Population Viability Analysis for a potential reserve for the Bilby (*Macrotis lagotis*) and Mulgara (*Dasycercus* spp) on the Yandeyarra Aboriginal Reserve and Kangan Pastoral lease, Pilbara Region of Western Australia.

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Summary
Using mortality and demographic data available from the literature, population viability analysis (PVA) was performed to determine a suitably sized area that would support self-sustaining populations of bilbies (*Macrotis lagotis*) and mulgaras (*Dasycercus spp.)*, without intervention or artificial management of the population. Since mulgara have smaller home ranges than bilbies and similar fecundity, any area determined to support a viable population of bilbies is highly likely to support a larger viable population of mulgaras. Therefore this study focused on analyses of the viabilities of bilby populations, as a critical determinant of the size of an area required to sustain a viable population of both bilbies and mulgara. This analysis indicated that a minimum area of approximately 50,000 ha of suitable bilby habitat is required to be able to support a viable population with a low probability (<0.1) of extinction over 100 years and no artificial management of the population. In this area and under the lowest mortality rate scenario, if 15 bilbies were used as founder stock, a population of approximately 120 could be sustained after 30 years. If 50 bilbies were used as founder stock, 200 bilbies could be sustained after 20 years. A 50 000 ha area would also sustain a mulgara population of approximately 1625 individuals. A 1,000 ha enclosure is considered unsustainable in the long term as it provides home range space for only six bilbies which the PVA predicts would persist for less than five years without management.

Introduction
Determining the viability of populations is an important task for the management of depleted populations (Boyce 1992, Beissinger 2002). Population viability analysis (PVA) is often used in conservation biology to help guide management decisions in the recovery of rare and threatened species (Lindenmayer and Possingham 1996). PVA uses data in an analytical or simulation model to calculate the risk of extinction or population viability (Ralls *et al*. 2002).

PVA has been used as a tool to determine the viability of populations for a wide range of organisms (for example see Haines *et al*. 2007, Fujiwara 2007, Southwell *et al*. 2008, Zeoli *et al*. 2008, Wakamiya and Roy 2009), and is used by International Union for the Conservation of Nature and Natural Resources Red List (IUCN 2012) to categorize populations based on their estimated viability status.

The population viability of a reintroduction of 15 bilbies (*Macrotis lagotis*) to a 34 000 ha reserve in central Australia was modeled by Southgate and Possingham (1995). They do not specify whether the reserve was fenced or included introduced predator control, however, it is unlikely that either was the case. Their analysis predicted that the population would persist for a median of eight years, or to 26 years by excluding the possible likelihood of drought in the analysis. They determined that adult mortality was a key determinant of population survival.

More recently, Pertuisel (2010), used PVA to model the viability of a translocated population of bilbies in a 250 000 ha reserve (Lorna Glen) in the rangelands of Western Australia. Between 2007 and 2009, 128 bilbies originating from captive and wild populations were translocated directly into the reserve which is managed for introduced predators by aerial baiting (Morris et al. 2007, Pertuisel 2010). Pertuisel (2010) modeled a range of initial population sizes between 50 and 500 individuals, and found that the population was unlikely to persist over 20 years without intervention. She found that mortality was a key determinant (of which 6 % was due to raptor predation, 40 % due to cat predation, 27 % due to lack of resources and 27 % unknown), the initial population size had a low influence on population viability, and that if the population was supplemented at any stage, a large number of supplementary individuals in one release would be more beneficial rather than a continuous release of low numbers of individuals over time. The Lorna Glen population was estimated at between 128 to 339 individuals in 2012 during a trial horseback survey (Burrows *et al*. 2012).

The aim of this study was to estimate the size of an area required to sustain a viable population of bilbies and mulgara over a 100 year period.

Brush-tailed mulgara (*Dasycercus blythi*) home ranges (males: 25.5 ha; females: 10.8 ha; Körtner *et al*. 2007) are much smaller than home ranges of bilbies (167 ha; Moseby and O'Donnell 2003). The fecundity of *D. blythi* is is similar to that of bilbies. *D. blythi* can have up to six young, and come into breeding condition each year for at least six years (Woolley 2008). Bilbies usually have two young up to four times each year for at most five years (McCracken 1990, Southgate *et al.* 2007). Little ecological work has been undertaken on the crest-tailed mulgara (*D. cristicauda*), however, home ranges and fecundity of are likely to be similar (Masters 2008). Due to the smaller home range of mulgaras, and their similar fecundity to bilbies, any area determined to support a viable population of bilbies is highly likely to support a larger viable population of mulgaras. Therefore this study focuses on analyses of the viabilities of bilby populations, as a critical determinant of the size of an area required to sustain a viable population of both bilbies and mulgara.

