Using population viability analysis to guide research and conservation actions for Australia's threatened malleefowl *Leipoa ocellata*

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Appendix Description of the Population Viability Analysis (PVA)

As described in the main text, the PVA is based on the results of an individual-based simulation of a non-spatial, isolated population of malleefowl. This model follows each individual in the population separately, assessing whether they survive and reproduce according to probabilities that vary with the individuals' characteristics and local environmental conditions. These probabilities are derived and quantified in Table A1. The life of each malleefowl follows the schematic shown in Fig. A1, through five distinct life stages. Individuals begin life in the egg stage, where they remain for a single 3-month season. A given proportion p_1 survive to enter the hatchling stage, depending on the presence of intensive local fox baiting and the amount of rainfall during that season. Unusually large amounts of rainfall cause higher mortality rates. Hatchlings are sexed according to an unbiased 50% probability. Individuals remain as hatchlings for another season, by which time they are 3 months old. They then enter the juvenile stage with probability p_2, a parameter that depends on the presence of fox baiting. After another season, at the age of 6 months, juveniles transition to become subadults with probability p_3, a value that depends on the presence of fox baiting. Juveniles remain as subadults until they reach 2 years of age (i.e. for six seasons), surviving through each season with probability p_4. If an individual survives subadulthood they enter the adult stage, where they remain for the rest of their life. Seasonal survivorship in this phase occurs with probability p_4, the same probability as during the subadult stage, and a value that is not affected by the presence of fox baiting. If an adult survives to become 25 years old, mortality in the following season is guaranteed by setting probability $p_5 = 1$.

Each year individuals in the adult stage reproduce. Adults from different sexes form pair bonds; surplus individuals of either sex cannot reproduce until an existing bond is broken by mortality, or an adult of the opposite sex is recruited from the subadult stage. Each adult female produces f eggs, where f is drawn from the normal distribution given in Table A1. Severe drought conditions can cause the suspension of breeding with a probability defined in Table A1. To assess population viability, a population was initialized according to conditions described in Table A1. The fate of each malleefowl, as well as any new offspring created, is followed for 20 years. The population at the end of a simulation, and the characteristics of surviving individuals (e.g. sex, age) is collated for analysis. To address the viability implications of demographic and environmental variability, we repeat the simulation 1,000 times. The simulation model was coded using *Matlab v. 2010b* (Mathworks, Natick, USA). The code is available from the authors on request.

The model formulation shown in Fig. A1 was selected to take advantage of all existing information on malleefowl dynamics, without adding life stages or parameters that could not be uniquely parametrized. Each of the parameters shown in Fig. A1 could take a separate value, and vary with fox baiting if data supported such a conclusion. Additional life stages could also be added to the model, if mortality and reproductive dynamics during these new stages could be confidently ascribed unique values. In the absence of additional information, however, the most parsimonious model structure was used.

TABLE A1 Demographic and environmental parameters used in the PVA model, with values obtained from the literature (with sources), and the values used.

Parameters	Values in the literature	Values used in model
Initial population size	32 adults (Priddel & Wheeler, 2003)	32 adults, 4 juveniles, 24 hatchlings[1]
Carrying capacity	87 nesting mounds (Priddel & Wheeler, 2003)	500[2]
Age of first reproduction	2 years (Brickhill, 1987)	2 years
Clutch size	18.6 (Frith, 1959), 13.8 ± 95% CI 4.1 (Booth, 1987), 15.6 (Brickhill, 1987), 19.8 ± SD 5.5 (Benshemesh, 1992), 14.1 ± SD 5.8 (Priddel & Wheeler, 2005)	$f \sim N(\mu = 16.6, \sigma = 4.5, [0, \infty])$[3]
Maximum age	25 years (BirdLife International, 2010)	25 years (i.e. $p_5 = 1$)
Percentage surviving (no fox control)		
Eggs laid–chick emerging from nest	49.5% (Frith, 1959), 81.8% (Booth, 1987), 51.3% (Brickhill, 1987), 86.1% (Benshemesh, 1992)	
Egg survival probability		$p_1 = 0.67$[4]
1 day–1 week	50% (Priddel & Wheeler, 1996), 48% (Priddel & Wheeler, 1994)	
1 day–2 weeks	20% (Priddel & Wheeler, 1996), 33% (Priddel & Wheeler, 1997), 29% (Priddel & Wheeler, 1994)	
1 day–1 month	25% (Priddel & Wheeler, 1997), 4.2% (Priddel & Wheeler, 1996), 25% (Benshemesh, 1992)	
1 day–3 months	0% (Priddel & Wheeler, 1996), 17% (Priddel & Wheeler, 1997), 0% (Priddel & Wheeler, 1994).	
Hatchling survival probability		$p_2 = 0.02$[5]
3–6 months	47% (Priddel & Wheeler, 1997)	
Juvenile survival probability		$p_3 = 0.47$[6]
3–4 years (adult)	230 survival events & 25 deaths over 10 years (Priddel & Wheeler, 2003)	
Subadult & adult survival probability		$p_4 \sim \beta(26{,}231)$[7]
Percentage surviving (fox control)		
Eggs laid–chick emerging from nest	84.0% (Frith, 1959), 81.8% (Booth, 1987), 56.9% (Brickhill, 1987)	
Egg survival probability		$p_1 = 0.74$[8]
1 day–3 months	42% (Priddel & Wheeler, 1997)	
Hatchling survival probability		$p_2 = 0.42$[9]
3–6 months	53% (Priddel & Wheeler, 1997)	
Juvenile survival probability		$p_3 = 0.53$[10]
3–4 years (adult)	230 survival events, 25 deaths over 10 years (Priddel & Wheeler, 2003)	
Subadult & adult survival probability		$p_4 \sim \beta(26{,}231)$[7]

