The conservation and management of the bilby (*Macrotis lagotis*) in the Pilbara

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Summary

The greater bilby (*Macrotis lagotis*) is a burrowing marsupial that was once wide spread across most of mainland Australia. Since European colonisation, the introduction of the cat and fox, changed fire regimes, the degradation of bilby habitat through pastoralism, introduced herbivores, and clearing, the range and abundance of greater bilbies have contracted severely and bilbies have disappeared from at least 80 % of their former range.

Populations of bilbies still persist in parts of the Pilbara. The aim of this project is to improve our understanding of the distribution, and demographics of bilbies in the Pilbara, and provide information to environmental regulators and resource development companies that will allow appropriate management to ensure the persistence of this species in the Pilbara.

An extensive data set of bilby records in the Pilbara continues to be collated from existing sources and field surveys. Bilbies in the Pilbara were found to be associated with stands of particular plant species, especially some *Acacia* spp. which provide the major food resource for bilbies in the Pilbara in the form of cossid moth larvae (grubs) found in their root systems. Preliminary distribution modelling identified soil type and depth, and elevation as major relative contributing variables to predict likely bilby habitat.

The type of sign that can be used to confirm the presence of the greater bilby in comparison to sign that should only be used to flag potential presence is described. A protocol to assess potential activity and verify bilby presence and a sampling technique is outlined. A set of interim guidelines for occupancy surveys and surveys to detect the presence or absence of bilbies, and assess the importance of habitat, were developed to promote standardisation and comparability. These interim guidelines are based on best practice techniques used nationally, and form a template to be reviewed by researchers, consultants and Traditional Owner rangers involved in bilby surveys, to produce a final set of best practice guidelines, which will be compatible with techniques used nationally.

The detectability of bilby sign from remotely piloted aircraft (RPA) was investigated. Altitude and speed had significant effects on the proportion of bilby diggings detected, and it was found that an altitude of 12 m at 6-8 km/h resulted in increased detection rates. A number of other variables need to be examined including different vegetation types and lighting conditions. It is recommended surveys using RPA incorporate ground-truthing of both positive and no detections, to determine false positive and false negative error. This technique showed future potential and will be further developed.

A study of the effect of storage technique of bilby scats on DNA degradation found no difference in amplification or error rates between dried or frozen samples. Storing samples dry is more practical in the field, and it is recommended that samples are stored and transported in tubes with silica gel beads and cotton wool to protect the sample. The population abundance monitoring technique using DNA extracted from scats quantitatively collected from populations in the field continues to be implemented at sites in the Pilbara and elsewhere. We recommend this technique to be used as a standard method to monitor numbers of individuals within populations. Monitoring using this technique found that populations in the Pilbara are geographically isolated and consist of a small number of individuals. This means that they are likely to be vulnerable to threats, a key one being unmanaged fire regimes, which likely contributed to the loss of two populations. Management of populations in the Pilbara should initially assign priority to fire management to prevent large scale hot fires affecting populations.

1 Introduction

The greater bilby (*Macrotis lagotis*) is a burrowing marsupial that was once wide spread across most of mainland Australia (Marlow 1958; Southgate 1990a; Friend 1990; Gordon *et al.* 1990; Johnson and Southgate 1990; Abbott 2001; Abbott 2008; Bradley *et al.* 2015; Figure 1). The greater bilby is now listed as Vulnerable under the Commonwealth *EPBC Act* 1999 (EPBC 1999); Schedule 3 - Fauna that is rare or is likely to become extinct as vulnerable fauna, under the Western Australian *Wildlife Conservation Act* 1950 (Government of Western Australia 2015); and internationally listed as Vulnerable on the IUCN Red List of Threatened Species (IUCN 2014).

Since European colonisation of Australia, the range and abundance of greater bilbies have contracted severely (Southgate 1990a; Bradley *et al.* 2015; Figure 1). Since the late 1800s, greater bilbies have disappeared from at least 80 % of their former range (Southgate 1990a; Figure 1), and the lesser bilby (*Macrotis leucura*), a closely related species, has become extinct (IUCN 2008).The decline in bilbies has been attributed to a number of threats working directly or in combination with each other. These threats include predation by introduced cats and foxes (Paltridge 2002; Bradley *et al.* 2015), changed and inappropriate fire regimes (Southgate and Carthew 2006; Southgate and Carthew 2007; Southgate *et al.* 2007; Bradley *et al.* 2015), and the degradation of bilby habitat through pastoralism, introduced herbivores, and clearing (Southgate 1990a; Pavey 2006; Bradley *et al.* 2015; Department of Environment 2016).

The current distribution of the greater bilby (hereafter referred to as the bilby) is now restricted to the Tanami Desert, Northern Territory (Johnson and Southgate 1990), the Great Sandy and Gibson Deserts, parts of the Pilbara and Kimberley in Western Australia (Friend 1990), and an outlying population between Boulia and Birdsville in south-west Queensland (Gordon *et al.* 1990). In the Pilbara, bilbies occur approximately east of a line extending south of Karratha (Figure 1 and Figure 2). In WA, bilbies have been successfully reintroduced to Francois Peron National Park in Shark Bay, and Matuwa IPA (Lorna Glen) in the northern Goldfields.

From the literature summarized in Table 1, suitable habitat for bilbies can be defined as level or undulating plains including watercourses and dune systems, composed of cracking clay, soil or sand that allows burrowing, with vegetation consisting of open-tussock Mitchell grass (in SW Queensland) or hummock grassland (spinifex), with low shrubland, usually *Acacia* dominated. Habitat which is steep and/or rocky which does not allow burrowing may be used for foraging if it is adjacent to suitable burrowing habitat. The critical characteristic of suitable habitat for bilbies is the availability of a soil or sand substrate that enables the construction of burrows.

The aim of this project is to improve our understanding of the distribution, and demographics of bilbies in the Pilbara, and provide information to environmental regulators and resource development companies that will allow appropriate management to ensure the persistence of this species in the Pilbara.

Specifically, the objectives of this project are to:

1. Gather recent and historic records in order to understand and predict the distribution of bilbies in the Pilbara
2. Develop and implement a broad-scale survey technique
3. Develop a fine-scale population monitoring technique and implement long-term population monitoring
4. Understand the effects on demographics of bilby populations in the Pilbara

A draft recovery plan was prepared in 2006 (Pavey 2006), however, this was superseded by an interim conservation plan in 2015 (Bradley *et al.* 2015). The aim and objectives of this project are consistent with the goals and actions of the interim conservation plan (Table 2). In particular, this project addresses the goal to implement a program of priority research (Bradley *et al.* 2015).

In order to seek broad collaborative agreement on the research agenda, the Western Australian Department of Parks and Wildlife hosted a workshop where research priorities were identified through a facilitated process (Cramer *et al.* 2016). Five key areas for future research effort were identified:

1. Refine survey methods appropriate for all habitat types
2. Improve understanding of habitat use in relation to substrate type and food resources
3. Improve understanding of the genetic structure of (meta)populations
4. Improve understanding of the threat posed by introduced predators and herbivores
5. Improve understanding of how fire regimes affect bilby conservation

The aim and objectives of this project also align with the research priorities for the greater bilby in the north of Western Australia (Table 2; Cramer *et al.* 2016).

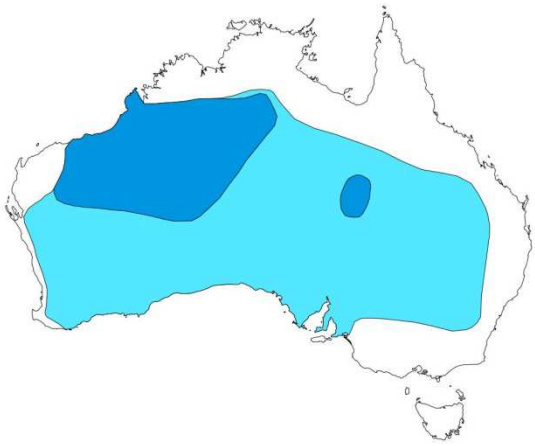

Figure 1. Current (■) and former (■) distribution of the greater bilby.

Table 1. Published accounts of suitable bilby habitat characteristics.

Substrate	Vegetation	Terrain	Area	Reference
Soils from 0.6 m depth to siliceous sands >2 m depth. Textures of soils from coarse sand to light medium clay. Uniform texture profiles, non-calcareous gradational soils and duplex soils	Woodlands of low (<10 m) trees with *Acacia* spp. rich understorey. Shrub steppe communities, to tussock/forb grasslands in SE Queensland.	Level plains to undulating plains and rises, gently inclined, slope never exceeding 6 %.	Central deserts and SE Queensland	Southgate (1990b)
Stone-free Cretaceous sediments of cracking clays, friable on the surface (usually 35 % clay) with a denser (45-70 % clay) subsoil	Grassland downs, Mitchell grass (*Astrebla pectinata*) and feathertop wiregrass (*Aristida latifolia*) in the form of open-tussock grassland, saltbush (*Atriplex* spp.) herblands and open succulent shrubland of Queensland bluebush (*Chenopodium auricomum*) and canegrass (*Eragrostis australasica*)	Adjacent to watercourses, not hilly.	SW Queensland	Lavery and Kirkpatrick (1997)
Sandy soils with rocky outcrops, laterite rises and low-lying palaeodrainage systems	Spinifex grasslands (mainly *Triodia basedowii*, *T. pungens* and *T. schinzii*) with low shrub cover of *Acacia* spp. *Melaleuca* spp. in palaeodrainage channels.	Rises and low-lying drainage systems	Tanami Desert, Northern Territory	Southgate *et al.* (2005)
Dune and sand substrate, laterite/rock features and drainage/calcrete substrates	Three spinifex or hummock grass species (*Triodia pungens*, *T. schinzii*, and *T. basedowii*), with an overstorey of scattered shrubs and trees; shrub species	Rises and low-lying drainage systems	Tanami Desert, Northern Territory	Southgate *et al.* (2007)
Cracking clays, sandplains, dunefields sometimes containing laterite, massive red earths.	Mitchell grass (*Astrebla pectinata*), hummock grassland (*Triodia* spp.) and *Acacia* shrubland.	Plains, dune fields.	Extant range	Johnson (2008)

Table 2. Alignment of this project with the goals of the interim conservation (Bradley *et al.* 2015) and research priorities for the greater bilby in the north of Western Australia (Cramer *et al.* 2016).

Objectives of this project	Alignment with the interim conservation plan goals (Bradley *et al.* 2015)	Alignment with research priorities for the greater bilby in the north of Western Australia (Cramer *et al.* 2016)
1. Gather recent and historic records in order to understand and predict the distribution of bilbies in the Pilbara	5. Share, collate and report information effectively	2. Improve understanding of habitat use in relation to substrate type and food resources
2. Develop and implement a broad-scale survey technique	4. Agree and implement monitoring and survey methods	1. Refine survey methods appropriate for all habitat types 2. Improve understanding of habitat use in relation to substrate type and food resources
3. Develop a fine-scale population monitoring technique and implement long-term population monitoring	4. Agree and implement monitoring and survey methods	1. Refine survey methods appropriate for all habitat types 3. Improve understanding of the genetic structure of (meta)populations 4. Improve understanding of the threat posed by introduced predators and herbivores 5. Improve understanding of how fire regimes affect bilby conservation
4. Understand the effects on demographics of bilby populations in the Pilbara	1. Manage predators effectively 6. Manage appropriate fire regimes 7. Mitigate grazing and land-use issues	3. Improve understanding of the genetic structure of (meta)populations 4. Improve understanding of the threat posed by introduced predators and herbivores 5. Improve understanding of how fire regimes affect bilby conservation

2 Collation of current and historic distributional data

Current and historic records of bilbies in the Pilbara have continued to be accessed from the following sources:

- Published literature
- "Grey" literature (including consultants and CALM/DEC/Parks and Wildlife reports)
- Western Australian Department of Parks and Wildlife, Western Australian Museum (WAM) and other national databases
- Liaison with Parks and Wildlife staff, ecologists, consultants and land holders/users
- Field trips to the Pilbara region

To date 1515 records of bilbies have been collated and populated into the Pilbara Threatened Fauna Database (Figure 2) which is linked to display records through the Department's NatureMap portal (DPaW 2017). Records collated range from 1901 to 2017 and peak between 2010 and 2017 (Figure 3).

2.1 Management implications

- Better understanding of where bilbies are present in the Pilbara for environmental impact assessment (EIA) processes
- Sufficient presence data now gathered to enable informed modelling of the distribution of bilbies in the Pilbara (see Section 4.4.2).