Limitations

Life history parameters

The PVA uses life history data derived from published literature (Tables 1, 2 and 3). Some of these parameters have been measured from captive bred and released cohorts of animals (eg Southgate and Possingham 1995) and are not sourced from wild populations. Therefore the analysis is based on the best available data, and some parameters such as mortality (eg from Pertuisel 2010) are high, and could be different under situations where predators are managed. Therefore we have used alternately available data to run the PVA for several scenarios (eg alternate mortality scenarios from different sources; see methods section).

Management options

This analysis specifically deals with the scenario of a self-sustaining population with no intervention or management. Alternate management scenarios exist, for example:

1. A highly managed conservation reserve, with control of feral competitors and predators, weeds and fire.
2. Management of the population including techniques such as supplementary feeding or reintroductions of new animals into the population, with the aim of a self-sustaining population.

Methods

VORTEX v9.99b (Lacy *et al*. 2012) was used to analyse population viability over a 100 year period, with parameters inputted as recommended by Miller and Lacy (2005). Life history parameters of bilbies were used from Pertuisel (2010) (Table 1), with the exception of mortality rates (for which three scenarios were analysed), initial population size, inbreeding depression and carrying capacity.

Mortality Rates

The three different mortality rate scenarios were: 1) Mortality data as used in Pertuisel (2010); 2) mortality data as used in Pertuisel (2010), but without the effects of cat predation; and, 3) mortality data as used in Southgate and Possingham (1995). Figures for these mortality rate scenarios are shown in Table 2.

Carrying Capacity (K)

Carrying capacity is the number of individuals of a particular species that a particular environment can support. This is estimated by using the species' home range. Analyses were run for 11 values of the carrying capacity parameter (K). Initially, analyses for K of 50, 100, 200, 300, 400, 500 and 1000 were completed. Using the mean home range of both male and female bilbies (167 ha; Moseby and O'Donnell 2003), the areas of these values of K were calculated (Table 3). Next, K was calculated for three different estimates of suitable bilby habitat located in the Yandeyarra Aboriginal Reserve and Kangan Pastoral Lease (Table 3, also used in the desktop study of suitable bilby habitat - Task 2a), and used in analyses. Finally, K = 6 was used in the PVA of a 1000 ha fenced enclosure.

Initial Population Size

All analyses were run for initial population sizes of 15 and 50 individuals. Analysis of an initial population size of 15 individuals is similar in number if bilbies are to be translocated into the area and also allows comparison to results from Southgate and Possingham (1995); analysis of an initial population size of 50 individuals allows comparison to the results of Pertuisel (2010), and potentially replicates the situation of bilbies already being present in the area, resulting in an increased gene pool, which is important for the effects of inbreeding depression.

Inbreeding Depression

Since a value of inbreeding depression for bilbies is not available in published literature, the value was set at 3.14 equivalents (the median of 40 mammalian populations of 38 species surveyed by Ralls *et al*. 1988) with 50 % of that due to lethal alleles, as recommended by Miller and Lacy (2005). Both the predicted numbers of individuals persisting in the population, and the probability of extinction of the population were plotted.

Table 1. Life history parameters used in the VORTEX (Lacy *et al.* 2012) PVA.

