INSTITUTE OF BIOLOGICAL, ENVIRONMENTAL AND RURAL SCIENCE
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Evaluation of conservation measures for a specific endangered species

Bettongia penicillata

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An exercise in mathematical population modeling and its relationship to the conservation of an endangered species. Carried out as part of a 3rd year BSc (Hons) in Countryside Management

Contents

Bettongia penicillata ogilbyi (Brush Tailed Bettong, Woylie)

Class – Mammalia **Family – Potoroidae**

Order – Diprotodontia **Genus – *Bettongia***

Suborder – Macropodiformes **Species – *penicillata***

Description and Ecology

Woylie is the Nyoongar aboriginal name for *Bettongia penicillata*; also called the brush tailed Bettong; this is a small, ground dwelling, nocturnal marsupial growing to approximately 40cm long and weighing up to 1600g (Claridge et. al. 2007). It belongs to a group of animals sometimes known as "rat-kangaroos" and fulfils an important role in the ecology of the regions in which it lives. Once widespread across Australia, it distribution is currently much reduced, primarily to the eucalypt woodlands of southwestern Australia. This is an area of seasonal wet and dry, comparable to a southern European Mediterranean climate; soils in these regions are generally lateritic and can become very impermeable to water and nutrient poor during the dry season with attendant problems of water runoff and poor penetration in wet periods. The Woylies habit of digging for the sporocarps of hypogeous fungi, which comprise the major part of its diet, provides a more broken topsoil which helps both with topsoil health/biodiversity (Martin 2003) and infiltration of water into the subsoil (Garkaklis et.al. 1998) though there is also some evidence that some of their subsoil tunnels may create localised water repellent patches (Garkaklis et.al. 1999). The foraging activities of this animal also help with re-establishment of vegetation after the regular bush fire events common to this region (Lamont et.al. 1985). Large numbers of ectomycorrhizal fungi spores were found in faecal material; when pellets of Woylie faeces were applied to important local tree species, *Eucalyptus calophylla* and *Gastrolobium bilobum* they showed marked increases in growth rate, control studies demonstrated that stratification through the gut of the Woylie appeared to be the usual pre-treatment for this process. Seed caching by Woylies was also shown to be helpful in tree distribution, demonstrated in sandlewood species by Murphy et. al.(2005). Mitochondrial DNA (mtDNA) analysis (Pacioni et.al. 2010) has shown that there was, historically at least, long distance interbreeding, upwards of 150km between populations, demonstrating the vagile nature

of this species; however, habitat fragmentation has made this process increasingly unlikely now as populations have become more isolated.

Current conservation status, threats

This small marsupial species has led a chequered life since European habitation of Australia, very nearly joining the estimated 50% of all the world's mammal extinctions that have occurred in Australia in the last 200 years (Short and Smith 1994). Once widespread it was decimated by habitat destruction as native forests were cleared to produce farmland, compounded by introduced predators such as cats and red foxes; by 1975 only three natural populations remained; the Dryandra woodlands and the Tutanning and Perup (Upper Warren) nature reserves and it was considered extinct from central Australia. However, through conservation efforts such as Western Shield (DEC 2010a) to exclude non-native predators (fencing and poison baiting) and re-introduction programmes the Woylie recovered to a great extent and became the first species to be removed from the Commonwealth Endangered Species Act 1992. Unfortunately though, since 2001, monitoring of trapping rates for Woylies combined with population modelling, began to indicate numbers undergoing a huge decline; up to 95% in its areas of highest abundance and around 80% across its entire range (Figure 1).