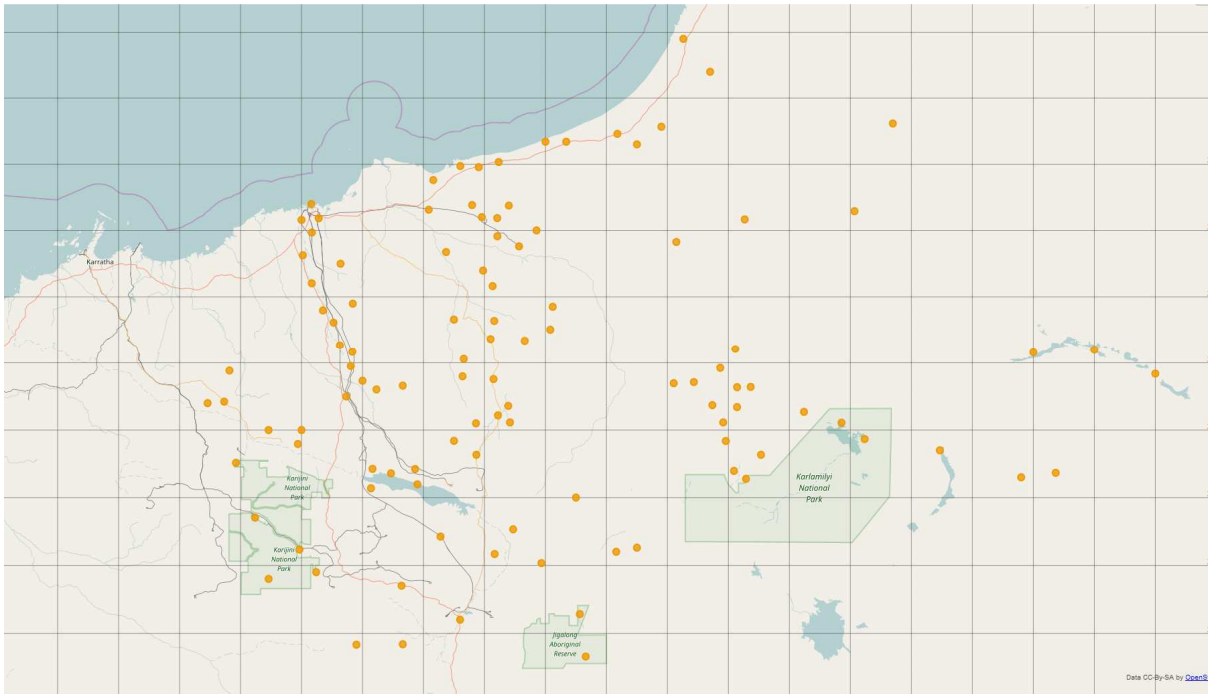

Figure 2. Bilby records (●) collated from the Pilbara region.

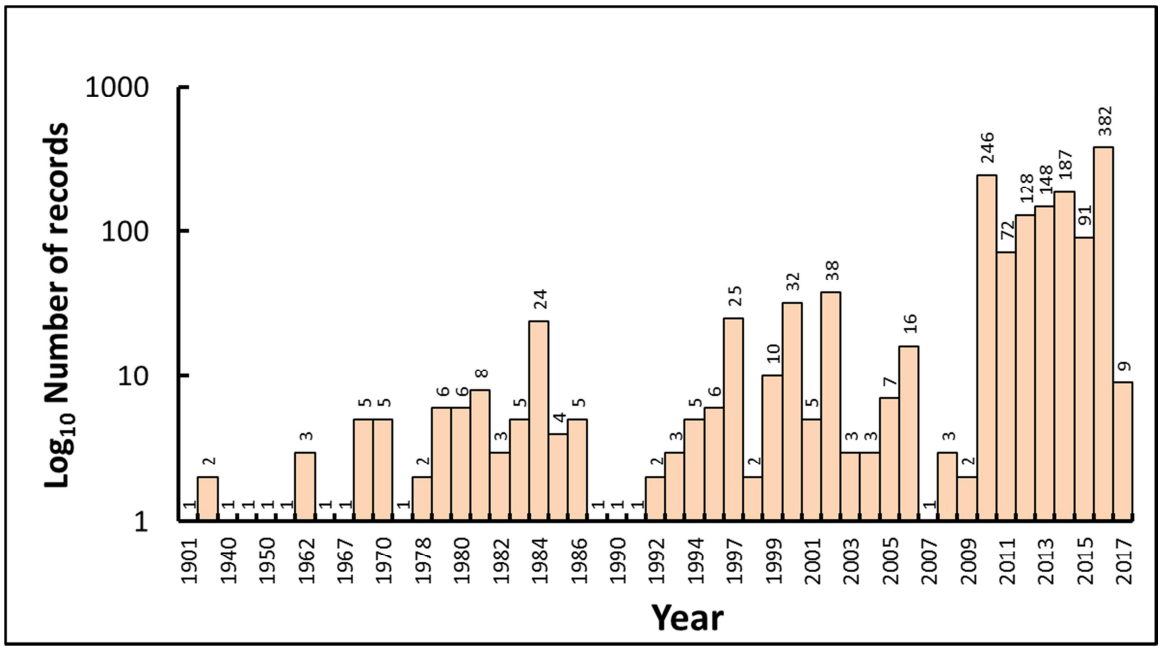

Figure 3. Frequency distribution of all collated bilby records from the Pilbara.

3 Presence/absence survey

3.1 Current survey

The current most effective and efficient methodology for on-ground survey for the presence/absence of bilbies without the use of aircraft is the 2 ha plot method described in Moseby *et al*. (2011) and developed by Southgate *et al.* (2005) and Southgate and Moseby (2008) . Only three types of sign provide definitive evidence of the presence of bilbies:

1. Tracks
2. Scats
3. Multiple diggings into the base of *Acacia* shrubs where grubs are accessed.

Burrows can easily be confused with varanid lizard or rabbit burrows by all but the most experienced observers, however, if there are occupied burrows then there will most likely be evidence nearby of at least one of the three signs described above. Descriptions and images of bilby sign can be seen in Appendix 2.

There are some limitations to this technique in the Pilbara region. In many areas in the Pilbara where bilbies are found, the substrate is not as sandy or soft, or may be covered by more leaf litter than in many of the desert areas. Therefore, bilby tracks may not be present in the frequency they are observed in desert areas, and the primary indicators of bilby presence within the 2 ha plots are scats and multiple diggings into the base of *Acacia* shrubs where grubs are accessed.

A further limitation of the 2 ha plot method is that the location of plots is usually limited to areas that can be accessed near vehicle roads and tracks. In October 2015 a quad bike was acquired for use in the Pilbara. The quad bike enables efficient ground access to establish plot surveys in areas not normally accessible on foot. As well as the advantage of accessing difficult to get to areas, the use of the quad bike has increased the number of plots surveyed per trip.

So far, 2112 plots in likely bilby habitat have been surveyed for the presence of bilbies across the Pilbara (

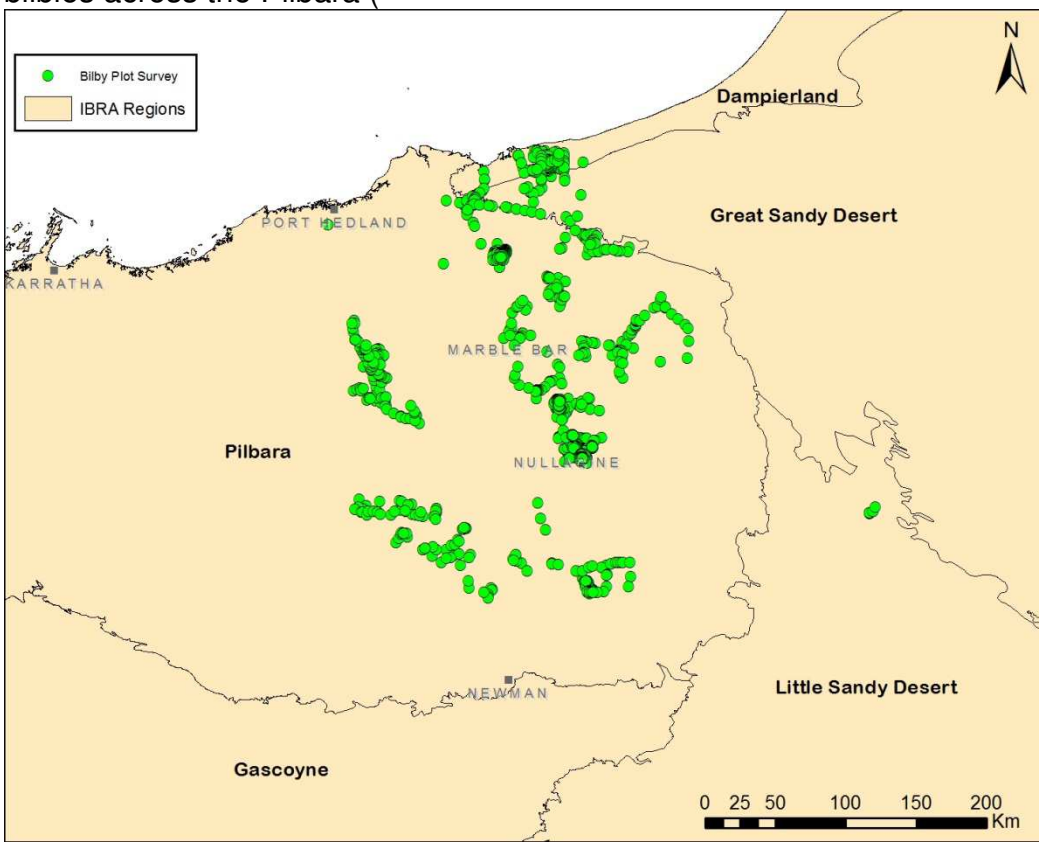

Figure 4). At 398 of these plots, confirmed evidence of bilby presence was recorded (Figure 5). These data will be available through the Department's NatureMap portal (DPaW 2017).

3.2 Management implications

- Better understanding of where bilbies are present in the Pilbara for environmental impact assessment (EIA) processes
- Sufficient presence data now gathered to enable informed modelling of the distribution of bilbies in the Pilbara (see Section 4.4.2).

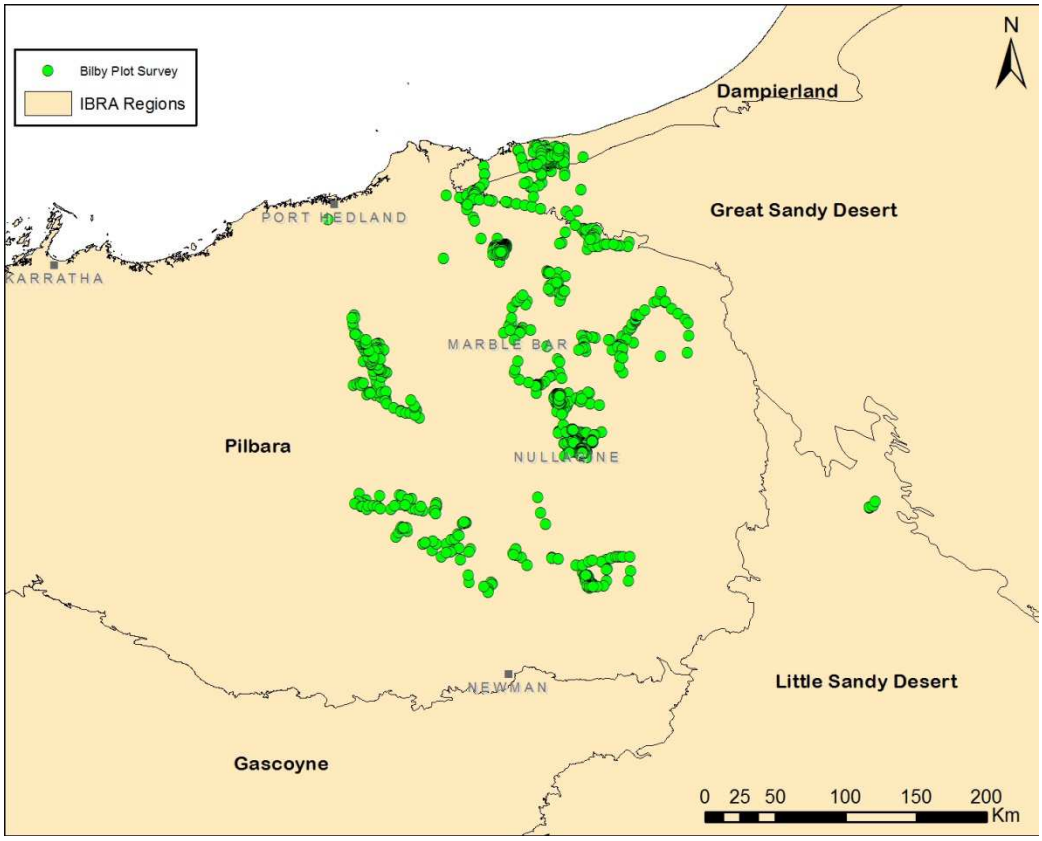

Figure 4. Plots surveyed for bilby presence across the Pilbara.

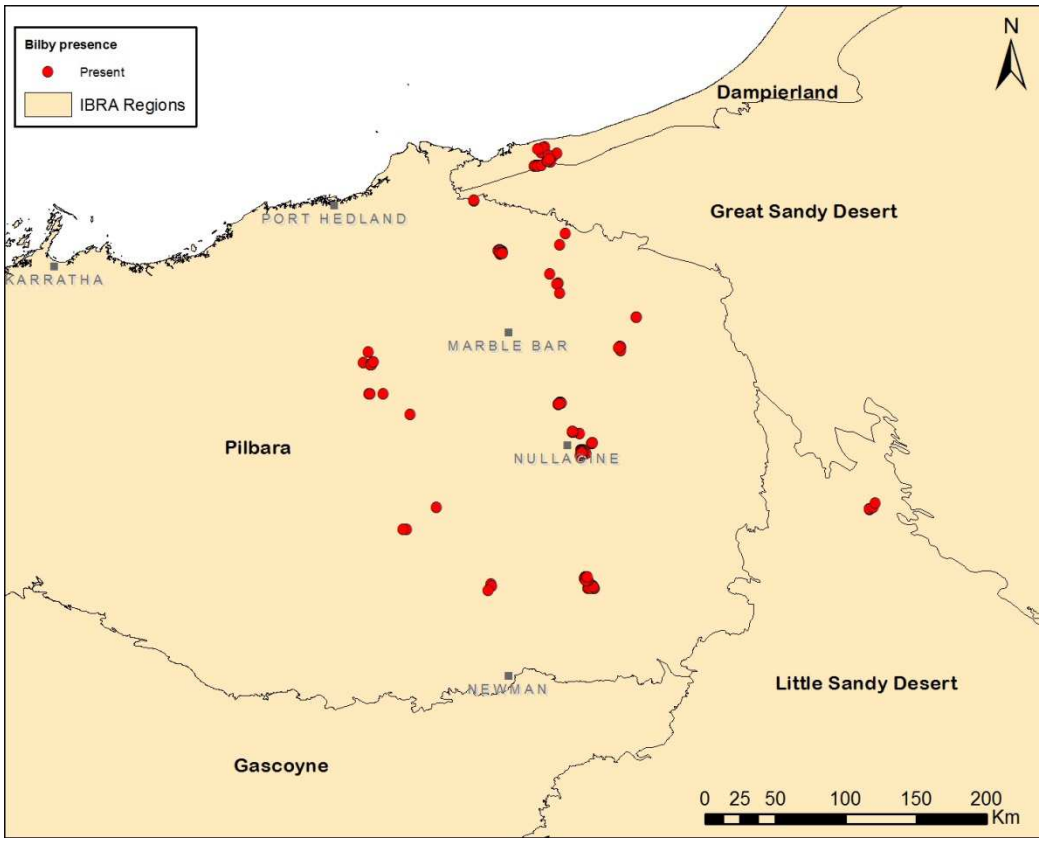

Figure 5. Bilby presence detected at survey plots across the Pilbara.