Parameter	Value	Source
Scenario Settings		
Number of iterations	1000	-
Number of years	100	-
Duration of each year	365	-
Extinction definition	Only one sex remains	-
Number of populations	1	(Moseby and O'Donnell 2003, Pertuisel 2010)
Species Description		
Inbreeding depression	Yes	-
Lethal equivalents	3.14	(Ralls et al. 1988, Miller and Lacy 2005)
Percent due to recessive lethals	50	(Miller and Lacy 2005)
EV concordanceof reproduction and survival	Yes	-
Number of types of catastrophes	0	(Southgate *et al*. 2007, Pertuisel 2010)
Reproductive System		
Polygynous	Yes	(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 number of broods per year	4	(McCracken 1990, Southgate *et al*. 2007)
Maximum number of progeny per brood	3	(McCracken 1990, Southgate *et al*. 2007)
Sex ratio at birth (% males)	60	(McCracken 1990, Pertuisel 2010)
Density dependent reproduction	No	-
Reproductive rates		
Percent of adult females breeding	78	(Pertuisel 2010)
EV in % breeding	10	(Pertuisel 2010)
0 broods	0	(Southgate and Possingham 1995)
1 broods	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)
Specify exact distribution	Yes	-
1 offspring	27	(Pertuisel 2010)
2 offspring	73	(Pertuisel 2010)
3 offspring	0	(Pertuisel 2010)
Mate Monopolization		
Percent males in breeding pool	100	(Pertuisel 2010)
Percent males successfully siring offspring	40.5	(Pertuisel 2010)
Mean # mates/successful sire	1.3	(Pertuisel 2010)
Harvest		
Nil		-
Supplementation		
Nil		-
Genetic management		
Nil		-

Table 2. Mortality rate parameters for the three mortality rate scenarios used in the VORTEX (Lacy *et al*. 2012) PVA.

Parameter	Value % (SD)
Pertuisel (2010)	
♀ mortality from age 0 to 1	70 (10)
Annual ♀ mortality after age 1	56 (10)
♂ mortality from age 0 to 1	70 (10)
Annual ♂ mortality after age 1	56 (10)
Pertuisel (2010) with mortality due to cat predation removed	
♀ mortality from age 0 to 1	70 (10)
Annual ♀ mortality after age 1	43 (10)
♂ mortality from age 0 to 1	70 (10)
Annual ♂ mortality after age 1	43 (10)
Southgate and Possingham (1995)	
♀ mortality from age 0 to 1	79 (10)
Annual ♀ mortality after age 1	9 (10)
♂ mortality from age 0 to 1	79 (10)
Annual ♂ mortality after age 1	9 (10)

Table 3. Carrying capacity parameters used in the VORTEX (Lacy *et al*. 2012) PVA.

Area of suitable bilby habitat (ha)	Carrying Capacity (K)	SD	Future change in K?
8 350	50	10	No
16 700	100	10	No
33 400	200	10	No
50 100	300	10	No
66 800	400	10	No
83 500	500	10	No
167 000	1 000	10	No
Likely areas of suitable bilby habitat available at the Yandeyarra Aboriginal Reserve and Kangan Pastoral Lease			
13 516 (estimate derived from Land Units; Dziminski *et al*. 2012)	81	10	No
20 407 (estimate derived from Regolith other than exposed rock; Dziminski *et al*. 2012)	122	10	No
24 565 (estimate derived from Geological Surfaces; Dziminski *et al*. 2012)	147	10	No
1 000 (proposed fenced enclosure)	6	0	No

Results

Numbers of individuals in the population and the probability of extinction for each area, and for both initial population sizes, using all three mortality rate scenarios are shown in Figure 1. Using mortality data from Pertuisel (2010), analyses predicted that populations only persist for 20 to 30 years, with no effect of the size of the area, or initial population size (Figure 1). Using mortality data from Pertuisel (2010), with mortality due to cat predation excluded, analyses predicted that the probability of extinction decreases, and numbers of individuals in the populations are increased (Figure 1). However, populations do not achieve stability, and numbers of individuals always continue to decrease, even in the largest area (167 000 ha), with an initial population size of 50 (Figures 1AA and 1AB). In both these scenarios, high mortality is the overriding parameter, preventing the simulated population in sustaining itself over the long-term.

Using mortality data from Southgate and Possingham (1995), analyses predicted that populations are approaching stability in a 50 100 ha area (Figure 1M, N, O and P). An initial population size of 50 individuals resulted in higher population stability, and a much lower probability of extinction for mortality rates from Southgate and Possingham (1995) in areas of 50 100 ha or greater (Figure 1O, P, S, T, W, X, AA and AB).

