MODELLING THE REINTRODUCTION OF BILBIES *MACROTIS LAGOTIS* (MARSUPIALIA: THYLACOMYIDAE) IN THE RANGELANDS OF WESTERN AUSTRALIA

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By

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Photos on the front page:

First line, from the left to the right:

- Rainbow in the rangelands of Lorna Glen: L. Pertuisel
- Bilby road sign: L. Pertuisel
- Aerial view of the Lindsay Gordon Lagoon system at Lorna Glen: L. Pertuisel
- Bilby burrow: L. Pertuisel
- Pink Lake at Lorna Glen: L. Pertuisel

Second line, from the left to the right:

- Aerial view of the rangelands of Lorna Glen: L. Pertuisel
- Bilby tracks: L. Pertuisel
- Bilby (Macrotis lagotis), available from: http://www.aspenparks.com.au/holiday-destinations/south-australia/roxby-downs/myall-grove-holiday-park/attractions.aspx
- Sand dune at Lorna Glen: L. Pertuisel
- Rangelands of Lorna Glen: L. Pertuisel

ABBREVIATIONS

CMR	Capture–Mark–Recapture
CWR	Critical Weight Range
DEC	Department of Environment and Conservation
FAI	Faunal Attrition Index
IBRA	Interim Biogeographic Regionalisation for Australia
ID	IDentification number
IUCN	International Union for the Conservation of Nature
IUCN/SSC	World Conservation Union's Species Survival Commission
K	Carrying capacity
PCBC	Peron Captive Breeding Center
PIT	Passive Integrated Transponder
PVA	Population Viability Analysis
RSG	Reintroduction Specialist Group

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SUMMARY

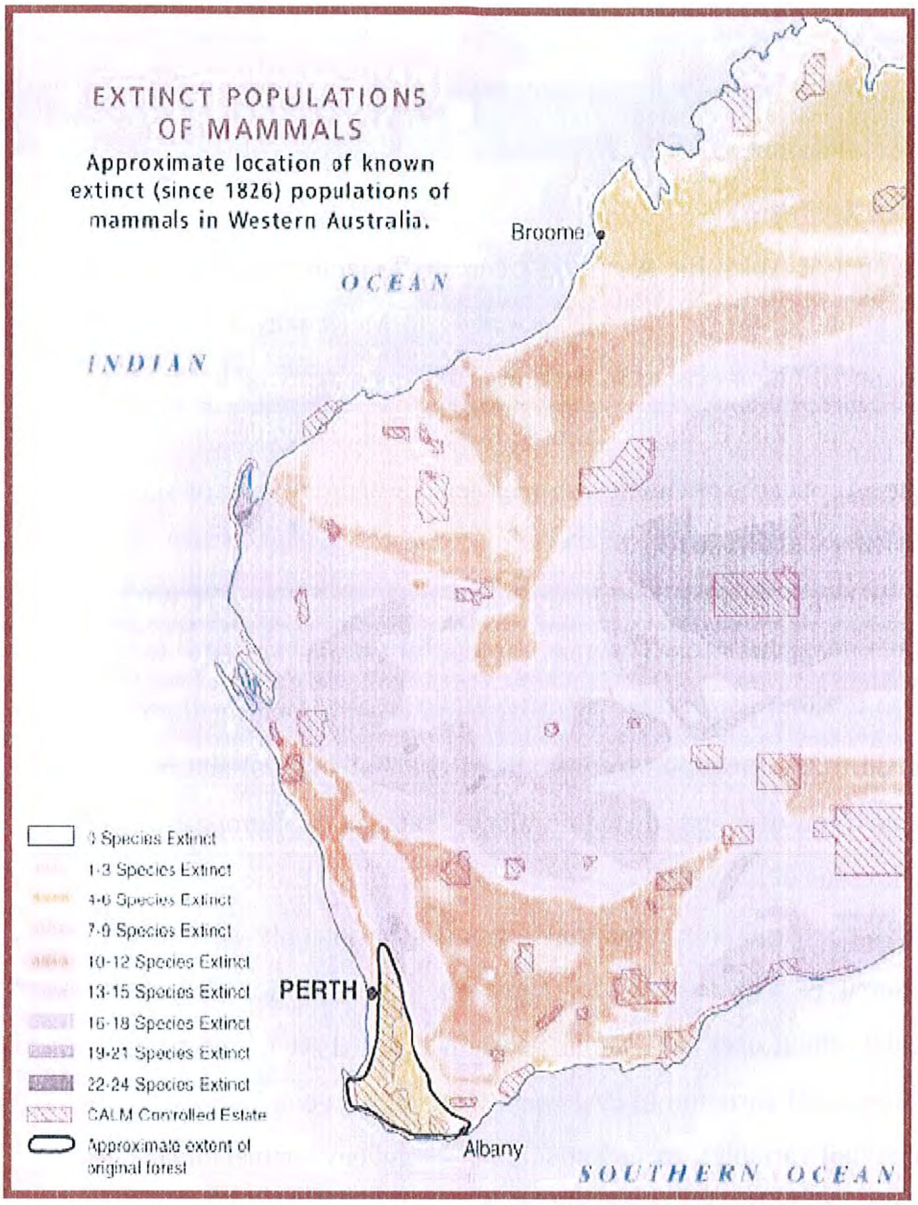

Figure 1: Number of mammal species extinct since 1826 in Western Australia (Abbott, 2009)

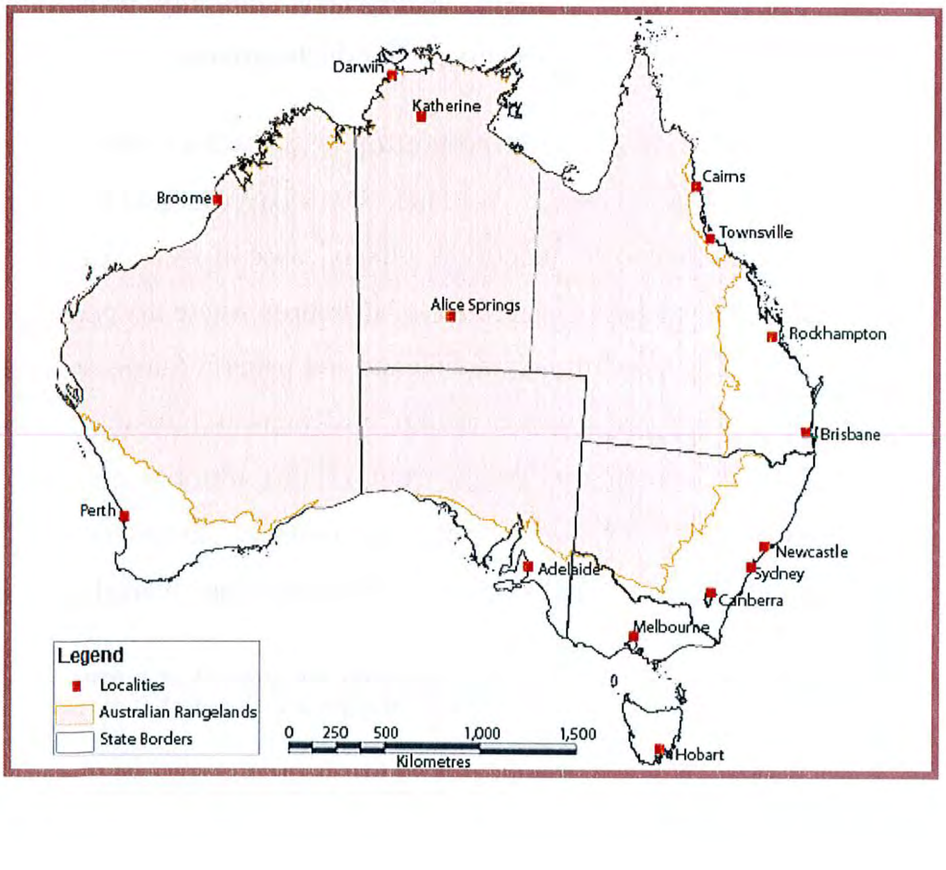

Figure 2: Australian rangelands boundary (Website 1)

1. Introduction

1. 1. Mammal decline in Australia

Since European settlement of Australia, Australia's terrestrial mammals have suffered a severe decline (Finlaysona et al., 2008) (Figure 1). According to McKenzie et al. (2007), 306 species of non-marine mammal fauna existed in Australia 200 years ago whereas only 84 remained in 2007. This is the highest rate for any continent in the world. However, due to the lack of assessment before the European settlement, the real decline of this range of species remains difficult to appraise (Bilney et al., 2010).

Australian arid zone mammal species, within the Critical Weight Range (CWR) of 35g–5.5 kg (Burbidge and McKenzie, 1989), have suffered disproportionately in the terrestrial mammal decline (Moseby et al., 2009). This extinction of small and medium size mammals has mainly attributed to the predation by introduced cat (Felix catus) and red fox (Vulpes vulpes), and the competition with introduced herbivores such as the European rabbit (Oryctolagus cuniculus) (Finlaysona et al., 2008).

However, the decline of Australian's terrestrial mammals is not only attributed to predators and competitors but it is also assigned to many other factors. McKenzie et al. (2007) have described a model which uses the Faunal Attrition Index (FAI[1]). According to them, more than 93% of the observed variation in FAI was explained by a combination of six variables. Two were environmental variables, mean annual rainfall and environmental change, and four were faunal variables, phylogenetic similarity, body-weight distribution, area, and proportion of species that usually shelter on the ground.

1. 2. Restoration and reintroduction as a tool in conservation biology

In the rangelands of Australia, which cover around 6 million km² (Figure 2), the loss of landscape functional integrity is a likely cause of known extinctions (Ludwig et al., 2004). This part of the country is defined as landscapes where the primary use is pastoral (Ludwig et al., 2004). Therefore, the vegetation and soil patterns have been clearly modified by clearing, grazing and fire, and a current goal of environmental agencies in Australia is to restore these rangelands. According to Trigger et al. (2008), restoration can be understood as "efforts to restore the land to a previous level of functionality".In this context, one action of restoration is the translocation of native species. The terminology related to translocation and

[1] *This FAI, defined by Ward (1989), "measures the progress of a fauna along a trajectory from an initial* position at which all species is P (persist) throughout their potential range in a region, to an ultimate point at *which all species are E (extinct)".*

reintroduction is fairly confusing. Armstrong and Seddon (2007) suggest that the best approach is to refer to the original terminology. Thus, a translocation can be defined as "the movement of living organisms from one area with free release in another", with three types of translocation: introduction, reintroduction and re-stocking (IUCN, 1987). From this point, reintroduction has been defined as the "intentional movement of an organism into a part of its native range from which it has disappeared or become extirpated in historic times as a result of human activities or natural catastrophe" (IUCN, 1987). Increasing reintroduction programs has lead to the formation of the Reintroduction Specialist Group (RSG), under the support of the World Conservation Union's Species Survival Commission (IUCN/SSC), and reintroduction biology is now becoming a specific branch in scientific research (Seddon et al., 2007).

In arid Australia, the extinction of burrower species such as the greater bilby (*Macrotis lagotis*) could affect not only the fauna biodiversity but also nutriment and soil dynamics (James et al., 2009). James and Eldridge (2007) argue that the role of native burrowers has not been assumed by other species digging pits such as the introduced European rabbit (*Oryctolagus cuniculus*). Therefore, the reintroduction of arid mammals creating burrows to part of their former range could play a unique role in ecosystem function and restoration (James et al., 2009). These species could be defined as allogenic ecosystem engineers (Read et al., 2008).

Yet, before any reintroduction is undertaken, the main objective remains to make sure that the translocation site is suitable to the species to be translocated. The control of the introduced predators and/or the competitors in combination with the management of the habitat could assure a long-term recovery of these threatened populations (Fischer and Lindenmayer, 2000; McKenzie et al., 2007).

1. 3. The use of post-release studies in population management

Another important aspect to ensure appropriate management of these populations is to undertake post-release studies of the species ecological parameters (Finlaysona et al., 2008). Radio-tracking and Capture–Mark–Recapture (CMR) studies are useful techniques to understand ecological parameters of wild mammal populations such as survivorship, size of the population, animal locations and movements (Monterroso et al., 2008). CMR studies need a high number of individuals trapped to provide an appropriate estimation of those parameters. In Addition, the assessment can often be influenced by many factors like the localization of the traps or the phenomenon of "trap-happy" and "trap-shy". On the other hand, radio-telemetry allows a rapid acquisition of individual locations (Lira and Fernandez, 2008). The radio-telemetry analyses assume that radio-collars and radio-transmitters do not affect the behavior and the survivorship of animals, and research is sometimes required to ensure that this is the case (Golabek et al, 2008). Therefore, both radio-telemetry and CMR studies have advantages and disadvantages and the use of other methods such as track counts or line transects will permit a better understanding of the ecological parameters of the reintroduced population.

1. 4. Population Viability Analysis, an important tool in the conservation of threatened species

In addition to post released studies or before a reintroduction project, Population Viability Analysis (PVA) can be undertaken for modelling the "future" of the populations. PVA is defined, by Ralls et al. (2002), as "an analysis that uses data in an analytical or simulation model to calculate the risk of extinction or a closely related measure of population viability". Prediction of the risk of population (or species) extinction uses parameters such as the demographic structure, the survival rate or the reproductive rates of the population (Brook et al., 2000). For example, PVA is an important tool used by the International Union for the Conservation of Nature and Natural Resources (IUCN) to list a species on the Red List as a threatened species (Hinrichsen, 2009). Moreover, PVA can be undertaken to assess which conservation strategy or management measure is suitable for the persistence of the threatened population (Coulson et al., 2001).

The VORTEX[2] computer program is an individual-based simulation of the effects of deterministic forces as well as demographic, environmental and genetic stochastic events on wildlife populations (Miller and Lacy, 2005). It is particularly useful when there is considerable uncertainty about several aspects of the species biology. In fact, VORTEX can be used to assess the persistence of the population across the plausible ranges of parameters that might characterize the population (Miller and Lacy, 2005). A detailed description of the package and its features is given in Lacy (1993) and Miller and Lacy (2005).

In spite of the considerable scepticism regarding the accuracy of PVA, a study by Brook et al. (2000) showed that PVA predictions were surprisingly accurate. Indeed, they conducted a retrospective test of PVA based on 21 long-term ecological studies, using several modelling software, including VORTEX, and they concluded that PVA is a valid and sufficiently accurate tool for assessing and managing endangered species.