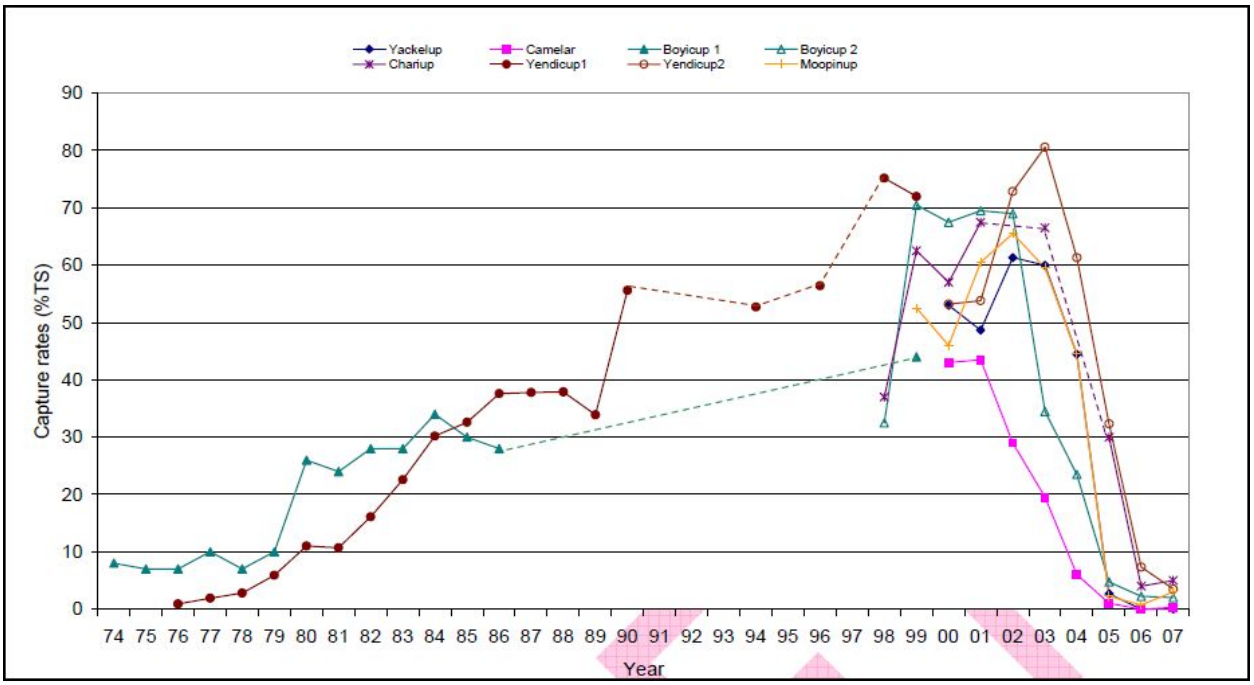

Figure 1 ***Capture rates of Woylies in Perup nature reserve (Upper Warren)*** **(WCPR 2010)**

In 2008, the Woylie was relisted as endangered under the State Wildlife Conservation Act 1950 (DEC 2010b) and it is listed on the IUCN red data list as critically endangered (IUCN 2010). Areas of its highest density, and seeming successful reintroduction, have shown the most acute declines and five areas of the Upper Warren region (Keninup, Balban, Warrup, Boyicup and Winnejup) were chosen for the main investigative effort. One area of high density Woylie population, Karakamia approximately 200km north of the Upper Warren (Karakamia 2010), has remained free of any signs of decline. This 275 ha sanctuary has a predator-proof fence around its entire perimeter and provides an excellent comparison population operating at its carrying capacity.

Conservation effort and policy

The major part of the current conservation effort is given to studying and understanding the mechanisms of the acute population declines of the last decade. The Woylie Conservation Progress Report (WCRP 2010) is the result of a huge collaborative effort both within the Australian Department of the Environment and with outside academic institutions such as Murdoch University in Perth; figure 2, below, shows a draft summary of the findings of these investigations. As can be seen, the primary hypothesis suggests that disease, spread through the faecal material of introduced predators, may be the ultimate agent of decline. It would appear that possible synergistic effects of infection by *toxoplasma* sp. and *trypanosoma* sp. nov may be leading to a reduced fitness in the Woylies resulting in them being far more susceptible to predation, particularly by cats. However, it remains unclear whether predators such as cats and foxes are taking advantage of moribund dying animals or whether these animals might have recovered given the chance.