For the three estimated areas of suitable bilby habitat available at the Yandeyarra Aboriginal Reserve and Kangan Pastoral Lease, none achieved a stable population that did not decrease over time (Figure 2). This was independent of mortality rate scenario and initial population size. A 1000 ha enclosure provides space for only six bilbies, which the PVA predicted to become extinct within five years without management or intervention (Figure 2M and N).

Discussion

Our analyses use three distinct sets of mortality data from previous studies, as well as life history data from a recent study of a reintroduction in Western Australia. Both previous PVAs (Southgate and Possingham 1995, Pertuisel 2010) relied on mortality estimates derived from captive bred individuals released into the wild, and the estimates of each study vary considerably (Table 2). Both studies (Southgate and Possingham 1995, Pertuisel 2010), as well as this study, indicate that levels of juvenile and adult mortality are key factors in the persistence of populations. This highlights the need to gain accurate mortality and life history data for bilbies from a landscape relevant to the area of consideration. Therefore the limitations of this study are that our results are based on mortality and life history data from captive bred bilbies, reintroduced in other areas outside the Pilbara region, and thus are indications of population dynamics that could occur given the available data.

Our results from mortality data derived by Pertuisel (2010) predict population extinction within 20 to 30 years regardless of available area or initial population size. This indicates mortality estimates used by Pertuisel (2010) are very high. The difference between this study and Pertuisel (2010) is that we include inbreeding depression in the PVA, however this has a limited effect and is overridden by the effects of mortality. When mortality due to cat predation is excluded, populations still did not achieve stability, still indicating inflated mortality.

Recent data from a trial horseback survey estimated a population of 128 to 339 individuals at Lorna Glen in 2012 (Burrows et al. 2012). There is too much variation in this estimate to determine if the population is following the trend predicted by Pertuisel (2010) from the originally translocated 128 individuals. Furthermore, only several years have elapsed since the translocations, which is not enough time to confirm long-term trends.

When using a more conservative mortality estimate (Southgate and Possingham 1995), our results indicate that populations stabilize in a self-sustaining area of 50 100 ha without any additional management such as feral animal management, supplementary feeding or supplementation of individuals. In this sized area, from an initial population of 15 individuals, an almost stable population of approximately 120 individuals is predicted to persist with a probability of extinction below 0.4 over 100 years. When the initial number of individuals is increased to 50, an almost stable population of approximately 200 individuals can be sustained with a probability of extinction below 0.1 over 100 years. Therefore, if we take the best case scenario using more conservative mortality estimates from Southgate and Possingham (1995), the area of suitable bilby habitat required to sustain a viable bilby population is no less that 50 000 ha. By using a mean home home range of both male and female mulgaras (18.15 ha; Woolley 2008) and a similar mean occupancy rate (population size/area of suitable habitat available) as derived from the bilby PVA (59 %), a 50 000 ha sized area would also likely sustain a population of approximately 1625 mulgaras.

The extent of suitable bilby habitat available at the Yandeyarra Aboriginal Reserve and Kangan Pastoral Lease was derived by three methods in a desktop analysis (Dziminski *et al*. 2012). The three estimates were 13 516 ha, 20 407 ha and 24 565 ha, which are all much smaller area that the 50 000 ha indicated by our results needed to sustain a viable bilby population, and when these sized areas were inputted into our PVA, none achieved a stable population.

When considering the best case scenario by using more conservative mortality estimates from Southgate and Possingham (1995), as well as an initial population size of 50 individuals, and the least conservative estimate of the largest area of suitable bilby habitat available (24 565 ha), population stability is still not achieved, however, there is a slow gradual decrease in numbers of individuals from a maximum population size of approximately 100 individuals. This gradual decrease is likely due to inbreeding depression. The PVA models used in this study do not include immigration/emigration (for which there is no available data) and assume a closed population. If there are already bilbies present, then this could be a source of increased genetic diversity, reducing the effects of inbreeding depression, and if the area of suitable bilby habitat is in fact 24 000 ha or more, then a possibility does exist for the persistence of a stable population. The real area of available suitable bilby habitat and if bilbies are present at the proposed site would need to be confirmed by survey.

Initially a 1000 ha enclosure (introduced predator and stock proof) was proposed as a suitable conservation area for bilbies. This area would only provide space for six bilbies based on a mean home range of 167 ha for both males and females (Moseby and O'Donnell 2003). An area that small, with such a small population is predicted by our PVA to persist for less than five years without intervention. This result is supported by the results of Southgate and Possingham (1995), in which a reintroduced population of 15 individuals to a similar sized area persisted for less than three years.