4 Improving survey techniques

4.1 Verification of bilby presence

The recognition of sign such as tracks, scats, diggings or burrows is widely used to detect rare or elusive species. There has been confusion regarding the verification of bilby sign. For example, rabbit and varanid lizard burrows, varanid lizard and echidna diggings and unclear rabbit tracks have all been recorded as confirmed bilby sign by untrained observers in the Pilbara region. We describe the type of sign that can be used to confirm the presence of the bilby in comparison to sign that should only be used to flag potential presence. Clear track imprints of the front and hind feet; diggings at the base of plants to extract root-dwelling larvae; and scats commonly found at diggings can be used individually, or in combination, to verify presence, whereas track gait pattern, diggings in the open, and burrows should be used to flag potential bilby activity but not to verify presence. We have developed a protocol to assess potential bilby activity and verify bilby presence from sign (Table 3).

4.1.1 Sign needed to verify bilby presence

4.1.1.1 Track and gait characteristics

Fresh tracks are distinctive and can be used to distinguish the bilby from other species. The hind track imprints are longer than the front, and narrower. The hind print is produced primarily by the fourth toe, with little conspicuous indentation caused by the short fifth toe. The toes and claws on the front foot produce three distinct parallel print marks of similar length. In comparison, rabbit (*Oryctolagus cuniculus*) tracks are rounded and the front and hind feet are similar shape and size; long and short nose bandicoots (*Perameles* and *Isoodon* spp.) produce distinctive prints from the fourth and fifth toes on the hind print and the toe and claw prints on the front feet are of uneven length; and, dasyurids and rodents produce a greater number of toe prints from the front and hind feet (Triggs 2004; Moseby *et al.* 2009). Bilbies move with a quadrupedal bounding overstep gait; the front imprints are staggered, and the hind remain mostly parallel. The same gait pattern is produced consistently by several other similar-sized mammal taxa including quolls, mulgara, bandicoots, rabbits and rats, and occasionally by some species such as brush-tailed possums (*Trichosurus vulpecula*). Consequently, clear track imprints that include confirmation of the three distinct parallel marks from the toes of the front foot and slender hind foot without clear side toe imprints are considered necessary to confirm bilby presence. It is not sufficient to rely on gait pattern alone.

4.1.1.2 Food and diggings

Bilbies are omnivorous, consuming a range of invertebrates including beetles, termites, and root-dwelling larvae, as well as plant material including seed and bulb (Southgate 1990b; Gibson 2001; Gibson and Hume 2004; Southgate and Carthew 2006; Navnith *et al.* 2009; Bice and Moseby 2013). Most food is obtained at the soil

surface or by digging among the subsoil, and diggings are generally a conspicuous feature where bilbies have been foraging. Bilbies have been described as ecosystem engineers (James and Eldridge 2007; Read *et al.* 2008; Newell 2008; James *et al.* 2011; Chapman 2013; Fleming *et al.* 2014) because of the amount of digging and soil turnover they create. However, a number of other taxa including varanid lizards, echidnas, rabbits, wallabies, bandicoots, mulgara and mice can also produce bilby-like diggings while foraging. The only diggings that can be uniquely attributed to the bilby are those at the base of shrubs or forbs for root-dwelling larvae (RDL). No other species remaining on mainland Australia are known to expose and rip open plant roots containing larvae. A range of beetles and moths have larvae that spend part of their life history living within root structures in a range of shrub and forb species. Most of the plant taxa containing RDL used by bilbies are *Acacia* species (Table 5), and many of these are prevalent on residual landforms with stony or lateritic soils (e.g. *A. rhodophloia, A. hilliana*). Some of these shrubs are very broadly distributed (e.g. *Senna notabilis*) while others are more limited to defined habitats (e.g. *A. trachycarpa*). Diggings at the base of shrubs with roots torn open are usually obvious and numerous, and can remain evident for months and even years, especially if the substrate is stony and not easily eroded by water.

4.1.1.3 Faecal pellets (scats)

Bilby scats can be found most readily on top of or within the sand-spoil of diggings produced while foraging, and sometimes near burrows; they are rarely found away from some form of bilby digging activity. Typically, a group of 2-5 pellets are deposited, each with a smooth coating and rounded ends. They are oblong shaped, longer than wide, and almost round in cross section as opposed to the more spherical rabbit scats. The scats are firm and usually contain a mixture of sand, plant and invertebrate material which can be discriminated relatively easily under low power magnification (x10 power). Bilby scats can persist for several months especially if buried within the spoil of a digging and there has been little rain.

No other remanent species on mainland Australia produce scats with these characteristics. Echidnas do not produce neat pellets and the ends are jagged where the longer extrusions break; their scats are usually dominated by ant and termite fragments, and plant material is rarely included. Similar-sized dasyurids do not produce scats with a comparable smooth coating and rounded ends. Some lizards and dragons including the thorny devil (*Moloch horridus*), and frogs can produce pellets that have smooth coating and can superficially resemble bilby scats. However, these scats are usually not encountered at diggings, generally contain little sand content, are relatively light and crumble easily, and white uric acid is sometimes present.

4.1.1.4 Burrow detection and use by bilbies

Bilbies construct burrows that can be up to 4.5 m long and 2 m deep (Smyth and Philpott 1968). The burrows may or may not spiral downwards, can have side

branches, and tunnels may be blocked by freshly dug soil (Smyth and Philpott 1968). The burrow entrances are round whereas the burrows of goannas and other reptiles are often crescent-shaped where the width is greater than the height. Most bilby burrows have a single entrance but 'aggregations' or 'warrens' with multiple burrow entrances can occur (Southgate 1990a; Lavery and Kirkpatrick 1997). An apron of excavated sand is usually evident. However, the burrows are not always conspicuous and some burrow entrances can be hidden under logs or termite mounds and the reuse of old, seemingly inactive burrows with inconspicuous or eroded (deflated) aprons can also occur (McRae 2004; R. Southgate pers. obs.). In addition, other species (e.g. cats, foxes, varanid lizards, echidnas, hopping mice and mulgara) can use or rework long inactive bilby burrows and make them appear active (Read *et al.* 2008; Hofstede and Dziminski 2017).

Multiple separate burrows can usually be found within an established foraging area. The burrows are used at times during the night and during daylight hours for rest and refuge. A burrow is most often used by a single individual, but female and young, and occasional female:female or male:female sharing can occur. Repeat use of existing burrows is common, but the same burrow is infrequently used on consecutive days and individuals can use up to 18 of these burrows concurrently over several months (Southgate and Possingham 1995; Moseby and O'Donnell 2003). Furthermore, an individual may visit and enter a number of burrows each night while foraging. Males have been recorded visiting more burrows than females in south west Queensland (McRae 2004). Over time, new burrows are constructed, others are ignored and some eventually become abandoned (Lavery and Kirkpatrick 1997). Burrows may be scarce and difficult to find in recently colonised areas, sparsely distributed in some habitats (22 burrows per km^2: Smyth and Philpott 1968) or abundant in persistently occupied areas (hundreds of burrows per km^2: McRae 2004).

Consequently, we consider that bilby occurrence should not be based solely on the detection of bilby-like burrows because some burrows can be difficult to detect (potentially resulting in false-absence or omission error) and burrow use and refurbishment by a range of species can be misclassified as bilby activity (potentially resulting in false-presence error).

This project was undertaken in collaboration with Rick Southgate (Envisage Environmental), Rachel Paltridge and Glen Schubert (Desert Wildlife Services) and Glen Gaikhorst (GHD Australia).

Table 3. Protocol to assess potential bilby activity and verify bilby presence from sign.

Sign	Significance	Recommended actions
Burrow or burrows located	Potential bilby activity Presence not confirmed	Continue to search surrounding area for: 1. Scats, clear tracks and multiple diggings into roots of RDL vegetation*. 2. Record dimensions of burrow circumference, photograph with scale, describe presence of apron and age since last activity.
Diggings located	Potential bilby activity Presence not confirmed	Continue to search surrounding area for: 1. Scats, especially within spoil of diggings, clear tracks, multiple diggings into roots of RDL vegetation*. 2. Record age and characteristics of diggings (e.g. identify what diggings are into – termites, spider burrows, seed stores of ants, etc).
Unclear tracks (e.g. only gait pattern identified)	Potential bilby activity Presence not confirmed	Continue to search surrounding area for: 1. Clear tracks, scats, multiple diggings into roots of RDL vegetation*. 2. Measure the length and width of several track groups, photograph with scale. 3. Determine any other species responsible for tracks detected.
Clear tracks (three distinct parallel marks from front feet identified, hind foot imprint narrow with indistinct side toes)	Presence confirmed	1. Record group width and length of several sets, assess if juveniles present (Southgate 2005). 2. For further confidence search surrounding area for scats, multiple diggings into roots of RDL vegetation*. 3. Record and describe any digging or burrow activity encountered.
Scats (commonly found hidden within spoil of diggings)	Presence confirmed	1. Collect several sets, store each set dry in separate paper bags or vials with silica gel beads and cotton wool, assess if juveniles present from pellet size. 2. For further confidence, search surrounding area for clear tracks and multiple diggings for RDL. 3. Record and describe other digging or burrow activity encountered.
Multiple diggings into roots of RDL vegetation*	Presence confirmed	1. Identify plant species harbouring RDL, collect botanical specimen if uncertain for identification and vouchering. 2. For further confidence, search for tracks and scats if diggings are fresh. If diggings are old, search surrounding area for other long lasting sign: burrows, other diggings.

*Vegetation containing RDL that bilbies use as a food resource (commonly *Acacia* spp. – see Table 5).

4.2 Standardisation and development of best practice occupancy survey techniques

Various, incomparable presence/absence or occupancy survey techniques for bilbies are being used or being proposed to be used across Western Australia. In order to promote standardisation and comparability a set of interim guidelines based on best practice techniques used nationally have been developed. These interim guidelines form a template to be reviewed by researchers, consultants and Traditional Owner rangers involved in bilby surveys, to produce a final set of best practice guidelines, which will be compatible with techniques used nationally. These interim guidelines will be available electronically on the Department's website. The standardised data sheet for 2 ha Sign Plot Surveys is included in Appendix 3. The data sheet and App templates for recording data captured during sign plot surveys can be requested from the Department.

This work was undertaken in collaboration with Rick Southgate (Envisage Environmental).

Box 1. **Interim guidelines for occupancy surveys of bilbies across large areas in Western Australia.**

Background

This document provides interim guidelines for surveys of the threatened greater bilby (*Macrotis lagotis*) to detect their presence or absence 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 and indigenous ranger groups are likely to have these skills.

Surveying for bilby sign

A number of techniques have been applied to survey for sign of 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, introduced 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 observer's ability to *find* the species in the landscape, not where the species *is* in the landscape.

In order to address issues with the variability in detecting all sign or all individuals within a sampled area, resampling of sites is recommended to allow the probability of the area being occupied and the detectability of sign to be estimated. Surveys should be repeated within 1-4 months to account for imperfect detection and observer 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 which includes residual landforms (e.g. laterite rises) and habitat types where shrubs containing root dwelling larvae (RDL) are common; loamy or sandy soils associated with paleodrainage features and perched drainage lines that often harbour *Cyperus bulbosus*; and sand plain and dune fields. 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 (e.g. in grids where cameras are spaced 1-2 km apart).

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 south west Queensland 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.

Box 2. **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.**

Background

This document provides interim guidelines for detecting the current or recent presence or asserting the absence of bilbies, and assessing the importance of the habitat proposed to be impacted (e.g. 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 and indigenous ranger groups 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 are 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 impacts to 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 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.

4.3 Management implications

- Better understanding of where bilbies are present in the Pilbara for EIA processes
- Better understanding of the type of habitat and in particular vegetation that bilbies are associated with in the Pilbara for EIA processes and for Level 2 or targeted surveys
- Better understanding of what type of sign can be used for detection of bilbies in the Pilbara for Level 2 or targeted surveys
- Sufficient presence data now gathered to enable informed modelling of the distribution of bilbies in the Pilbara (see Section 4.4.2).

4.4 Aids to identification of likely bilby habitat

4.4.1 Key plant species

Preliminary observations in the Pilbara have revealed that as well as always being found in areas where the substrate of sand, soil, sandy clay, or sandy gravel is suitable for burrowing, there is an association with particular *Acacia* spp. that bilbies use for food resources (Table 4). At sites where bilbies are found, these *Acacia* spp. typically form monospecific stands that provide resources in the form of cossid larvae (grubs) which is the major food resource for bilbies in the Pilbara.

Subsequently, an extensive review of all literature and other sources was undertaken to collate observations of all known plant species where consistent and repeatable observations have been recorded of bilbies digging into the roots to obtain RDL.

Identification of these species (Table 5) will aid in the identification of suitable bilby habitat.