[2] Software program: Lacy R.C., Borbat M., and Pollak J.P. (2009). VORTEX: a stochastic simulation of the extinction process, version 9.99. Chicago Zoological Society, Brookfield, USA.

1. 5. The study

1.5.1. Operation Rangelands Restoration

In Western Australia, after the acquisition of Lorna Glen pastoral lease by the Western Australian Government in 2000, an ecological integrated project commenced, called "Operation Rangelands Restoration" and led by the Department of Environment and Conservation (DEC). One of the goals of this project is the reintroduction of 11 arid zone mammal species (Appendix A) to almost 600,000 hectares of rangelands in the north-eastern Goldfields of Western Australia by 2020 (DEC, 2007). The project team includes staffs from different divisions of the DEC: Goldfields Region (Kalgoorlie), Science Division and Nature Conservation Division (DEC, 2007).

1.5.2. The bilby, one of the Critical Weight Range species

- Biology and ecology

The bilby, *Macrotis lagotis*, is a semi-fossarial, nocturnal, medium-sized marsupial of the family Thylacomyidae (Figure 3). Its long, soft, blue-grey fur, large ears and long pointed muzzle make the bilby a characteristic marsupial (Figure 4). The long black and white tail is crested throughout its length and is necked on the extreme tip (Figure 5). The robust forelimbs and stout claws are used to dig burrows and extract food from the soil. The species is strongly sexually dimorphic in size (Table 1) with a weight of 1000-2500 for adult males and 800-1100 for adult females (Johnson, 2008).

The range of different habitats (Table 2) described by Southgate (1990b) indicate that the bilby is a flexible species. Three major vegetation types were recognized: open grassland growing on uplands and hills, mulga lands[3] growing on ridges and rises, and hummock grasslands[4] on plains and alluvial areas. However, it has been shown that the species required sandy or loamy soil for digging burrows and a low amount of ground cover to allow a good mobility for foraging (Southgate, 1990b).

Foraging areas are characterized by numerous scattered excavations. The diet of the species includes insects and their larvae, seeds, bulbs, fruit and fungi (Johnson, 2008). Gibson *et al.* (2002) have shown that the portion of plants in fecal pellets was relatively constant between seasons, whereas the frequency of invertebrate, mostly termites, was higher during summer than winter. In contrast with most of the introduced predators (cats, foxes, dogs) or competitors (rabbits, cows), a lack of free water is not an ecological barrier for the bilby (Gibson *et al.*, 2002).

[3] Mulga lands: vegetation association characterized by the presence of Acacia sp., known as mulga.
[4] Hummock: vegetation association characterized by the presence of species from the genus Triodia (commonly known as spinifex), it's the more dominant vegetation type in Australia.

Kingdom	Animalia
Phylum	Chordata
Class	Mammalia
Infraclass	Marsupialia
Order	Peramelemorphia
Family	Thylacomyidae
Genus	Macrotis
Binomial name	*Macrotis lagotis* (Reid, 1837)
Common name	Bilby
Other common names	Greater Bilby, Rabbit-eared Bandicoot
Aboriginal name used in Lorna Glen	Ninu

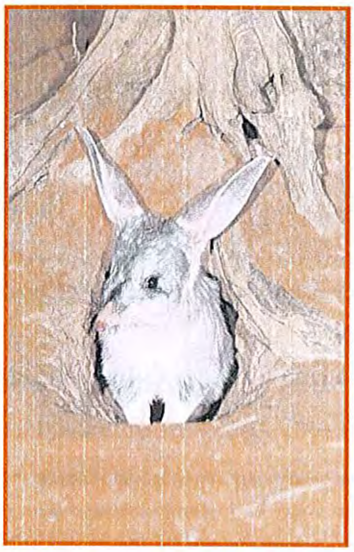

Figure 3: Scientific classification of the Bilby, Macrotis lagotis (Friend et al., 2008)
Photo: Bilby in a burrow entrance, available from Website 2

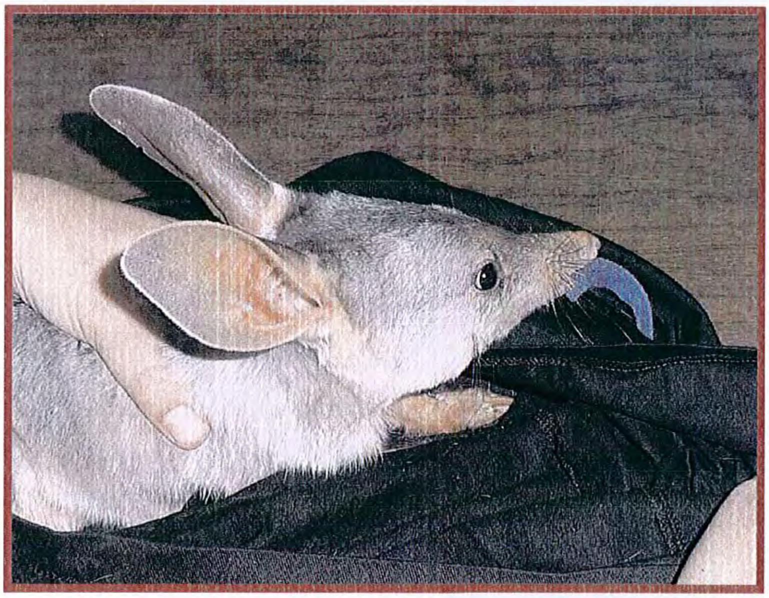

Figure 4: The bilby, a characteristic marsupial
Photo: L.Pertuisel

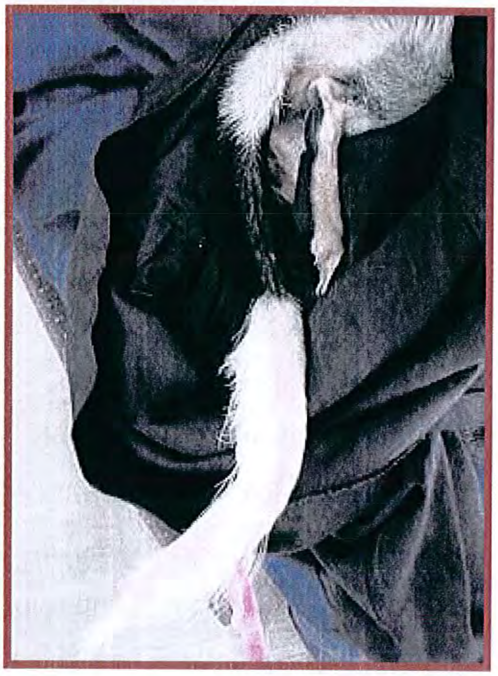

Figure 5: Bilby's black and white tail
Photo: E.Miller

Size	*Females*	*Males*
Head and body length (mm)	290-390	300-550
Tail length (mm)	200-278	200-290
Weight (g)	800-1100	1000-2500

Table 1: Length and weight of females and males bilbies (Johnson, 2008)

Bilbies are some of the most powerful burrowing animals in Australia (Read *et al.*, 2008) and they can construct a system that may be 3 meters long and up to 1.8 meters deep (Johnson, 2008). They are not restricted to one burrow and having many burrows suggest continual movement in response to changing availability of food (Moseby and O'Donnell, 2003). They live singly or in pairs and often occur at low density (Southgate *et al.*, 2005). Female bilbies reintroduced in northern South Australia had a home range of 0.18km2 and was significantly smaller than home range of males, 3.16km2 (Moseby and O'Donnell, 2003).

M. lagotis has a brief gestation period and rapid development of young (McCracken, 1990). Females can breed at any time of the year and breeding seasons appear to vary according to food availability and environment (McCracken, 1990; Southgate *et al.*, 2000). They reach sexual maturity at about six months of age but they may need to weigh about 600g before raising their first litter (Southgate *et al.*, 2000). Litters comprise 1-3 young with a sex-ratio at birth of approximately 1:1 (McCracken, 1990). The gestation period is estimated as 14 days, initial pouch exit occurs about 71-80 days latter and the young remain dependent on the mother for approximately 14 days, for a total mean period of pouch life and weaning of about 90 days (McCracken, 1990; Southgate *et al.*, 2000).

In captivity, longevity can commonly exceed 5 years but little is known about longevity in the wild (Southgate *et al.*, 2000).

A threatened species

Historically, the greater bilby occupied a large part of arid and semi-arid Australia (Figure 6) and at the time of European settlement, it was distributed over 70% of Australia (Southgate, 1990a). As part of CWR mammalian species (Southgate, 1994), bilbies have suffered a severe decline and now only occur in less than 20% of its former range (Southgate *et al.*, 2007) (Figure 6). Wild populations are currently distributed from the western desert region of the Northern Territory to Western Australia (Great Sandy, Gibson and Tanami deserts) (Figure 6) (Southgate *et al.*, 2007; Pavey, 2006). In addition, bilby populations can be found in south-western Queensland (Southgate *et al.*, 2007; Pavey, 2006).

The species is listed as vulnerable under the Environment Protection and Biodiversity Conservation Act (1999) and as a Schedule 1 species under the Western Australian Wildlife Conservation Act (1950) (Thompson and Thompson, 2008). It is also listed as vulnerable under the IUCN Red List of threatened species (Friend *et al.*, 2008).

Vegetation and soil	*Characteristics*	*Representative area*
1. Sparse grass/forbland a. Gravelly desert loams b. Deep brown calcareous	Uplands and hills, low fire frequency	South-west Queensland
2. Mulga lands a. Mulga/witchetty bush, lateritic red earths b. Pure mulga stands	Fire sensitive ridges and rises	Gibson Desert, scattered north of Alice Spring; in Pilbara, Great Sandy and Tanami Desert
3. Hummock grasslands a. Siliceous sands and red earths b. Calcareous and siliceous loams	Plains and alluvial areas, high fire frequency	Tanami, Great Sandy Desert, Dampier Land, Kimberley, East Pilbara

Table 2: Habitat types used by Macrotis lagotis (Southgate, 1990b)

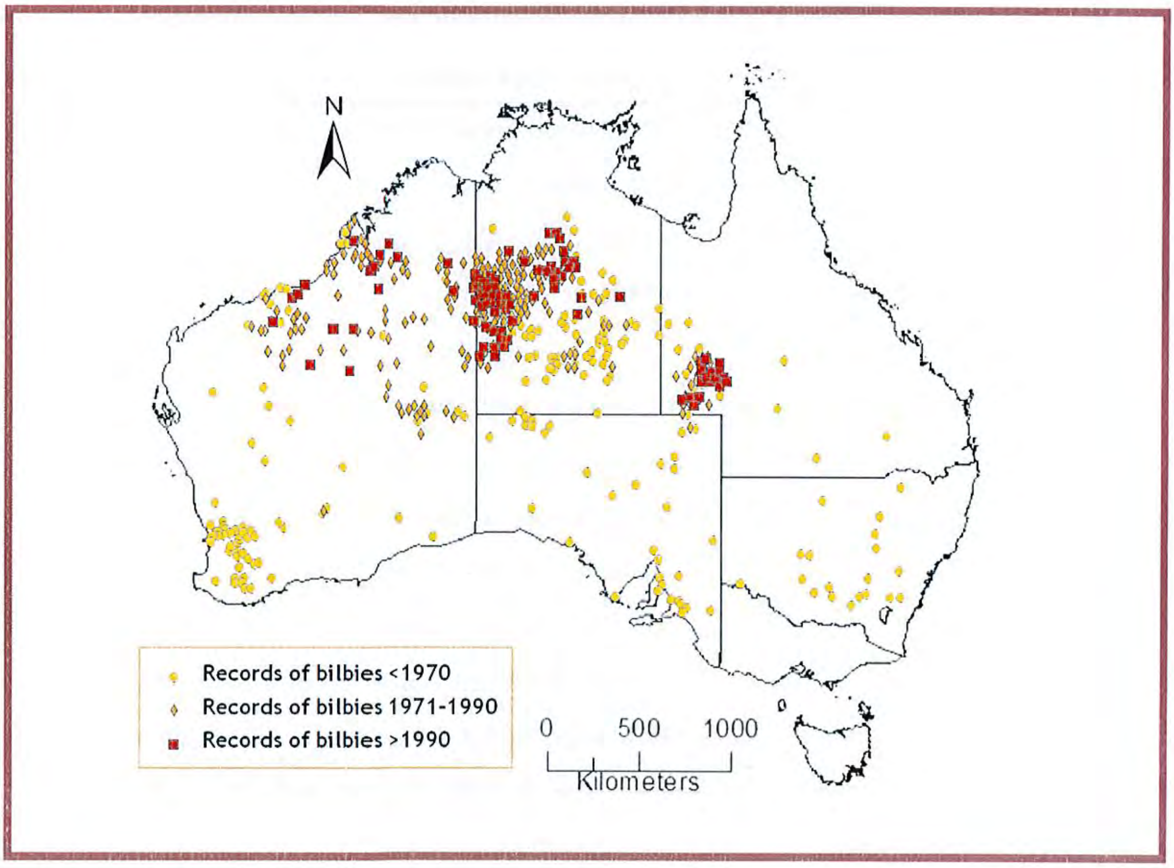

Figure 6: Distribution of bilbies in Australia: up to 1970, between 1971 and 1990, and after 1990. One point represents a record of a bilby.
Map: L.Pertuisel, modified from Pavey (2006)

1.5.3. Aims of the study

The present study assesses the success of the bilby reintroduction in the rangelands of Western Australia in terms of:

1. Summarize and analyze field ecological data

Existing data of radio-tracking and Capture-Mark-Recapture (2007-2009) will be examined in an attempt to assess some of the parameters needed for a Population Viability Analysis. Field work will also be undertaken at Lorna Glen (2010) on the established bilby population to have a better understanding of the bilby biology and to obtain additional ecological information.

2. Undertake Population Viability Analysis

Three different scenarios will be run using the modelling software VORTEX: (1) founder population size, (2) mortality rate and (3) supplementation. Sensitive analysis will be examined to assess which factors have the greatest influence on the projected population performance in terms of management measures. Also, these results will provide ecological information needed to run a more robust PVA in terms, still, of management actions which might be designed to improve the current status of the reintroduced population.