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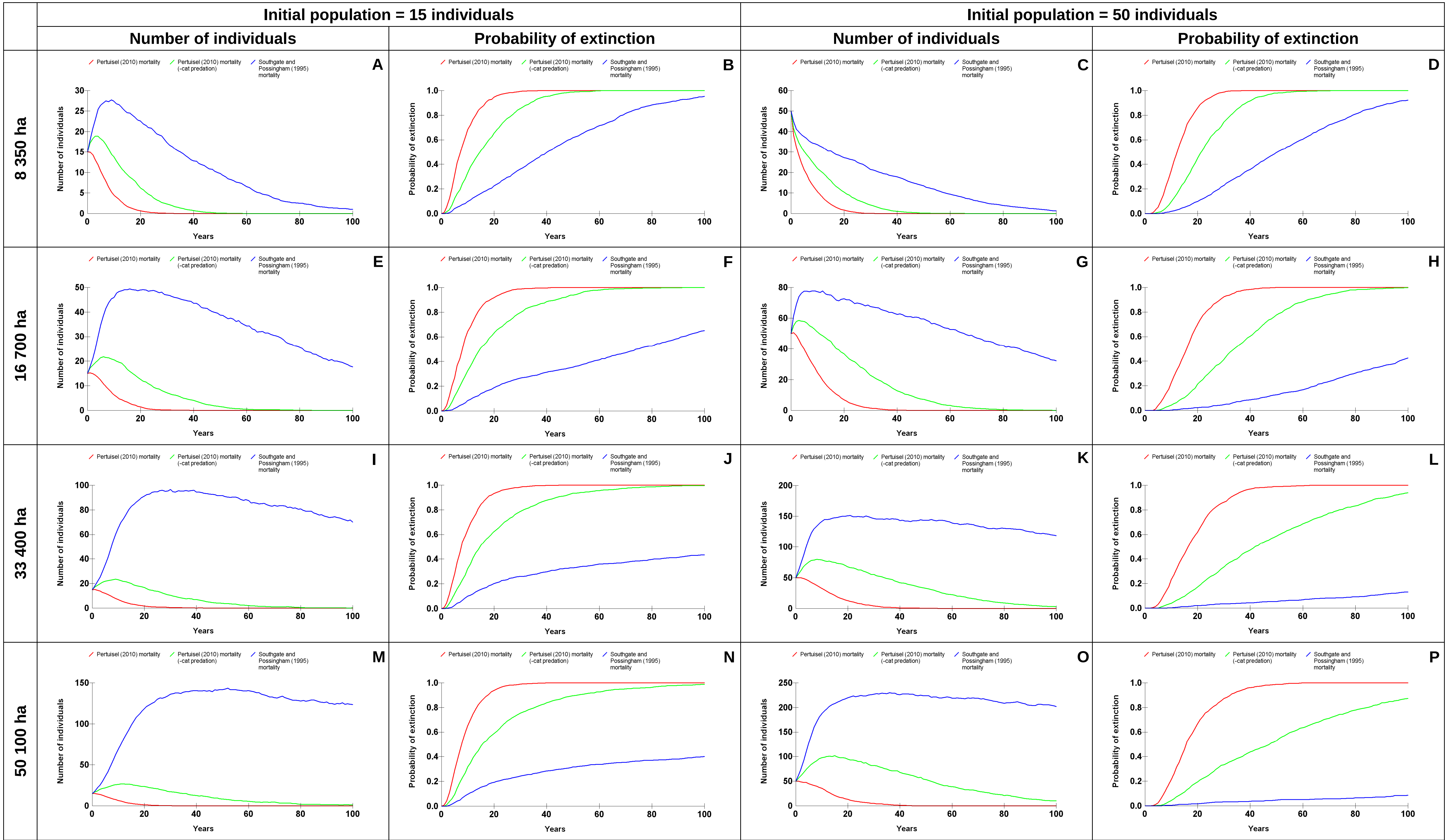

Figure 1. Number of individuals and the probability of extinction of bilby populations modeled for three mortality rate scenarios (line colours), initial population sizes of 15 and 50 individuals (X-axis of the figure panel), in different size areas (ha) of suitable bilby habitat (Y-axis of figure panel).