4.4.2 Physical habitat characteristics

Using presence data gathered in Sections 2 and 3, habitat modelling using physical habitat characteristics (topography, geology and soil properties) was commenced in 2017. Modelling is being undertaken using Maxent (Phillips *et al.* 2017). Preliminary models are presented in Figure 6 and Figure 7. Preliminary distribution modelling identified soil type and depth, and elevation as major relative contributing variables to predict likely bilby habitat (Table 6 and Table 7). This work is being undertaken in collaboration with Mark Cowan (Parks and Wildlife).

4.4.3 Management implications

- Better understanding of where bilbies may be present in the Pilbara for EIA processes
- Better understanding of the type of habitat that bilbies are associated with in the Pilbara for EIA processes and for Level 2 or targeted surveys

Table 4. *Acacia* associations at sites where bilbies were found in the Pilbara.

Area	*Acacia* association	Image
Turner River	Stands of *A. stellaticeps* and *A. bivenosa*	
Hillside	*A. trachycarpa* along drainage lines	
Nullagine	Stands of *A. trachycarpa* (dwarf form)	

Area	*Acacia* association	Image
McPhee Creek	Stands of *A. trachycarpa* (dwarf form) and *A. bivenosa*	
Warralong	Stands of *A. colei*	
Roy Hill Station	Stands of *A. melleodora* and *A. dictyophleba*	
Pardoo	Stands of *A. monticola*	
Yarrie	Stands of *A. stellaticeps* and *A. trachycarpa* (dwarf form)	
Meentheena	Stands of *A. bivenosa*	
Warrawagine	Stands of *A. colei*	

Area	*Acacia* association	Image
Kintyre	Stands of *A. dictyophleba*	

Table 5. Known plant species that consistent and repeatable observations have been recorded of bilbies digging into the roots to obtain root dwelling larvae (RDL).

Plant species	Larvae type	Location	Bioregion*	Reference
Fabaceae				
Acacia spp.		Northam, WA	AVW	Gould (1863); Leake (1962)
Acacia spp.		Queensland		Longman (1922)
Acacia acradenia	*Endoxyla* sp., Cossidae; Cerambycidae	Twin Bonanza mine, northwest Tanami	TAN	Liddle (2016); R. Paltridge and A. Schubert (pers. obs.)
A. acuminata	Cerambyx sp., Cerambycidae	Wheatbelt, WA	AVW	Whittell (1954); Jenkins (1974); Abbott (2001)
A. bivenosa	Cossidae	Pilbara, WA	PIL	M. Dziminski (pers. obs.)
A. brachystachya		Warburton ranges, WA	CER, GID, GVD	R. Southgate (pers. obs.)
A. colei	Cossidae	Pilbara, WA	PIL	M. Dziminski (pers. obs.)
		Dampier Peninsula, WA	DAL	G. Gaikhorst (pers. obs); M. Dziminski (pers. obs.)
A. dictyophleba		Pilbara, WA	PIL	M. Dziminski (pers. obs.)
		Western Great Sandy Desert, WA	DAL, GSD	M. Dziminski (pers. obs.)
	Cossidae	Matuwa (Lorna Glen), WA	GAS, MUR	F. Morris (pers. comm.); M. Dziminski (pers. obs.)
A. effusifolia	Cossidae	Mount Gibson AWC Sanctuary, WA	YAL	M. Dziminski (pers. obs.)
A. eriopoda		Dampier Peninsula, WA	DAL	G. Gaikhorst (pers. obs)
A. aff. *grasbyi*	Cossidae	Matuwa (Lorna Glen), WA	GAS, MUR	M. Blythman (pers. comm.); M. Dziminski (pers. obs.)
A. hilliana		Tanami Desert, NT	TAN	R. Southgate (pers. obs); R. Paltridge and A. Schubert (pers. obs.)
		Northern Great Sandy Desert, WA	GSD	R. Southgate (pers. obs)
		Kiwirrkurra, WA	GID, GSD	R. Paltridge and A. Schubert (pers. obs.)
A. kempeana		Tanami Desert, NT	TAN	Johnson (1979); P. K. Kaltz (pers. comm.); R. Southgate (pers. obs.)
A. lysiphloia		Tanami Desert, NT	TAN	D. F. Gibson (pers. comm.)
	Endoxyla sp., Cossidae; *Maroga* sp., Xylorytidae and Cerambycidae	Twin Bonanza mine, northwest Tanami	TAN	Liddle (2016); R. Paltridge and A. Schubert (pers. obs.)
		Tennant Creek area	DMR	R. Paltridge and A. Schubert (pers. obs.)
A. melleodora		Kiwirrkurra, WA	GID, GSD	R. Paltridge and A. Schubert (pers. obs.)
	Cossidae	Pilbara, WA	PIL	M. Dziminski (pers. obs.)
A. monticola		Twin Bonanza mine, northwest Tanami	TAN	R. Paltridge and A. Schubert (pers. obs.)
		Western Great Sandy Desert, WA	DAL, GSD	M. Dziminski (pers. obs.)
A. rhodophloia		Warburton WA	CER, GID, GVD	R. Southgate (pers. obs)
A. stellaticeps	Cossidae	Pilbara, WA	PIL	M. Dziminski (pers. obs.)
		Western Great Sandy Desert, WA	DAL, GSD	M. Dziminski (pers. obs.)

A. trachycarpa	Cossidae	Pilbara, WA	PIL	M. Dziminski (pers. obs.)
A. trachycarpa - dwarf variant described in Maslin et al. (2010)	Cossidae	Pilbara, WA	PIL	M. Dziminski (pers. obs.)
A. tumida		Dampier Peninsula, WA	DAL	Ecologia (2015; 2016); M. Dziminski (pers. obs.)
Indigofera georgei		Kiwirrkurra, WA	GID, GSD	R. Paltridge and A. Schubert (pers. obs.)
Senna artemisioides		Mount Gibson AWC Sanctuary, WA	YAL	M. Dziminski (pers. obs.)
S. notabilis		Tanami Desert, NT	TAN	Liddle (2016); D. F. Gibson (pers. comm.); R. Paltridge and A. Schubert (pers. obs.)
		Kiwirrkurra, WA	GID, GSD	R. Paltridge and A. Schubert (pers. obs.)
		Dampier Peninsula, WA	DAL	M. Dziminski (pers. obs.)
		Pilbara, WA	PIL	M. Dziminski (pers. obs.)
S. oligophylla		Tanami Desert, NT	TAN	D. F. Gibson (pers. comm.)
S. venusta		Tanami Desert, NT	TAN	Johnson (1979)
Frankeniaceae				
Frankenia spp.		Tanami Desert, NT	TAN	K. Johnson (pers. comm.)
Poaceae				
Eragrostis eriopoda	Lepidoptera	Warburton ranges, WA	CER, GID, GVD	Smyth and Philpott (1968)
E. laniflora	Lepidoptera	Warburton ranges, WA	CER, GID, GVD	Smyth and Philpott (1968)
Proteaceae				
Grevillea refracta		Dampier Peninsula, WA	DAL	G. Gaikhorst (pers. obs)
Sapindaceae				
Dodonaea hispidula		Dampier Peninsula, WA	DAL	G. Gaikhorst (pers. obs)

*AVW: Avon Valley Wheatbelt; CER: Central Ranges; DAL: Dampierland; DMR: Davenport Murchison Ranges; GAS: Gascoyne; GID: Gibson Desert; GVD: Great Victoria Desert; GSD: Great Sandy Desert; MUR: Murchison; PIL: Pilbara; TAN: Tanami; YAL: Yalgoo. This data was collated in collaboration with Rick Southgate (Envisage Environmental), Rachel Paltridge and Glen Schubert (Desert Wildlife Services) and Glen Gaikhorst (GHD Australia).

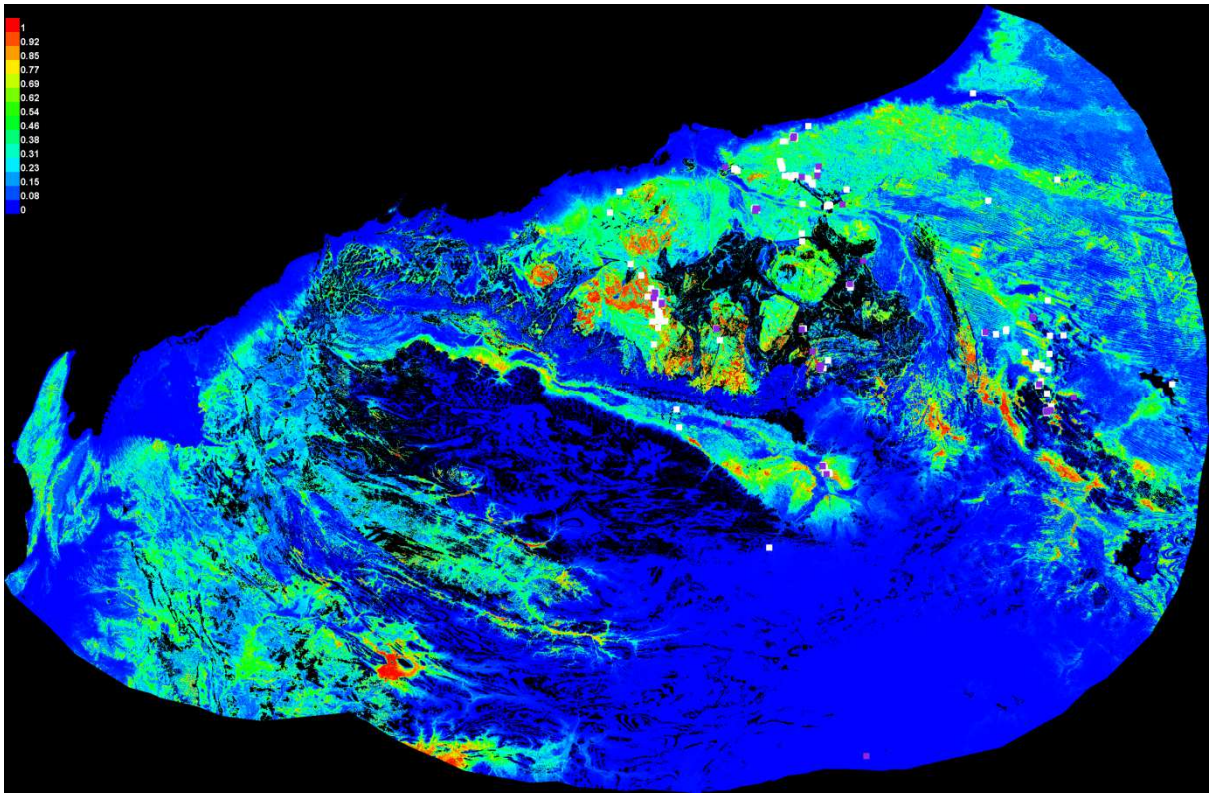

Figure 6. Maxent model of suitable bilby habitat based on TERN Soil layers, geology and elevation. Area included is the Pilbara IBRA region with a 200 km buffer. Warmer colors show areas with better predicted conditions.

Table 6. Relative contributions of variables to the Maxent model of suitable bilby habitat based on TERN Soil layers, geology and elevation

Variable	Percent contribution	Permutation importance
Digital elevation model	41.4	44.7
Depth of soil (m)	15.8	16.6
Depth of Regolith (m)	11	6.8
Geology	8.4	3.4
Sand % at 1-2m depth	7.3	7.9
Silt % at 1-2m depth	6.1	11.5
Regolith	4	2
Coarse fragments % at 1-2m depth	3.8	3.3
Clay % at 1-2m depth	2.2	3.8

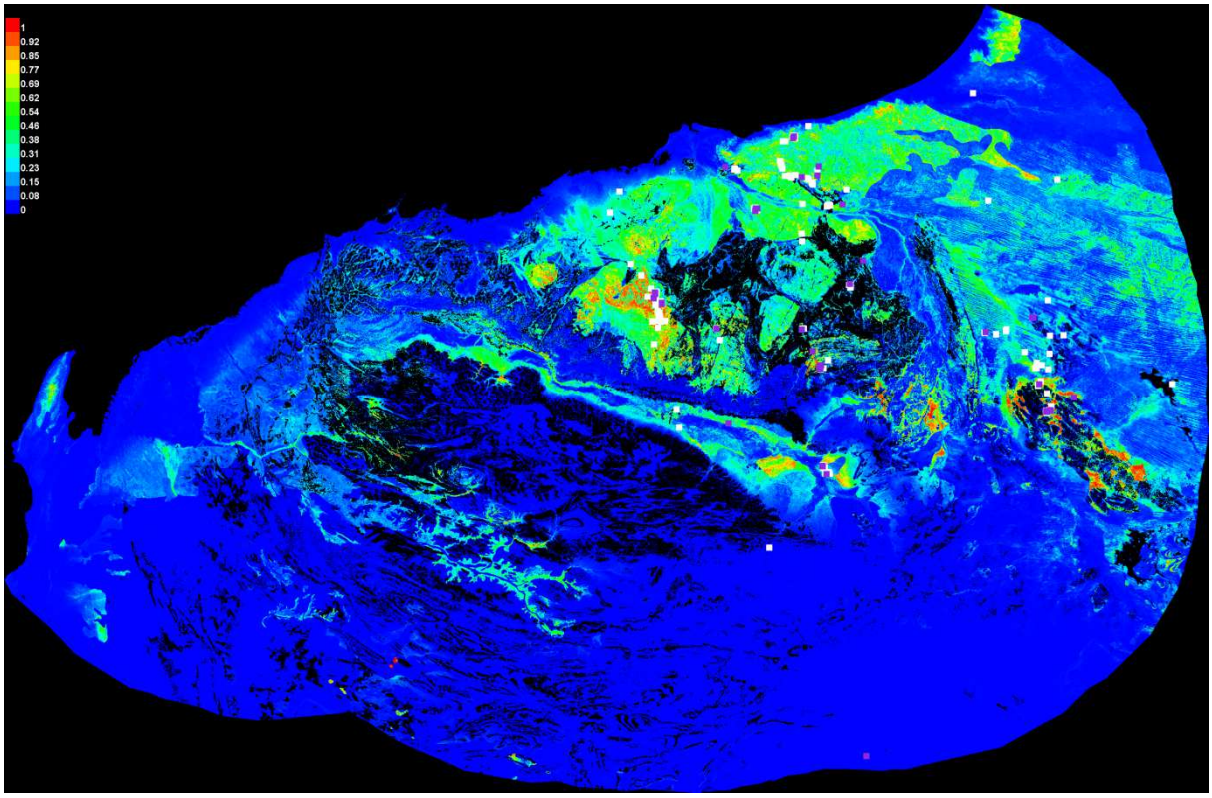

Figure 7. Maxent model of suitable bilby habitat based on Australian Atlas of Soils, TERN Soil layers, geology and elevation. Area included is the Pilbara IBRA region with a 200 km buffer. Warmer colors show areas with better predicted conditions.