2. MATERIAL AND METHODS

2. 1. Lorna Glen

Lorna Glen was acquired by the Western Australian Government in 2000 and it is managed jointly by the Department of Environment and Conservation and the Wiluna aboriginal community. It is a formal pastoral lease about 1100 kilometers north-east of Perth and 160 kilometers north-east of Wiluna (Figure 7). This 250,000 ha area overlaps two Interim Biogeographic Regionalisation for Australia (IBRA[5]) regions: Murchison and Gascoyne (Website 3). It contains at least 20 different land systems and vegetation types such as hummock grasslands, shrublands or low woodland with mulga (Appendix B1 and B2).

The region of Lorna Glen is considered as a desert mainly due to its typical climate of an Australian arid region. The daily temperatures vary from 20°C to 40°C in summer and can decrease to 5°C or less in winter (Figure 8). It's an area of low rainfall and the mean rainfall is 250mm per annum. However, high rainfall is possible at any given time and monthly rainfall can be very different from one year to another (Figure 9).

[5] IBRA: Interim Biogeographic regionalization of Australia developed by the Australian Government's Department of the Environment, Water, Heritage and the Arts.

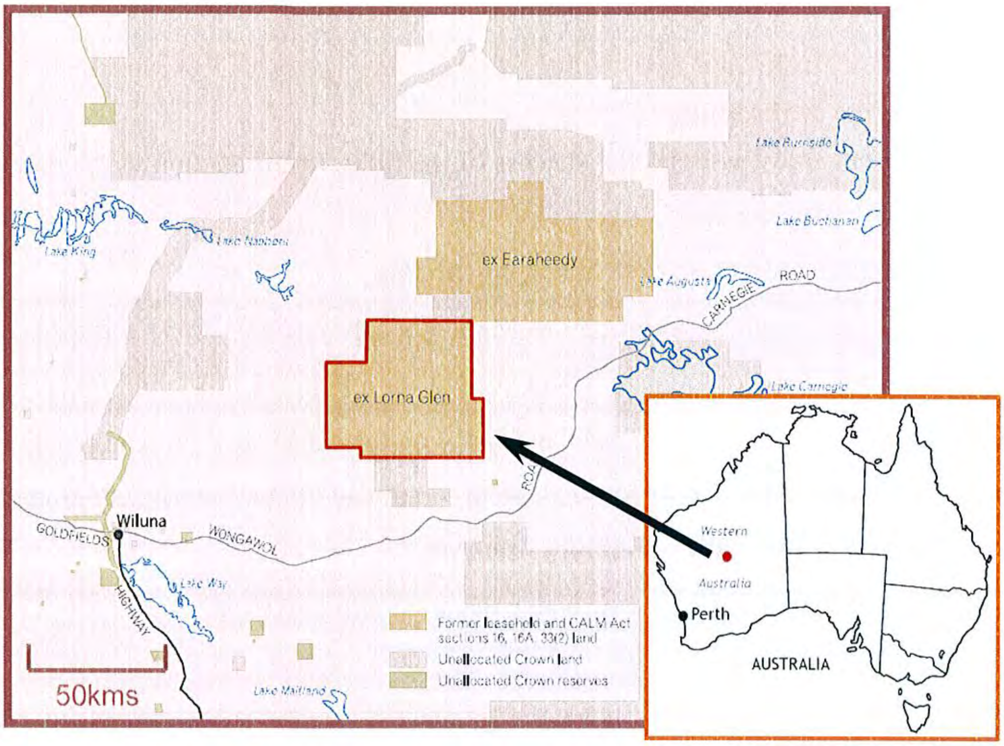

Figure 7: Localization of Lorna Glen pastoral lease
Map: L.Pertuisel, modified from DEC (2007)

Figure 8: Mean daily temperatures by month in Wiluna (data available on Website 4)

Figure 9: Mean monthly rainfalls in Lorna Glen (data recorded from 1940 to 2007)

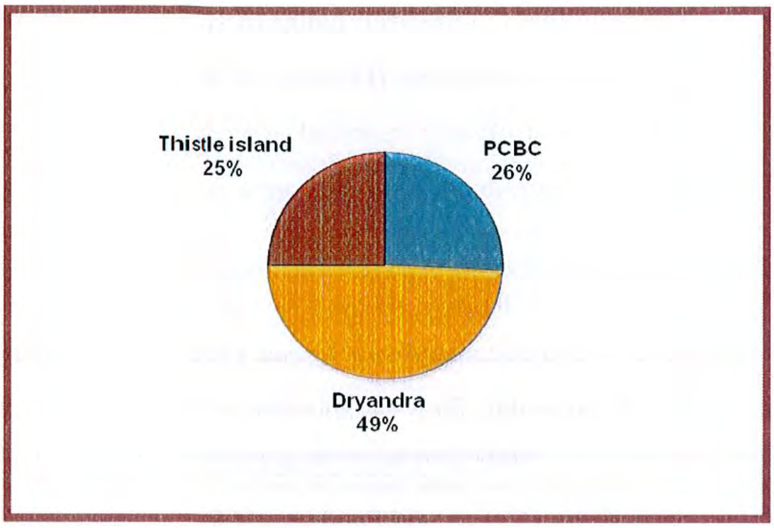

Figure 10: Proportion of sourcing bilbies for the reintroduction from different populations: Peron Captive Breeding Center (PCBC), Dryandra woodland ecology centre and Thistle Island

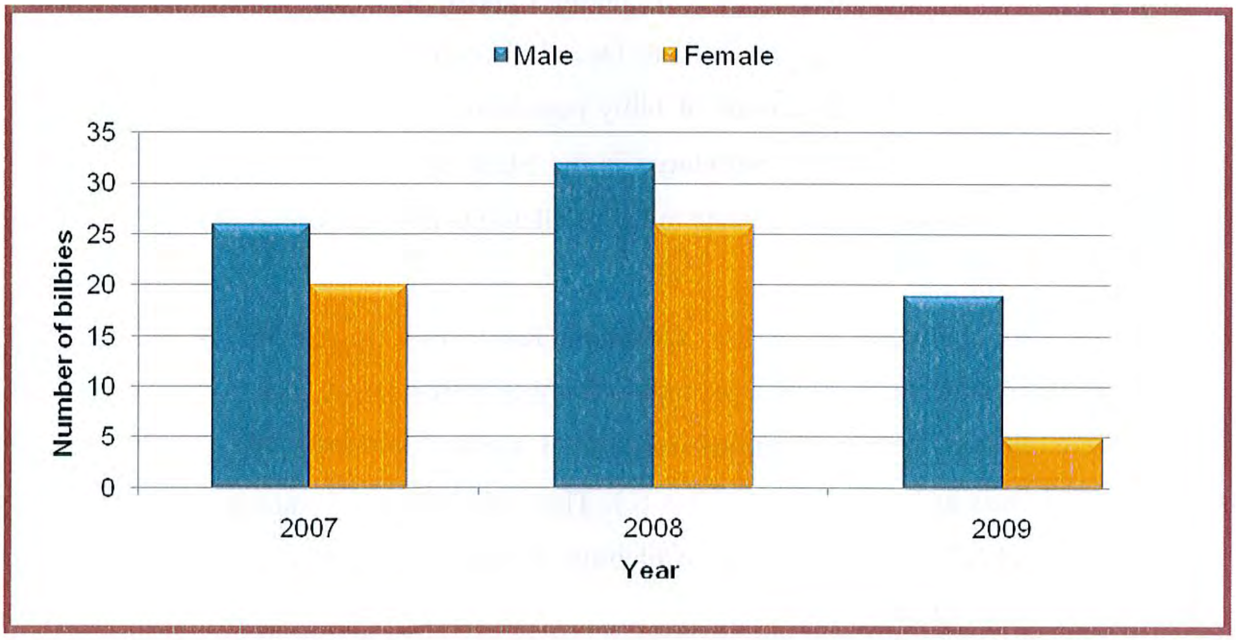

Figure 11: Proportion of males and females released bilby per year

Small rodents and small carnivorous marsupial of the family Dasyuridae[6] are the last native mammals remaining from the 37 terrestrial mammal species which may have occurred in Lorna Glen prior to the European settlement (Dunlop and Morris, 2009). Potentially, Lorna Glen could support one of the most diverse mammal assemblages in arid Australia (Morris and Dunlop, 2008). Mammal reintroduction in this area will contribute to the long-term recovery of native threatened species, but also to the restoration of rangeland ecosystems.

A key objective in any reintroduction remains to make sure that the translocation site is suitable to the species to be translocated. At Lorna Glen, it was important to control predator abundance and more particular, feral cat abundance. For this reason, feral cat baiting has been conducted annually since 2004 and their abundance has been reduced by about 2/3 in 2007, 10 cats or less per 100 km (Morris and Dunlop, 2008).

2. 2. Bilbies reintroduced

2. 2.1. Sourcing bilbies for reintroductions

The bilbies released in Lorna Glen between 2007 and 2009 originated from both captive and wild population (Figure 10). Peron Captive Breeding Center (PCBC) and Dryandra woodland ecology centre are both fenced enclosure although Dryandra woodland reserve recreate more wild conditions of bilby populations. Bilbies from Thistle Island, in South Australia, are wild animals introduced in the island in the 1990's. However, PCBC is the closest in vegetation type and climate to Lorna Glen (Dunlop and Morris, 2008).

2. 2.2. Releases

The first reintroduction of the "Operation Rangelands Restoration" project was in 2007 with the release of 46 bilbies in August-October period. On August 2008, another 57 bilbies were released, and the 24 animals released in August 2009 made a total of 128 bilbies that were released in Lorna Glen (Figure 11). The male-biased sex ratio in the population (approximately 1.5:1) is only due to the availability of more males in breeding centers and not to the wishes of the DEC.

Following a report on the selection of release sites for bilbies (Morris et al., 2007), three areas (Appendix C) have been selected, based on knowledge of habitat used by bilbies.

[6] Dasyuridae: family of carnivorous marsupial that includes the mulgaras, the quolls (formerly called "native cats"), dunnarts (formerly known as "marsupial mice and rats"), Tasmanian devil, and their allies.

2. 3. Field methods

2. 3.1. Trapping and radio-tracking between 2007 and 2009

➢ **Radio-tracking**

Radio-tracking has been used for monitoring the survivorship, refuge use and movements of the released animals in the firsts months following the reintroduction. For each release, a proportion of bilbies (Figure 11) has been fitted with tail-mounted radio-transmitters (Sirtrack), with a four month battery life and mortality mode latched after 6 hours of inactivity. Daily radio-tracking from the ground was conducted over 98 days following the first release (between August and November 2007), using handheld aerials (detection range of 500 meters) and a pump up aerial (detection range of 1000 meters). Following the second release in 2008, bilbies fitted with radio-transmitters were daily radio-tracked over 87 days (August-November period). Radio-tracking has been conducted opportunistically in 2009, following the third reintroduction of bilbies.

➢ **Trapping**

In addition to the radio-tracking monitoring, trapping using the method of Capture-Mark-Recapture has been performed during August-December 2007 period, August-September 2008 period and December 2008. The reintroduction of the released and marked animals is considered as the "Capture" and "Mark" events. Trapping sessions allow the "Recapture" of the bilbies. Each animal is identified thanks to a Passive Integrated Transponder (PIT) tag with a single animal identification number (ID).

2. 3.2. Trapping protocol in 2010

Trapping sessions in 2010 were conducted from 21 to 31 April and from 2 to 11 June. Tracks, feeding excavations, scats or active burrows (Figure 12) were used to detect the presence or not of bilbies in the prospected areas (Appendix D). Sheffield traps (220x220x550mm, Figure 13, Website 5) were set at dusk and baited with a mixture of rolled oats and peanut butter. In addition, traps were covered in hessian sacks to protect animals from the sun in early morning. Five sites were trapped during the two periods of trapping and each site was trapped between 2 and 4 nights. Indeed, *M. lagotis* is known to be an allusive species and to not easily enter in the traps (Southgate *et al.*, 1995; Southgate *et al.*, 2005; Southgate, 2005). Traps were checked and closed for the day in early morning, in the couple hours after sunrise. Closing of the traps during day time reduces the likelihood of catching diurnal animals like goannas[7]. Considering the trapping sessions were localized in

[7] Goanna: name used to refer to any number of Australian monitor lizards of the genus *Varanus*.

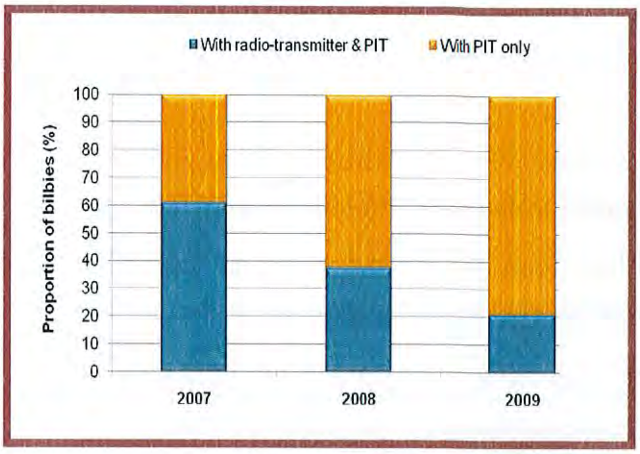

Figure 12: Proportion of bilbies fitted with radio-transmitters and PIT or just with PIT, per year