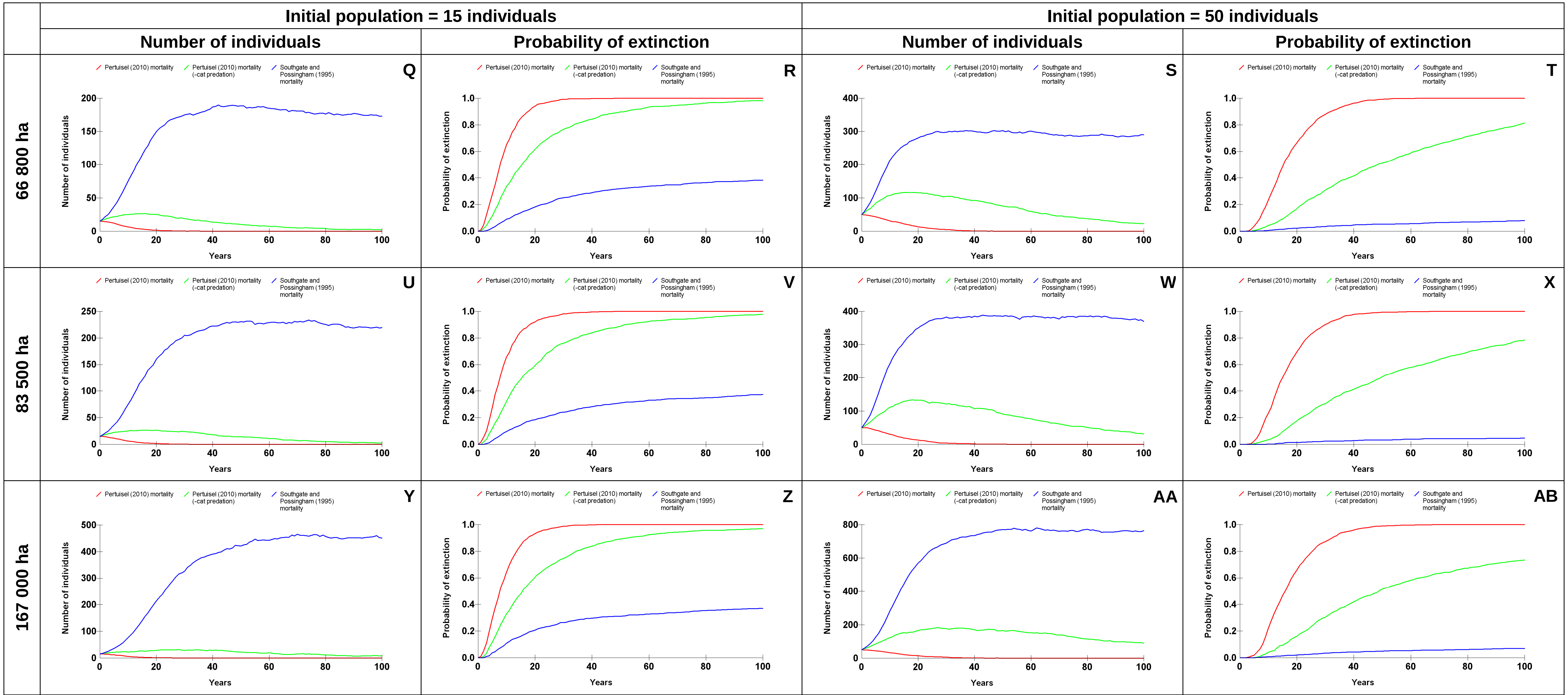

Figure 1. (*continued*) Number of individuals and the probability of extinction of bilby populations modeled for three mortality rate scenarios (line colours), initial population sizes of 15 and 50 individuals (X-axis of the figure panel), in different size areas (ha) of suitable bilby habitat (Y-axis of figure panel).