Table 7. Relative contributions of variables to the Maxent model of suitable bilby habitat based on Australian Atlas of Soils, TERN Soil layers, geology and elevation.

Variable	Percent contribution	Permutation importance
Australian Atlas of Soils	42.9	46.7
Digital elevation model	21.8	29.5
Depth of soil (m)	10.1	9.1
Depth of Regolith (m)	6.3	2.6
Sand % at 1-2m depth	4.3	6.4
Clay % at 1-2m depth	3.6	1.4
Silt % at 1-2m depth	3.3	2.8
Geology	3.1	0.5
Coarse fragments % at 1-2m depth	2.6	0.9
Regolith	2.1	0.2

4.5 Detectability of bilby sign using remotely piloted aircraft

Three survey techniques for detecting the presence of bilbies were tested for efficiency and reliability by Southgate *et al.* (2005). Their evaluation of transect, plot, and aerial survey techniques for detecting bilby sign (tracks, diggings and burrows) determined that aerial survey using helicopters was the most reliable, and cost- and time-efficient method.

Costs for helicopter use in remote areas is still very expensive, however emerging remotely piloted aircraft (RPA: drones or UAV) technology may prove an even more cost-effective and practical technique for aerial surveys. Areas that are inaccessible to on-ground plots may be surveyed by RPA to detect the presence/absence of bilby burrows and diggings using live-feed video imagery. Live-feed video imagery negates the need for lengthy post-processing, and provides immediate on-ground results. Changes to federal legislative requirements for operators to no longer require an operator's certificate or remote pilot licence for RPAs under 2 kg (CASA 2016; CASA 2017). This has made utilising this technology an even better prospect for environmental research, as it is now more cost-effective and more easily sourced and implemented.

Initial trials at Matuwa (Dziminski and Carpenter 2016) indicated that bilby sign in both burnt and unburnt areas could be detected using RPA. It was hypothesised that various factors may contribute to the detectability of bilby sign by RPA, some of which include altitude, speed, camera angle and field of view, atmospheric conditions (light levels, sun angle, shadows) and vegetation. We investigated the effects of altitude, camera angle and speed with the aim of determining the effect of these factors on the detectability of bilby sign. Video imagery from overflights of an area of bilby activity in the Pilbara was recorded (Figure 8A). The area was flat, sandy and gravelly soil with unburnt stands of *A. trachycarpa* with an understory of *Triodia* spp. (Figure 8B). Preliminary trial flights over known burrows indicated that burrows were difficult to detect due to being obscured by vegetation, and that diggings were more numerous and obvious to observe. Angling the camera forward (rather than viewing directly vertical) enabled the observer to view into and beneath vegetation to a degree. Trial flights also indicated that around midday was the best time to record or view imagery, because long shadows did not obscure diggings.

Video imagery was recorded along the same flight path for each recording. The flight path was ground-truthed and locations of all diggings in the field of view (FOV) were recorded. Recordings were around midday, with atmospheric conditions cloudless and sunny. Video and camera settings were: 1080p resolution; 23 fps; ISO 100; shutter speed 1/2500; Exposure Value -2/3; F2.8. The 12 treatments included three factors. The first factor, altitude, contained two levels (12 m and 25 m above ground level), the second factor, camera angle, also contained two levels (45° and 56.25°) and the third factor, speed, contained three levels (6, 8 and 10 km/h). Altitude and camera angle both affect the FOV and these are shown in Table 8 and Figure 9.

Videos of each treatment were viewed by 13 observers on a 21.5" monitor at 1080p resolution, and observers scored the number of diggings detected. ANOVA was used to compare the effects of the three fixed factors on the number of diggings

detected by observers. Observers were included in the model as a random, blocking factor. The post-hoc tests performed were least significant difference (LSD) pairwise multiple comparisons. The proportions of diggings detected for significant effects were calculated from the actual number of diggings for each corresponding flight path FOV counted during ground-truthing (Figure 10).

There were no significant effects of interactions (Table 9). There were significant differences in the main effects of altitude and speed (Table 9). Significantly more diggings were detected at the flight altitude of 12 m than 25 m (Figure 11). Significantly more diggings were detected at 6 km/h than at 10 km/h (Figure 11; LSD: $P = 0.004$). There was no significant effect of camera angle (Table 9).

Lower altitude decreased the FOV, however the detectability of bilby diggings increased threefold, justifying a clear advantage to using the lower altitude for detecting bilby sign when vegetation height permits. A decrease in speed resulted in an increase in detectability, however not to the same magnitude as altitude. Flying lower and slower resulted in higher detectability; however there is a trade-off between speed and the total distance a RPA can fly due to limited battery power. Therefore increasing the speed to 8 km/h with a slight cost in detectability will allow the RPA to cover 30 % more ground over a 20 min flight time.

From this study, we have identified lower altitude and slower speed result in increased detectability of bilby sign. At 12 m altitude approximately 20 % of sign is detected flying at 6 km/h which decreases to approximately 15 % of sign detected when speed is increased to 8 km/h. Further testing is required to confirm the benefits of slant imagery rather than the camera viewing vertically (straight down), that imagery from midday reduces shadows which interfere with detection of sign, and that burrows are less detectable than extensive areas of bilby diggings. Certainly anecdotally, extensive areas of bilby diggings were far more noticeable compared to single burrows, which required viewing from a particular angle to be detected. The technique requires further testing to determine the effects of different vegetation types, burn age of the vegetation and lighting conditions (cloudy days), all which are likely to affect detectability of sign.

As pointed out previously, the distance that can be traversed by commercially available multi-rotor RPA is currently limited by a battery life of approximately 20 mins. This enables a flight path of approximately 2 – 2.6 km at 6 – 8 km/h per battery. As battery technology increases and distances covered increase then the value efficiency of using RPA to search larger areas will rise. Since the technique is experimental, and has not been tested in varying habitat and vegetation types, ground-truthing both positive and nil detections is required to determine false positive and false negative error.

4.5.1 Management implications

- Ability to survey previously inaccessible areas for bilby presence in the Pilbara for Level 2 or targeted surveys
- A more efficient, cost-effective survey technique allowing more area to be surveyed in less time for Level 2 or targeted surveys

- More data on bilby presence in previously inaccessible areas of the Pilbara for EIA processes
- A quicker method of identifying a population and defining the boundaries of occupancy prior to population monitoring (see Section 5.1)
- A better understanding of the detectability of bilby sign from RPA, which can be applied in future surveys

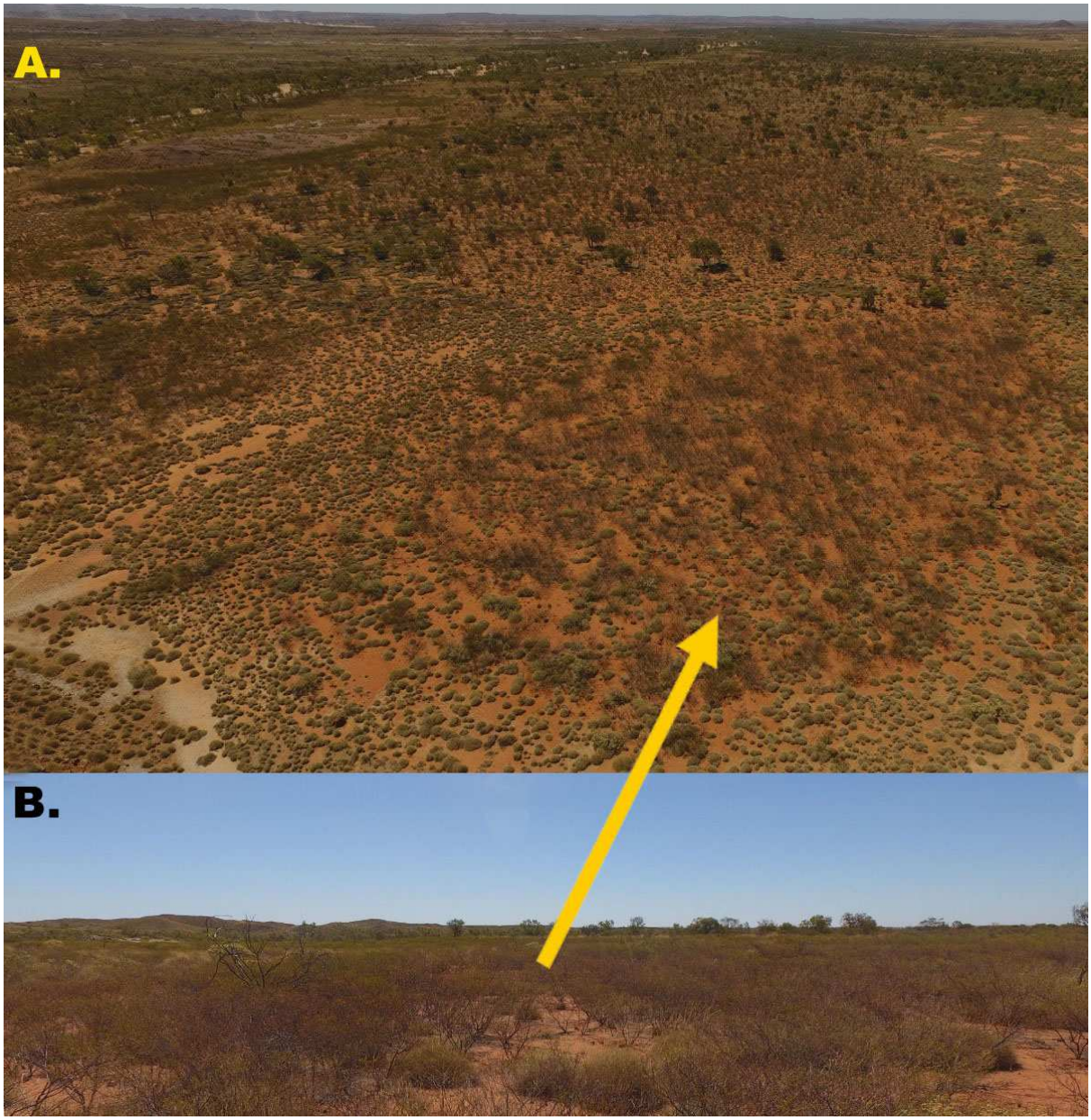

Figure 8. A. Aerial view of the area with bilby sign used for the experimental overflights. B. Ground view of the *Acacia trachycarpa* stand.

Table 8. Fields of view used in RPA flights to determine effects of altitude, camera angle and speed on detectability of bilby diggings.

Altitude (m)	Camera angle (°)	Field of view (ha)
12	45	0.52
12	56.25	0.40
25	45	1.06
25	56.25	0.85

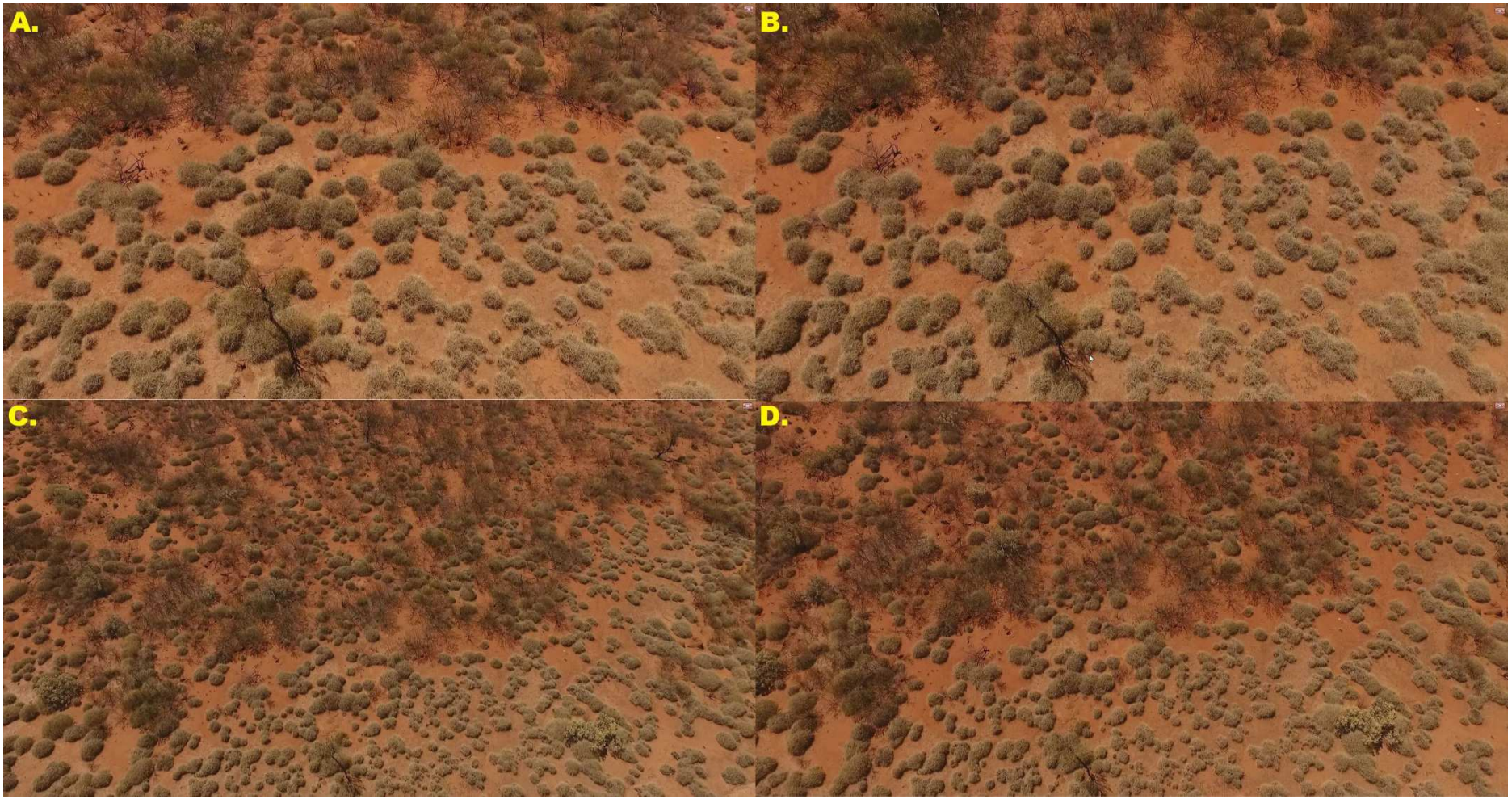

Figure 9. Camera FOV of each altitude and camera angle treatment: A. 12 m and 45°; B. 12 m and 56.25°; C. 25 m and 45°; 25 m and 56.25°.