Figure 13: Sheffield trap covered with hessian bag
Photo: L.Pertuisel

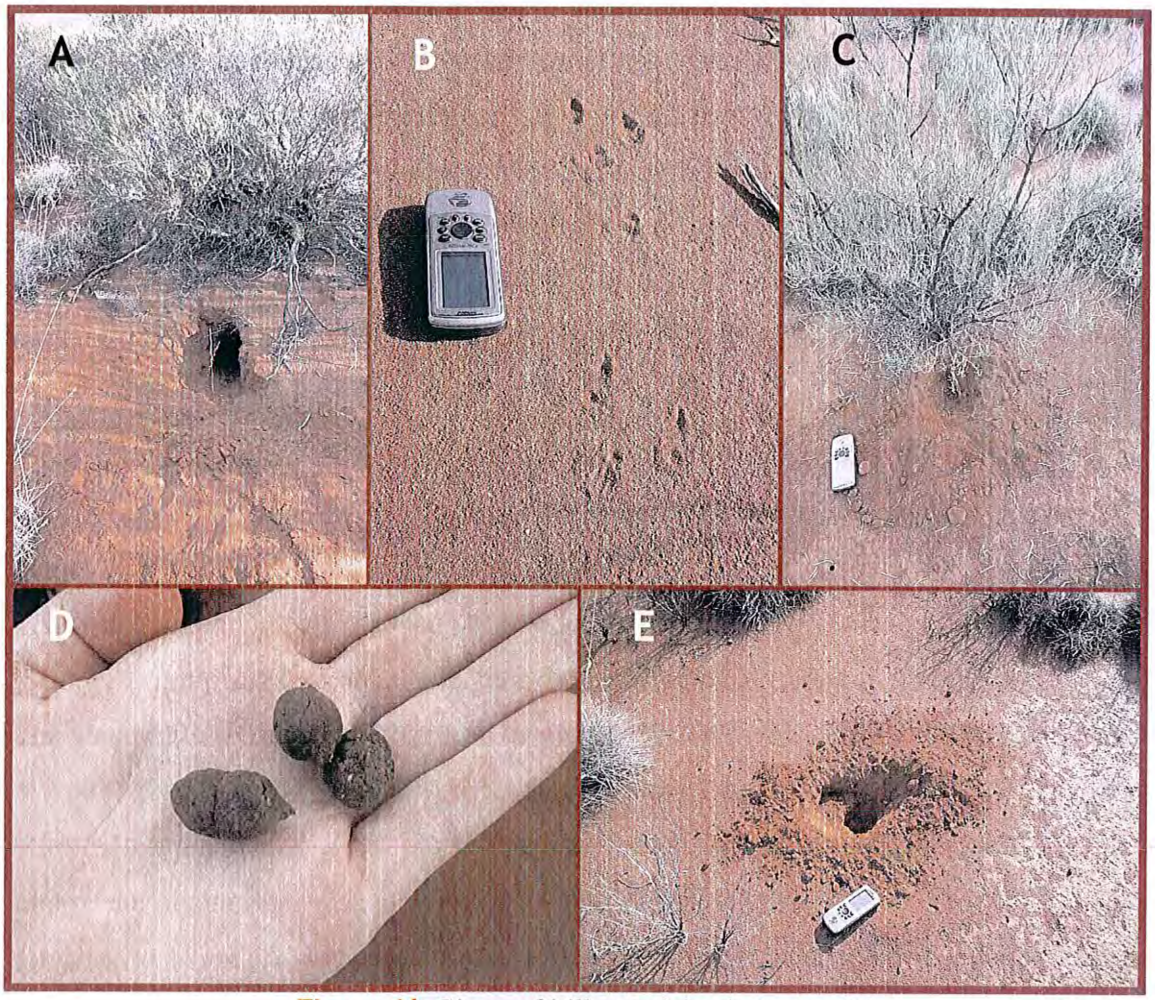

Figure 14: Signs of bilby activity in Lorna Glen
(A) Active burrow entrance; (B) Tracks; (C) Feeding excavation; (D) Scats; and (E) Feeding excavation
Photos: L.Pertuisel

Figure 15: Bilby caught in a Sheffield trap
Photo: E.Miller

Figure 16: Measurement of a bilby's foot
Photo: E.Miller

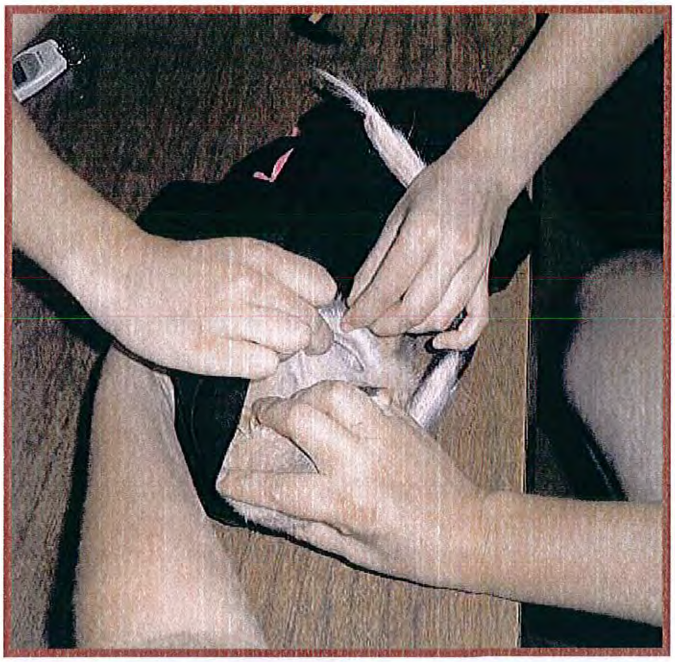

Figure 17: Checking of the pouch of a female bilby
Photo: E.Miller

different areas, each trapping session is detailed in Appendix E. Bilbies caught at night (Figure 15) were carried to the homestead in black bags in order to reduce the stress of the animals. Processing was conducted in the laboratory at the homestead so as to have quiet conditions. Length of the head, weight, diameter of the tail and length of the foot were measured for each bilby (Figure 16). For the female, it was needed to check their pouch for the reproductive rate (Figure 17), and for the male, the testis were measured. The length of pouch young was recorded, but their sex was not determined. All these parameters were written in a "Mammal trapping data sheet" (Appendix F) and entered later in an Excel data sheet. Animals were released in late afternoon at the same localization of their capture, directly into a burrow.

2. 4. Field data analysis

Microsoft Office Excel 2003 and 2007 have been used for summarizing and analyzing the field data.

2. 4.1. Mortality

The proportion of bilbies with radio-transmitter has been used as a sample to calculate the mortality rate of the total population. Indeed, the signal "live" or "dead" of the transmitter, as well as the recovery of the body/carcass, allows a more accurate estimation of the mortality rate. However, this method only considers bilbies dead in the 4 months following their release, time of the battery life. The assumption has been made that the death probability of reintroduced animals is the highest in the first months of the reintroduction. Thereby, it is assumed that additional deaths after the first 4 months don't impact significantly on the annual mortality rate. Between 2007 and 2009, 54 animals were fitted with radio-transmitters. Mortality reports have been used for calculating the proportion of each cause of probable bilby death. Almost all of the dead animals recorded are bilbies fitted with radio-transmitter. Thus, predicted bilbies remaining has been calculated based on this proportion.

2. 4.2. Breeding

The proportion of females breeding in the reintroduced population has been calculated thanks to the number of females caught during trapping sessions (2007-2010), even the new ones without PIT (2 females). Sub-adult females, determined thanks to their virginal pouch or their small weight (<600g), were set aside from the analysis. Also, a female recaptured a second time, in a delay of 3 months, was not considered as the breeding cycle was probably the same. The number of pouch young per litter was recorded with the same method.

2. 5. Population Viability Analysis

2. 5.1. Data input to VORTEX – Estimated parameters

A range of computer simulation programs can be used for PVA. VORTEX was used in this study for several reasons: (1) it is a complete modelling program, with many parameters input, and many options to change the values of the parameters and to assess their impact on the population; (2) it is appropriate for small populations; (3) it has been used in studies on other medium-sized marsupial species (Lunney *et al.*, 2002; Lindenmayer *et al.*, 1993; Lacy and Clark, 1990); and (4) it has a workable interface with the possibility of adding notes on every step of the project.

Some of the parameters used for running VORTEX simulations, like breeding or mortality, have been calculated from field data of the population reintroduced. However, in cases where there was a lack of information, available data, from literature about biology and demography of *M. lagotis*, where used to derive input values to VORTEX.

Some of the screens in VORTEX, including "Labels and state variables" or "Genetic management", have voluntarily not been considered, given the lack of information. The rational for the estimates of the parameters input in VORTEX (Table 3) is outlined below.

- **Population and time horizon**

Despite the long distance between several sites where bilbies have been recorded, the decision was made to consider the bilbies reintroduced as only one population. Indeed, it is documented that the species has a large home range (Moseby and O'Donnell, 2003). Moreover, bilbies in Lorna Glen are known to have moved between two sites separated by more than 20 kilometers by themselves. The current initial size of the population is unknown. However, estimation can be calculated thanks to the number of the bilbies released and the number of mortalities (see 2. 4.1. in material and methods).

Carrying capacity of bilby population in Lorna Glen has been estimated by patch area and home range size. The mean home range size for the bilby (male and female) in northern South Australia is 1.67km2 (Moseby and O'Donnell, 2003). Lorna Glen is an area of 6000km2; however, the assumption has been made that only 1/3 of the total area is suitable for the species *M. lagotis*, as it is function of habitat and resources. Moreover, a test with VORTEX using different values of carrying capacity (100, 500, 1000, 5000) showed that decreases of this parameter had a small-scale effect on the probabilities of extinction of the population (difference between 2 probabilities of extinction <0.03). For these reasons, it has been decided to fix the estimated carrying capacity at K=4000 individuals.

Parameter	*Value (SD due to EV[1])*	*Source*
No. of computer simulations	1000	This study
No. of years modelled	20	This study
No. of population	1	This study; Moseby and O'Donnell, 2003
Initial population size	50	This study
Carrying capacity (K)	4000 (10)	This study; Moseby and O'Donnell, 2003
No. of scenarios	3	This study
Inbreeding depression	Nil	No enough data to assess it
No. of type of catastrophes	0	This study; Southgate and Possingham, 1995; Southgate et al., 2007
Breeding system	Polygamous	Johnson and Johnson, 1983
Age of first offspring for females	1	McCracken, 1990; Southgate et al.,2007
Age of first offspring for males	1	McCracken, 1990; Southgate et al.,2007
Maximum age of reproduction	5	McCracken, 1990; Southgate et al.,2007
Maximum No. of brood per year	4	McCracken, 1990; Southgate et al.,2007
Maximum No. of young per brood	3	McCracken, 1990; Southgate et al.,2007
Sex ratio at birth (% of males)	60	McCracken, 1990; This study
% adult male in breeding pool	100	This study
Density dependant reproduction	Nil	No enough data to assess it
% adult females breeding	78* (10)	This study*
Probability of brood per year (%)		
1 brood	0	Southgate and Possingham, 1995
2 broods	17	Southgate and Possingham, 1995
3 broods	33	Southgate and Possingham, 1995
4 broods	50	Southgate and Possingham, 1995
Probability of offspring per brood and per year (%)		
1 offspring	27*	This study*
2 offspring	73*	This study*
3 offspring	0*	This study*
Mortality rates (%) - same for both sexes		
Mortality from age 0 to 1	70 (10)	Southgate and Possingham, 1995
Mortality after age 1	56* (10)	This study*
Harvest	No	This study
Supplementation	No	This study

Table 3: Assumptions used as initial input for variables in VORTEX for the basic scenario

[1] Standard Deviation due to Environmental Variation: since there are no enough data on environmental variation, standard deviation in fecundity, mortality rates and in carrying capacity was fixed at 10 % due to environmental variation.

* Refer to the results

The time horizon for the population projection has been set at 20 years since this is a time horizon relevant to management recommendations on the "Operation Rangeland Restoration" project. One thousand iterations were run for each scenario.

Catastrophes

Three types of rare events could be considered as catastrophes in this kind of population modelling: drought, big rainfall and fire. However, there is no information available that may pretend that those events have an impact on the population reintroduced. In addition, rainfall records in Lorna Glen since 1940 (Appendix G) show that the probability of the occurrence of a drought or a big rainfall could be estimated between 0.05 and 0.1. Moreover, Southgate and Possingham (1995) report that the maximum effect of drought or big rainfall events had little effect on bilby population. Regarding fire events, it could not be considered as a catastrophe for bilby population. In fact, seed from fire-promoted plants is one the key food resources used by the bilby (Southgate et al., 2007), so fire would be a favorable process in the ecology of this species.

Reproduction

The breeding system of M. lagotis is not well documented. However, in a behavioral survey of the bilby, Johnson and Johnson (1983) report that there is no evidence of monogamous pair bonds that are reformed each year. Thus, breeding system of M. lagotis is considered as polygamous.

Fecundity data input to VORTEX were derived using studies by McCracken (1990) and Southgate et al. (2007) as a guide. The assumptions were made to fix the age of the first reproduction, for males and females, at 1 year old, and the maximum age of reproduction at 5 years old. Adult breeding females were assumed to produce a maximum of 4 broods per year and 3 young per brood, and all adult males were assumed to be capable of breeding. According to McCracken (1990), sex ratio at birth in M. lagotis was found to be 1:1. However, regarding the availability of sourcing animals in this study, the sex ratio is male-biased and approaches 1.5:1.

The proportion of females breeding in the Lorna Glen population has been estimated thanks to the number of females caught during trapping sessions, with a new reproduction cycle in the wild (recapture at least 3 months after the time of the release, see 2. 4.2. in material and methods). The number of offspring per litter has been calculated using all the females captured during trapping sessions (see 2. 4.2. in material and methods). Only 3 females have been recaptured twice with a 3 months delay and one was a sub-adult at the first recapture, it's not enough to have an accurate assessment of the number of brood per female and per year. Moseby and O'Donnell (2003) record an average of 2.54 completed litters per female and per year for a bilby population reintroduced in northern South Australia. Based on an other reintroduction program at Watarrka National Park (Northern Territory, Australia), Southgate and Possingham (1995) report annual probabilities of 0 for zero and one litter per year, 0.17 for two litters per year, 0.33 for three and 0.5 for four.

Mortality rates

Annual mortality for adults (after age 1) has been estimated using the proportion of bilbies with radio-transmitter (see 2. 4.1. in material and methods). Annual mortality for juveniles (between age 0 and age 1) was derived from a modelling study of bilby reintroduction in southern North Territory (Southgate and Possimgham, 1995) and fixed at 70%. The assumption as been made that there is no difference in mortality rate between males and females.

Harvest and supplementation

It was decided to not consider any harvest or supplementation in the basic scenario for the modelling of the population reintroduced.

2. 5.2. Simulations

In addition to the basic scenario using the estimated parameters, three scenarios were modelled to identify factors witch may be critical to the survival of the Lorna Glen population. In the framework of this study, VORTEX was used to investigate: (1) the influence of founding population size on population viability; (2) the effects of the mortality rate on the population, and, in particular, the effect of a diminution in cat predation; and (4) the option of supplementing the population to increase the population viability.

Many factors could be investigated to identify their impact on the population. However, the decision was made to confine the analysis to those three parameters since they are relevant to management options.

