and relocation may be required, as animals could recolonise the site.

Additional notes

The methods for relocation by displacement are also appropriate for mulgara (*Dasycercus* species). In locations where both bilby and mulgara occur, Elliott traps should be used for mulgara as mulgara are unlikely to trigger cage traps. The approval conditions often include the relocation of both species.

All fauna species may be relocated from an area prior to vegetation clearing, even if there are no specific conditions on the approval.

Appropriate methods for the relocation of other fauna species will be considered during the assessment of a licence application to take fauna. For further information on fauna licences visit https://www.dpaw.wa.gov.au/plants-and-animals/licences-and-permits.

Important principles

- Prior to vegetation clearing, the occupancy of burrows identified during pre-clearing searches should be determined using remote cameras.
- Where occupancy is uncertain, the burrow should be considered as being potentially occupied and the protocols for 'occupied burrow' followed under the precautionary principle.
- Unoccupied burrows should be immediately filled in to prevent recolonisation.
- Displacement is the preferred fauna relocation method for occupied and potentially occupied burrows if suitable adjacent habitat is available.
- In instances where displacement of an occupied burrow has not been successful (or is not appropriate), capture and release may be applied. Capture and release should be undertaken in accordance with the department's standard operating procedures and by personnel with appropriate skills and experience.
- Burrows should immediately be filled to prevent recolonisation after displacement or relocation, and monitored to ensure recolonisation does not occur.
- If displacement of fauna from occupied or potentially occupied burrows is uncertain, clearing should approach in one direction and burrows hand excavated just prior to clearing.
- Additional pre-clearing searches and relocation may be required if more than two weeks lapses between the fauna displacement and the clearing, or clearing stages, or after clearing and other activities commencing (i.e. construction).
- Monitoring of displacement or release areas should be undertaken during and after clearing activities have concluded.
- Threat mitigation should be applied to displacement or release sites.

References and further reading

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Department of Biodiversity Conservation and Attractions Standard Operation Procedures (https://www.dpaw.wa.gov.au/plants-and-animals/96-monitoring/standards/99-standard-operating-procedures):

- *Cage traps for live capture of terrestrial vertebrates*
- *Animal handling and restraint using soft containment*
- *Hand capture of wildlife*
- *Hand restraint of wildlife*

- *Transport and temporary holding of wildlife*
- *Care of evicted pouch young.*

Acknowledgements

These guidelines were prepared by DBCA with major contributions from Martin Dziminski, Amy Mutton, Manda Page and Tracy Sonneman. Mike Bamford, Glen Gaikhorst and Rick Southgate, also made significant contributions.

Burrow Excavation

- Two individuals, each with a blunt-nosed shovel and/or garden trowels are required for burrow excavation. It may take up to several hours to excavate a bilby burrow, depending on its length and other characteristics.
- To maintain sight of the burrow, place the shovel handle down the burrow entrance as far as possible.
- Slice away the ceiling with the second shovel or trowel, removing sides and surrounding soils as required.
- Continue to slide the first shovel down into the burrow chamber so the burrow is not lost during excavation.
- Remove the soil with the second shovel or trowel as excavation proceeds and repeat.
- Excavate the burrow slowly and carefully and stop often to see if a bilby is within reach or the end of the burrow is visible (a torch maybe required). Be aware that other species maybe utilising the burrow.
- Do not collapse the burrow ahead of the shovel or trowel inside the burrow. Feel the shovel contact the other shovel with each stroke to avoid striking a bilby.
- Always excavate the burrow to its absolute end – be aware of forks, branches and plugged chambers and ensure all are excavated and inspected.
- If a fauna species is observed, it may be either displaced or captured. Note venomous species maybe present in burrows.
- If a juvenile bilby is captured, then reunite with mother if possible by direct insertion into the pouch and taping (refer to SOPs).
- After excavating the burrow, fill it in the remaining hole.

Appendix 6 Bilby poster

Bilby

Macrotis lagotis

Bilby burrow: note the high, dome shape.

Bilby.

Bilby diggings at the base of Acacias exposing roots.

Bilby diggings at the base of Acacias exposing roots.

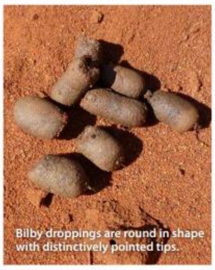
The bilby is a nocturnal, burrowing marsupial with large ears, soft, blue-grey fur, a long pointed snout and a black tail with a white tip. Body size can be up to 55cm long with a tail up to 29cm long.

Once found across most of arid and semi-arid Australia, the bilby is now only found in the Pilbara, Kimberley, north-western deserts in Western Australia and Northern Territory, and an isolated population in south-west Queensland.

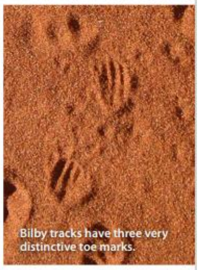
The presence of bilbies can be identified by large, high-arched burrows, distinctive tracks and scats, as well as diggings that are usually at the base of Acacia (wattle) shrubs to access grubs in the roots.

Parks and Wildlife is undertaking research on bilbies in the Pilbara. This research aims to survey where bilbies are in the Pilbara, and to develop long-term monitoring of populations.

If you see bilbies or their signs, or have historical information, visit **naturemap.dpaw.wa.gov.au/threatenedfauna** and upload your records, locations and photos. Alternatively, email **threatenedfauna@dpaw.wa.gov.au** or phone **(08) 9405 5100**. Your contribution will help in the conservation of this species.

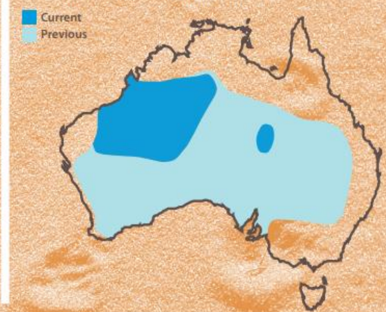


Bilby droppings are round in shape with distinctively pointed tips.



Bilby tracks have three very distinctive toe marks.

Bilby distribution throughout Australia



Department of Parks and Wildlife

For more information visit:
naturemap.dpaw.wa.gov.au/threatenedfauna