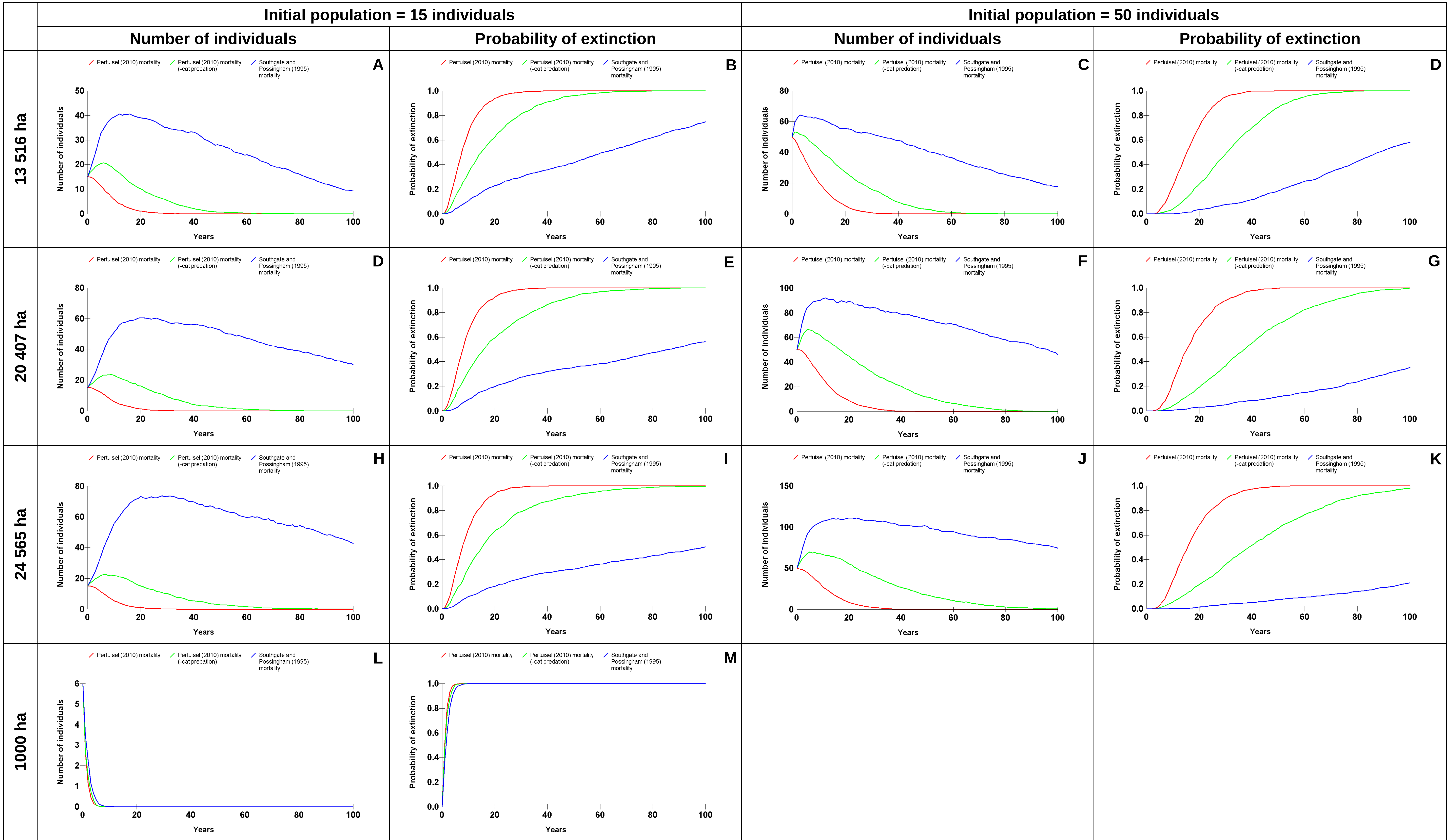

Figure 2. Number of individuals and the probability of extinction of bilby populations modeled for three mortality rate scenarios (line colours), initial population sizes of 15 and 50 individuals (X-axis of the figure panel), in three different size areas (ha) of suitable bilby habitat at the Yandeyarra Aboriginal Reserve and Kangan Pastoral Lease and for a 1000 ha enclosure (Y-axis of figure panel). Estimates of suitable bilby habitat at Yandeyarra Aboriginal Reserve and Kangan Pastoral Lease from Dziminski *et al*. (2012).