Data derived from the computer simulation analysis were: (1) deterministic and stochastic population growth rates (and SD); (2) mean year of first extinction; (3) probability of population extinction; and (4) mean population size (and SD).

Scenario 1: Increase initial population size

In this first scenario, the impact of founder population size on the survival of the population was examined by altering the initial population size. Initial population sizes of 50, 100, 150 and 200 animals were modelled.

- **Scenario 2: Decrease mortality**

The impact of several mortality rates was examined by considering mortality rates estimated: from all threatening processes (resources, cat and raptor predation, and unknown causes) or without cat predation. In addition, the impact of a general reduction in mortality has been studied (decrease of 20%, 40%, and 60%).

- **Scenario 3: Supplement the population**

In this third and last scenario, the impact of supplementation on the population was examined. Supplementation or re-enforcement can be defined as an "addition of individuals to an existing population of conspecifics" (IUCN, 1998). This scenario has been created to know if future translocations could reinforce the actual population and prevent it from a possible decline. The main goal was to test different approaches in supplementation, and their influence on the population viability. Supplementation of the population has been studied along two main dimensions: the total number of individuals that were released (100 or 200 individuals) and the temporal scale of stocking, whether the same number of individuals was released in a single year (year 5 or year 10), or during several years (5 years, or 10 years).

2. 5.4. Sensitivity analysis

To investigate the parameters most sensitive to the survival of the bilby population, a sensitivity analysis was performed. The sensitivity analysis measures the extent of change in the modelled population output values due to a known change in assumptions (Lunney et al., 2002). Considering the different scenarios defined above, all parameters were kept constant, except the one in focus, which was changed. Based on a recent modelling study using VORTEX (Jaric et al., 2010) and personal communication of the main author, a ranking technique has been applied to compare the results of the sensitivity analysis. The ranking method allowed giving a rank for each change in parameters, function of the importance of the change, regarding the outputs of the basic scenario. For each type of simulation outcomes considered (deterministic growth rate, stochastic growth rate, probability of extinction, and mean population size), the output simulation value from each of the sensitivity scenarios was subtracted from the basic scenario value. Then, for each output parameter, values were sorted. The higher rank[8] was given to the higher value and all the ranks were given decreasing function of the value, to finish with the number 1 for the rank of the lowest value. In addition, the sum of rank values of all resulting parameter outputs, for each change of each scenario, has been calculated.

[8] 16 in this study due to: 4 changes for scenario 1, 4 changes for scenario 2 and 8 changes for scenario 3

3. Results

3. 1. Quantitative results from the field data between 2007 and 2009

3. 1.1. Mortality

In total, 30 dead bilbies have been recorded since the first translocation in 2007. Causes of death have been assessed and recorded in a mortality report for each animal recovered. Four categories of causes of death have been described: lack of resources, cat predation, raptor predation, and unknown cause. The proportion of each cause for bilbies in Lorna Glen is shown in the figure 18. 39% of bilby deaths are due to cat predation, followed by the lack of resource and unknown cause (27%), and raptor predation only representing 7% of all the mortalities.

Mortality rate of bilby, taking cat predation into account, is about 0.56, whereas, the probability of death, without cat predation, is about 0.43 (Table 4).

Based on the proportion of bilbies fitted with radio-transmitters and the mortality rate, the predicted remaining size of the population is about 56 animals (Table 5).

3. 1.2. Breeding

Based on the 20 females caught during trapping sessions (2007-2010), 75% of adult females were breeding. In addition, 27% of these females had 1 offspring in the pouch, 73% of them had 2 young in the pouch, and none of them had 3 young in the pouch. The results are shown in table 6 and figure 19.

3. 2. Qualitative results from the trapping sessions in 2010

Only 2 bilbies were caught during all trapping sessions in two different sites separated by about 500m (sites 2 and 3, Appendix D and E). Tracks, scats and/or active burrows were found in these two sites. The animals caught were a male and a female. The male was in good condition and weighed 2090 grams. The female was also apparently healthy and was carrying 2 pouch young of about 70 millimeters. She was also fairly heavy with a weight of 1500 grams with the 2 little pouch young. Thanks to their PIT, they have been identified. They have been both released in August 2009 at the same localization of these two trapping sessions. During the 8 nights of trapping in these two areas, the female was caught three times and the male twice.

In spite of the tracks and foraging excavations in the last trapped area (number 5 in appendix D and E), no bilbies were caught.

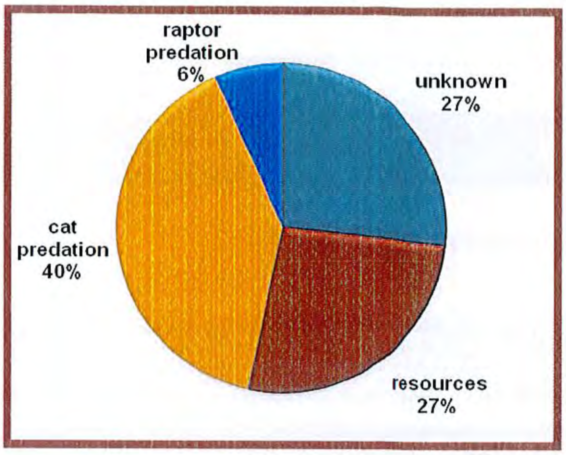

Figure 18: Proportion of bilby dead due to cat predation, raptor predation, lack of resources, and unknown cause

Release	Cause of death				Total of animal released		
	unknown	resources	cat predation	raptor predation	dead	with radio-transmitter	P(mort)
2007	4	3	7	2	16	28	0,57
2008	4	5	5	0	14	21	0,67
2009	0	0	0	0	0	5	0,00
				Total	30	54	0,56
				Without cat predation	18	42	0,43

Table 4: Probability of bilby mortality P(mort) taking, or not, cat predation into account

Released	With radio-transmitters		Mortalities		Maximum remaining		Predicted remaining	
	actual	% of released	actual	% of released	actual	% of released	actual	% of released
128	54	42,19	30	23,44	98	76,56	56,89	44,44

Table 5: Proportion of bilbies released, with radio-transmitter and dead, and calculation of maximum bilbies remaining and predicted bilbies remaining

	0 PY	1 PY	2 PY	3 PY	Total
Number of females	5	4	11	0	20
p (breeding or not)	0,25		0,75		1
p (PY per litter)	-	0,27	0,73	0	1

Table 6: Probability of females caught during trapping sessions (1) breeding or not, and (2) with 1, 2 or 3 pouch young (PY) per litter

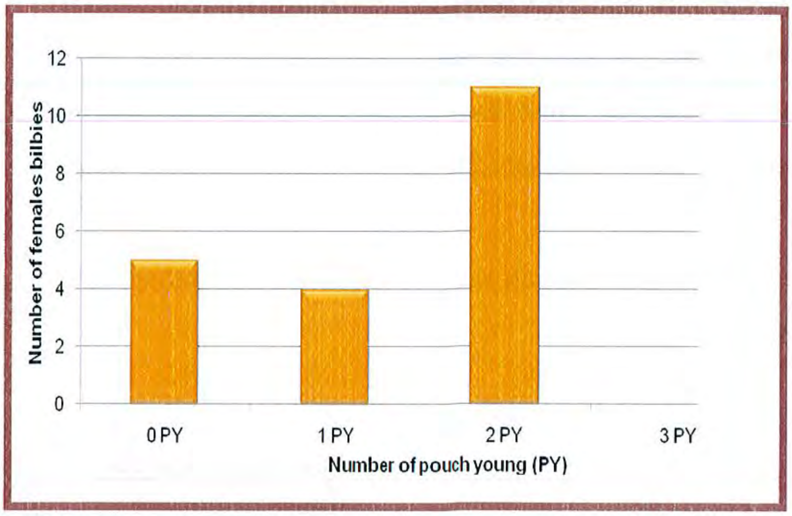

Figure 19: Proportion of adult female bilbies caught during trapping sessions with 0, 1, 2 or 3 pouch young

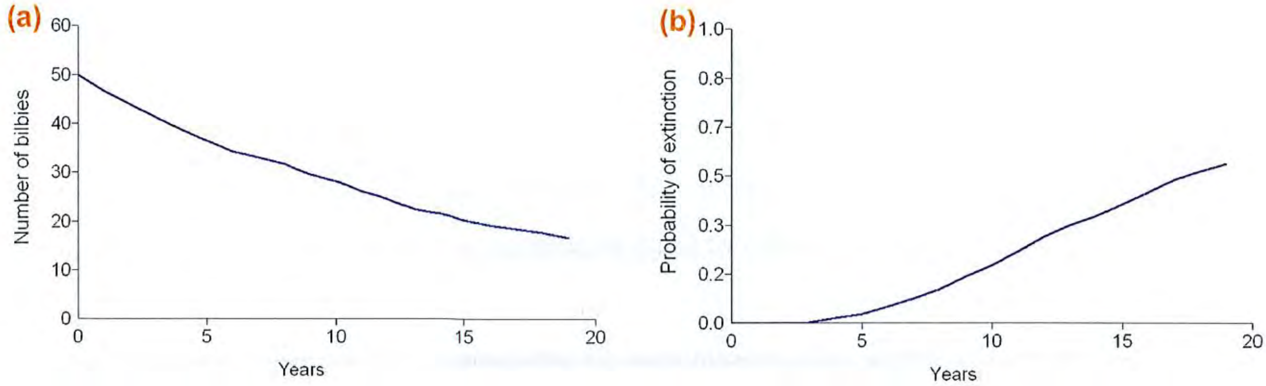

Figure 20: Mean population size (a) and probability of extinction (b) of the bilby population modelled over 20 years with basic assumptions of the parameters

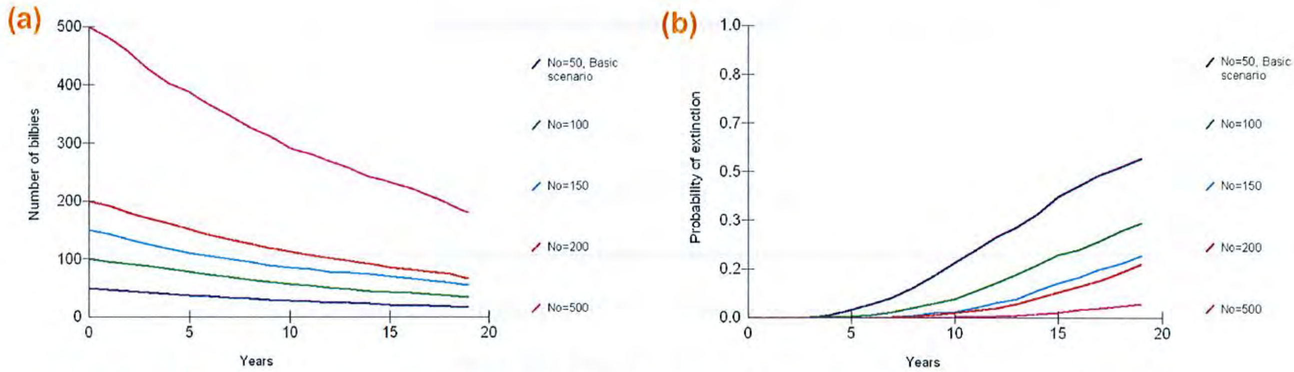

Figure 21: Mean population size (a) and probability of extinction (b) of the bilby population modelled over 20 years with different values of founder population size (No): **50**; **100**; **150**; **200**; and **500**

Scenario	*Deterministic growth rate*	*Stochastic growth rate [mean (SD)]*	*Years of first extinction [mean (SD)]*	*Propability of extinction*		*Size of the population [mean (SD)]*	
				Year 10	*Year 20 (SE)*	*Year 10*	*Year 20*
Basic assumptions No=50, all causes of mortality, no suppl	-0,054	-0.108 (0.381)	12.54 (4.32)	0,191	0.568 (0.0157)	28.17 (35.49)	15.81 (44.03)
Scenario 1 - Increase initial population size							
100	-0,054	-0.108 (0.354)	14.07 (3.85)	0.077	0.375 (0.0153)	60.90 (80.42)	35.29 (76.93)
150	-0,054	-0.110 (0.346)	15.16 (3.62)	0.034	0.281 (0.0142)	88.32 (102.81)	50.87 (101.77)
200	-0,054	-0.109 (0.335)	15.72 (3.23)	0.014	0.220 (0.0131)	116.01 (134.13)	62.57 (108.61)
500	-0,054	-0.101 (0.309)	17.43 (2.34)	0.000	0.072 (0.0082)	289.88 (313.37)	163.30 (267.13)
Scenario 2 - Decrease mortality rate							
Without cat predation	0.064	0.017 (0.299)	13.53 (3.99)	0.029	0.112 (0.0100)	92.09 (103.22)	183.30 (313.87)
Decrease 20%	0.048	-0.003 (0.313)	13.70 (4.24)	0.040	0.159 (0.0116)	79.16 (88.14)	131.86 (263.30)
Decrease 40%	0.139	0.095 (0.282)	12.97 (5.08)	0.011	0.033 (0.0056)	196.76 (195.32)	712.00 (878.90)
Decrease 60%	0.220	0.184 (0.247)	9.00 (2.83)	0.001	0.002 (0.0014)	451.61 (403.15)	2182.36 (1393.56)
Scenario 3 - Supplement the population							
N=100, Y5	-0,054	-0.020 (0.482)	16.13 (4.54)	0,001	0.116 (0.0101)	123.55 (88.69)	77.63 (126.29)
N=200, Y5	-0,054	0.010 (0.571)	16.67 (4.70)	0.001	0.047 (0.0067)	222.37 (149.83)	129.12 (193.84)
N=100, Y10	-0,054	-0.023 (0.532)	8.87 (4.33)	0.000	0.039 (0.0061)	128.04 (37.73)	90.17 (100.16)
N=200, Y10	-0,054	0.012 (0.618)	7.37 (2.32)	0.000	0.006 (0.0024)	228.83 (35.46)	166.44 (178.76)
N=20, Y1-5	-0,054	-0.028 (0.346)	16.91 (2.55)	0.000	0.161 (0.116)	114.85 (95.48)	64.96 (102.49)
N=40, Y1-5	-0,054	0.003 (0.354)	17.93 (1.80)	0.000	0.075 (0.0083)	209.37 (168.13)	109.59 (4.84)
N=10, Y1-10	-0,054	-0.013 (0.323)	18.04 (1.68)	0.000	0.079 (0.0085)	125.32 (81.27)	76.63 (116.93)
N=20, Y1-10	-0,054	0.022 (0.314)	18.24 (1.30)	0.000	0.025 (0.0049)	219.83 (121.55)	141.31 (199.53)

Table 7: Changes in assumptions and the resulting effects on the modelled population

3. 3. Scenario outputs

3. 3.1. Basic scenario

Table 3 (see 2. 5.1. in material and methods) summarizes the range of basic assumptions for life-history parameters of bilby population reintroduced in the rangelands of Western Australia.