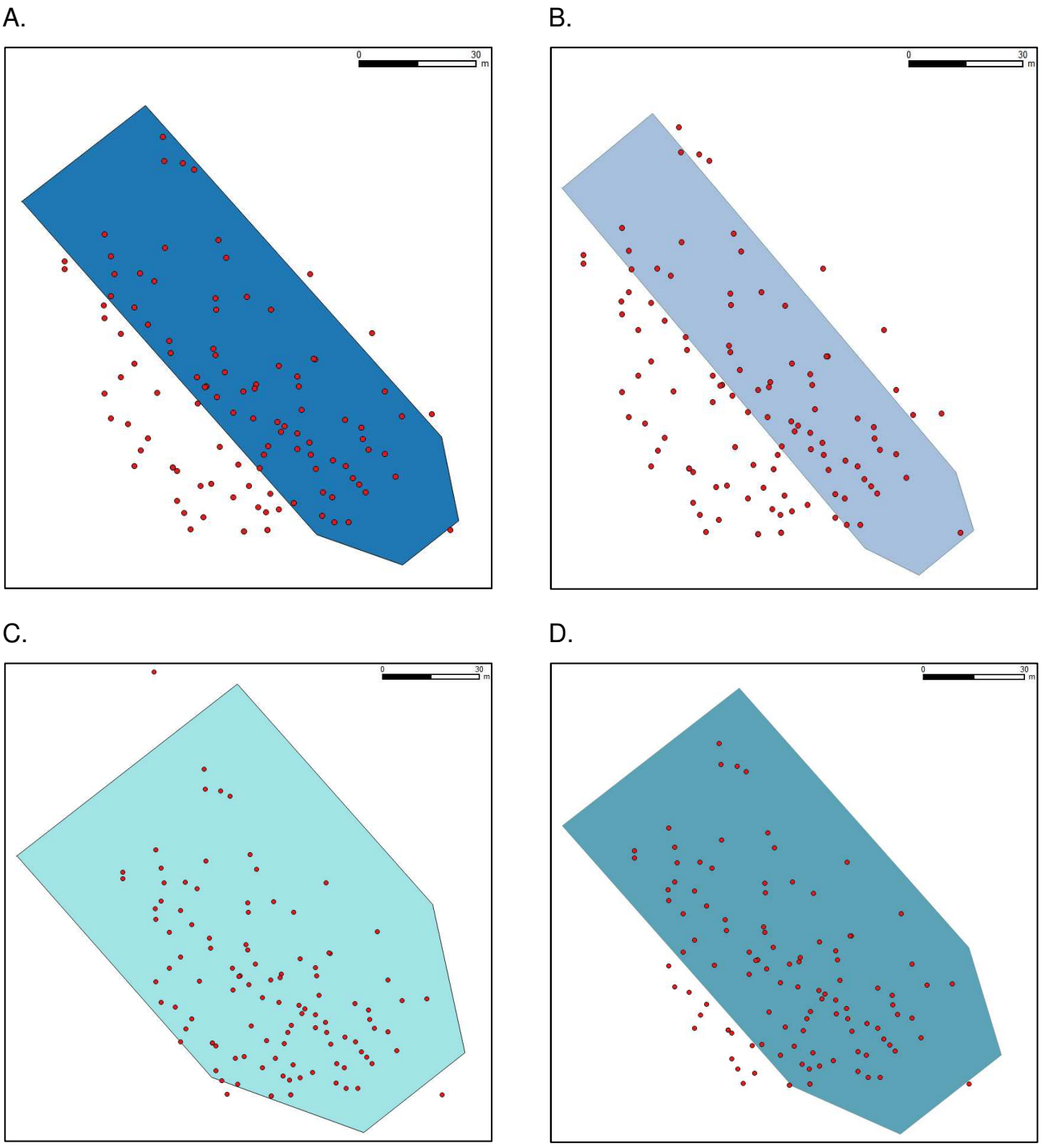

Figure 10. Bilby diggings recorded during ground-truthing (●) and the flight path FOV (camera FOV × flight path length) of each altitude and camera angle treatment: A. 12 m and 45°; B. 12 m and 56.25°; C. 25 m and 45°; 25 m and 56.25°. Scale bars represent 30 m.

Table 9. ANOVA of the number of detections of bilby diggings.

Source	d.f.	MS	*F*	*P*	Effect size (η_p^2)
Observer	12	55.120	3.693	<0.001	0.251
Altitude (A)	1	762.981	51.113	<0.001	0.279
Camera angle (C)	1	1.083	0.073	0.788	0.001
Speed (S)	2	63.404	4.247	0.016	0.060
A×C	1	1.853	0.124	0.725	0.001
A×S	2	24.981	1.673	0.192	0.025
C×S	2	5.583	0.374	0.689	0.006
A×C×S	2	7.160	0.480	0.620	0.007
Error	132	14.927			

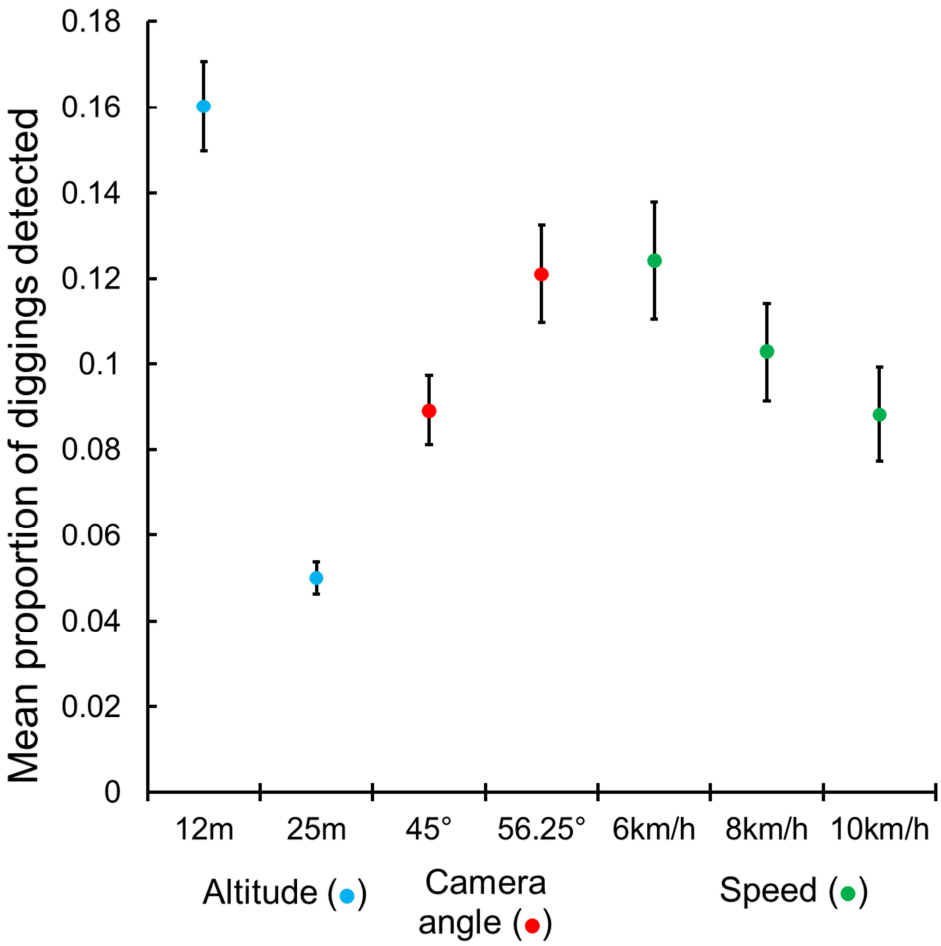

Figure 11. Mean proportions (±1 S.E.) of diggings detected for each main effect.

5 Population monitoring

5.1 Abundance monitoring: Genotyping individuals from scats

To date, the most common techniques that are used to "monitor" bilbies only provide presence/absence data and no data on the actual abundance or numbers of bilbies at populations (Lavery and Kirkpatrick 1997; Moseby and O'Donnell 2003; Southgate *et al.* 2005; Bradley *et al.* 2015). Although monitoring using presence/absence is important to gain an understanding of changes in occupancy and patterns of movements across the landscape, abundance monitoring provides information about actual numbers of bilbies within populations. Monitoring numbers of bilbies within populations provides data on demographic fluctuations that can be caused by threats or changes in the surrounding environment.

Bilbies are trap-shy, are not consistently attracted to any form of bait, and reliably trapping an individual involves finding an occupied burrow and fencing it in with traps or digging traps into the burrow (Southgate *et al.* 1995; Lavery and Kirkpatrick 1997; Moseby and O'Donnell 2003). This technique involves a lot of effort and is a partially destructive method of sampling. Therefore, bilbies are not suitable for efficient mark-release-recapture studies.

The use of tracks is an unreliable indicator of numbers, especially when densities are high (Paltridge and Southgate 2001; Southgate *et al.* 2005). Some surveys have made use of burrow counts (e.g. Burrows *et al.* 2012), however the correlation between burrows and bilby numbers is poor and unreliable (Southgate *et al.* 1995; Lavery and Kirkpatrick 1997). A single bilby may use up to 18 burrows, sometimes up to 1 km apart, and may use up to 3 different burrows per night (Lavery and Kirkpatrick 1997; Moseby and O'Donnell 2003). Therefore, although burrows and tracks are a good indicator of presence, they are poor indicators of abundance.

Bilby scats are relatively easy to find, are distinctive and cannot be confused with the scats of other species by trained observers (Moseby *et al.* 2009). Simply counting scats is not reliable as there is no way of excluding recounts of individuals, and the use of distance sampling of bilby scats requires the scat deposition and decay rates to be accurately known (Lollback *et al.* 2015) to estimate the number of bilbies. These rates vary with location and season (Lollback *et al.* 2015). However, quantitatively sampling bilby scats, but coupling this with genotyping individuals using DNA from their scats, allows a more accurate calculation of bilby numbers within populations. Furthermore, a genetic snapshot of the population shows the relatedness of individuals as well as the relationship and connectivity with other nearby and distant populations or family groups. This non-invasive technique is the population monitoring tool that Parks and Wildlife have developed, recommend and have implemented at monitoring sites across Western Australia.

Line transects of 1-3 km in length and 50 x 50 m plots were tested to quantitatively collect scats. Scats were more reliably and efficiently collected from transects, which also had the benefit of sampling across the home ranges of multiple individuals. DNA is extracted from scats using a commercial stool DNA kit with some modifications to

the standard process. Individuals are genotyped across seven polymorphic microsatellite loci (Moritz *et al.* 1997; Smith *et al.* 2009). Viable DNA can reliably be extracted from scats that were deposited up to two weeks previously (Carpenter and Dziminski 2016).

After a series of pilot studies and trial monitoring sites and improvements to the extraction technique (Dziminski and Carpenter 2016) this technique has been implemented to monitor populations in the Pilbara and elsewhere in Western Australia (see Section 5.2).

The technique involves:

1. Identifying a population and defining the boundaries of occupancy or alternatively defining a portion of a continuous area that is occupied by bilbies.
2. Overlaying transects to evenly sample the defined area.
3. Traversing the transects, collecting scat samples and recording positional data.
4. Extracting DNA, PCR, fragment analysis and genotyping individuals from scat samples.
5. Analysis of spatial and genetic data and abundance.

In order to maximise the efficiency of the technique and increase the quality of the data the following recommendations are provided:

- Only fresh scat samples up to two weeks old should be collected (Carpenter and Dziminski 2016). Although determining the age from the look of scats can be difficult unless they are crumbling or falling apart, the digging associated with the scat can be used to determine freshness. If the spoil of the associated digging is degraded, weathered, hardened and flattened then it is likely very old. If the spoil looks recently dug and is still a different colour it is likely fresh.
- Samples should not be collected if there has been rain at the site during the past two weeks. Rain degrades the DNA on scats (Piggott 2004; Brinkman *et al.* 2009) and many will not yield viable DNA. It is best to time monitoring with a window of at least 2 weeks of no prior rain.
- Scats should be stored in tubes with silica gel beads with a cotton wool bud separating the sample from the beads (see Section 5.3).