Table A1 (Continued)

Parameters	Values in the literature	Values used in model
Drought (1 in 85 year low rainfall)	In 2007 10.5 mm of rain was recorded in Windarling (M. Bamford, unpubl. data)	No breeding, with probability $p_d = 0.012$[11]
Rainfall sufficient to cause egg mortality	In 1984 > 100 mm rain caused mass egg mortality (Brickhill, 1987)	Clutches lose random proportion of eggs, with probability $p_f = 0.016$[12]

[1]In 1986–1987, 32 breeding adults were observed in a patch of remnant vegetation near Yalgogrin, central New South Wales (Priddel & Wheeler, 2003). We initialized the PVA simulation with these adults (to which we assigned uniformly distributed random ages ranging between 2 and 11, with a mean age of 6.5). The number of non-breeding individuals in the population was not identified but we estimated their numbers based on the observed rate of recruitment into the population over the subsequent 10 year period. An average of 1.4 individuals were recruited into the breeding population per year, which, given the estimated probabilities of subadult mortality, could be maintained by 4 juveniles and 24 hatchlings.

[2]The Yalgogrin site contained 87 known nesting mounds, sufficient to support 174 adults. The maximum carrying capacity of the site was set at 500, including juveniles and hatchlings, to ensure ample room for growth. The declining dynamics of the population ensured that this value was never reached and had no impact on the population dynamics.

[3]The literature contains five estimates of malleefowl clutch size. Two are point estimates, two have standard deviations, and one has a 95% confidence interval. We assumed that each of these values described the shape of a normal distribution (distributions for the point estimates were assumed to have zero standard deviation). We constructed a truncated (i.e. non-negative) distribution for clutch size by randomly selecting 10,000 values from each of these distributions. In the model we simulated clutch size with a truncated normal distribution based on the first two moments of this composite distribution.

[4]We found four point estimates of egg success in the absence of fox control. The PVA simulation assumed that the probability an egg successfully hatched was the mean of these values. The value of 81.8% was recalculated from the data included in Booth (1987) to exclude eggs broken by observer. The values of 51.3 and 86.1% represent the mean across 3 years of data in Brickhill (1987) and Benshemesh (1992).

[5]We found 11 point estimates describing survival during the hatchling stage in the absence of fox control. These studies observed individuals from birth to an age that ranged between 1 week and 3 months. We assumed that each of these values reflected a constant survival rate during the hatchling stage and extrapolated each to give an estimate of the probability of survival for the first 3 months (i.e. the hatchling stage). Our estimate of hatchling survival probability was the mean of these 11 values.

[6]Only a single study reported a point estimate of the proportion of juveniles surviving for 3 months in the absence of fox control. We used this value in the PVA.

[7]Although we could find no reports of adult mortality in the absence of fox control, Priddel & Wheeler (2003; their Table 5) followed a large number of malleefowl across 11 years, recording 255 events: 230 survived, 25 died. Assuming these events represented 255 outcomes of a Bernoulli trial, the posterior probability of adult survival is β-distributed with parameters $\alpha = 26$, $\beta = 231$. For each adult individual in the PVA, each year, we used a random selection from this distribution as the probability of survival.

[8]We found three point estimates of egg success that could be used to predict outcomes in the presence of fox control. The PVA simulation assumed that the probability an egg successfully hatched was the mean of these values. These three values were collected in the absence of fox control but the level of predation of eggs by foxes was calculated and this source of mortality was removed from the estimate.

[9]Only a single point estimate describes the survival of hatchlings in the presence of fox control. This study observed survivorship over the entire hatchling stage (1 day–3 months) at the baiting intensity described in the main text. We used this point estimate. This is taken from the first release of captive reared chicks with localized intensive fox baiting (Priddel & Wheeler, 1997).

[10]Only one point estimate described juvenile survival in the presence of fox control, and we used this value. These data are taken from the first release of captive reared chicks with localized intensive baiting for foxes (Priddel & Wheeler, 1997), and cover the entire juvenile life stage.

[11]M. Balmford reported that a population of c. six breeding pairs of malleefowl near Windarling, Western Australia, did not breed at all during a severe drought in 2007, when only 10.5 mm of winter rainfall was recorded. The probability that the total winter rainfall would be less than this total was calculated based on 100 years of seasonal rainfall data from the Australian Bureau of Meteorology.

[12]Data in Brickhill (1987) showed a 24-hour rainfall event of > 100 mm, after which 13.7% of eggs were lost. Brickhill argued that death was caused by excessive rainfall preventing embryo respiration. Based on data from the Australian Bureau of Meteorology such a high-rainfall event can be expected to occur in 1.6% of years.

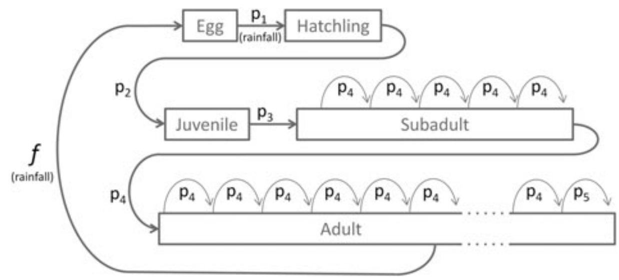

FIG. A1 Schematic of the individual-based population model underpinning the PVA. Each individual follows the life-history trajectory shown, with mortality and reproduction being applied seasonally as indicated by the various probabilities (p). Multiple transitions within a single life stage (e.g. the five transitions within the subadult life stage) represent the number of seasons an individual spends in that stage. Dotted lines in the adult life stage omit multiple seasons.