The simulation, using basic assumptions of parameters over 20 years, indicates that the population growth rate of the bilby population is negative (r=-0.108, SD[9]=0.381), therefore the population is declining. About 30% of the founder population size is remaining at year 20 (Figure 20a). The probability of extinction after 20 years is 0.568 (SE[10]=0.0157) (Figure 20b), it means that, in 1000 simulations of the population modelled for 20 years, more than a half went extinct.

3. 3.2. Scenario 1 – Increase initial population size

An augmentation of the founder population size of the modeled population allows decreasing the mean probability of extinction until 0.072 for an initial number of 500 bilbies (Table 7 and figure 21b). However, the mean stochastic growth rates are fairly similar for all the simulations (stoch r is about -0.1, Table 7) and the population is still declining (figure 21a). In addition, the mean population size is about 30-35% of the initial population size, for all the different values of the parameter (Table 7 and figure 21a).

3. 3.3. Scenario 2 - Decrease mortality

Not considering cat predation in mortality causes of the bilby allowed a diminution of the probability of extinction until 0.112 (Table 7). This probability is still significantly high (P>0.05), however, it is lower than the 0.568 probability of going extinct for the population modelled with basic scenario. A decrease of 60% of the adult mortality rate (males and females) shows a mean final population size of more than 2000 individuals and a no significant probability of extinction (P=0.002) (Table 7 and figures 22 a+b). Moreover, a lower decrease of 40% also leads to a no significant extinction probability of 0.033 over 20 years (Table 7) and the figure 22a shows that the population is increasing. In any case, a 20% decrease of the adult mortality rate creates the increase of the bilby population size (Figure 22a).

3. 3.4. Scenario 3 – Supplement the population

Table 7 indicates that the stochastic population growth rate is only positive when

[9] SD: Standard Deviation
[10] SE: Standard Error

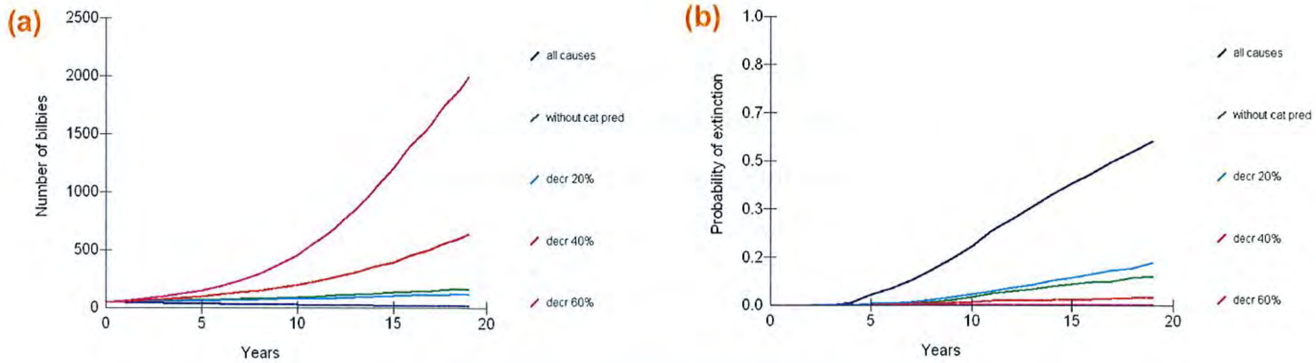

Figure 22: Mean population size **(a)** and probability of extinction **(b)** of the bilby population modelled over 20 years with different values of mortality rate: mortality rate due to all causes of death; mortality rate without bilby deaths due to cat predation; and general decrease of the mortality rate by 20%; 40%; and 60%

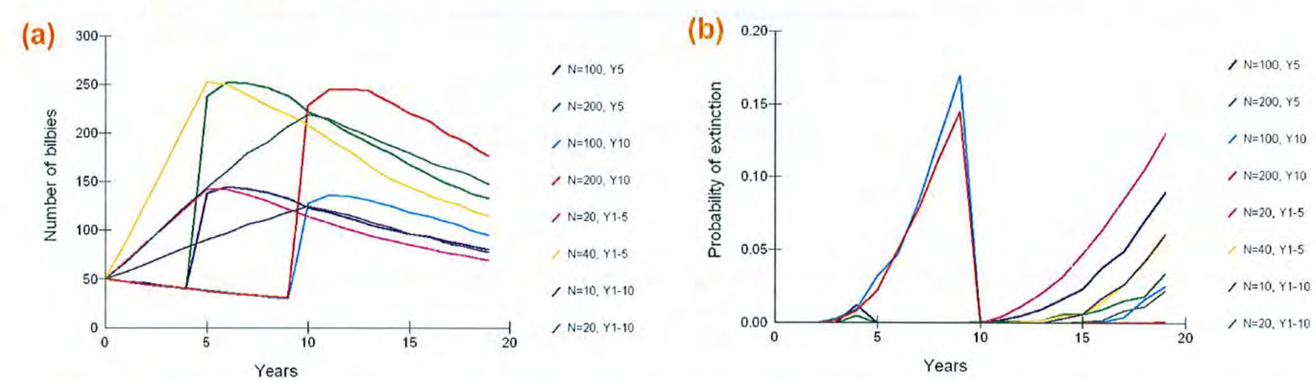

Figure 23: Mean population size **(a)** and probability of extinction **(b)** of the bilby population modelled over 20 years with different values of supplementation: only one supplementation of 100 animals at year 5; only one supplementation of 200 animals at year 5; only one supplementation of 100 animals at year 10; only one supplementation of 200 animals at year 10; supplementation of 20 animals every year during 5 years; supplementation of 40 animals every year during 5 years; supplementation of 10 animals every year during 10 years; supplementation of 20 animals every year during 10 years

In all these cases, it has been decided to supplement the population with as much females as males

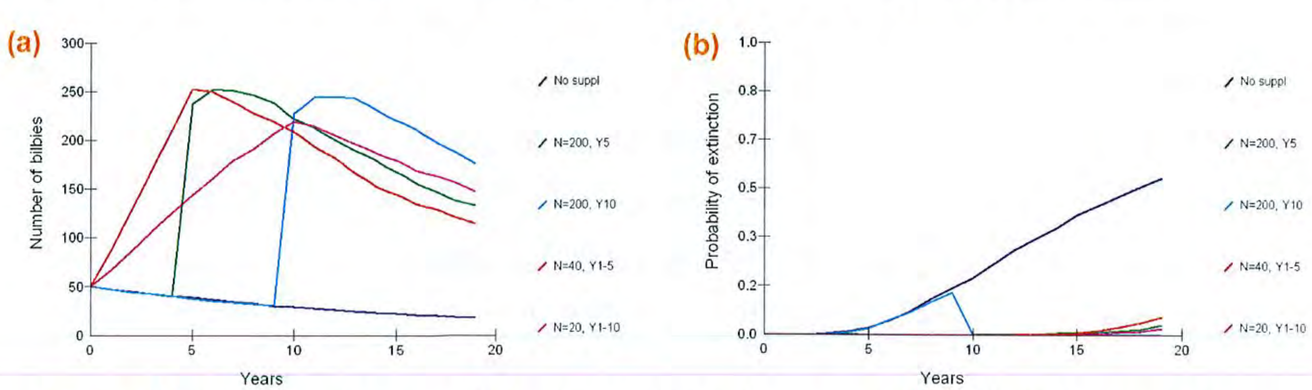

Figure 24: Mean population size **(a)** and probability of extinction **(b)** of the bilby population modelled over 20 years with different values of supplementation: no supplementation; only one supplementation of 200 animals at year 5; only one supplementation of 200 animals at year 10; supplementation of 40 animals every year during 5 years; supplementation of 20 animals every year during 10 years

In all these cases, it has been decided to supplement the population with as many females as males and the total number of animal released is equal to **200** the total number of bilbies supplemented is equal to 200. However, the difference between each stochastic growth rate is really small (less than 0.05) and the standard deviation fairly high (more than 0.3). The 4 simulations with 100 individuals supplemented and the 4 ones with 200 individuals supplemented show the same trends, considering the mean size of the population over 20 years (Figure 23a). The scenario with 200 individuals released at once in the tenth year of the simulation has the best decrease of the probability of extinction (Figure 23b). Also, the probability of extinction is not significant ($P<0.05$) for 3 of the 4 simulations with bilbies released at once (N=200, Y5; N=100, Y10; and N=200, Y10) (Table 7). Regarding the final mean population size at year 20 for 200 individuals translocated (Figure 24a), it seems more relevant to release a high number of animals at once and during the latest years of the simulation (N=200, Y10). Figure 24b demonstrates that any supplementation of 200 bilbies leads to decrease the final probability of extinction to more than 85% of the basic value (with no supplementation).

3. 4. Sensitivity analysis

The ranking technique allowed giving an index of the impact of a change in a parameter. Table 8 presents the influence of each change of the parameters considered (founder population size, adult mortality rate, and supplementation) for 4 output parameters (deterministic growth rate, stochastic growth rate, probability of extinction, and mean population size). According to those results, the most influential parameter on the overall model behaviour is the adult mortality rate. Indeed, the three simulations with the biggest total rank value are: a 60% decrease of the adult mortality rate, a 40% decrease of this same rate, and the suppression of cat predation in mortality causes. Except for an initial population of 500 bilbies, the founder population size has a low or no influence, especially for both deterministic and stochastic growth rates. The supplementation of 200 individuals during the tenth year has an important impact on the population in term of probability of extinction (rank 15), and a moderate impact in terms of the both population growth rates (rank 6.5 and 12) and mean population size (rank 7). In contrast, a mortality rate decrease of more than 40% of the basic value leads to the highest influence on the population, considering all 4 output parameters. In addition, it has to be said neither the increase of the initial population size nor the supplementation of the population has an impact on the deterministic growth rate of the modelled population (difference with the basic scenario equal to 0).

Changes of the input parameters	Difference with basic scenario				Rank of the output parameters				Total ranking value
	det λ	stoch r	PE	Pop size	det λ	stoch r	PE	Pop size	
Decrease 60%	0,274	0,292	0,566	2166,55	16	16	16	16	64
Decrease 40%	0,193	0,203	0,535	696,19	15	15	14	15	59
Without cat predation	0,118	0,125	0,456	167,49	14	13	8	14	49
N=200, Y10	0	0,12	0,562	150,63	6,5	12	15	7	40,5
N=200, Y5	0	0,118	0,521	113,31	6,5	11	12	9	38,5
Decrease 20%	0,102	0,105	0,409	116,05	13	9	6	10	38
N=40, Y1-5	0	0,111	0,493	93,78	6,5	10	10	8	34,5
N=20, Y1-10	0	0,13	0,318	125,5	6,5	14	3	11	34,5
500	0	0,007	0,496	147,49	6,5	4	11	12	33,5
N=100, Y10	0	0,085	0,529	74,36	6,5	6	13	7	32,5
N=10, Y1-10	0	0,095	0,489	60,82	6,5	8	9	5	28,5
N=100, Y5	0	0,088	0,452	61,82	6,5	7	7	6	26,5
N=20, Y1-5	0	0,08	0,407	49,15	6,5	5	5	4	20,5
200	0	0,001	0,348	46,76	6,5	2	4	3	15,5
150	0	0,002	0,287	35,06	6,5	3	2	2	13,5
100	0	0	0,193	19,48	6,5	1	1	1	9,5

Table 8: Sensitivity analysis - changes in assumptions and the resulting effects on the output parameters using a ranking technique

det λ: deterministic growth rate; stoch r: stochastic growth rate; Yext: years of first extinction; PE: probability of extinction

Parameters are sorted in each table according to the total ranking value, from the highest to the lowest. Underlined values are the 3 highest ranks for each output parameters; and changes of the output parameters have a different colour according to the scenario: Scenario 1, Scenario 2, and Scenario 3.

4. Discussion

4. 1. General results of the PVA

Population Viability Analysis was undertaken on a translocated population of bilbies (*Macrotis lagotis*) at Lorna Glen, in the Western Australia rangelands. The results of this PVA modelling suggest the following conclusions: (1) using some predicted and derived population parameters, it is unlikely that the population will persist without further intervention; (2) supplementing the population by releasing a larger number of animals at once (>100 individuals) is more relevant than adding fewer individuals every year over a certain period of time; (3) a reduction in the mortality rate is the only scenario that allowed a positive deterministic growth rate of the population; and (4) the initial population size has a low influence on the viability of the population. However, these results are preliminary, based on the best available data and estimates of the parameters from field study and literature. Regarding the following discussion, it should be noted that a PVA does not reveal what will actually happen, but provides a prediction of the likely behaviour of the population in response to the parameters of the model (Lacy and Clark, 1990).

The modelled population of reintroduced bilbies in the rangelands of Western Australia can't survive in the long term with calculated parameters and assumptions made from the literature. Therefore, if the assumptions are close to the reality and if there is no change in management actions, the reintroduction of the bilby population would be unsuccessful. However, considering the lack of information for some of the input parameters needed in VORTEX, the best guesses entered may not be accurate. For example, a juvenile mortality rate of 70% was based on the only study where this value had been found in the literature (Southgate and Possingham, 1995). At Lorna Glen, it is estimated that juvenile mortality was closer to 50%; one out of two young born generally survive to maturity (personal communication). This reduction in juvenile mortality would have a significant impact and improve both population growth rates (deterministic and stochastic) and decrease the probability of extinction (Appendix H, figure a). Indeed, under this scenario, the population increased rapidly to reach a size of more than 3000 individuals after 20 years (Appendix H, figure b). Nevertheless, parameters like "genetic management" or "inbreeding depression" have not been considered in this analysis. This would be very interesting in terms of genetic diversity and evolution of the population, especially with captive-bred animals (Amstrong and Seddon, 2007; Lacy, 1994). Moreover, it has to be noted that the PVA can overestimate the viability of small populations if genetic effects are ignored (Miller and Lacy, 2005).