Parks and Wildlife Bilby Research Team staff can provide advice and assistance to set up and implement monitoring sites in collaboration with local partners. This will be a consultative process where Parks and Wildlife staff will teach and assist partners in setting up the monitoring site, with the goal of all the on-ground work and future monitoring events being undertaken by the partner. Parks and Wildlife can undertake molecular work and analyses as a service (Dziminski 2015a; Dziminski 2015b; Dziminski 2015c).

Utilising scats as opposed to sourcing tissue or blood for DNA samples has the benefit of reducing direct impacts to species being studied (Murphy *et al.* 2000; Piggott and Taylor 2003; Vynne *et al.* 2012; Ramón-Laca *et al.* 2015). This is

particularly useful in the case of threatened species, such as bilbies, which are likely vulnerable to disturbance (e.g. Puechmaille and Petit 2007; Baldwin *et al.* 2010).

5.1.1 Management implications

- A reliable technique for abundance measures for bilby populations.
- Provides a standard technique for monitoring populations for EIA processes and determining the effects of threats and success of threat management activities.
- Satisfies the needs for consistency with on-going bilby monitoring programs in Western Australia.

5.2 Implementation of population monitoring

In 2016, population monitoring was undertaken at five populations in the Pilbara, one in the central rangelands (Matuwa IPA) and one in the Gibson Desert (Kiwirrkurra). Populations of bilbies in the Pilbara contain low numbers of individuals (Table 10) and are isolated (Figure 12). The Matuwa population is within a large area that has had introduced predator control, stock exclusion and fire management for more than 12 years. The Pilbara populations are unmanaged.

5.2.1 Lost populations

5.2.1.1 Pardoo

The Pardoo population was not monitored in 2015 due to only the tracks of one individual and one scat being found towards the end of 2014, with no other fresh evidence of any bilby presence. The area was searched in all directions out to 5 km on foot, and then out to 20 km by vehicle. No bilby evidence was found. Bilby populations in desert areas have been recorded moving up to 2.3 km per year and one population was recorded moving 10.5 km in 3 years (Southgate and Possingham 1995). This search was conducted over several days and was assessed to be thorough enough to detect the population if it had shifted. During the search at least four feral cats were observed jumping out of old disused bilby burrows. Furthermore, nearly the entire area had been burnt sequentially in 2012, 2013 and 2014 by large-scale hot fires, and only several small patches of the once thick stands of *Acacia monticola* remained in the area. These *Acacia* stands provide the major food resource for bilbies in the area in the form of cossid moth larvae within the root systems.

In 2013, at least eight individuals were present in this area (Table 10), this population was confirmed as being in the same location since at least 2012 and there is anecdotal evidence from locals that bilbies were present at this location for up to 20 years. It is possible that the multiple large-scale, hot fires have wiped out all the food resources for bilbies in the area, and coupled with an increase in cat predation, have caused bilby numbers to severely decline at this location. A further extensive week-long search in 2016 confirmed bilbies are now absent from this area.

5.2.1.2 McPhee Creek

Population monitoring was to commence in 2016 at a bilby population known to exist for a number of years at McPhee Creek (Outback Ecology 2014). The site was visited in 2014 and late 2015, with extensive fresh bilby activity recorded confirming an active population. At the end of October 2015 an extensive large, hot wildfire had burnt the entire area and surrounding landscape.

The site was visited twice in 2016 with no active evidence of bilby activity detected. Evidence of several old burrows and relict RDL diggings dating to late 2015 were observed. The surrounding area was searched extensively for one week out to 20 km by foot, quad bike and vehicle, with no evidence of bilbies detected. The site was visited in May 2017 again with no evidence of bilbies detected. Only very small patches of suitable habitat remained unburnt. The destruction of suitable habitat, as well as the increased predation risk caused by the destruction of all cover, likely led to the extinction of this population under similar circumstances to the Pardoo population.

5.2.2 Management implications

- Provides baseline measures of abundance within populations in the Pilbara for future EIA processes.
- Populations in the Pilbara are isolated and consist of a small number of individuals. This means that they are likely to be very vulnerable to threats and any disturbance.
- Management of threats with priority for fire management is required in the Pilbara to prevent further loss of populations.

Table 10. Numbers of individuals identified from scats collected along transects at monitoring sites*.

Population	2013		2014		2015		2016	
	Scats yielding DNA / Scats collected (% yielding DNA)	Individuals identified on transects	Scats yielding DNA / Scats collected (% yielding DNA)	Individuals identified on transects	Scats yielding DNA / Scats collected (% yielding DNA)	Individuals identified on transects	Scats yielding DNA / Scats collected (% yielding DNA)	Individuals identified on transects
Pardoo	9/40 (23%)	8	0/1 (0%)	-	-	-	-	-
Turner River[1]	-	-	19/50 (38%)	2	6/19 (32%)	1	5/40 (13%)	2
Hillside[1]	-	-	16/49 (33%)	4	0/3 (0%)	At least 1	0/4 (0%)	At least 1
Nullagine	-	-	7/44 (16%)	2	28/46 (61%)	5	40/82 (48%)	8
Yarrie[2]	-	-	-	-	15/62 (24%)	10	7/33 (21%)	2**
Warralong	-	-	-	-	-	-	18/56 (32%)	6
Matuwa	-	-	-	-	118/215 (55%)	23	56/133 (42%)	25
Kiwirrkurra[3]	-	-	-	-	-	-	7/19 (37%)	4

1. Monitored in collaboration with FMG, *ecologia*, Ecoscape.

2. Monitored in collaboration with BHP, Biologic.

3. Monitored in collaboration with Kiwirrkurra Rangers, Central Desert Native Title Services, Desert Wildlife Services.

* Preliminary results pending final data analyses.

** Only a subset of scats (33 out of 72 collected) genotyped, therefore figure may be underestimated.

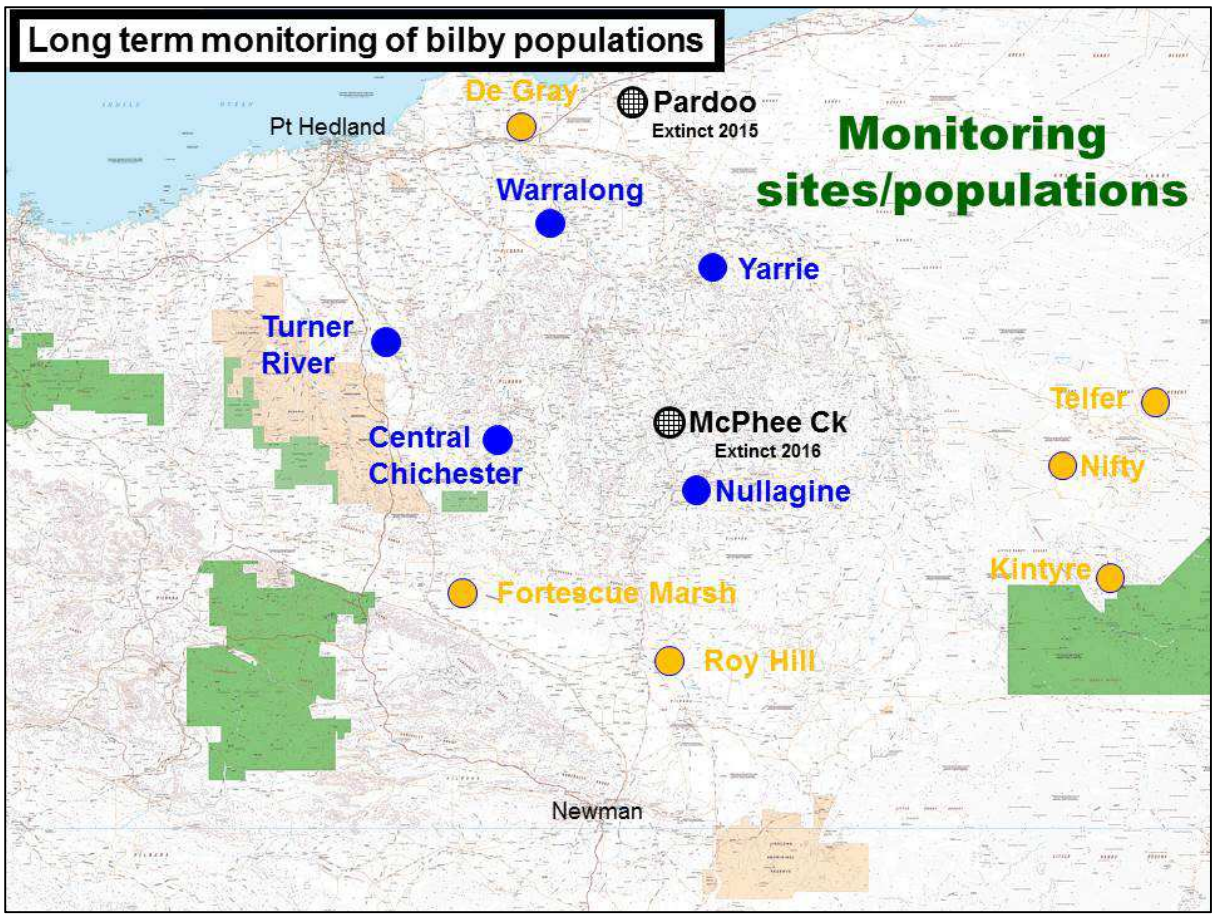

Figure 12. Current (●), potential future (●) and locally extinct (O) population monitoring sites.

5.3 Comparing the effects of storage methods on the quality of DNA from bilby faecal pellets

In order to implement population monitoring using DNA extracted from bilby faecal pellets, specimens collected from the field must be stored and transported to the laboratory for DNA extraction, which can occur up to several weeks after collection. Storage methods must preserve the sample and DNA effectively, protect the sample during transportation, and be practical and able to be used easily in the field. Storage methods that have been used and proposed include:

- Dry:
  - 30 ml vials with silica gel beads (⅓ of vial filled),
  - paper envelopes
- Frozen:
  - Paper envelopes

The aim of this study was to determine the optimal storage technique for bilby faecal pellets to be used for later DNA extraction.

Faecal pellets from piles deposited by a single individual were collected in the field and assigned to one of the three treatments above. Using pellets from the same pile allowed us to control for time since deposition. It also allowed for direct comparison

of genotypes from each individual. Envelopes containing samples to be frozen were placed in a freezer at the end of the collection day. Frozen samples were transported in a portable freezer (Engel). Dry samples were kept at ambient temperature.

DNA was extracted eight weeks after sample collection using a commercial stool DNA kit. Four polymorphic microsatellite markers were used to genotype samples. A similar experiment was set up concurrently to examine the effects of storage technique over a longer period (12 months). This experiment is still underway and here we only present results for the short-term storage trial.

We found no significant differences in amplification, false allele and allelic dropout rates between the three storage techniques (Figure 13). We observed that approximately 13 % of pellets stored in envelopes (either dry or frozen) were crushed during transportation, whereas none stored in vials were crushed. Freezing samples added a complexity, especially for transport or postage, in remote areas, and preserving samples dry was more practical. Vials protected samples from being crushed during transport and storage; however we noticed that silica gel beads rub against the sample during movement and may result in the removal of epithelial cells from the surface of samples. To alleviate this effect we now use a cotton wool bud in the tube between the silica gel and samples. We recommend bilby faecal pellets that are to be used for DNA extraction be stored in tubes with silica gel beads and cotton wool.

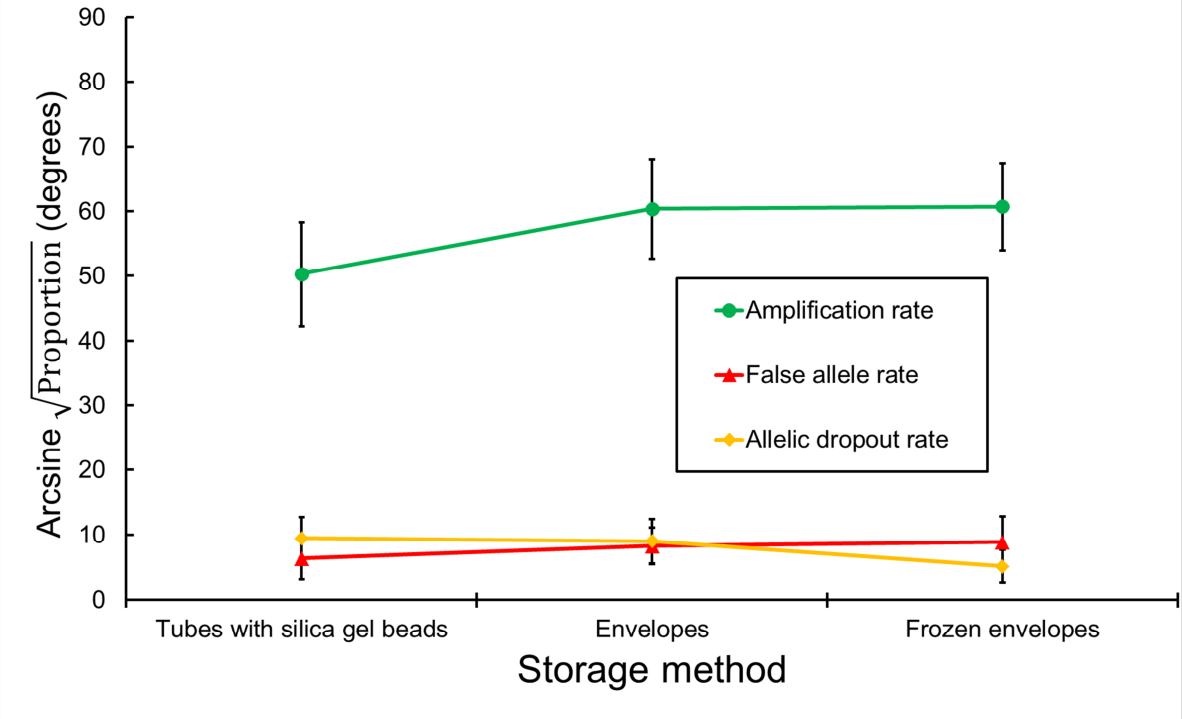

Figure 13. The mean proportions of samples that amplified (●), false alleles (▲), and missing alleles (◆) from DNA extracted from bilby faecal pellets stored tubes with silica gel beads, envelopes and frozen in envelopes.