Similarly, increasing the founder population size leads to a decrease in the probability of extinction after 20 years. However, this scenario can't be seen as a management action since the population is still declining due to the same negative growth rate. Another parameter has to be changed to allow the survival of the population in the long-term.

A reduction of mortality of at least 20% is required to allow a sustainable growth rate of the bilby population at Lorna Glen. Despite the successful feral cat baiting program (Morris and Dunlop, 2008), cat predation remains the primary cause of bilby mortality. If cats could be eradicated, the bilby population would grow. However this is unlikely without the complete fencing of the Lorna Glen area (250,000ha). Considering that the lack of resources is the second principal cause of bilby death, it could be beneficial to install some feeding stations in the areas where bilbies have been released. However, the ultimate aim of a reintroduction is to permit the recovery of a self-sustaining wild population (IUCN, 1998), so these feeding stations should be removed as the population becomes established. Another management suggestion would be to acclimatise the bilbies in a pen during a pre-released period (Southgate *et al.*, 2000). Indeed, Seddon *et al.* (2007) report several studies using preconditioning pens in reintroduction projects. A bilby population reintroduced in northern South Australia was considered successful after it had been pre-released into a 10 hectare pen within the main exclosure of the reserve, free of rabbits, cats and foxes (Moseby and O'Donnel, 2003). An 1100 ha fenced acclimatisation pen has been established at Lorna Glen and is being used as part of the reintroduction programme focusing on boodies (*Bettongia lesueur*) and golden bandicoots (*Isoodon auratus*). The pen provides protection from cat and fox predation and allows the animals to adjust to their new surroundings before being released.

Results of the PVA showed that the supplementation of the population is important to increase the long-term viability of the population. Moreover, multiple simulations predicted that, in terms of management options, it is more important to supplement the population with a large number of individuals (N=200) rather than more frequent supplementation with lower numbers of animals. Similar results have been found in other studies (Fischer and Lindenmayer, 2000; Southgate and Possingham, 1995). As bilbies for reintroduction come from captive breeding centres, it would be better to wait for a greater number of bilbies (>100) to be available and release them at the same time. However, because the species is assumed to have a short lifespan (personal communication; Southgate et al., 2000), it may be difficult to source a high number of animals at any one time, unless sourcing bilbies from several captive breeding centres for the same release. In any case, it would be worthwhile releasing 100 animals every 2 years, instead of 50 animals every year.

4. 2. Critics of the methods

It would have been interesting to use the program MARK[11] (White and Burnham, 1999) to analyze the capture-mark-recapture data. Indeed, it is widely used to estimate input parameters of a PVA such as survival and fecundity rate, or the size of the population (White et al., 2002). However, many assumptions underpin this program and, after the consideration of the field data, it has been decided that the data were not suitable for this kind of analysis (White and Burnham, 1999).

The utilization of one particular method to compare results of the sensitivity analysis is unclear. Indeed, PVA studies using the program VORTEX can use very different methods and one could be more appropriate than another. However, the ranking method applied in the present study had been used by Jaric et al. (2010) and compared with another approach, a regression analysis. The authors concluded that both methods, which have been applied to the assessment of the results of the sensitivity analysis, had a high concordance in their results.

4. 3. Implications for management and monitoring of the population reintroduced in Lorna Glen

The results of the population monitoring, since 2007, show that the bilby population is still persisting at Lorna Glen. Indeed, there are still activity signs such as active burrows, feeding excavations or tracks in different areas. Moreover, the capture of a couple of apparently healthy bilbies, and 2 pouch young, 8 months after their release, demonstrates that some habitats found on Lorna Glen are suitable for the bilby. However, the number of bilbies remaining in these rangelands is difficult to assess, as it is difficult to trap this species (Southgate et al., 1995; Southgate et al., 2005; Southgate, 2005) and its "nomadic" behaviour (Moseby and O'Donnell, 2003). Also, if the predicted high mortality rates are accurate, it is possible that the reintroduced population is slowly declining, as the PVA suggested. Currently, there are plans to develop a method of monitoring bilby presence/absence across the landscape at Lorna Glen using the "Cybertracker" program (Website 6) and handheld Personal Digital Assistant (PDA) recorders (personal communication, K.Morris). This will provide some insights into the distribution of bilbies at Lorna Glen and, over time,

[11] Software: White G.C. MARK: mark and recapture parameter estimation, version 6.0. Colorado State University, Fort Collins, USA.

movements of animals in different habitat types.

In the present study, it was decided to focus this PVA only on three parameters that can be manipulated by DEC: founder population size, supplementation and mortality rate. Nevertheless, it would be worthwhile conducting other PVA of the bilby population, in the future, to study in-depth the effect of changes in other parameters, such as the fecundity rates.

Many of the population input parameters were estimated rather than based on biological or ecological knowledge. Further studies, such as CMR survey, should focus on the estimation of both juvenile and adult mortality rates, and also on the assessment of reproductive rates, such as the probability of brood per year and per female. Additional information on habitat utilization and home range size, via radio-tracking studies, would also be beneficial to permit estimates of carrying capacity to be made. As mentioned above, future releases should be done with a higher number of animals (>100) but with several little groups in different areas. At the first bilby release in 2007, all the founders (about 50 bilbies) were placed in close proximity to each other and this aggregation led to high rates of cat mortality in the first few months (Appendix A). Subsequent releases of individuals or pairs, at about 300m intervals, have resulted in lower rates of cat predation.

Finally, the survivorship of the released bilbies in their new wild environment could be improved further through the use of the acclimatization pen at Lorna Glen. However, it is likely that this pen will be used primarily for other mammal species that are highly vulnerable to cat predation such as mala (*Lagorchestes hirsutus*) and boodies (*Bettongia lesueur*); as it is known that bilbies can survive in this environment, at least in the short term.

4. 4. PVA as a management tool in conservation biology

Following a retrospective test of PVA based on 21 long-term ecological studies, Brook *et al.* (2000) concluded that PVA is a "sufficiently accurate tool for assessing and managing endangered species". Indeed, they found that simulated PVA outcomes, such as the risk of extinction or the population size projections, did not differ significantly from reality. However, in 2001, Coulson *et al.* suggested that this conclusion was too strongly worded because of a biased sample[12]. Finally, they argued that PVA can only be accurate if two criteria are met: (1) data are extensive and consistent (**data quality**), and (2) future values of parameters used in PVA are correlated to the actual values (**future distributions**).

[12] "The case studies they (Brook *et al.*) chose for their analyses were long term and not typically from populations of endangered species, data were of high quality and only one population went extinct", Coulson *et al.* (2001)

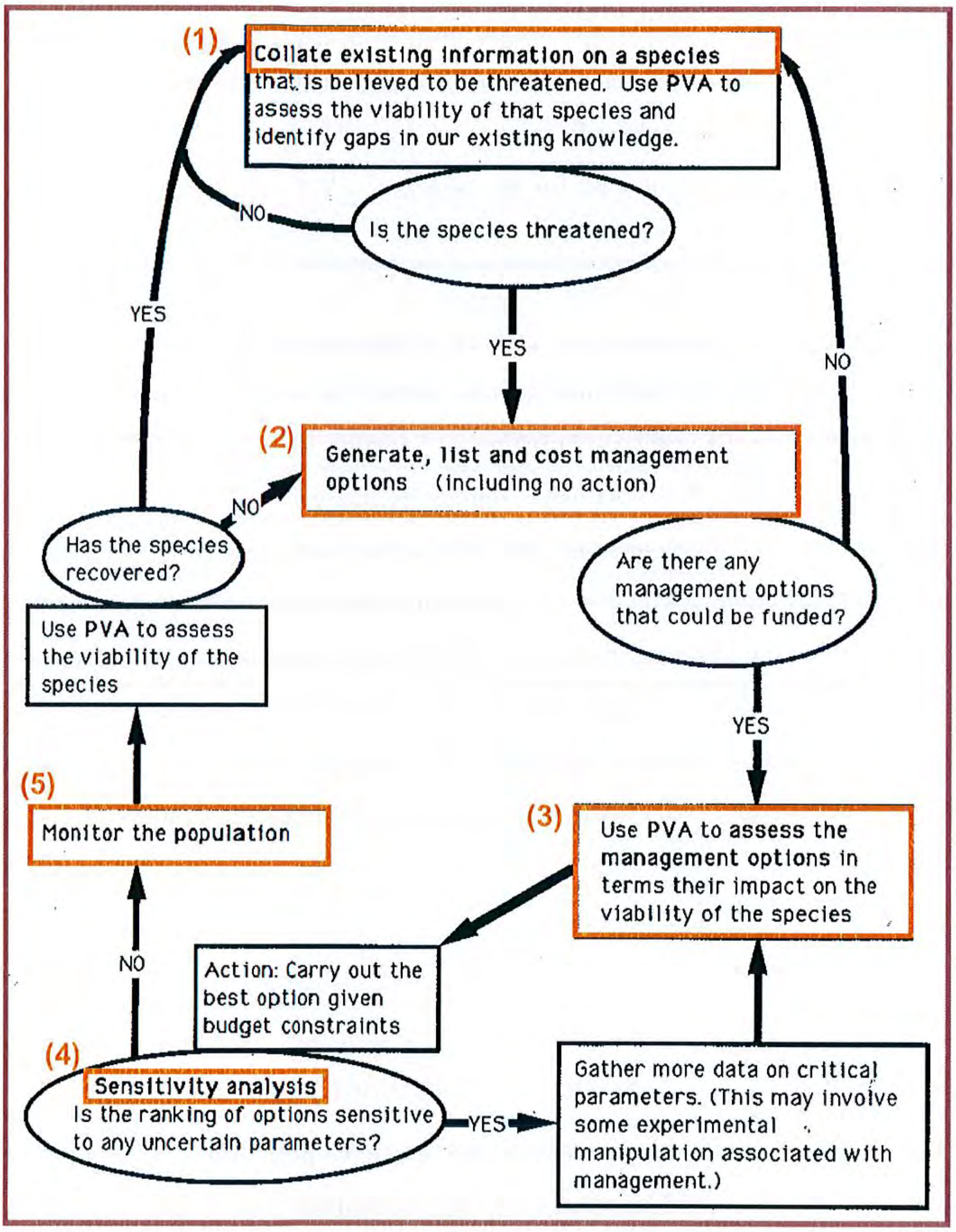

Figure 25: Key steps and iterative framework for threatened species management and species recovery programmes (Possingham et al., 1993)

Nevertheless, PVA is a useful tool in determining which parameters may have a large impact on the population viability and which ones may not (Possingham *et al.* 1993); and thus, to be able to procure more accurate data for further studies. In addition, it is noted that there is uncertainty about the value of many parameters. However, because of the process of collecting and assembling input data for the analysis, PVA will help to highlight gaps in existing data and indicate information of greatest importance to collect in the field (Possingham *et al.* 1993; Southgate and Possingham, 1995).

According to Possingham *et al.* (1993), a sequence of five steps, using PVA, will improve the management of threatened species within recovery programmes: (1) collating existing information on the species; (2) listing and costing management options; (3) ranking management option using PVA; (4) using sensitivity analysis to test the ranking and guide future research; and (5) implementing the best option with repeated monitoring and re-evaluation of the programme (Figure 25). Following these five steps would lead to a better understanding of the reintroduced population and the implementation of management options. Finally, Seddon *et al.* (2007) suggest that the best reintroduction attempts will be made by multidisciplinary teams of resource managers and scientists working in close collaboration, and that recovery programs will only benefit from both good management and good research.

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APPENDIX

Appendix A: The 11 arid zone mammal species proposed to be reintroduced in the rangelands of Lorna Glen (Western Australia) by 2020 (Dunlop and Morris, 2009)

(1) reintroduction since 2007

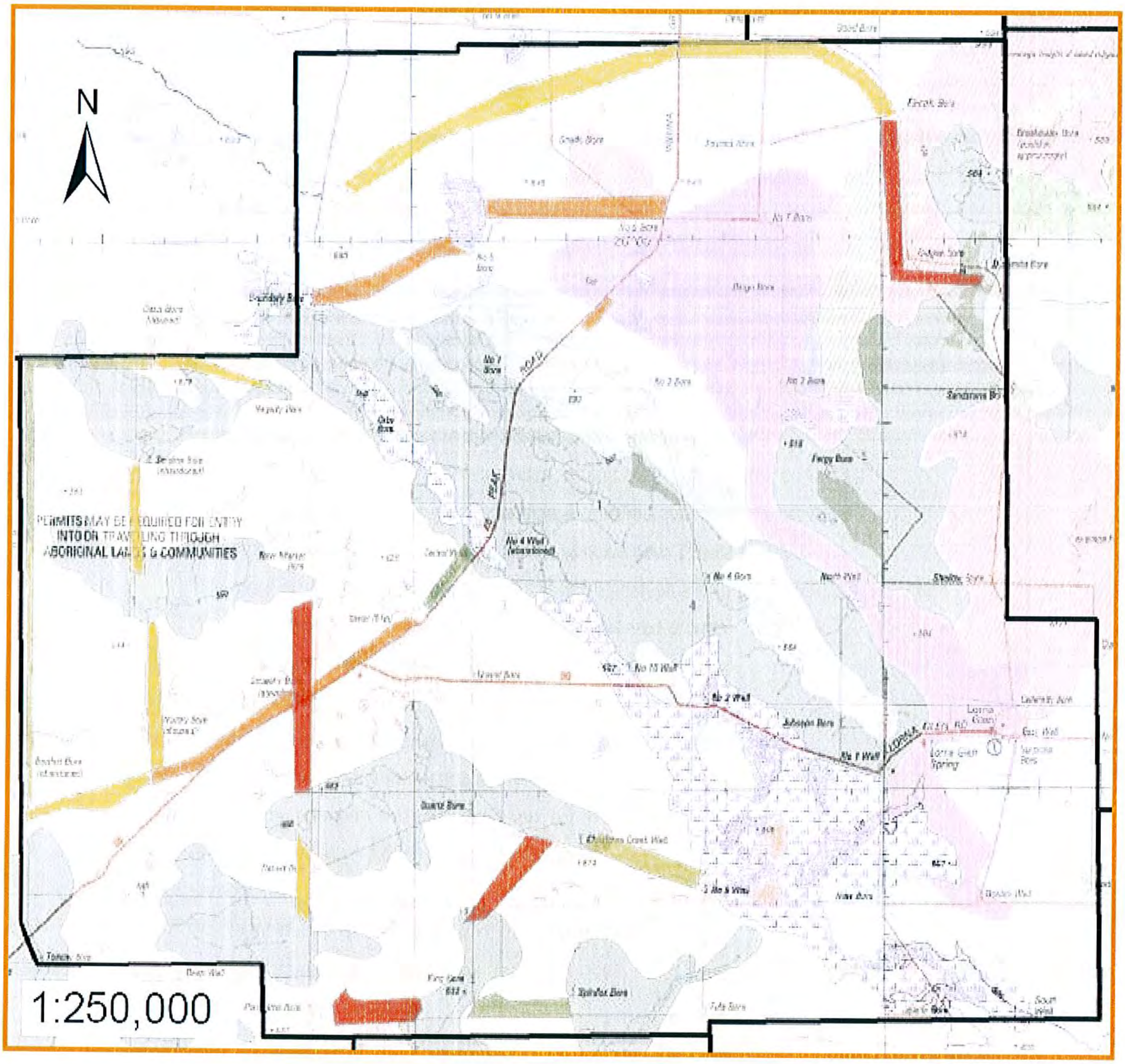
(2) reintroduction in 2008, unsuccessful

(3) reintroduction in a pen with a predator-proof fence in 2010

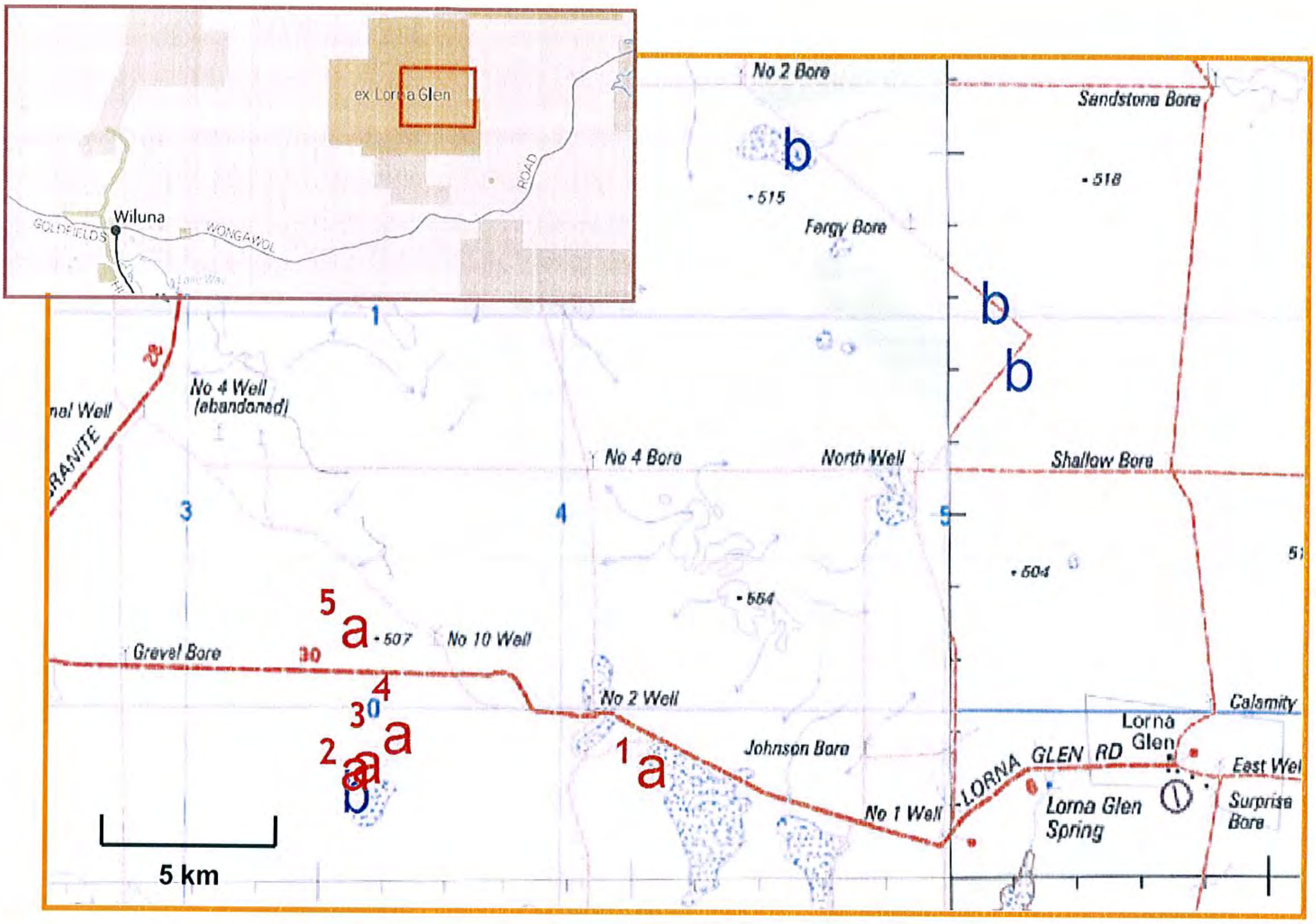
These species are earmarked for reintroduction to their former range at Lorna Glen ex-pastoral lease.

- Bilby (*Macrotis lagotis*) –Vulnerable; locally extinct.
- Brushtail possum (*Trichosurus vulpecula*) – Not threatened, but locally extinct.
- Mala (*Lagorchestes hirstus*) – Vulnerable; extinct on the mainland, three island populations.
- Boodie (*Bettongia lesueur*) – Vulnerable; healthy island populations but extinct on the mainland (except for fenced populations on Heirisson Prong and Dryandra woodland).
- Golden bandicoot (*Isoodon auratus*) – Vulnerable; extinct in the arid zone, healthy island populations, mainland populations persist in the Kimberley region.
- Western barred bandicoot (*Perameles bougainville*) – Endangered; extinct on the mainland (except for fenced population on Heirisson Prong), occurs on three islands.
- Numbat (*Myrmecobius fasciatus*) –Vulnerable; extinct in the arid zone, but persisting in the south-west of WA.
- Red-tailed phascogale (*Phascogale calura*) – Endangered; extinct in the arid zone, but persisting in the south-west of WA.
- Chuditch (*Dasyurus geoffroii*) – Vulnerable; extinct in the arid zone, but persisting in the south-west of WA.
- Shark Bay mouse (*Pseudomys fieldi*) –Vulnerable; extinct in the arid zone, restricted to three islands.
- Pale field-rat (*Rattus tunneyi*) – not listed as threatened but has suffered a large range contraction and is locally extinct.

Appendix B1: Vegetation types and burning proposals at Lorna Glen, map (Department of Environment and Conservation, 2007)



Appendix D: Prospected areas in Lorna Glen in 2010 (1) with trapping sessions (Appendix E) ; and (2) without trapping sessions



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MAMMAL TRAPPING DATA SHEET

Please use pencil for recording data. Use new sheet for each survey unit and day of trapping.

Project	
Survey Location	
Survey Unit	

Must enter on all sheets

Personnel:		
		Year:
	Animal Handling	Data recording

* See Data Codes for use with Trapping Data Sheet and Fauna File

Date d/m	Trap type/ Num	Species	Sex *	Implant No or		N/R /RT *	Tot wt Bag wt	Animal wt (g)	Age *	Fate* – notes	Radio Frequency	Head L/W	Pes S/L	Tibia L	Pouch	PY/ CR	Comments
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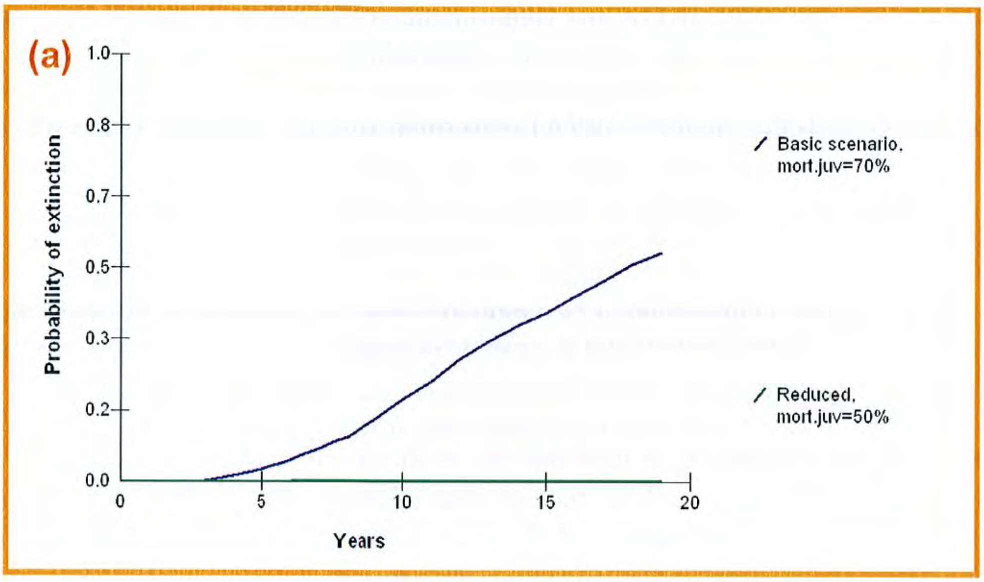
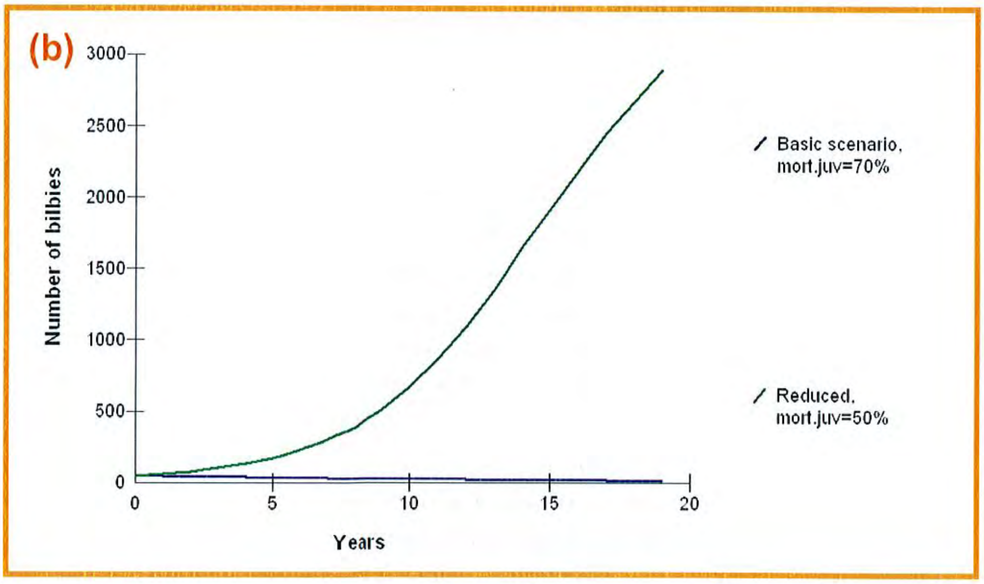
Appendix F: Mammal trapping data sheet used to write the measurements of bilbies caught during trapping sessions

Appendix H: Probability of extinction **(a)** and mean population size **(b)** of the bilby population modelled over 20 years on a trial scenario with reduce juvenile mortality rate: 70% (basic scenario); and 50% (reduced)





ABSTRACT

Australian arid zone mammals, within the Critical Weight Range (CWR) of 35g-5.5kg, have suffered a severe decline since European settlement. One goal of the "Operation Rangelands Restoration" program, led by the Department of Environment and Conservation (DEC) of Western Australia, is the successful reintroduction of 11 species of native mammals. One of these is a vulnerable marsupial species: the bilby (Macrotis lagotis). Through a Population Viability Analysis (PVA) performed with the software VORTEX, the present study assesses the current status of this reintroduced population and the implementation of different management options which might improve its likelihood of successful establishment. The results of this PVA modelling suggest a series of conclusions: (1) using some predicted and derived population parameters, it is unlikely that the population will persist without further intervention; (2) supplementing the population by releasing a larger number of animals (>100 individuals) is more important than adding fewer individuals every year over a certain period of time; (3) a reduction in the mortality rate is the only scenario that allowed a positive deterministic growth rate of the population; and (4) the initial population size has a low influence on the viability of the population. All these results are examined in order to contribute to the best management of the population and the realization of furthers studies. Finally, the utilization of PVA as a management tool in conservation biology is discussed.

Key words: Reintroduction; Bilby Macrotis lagotis; Population Viability Analysis; VORTEX; Population management; Australian rangelands; threatened species.

RESUME

Depuis l'installation des Européens en Australie, les mammifères des régions arides, d'un poids critique allant de 35g à 5.5kg, ont sévèrement décliné. Un des objectifs du programme "Operation Rangelands Restoration" en Australie Occidentale, mené par le Département de l'Environnement et de la Conservation (DEC), est de réintroduire avec succès 11 espèces de mammifères. L'une d'entre elles, le bilby (Macrotis lagotis), est un marsupial classé comme espèce "vulnérable". A travers une analyse de viabilité de population, réalisée grâce au logiciel VORTEX, cette étude évalue le statut de la population réintroduite et la mise en œuvre de différentes options de gestion pouvant être désignées à l'amélioration de son statut actuel. Les résultats de cette analyse suggèrent plusieurs conclusions : (1) les valeurs supposées des paramètres d'entrée ne permettent pas une survie à long terme de la population ; (2) le supplément d'animaux a un impact positif plus important sur la survie de la population lorsqu'il est effectué avec un nombre important d'individus pour un même lâché ; (3) une réduction du taux de mortalité adulte est le seul scenario permettant un taux de croissance de la population positif ; et (4) le nombre initial d'individus relâchés a une faible influence sur la viabilité de la population. Tous ces résultats sont examinés afin d'améliorer la gestion de la population de bilbies réintroduite, ainsi que de permettre la réalisation d'études complémentaires. Enfin, l'utilisation d'analyses de viabilité de population en tant qu'outil pour la biologie de la conservation est discutée au travers de cette étude.

Mots clefs: Réintroduction ; Bilby Macrotis lagotis ; Analyse de viabilité de population ; VORTEX ; Gestion de populations ; Rangelands australiens ; espèces menacées.