5.3.1 Management implications

- Ability to retain samples prior to extraction, provided scats are kept in dry, cool conditions.
- Technique developed to improve the storage, extraction and amplification of bilby faecal DNA.
- Scats can be easily sourced, stored and transported by external agents (communities, mining companies, consultancies, environmental groups) and submitted for genotyping.

6 2016 Ninu Festival

Parks and Wildlife sponsored the Ninu (Bilby) Festival in 2016 which was held at Kiwirrkurra in the Gibson Desert. The festival was hosted by the Kiwirrkurra Rangers, Kiwirrkurra Community and facilitated by Central Desert Native Title Services.

The purpose of the festival was to bring together indigenous ranger groups and scientists working to conserve and manage bilbies in the wild. Over 150 participants attended from all mainland states and territories. A traditional welcoming ceremony was held at an important Ninu Dreaming site. Senior knowledge holders presented cultural knowledge of bilbies and shared stories about the significance of bilbies to Traditional Owners.

Ranger groups and scientists presented and shared information on research and management being undertaken on bilbies around the country. Martin Dziminski delivered two presentations on research being undertaken by the Department in the Pilbara, Kimberley and deserts of Western Australia, as well as the reintroduction of bilbies to Matuwa (formerly Lorna Glen).

The festival promoted the sharing of ideas and information and led to stronger links between ranger groups working on bilbies and researchers. Details of the festival can be found in Paltridge (2016) and Walsh and Custodians of the Bilby (2016).

6.1.1 Management implications

- Stronger relationships developed with Traditional Owners and Indigenous Ranger Groups
- Greater awareness and indigenous community support of issues surrounding bilby conservation issues
- More opportunities for collaborative management of bilby populations

7 Ongoing work

The following ongoing work is planned to continue in 2017 and beyond:

- Continuing collation of records from external sources.
- Maintenance of the Pilbara Threatened Fauna Database and websites.
- Maintain public awareness of bilbies in the Pilbara Region through continuation of media engagement, public seminars/presentations and distribution of posters.
- Continue work on modelling the distribution of bilbies in the Pilbara and ground-truth sites to validate the resulting models.
- Continue survey of the Pilbara using the existing 2 ha plot methodology when possible, focusing on unsurveyed areas identified from distribution modelling.
- Continue experimentation of RPA technology to survey for bilbies in the field.
- Continue monitoring populations, aiming for community and stake holder engagement and involvement in population monitoring.
- Commence implementation of threat management with initial focus on fire management at selected populations with community and stake holder engagement and support.
- Initiate population genetics project using existing bilby DNA library collected from population monitoring and opportunistically collected scats.
- Initiate diet analysis of surplus scats collected during population monitoring and opportunistically collected scats.

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Global Gypsies – Lorna Glen trial transects

Martu - Traditional Owners of Matuwa

Nullagine Community School and Community

Roy Hill Station

Yarrie Station - Annabelle Coppin

Pardoo Station

Millennium Minerals – Chris Goti

Aditya Birla Nifty – Michael Robinson

Cameco – Tim Duff

Rangelands NRM Western Australia

Paul Gioia – NatureMap Theme (Department of Parks and Wildlife)

Roy Hill

ecologia

Biologic

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Gooitzen Van Der Meer for the illustration of the bilby burrow

Offset Funding

Fortescue Metals Group

Millennium Minerals

Roy Hill

Appendices

Appendix 1 Publications

The following publications have been produced from this research:

Bradley, K., Lees, C., Lundie-Jenkins, G., Copley, P., Paltridge, R., Dziminski, M., Southgate, R., Nally, S., and Kemp, L. (2015). 2015 Greater Bilby Conservation Summit and Interim Conservation Plan: an Initiative of the Save the Bilby Fund. IUCN SSC Conservation Breeding Specialist Group, Apple Valley, MN.

Carpenter, F., and Dziminski, M. A. (2016). Breaking down scats: degradation of DNA from greater bilby (*Macrotis lagotis*) faecal pellets. *Australian Mammalogy* http://dx.doi.org/10.1071/AM16030.

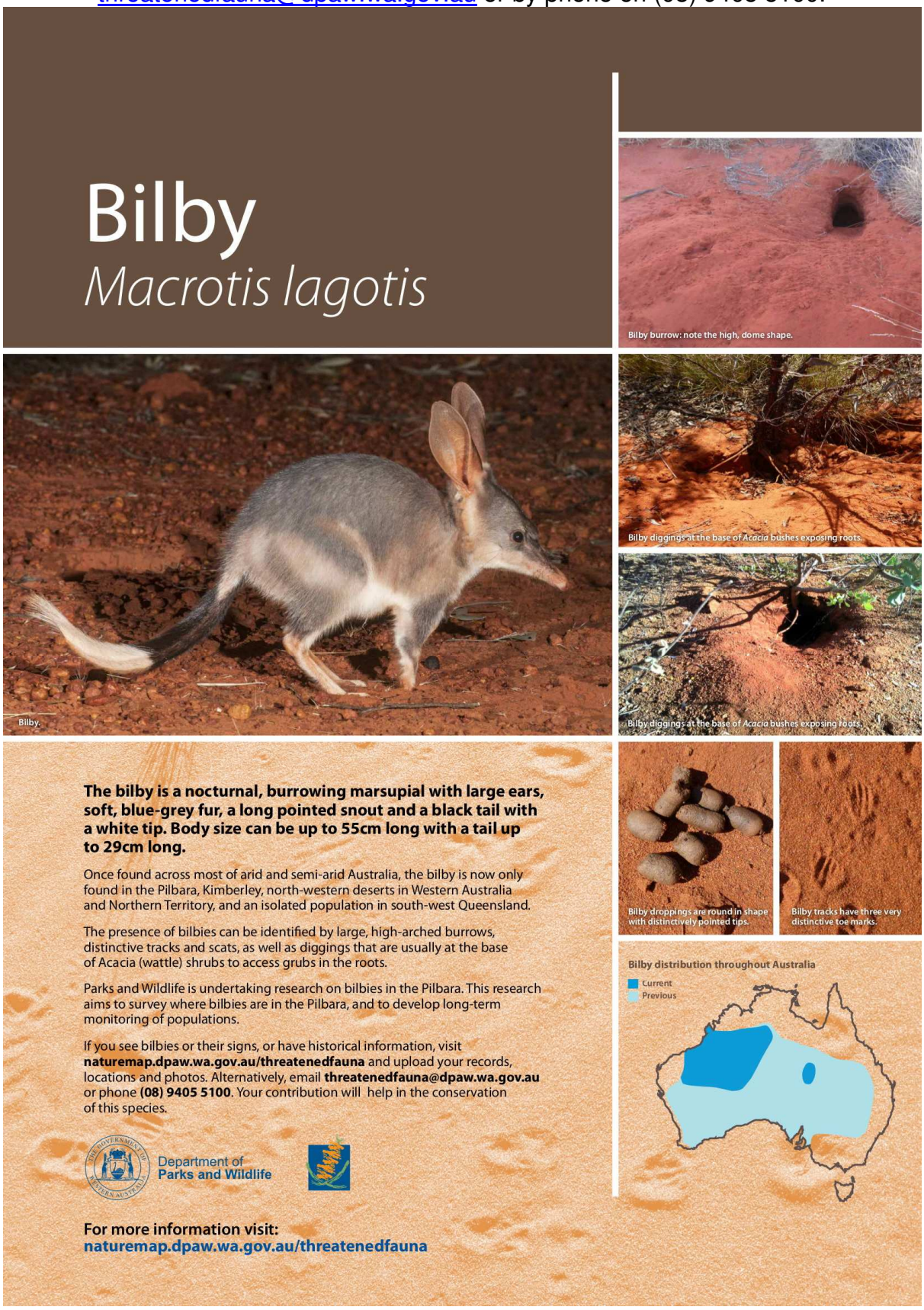
Cramer, V. A., Dziminski, M. A., Southgate, R., Carpenter, F., Ellis, R. J., and van Leeuwen, S. (2016). A conceptual framework for habitat use and research priorities for the greater bilby (*Macrotis lagotis*) in the north of Western Australia. *Australian Mammalogy* http://dx.doi.org/10.1071/AM16009.

Hofstede, L., and Dziminski, M. A. (2017). Greater bilby burrows: important structures for a range of species in an arid environment. *Australian Mammalogy*. doi:10.1071/AM16032

Southgate, R., Dziminski, M. A., Paltridge, R., Schubert, A., and Gaikhorst, G. (Submitted). Verifying bilby presence and the systematic sampling of wild populations using the 2 ha sign-based monitoring protocol – with notes on aerial and ground survey techniques and asserting absence. *Australian Mammalogy*.

Appendix 2 Bilby Poster

The poster below can be requested by contacting threatenedfauna@dpaw.wa.gov.au or by phone on (08) 9405 5100.



Appendix 3 Standardised data sheet for 2 ha Sign Plots

The data sheet below can be requested by contacting threatenedfauna@dpaw.wa.gov.au or by phone on (08) 9405 5100.

This data sheet was developed in collaboration with WWF and Environs Kimberley with advice from experts using sign plots for occupancy surveys across Australia.

2HA SIGN PLOT DATASHEET v1.2

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 (Approximately 200m x 100m)

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

4. RECORD ABUNDANCE AND AGE OF SIGNS AT END OF WALKING 2 HA PLOT (1,2 or 3 in last two columns below)

Abundance of Sign:
1. Sign in all 4 quarters of plot ●
2. Sign in half to ¾ of plot ◑ ◕
3. One individual or only 1/4 of plot ◔

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)	Tracks	Scats	Burrow	Digging	Digging into roots of plants	Other (eg sighting, remains, nest, resting place etc – add)	Juveniles present?	Abundance of all sign (1,2,3)	Age of most recent sign (1,2,3)	Tick only if this observation is on road/track next to plot
Bandicoot										
Bettong										
Bilby										
Dingo										
Echidna										
Euro										
Hopping mouse										
Kangaroo Red										
Large Rat										
Marsupial mole										
Mulgara/Ampurta										
Possum										
Quoll										
Small rodent/Dunnart										
Wallaby Agile										
Wallaby Hare										
Wallaby Northern Nailtail										
Wallaby unknown										
Lizard - Goanna small										
Lizard - Goanna large										
Lizard - Medium										
Lizard - Small										
Lizard - Great Desert Skink										
Sand slider (Lerista)										
Snake										
Bird - Turkey (Bustard)										
Bird - Curlew										
Bird - Emu										
Bird - Hopping										
Bird - Walking										
Bird - Quail										
Insect										
Other...										

2HA SIGN PLOT DATASHEET v1.2

Species (add if not listed)	Tracks	Scats	Burrow	Digging	Digging into roots of plants	Other (eg sighting, remains, nest, resting place etc – add)	Juveniles present?	Abundance of all sign (1,2,3)	Age of most recent sign (1,2,3)	Tick only if this observation is on road/track next to plot
Cat										
Camel										
Cow										
Donkey										
Fox										
Goat										
Horse										
Pig										
Rabbit										

5. WHEN FINISHED WALKING RECORD THE FOLLOWING

Plot type (circle one) Random Targeted at habitat Known location of target species

Plot sequence (circle one) First time Repeat sample Unknown

Landform type

☐ Drainage line ☐ Isolated dune ☐ Breakaway ☐ Other (type in below)
☐ Salt lake system ☐ Dune field ☐ Hill _____
☐ Plain ☐ Laterite/stony rise ☐ Range

Soil type (substrate)

☐ Sand ☐ Sandy soil ☐ Clay ☐ Other (type in below)
☐ Gravelly sand ☐ Soil ☐ Gravel _____

Vegetation structure

☐ Shrubland ☐ Open woodland ☐ Dense woodland ☐ Open grassland

Main long-lived overstory vegetation species (eg. Eucalypt; Acacia, bloodwood, mixed shrubland; Mulga; other)

_____

Overstory % cover (circle) <1% 1-5% 5-25% >25%

Main long-lived understory vegetation species (eg. Spinifex; Buffel grass; Acacia; Other)

_____

Understory % cover (circle) <5% 5-10% 10-30% >30%

If there are bilby diggings into roots what species are they?_____

What percentage of the plot is suitable for tracking (eg sand or dirt)? 0-25% 25-50% 50-75% 75-100%

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

What size animal tracks would you be able to see and what proportion of the route you walked was like this? (tick and circle)

☐ No tracks (eg leaf litter, rock etc) <25% 25-50% 50-75% >75%
☐ Big animals only (eg camel, dingo, kangaroo tracks only) <25% 25-50% 50-75% >75%
☐ Big and medium animals, (eg agile wallaby, cat, bilby, echidna, goannas) <25% 25-50% 50-75% >75%
☐ Big to small animals (eg hopping mice, small birds, insects etc) <25% 25-50% 50-75% >75%

2HA SIGN PLOT DATASHEET v1.2

Shadow (look at own shadow and circle one): Distinct shadow Slight shadow No shadow

Time since rain (enter number) ☐ Days ☐ Weeks ☐ Months

Time since strong wind (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:
Parks and Wildlife - threatenedfauna@dpaw.wa.gov.au, Woodvale Wildlife Research Centre, Bilby Research, Locked Bag 104 Bentley Delivery Centre WA 6983. (08) 9405 5105

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