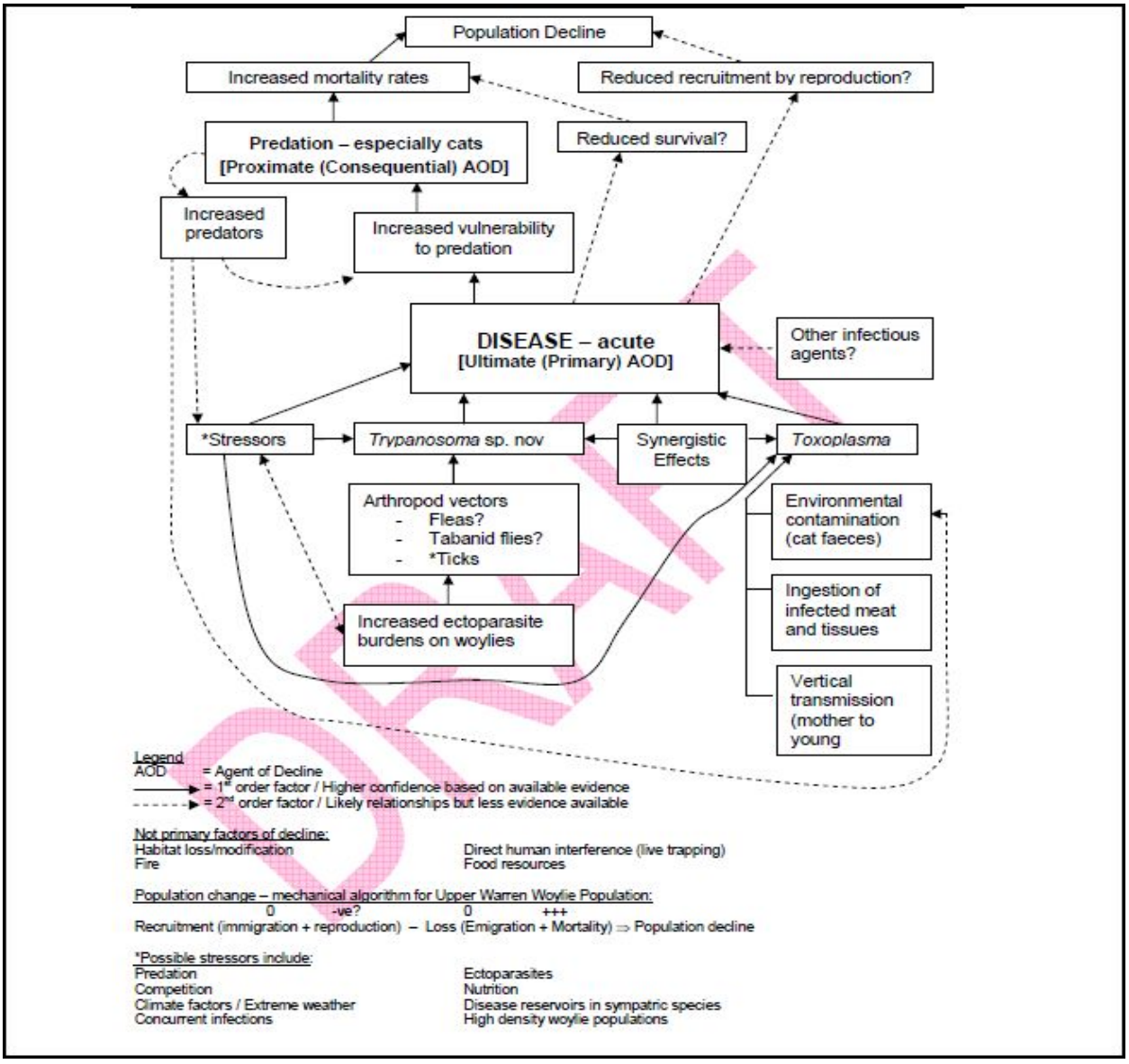

Figure 2 ***Schematic showing the leading hypothesis of causes of Woylie declines in the Upper Warren region; based on preliminary and untested inferences.*** **(WCPR 2010)**

Given that the main contributing factors seem to be directly linked with introduced predator species, both as predators and as disease vectors, the main practical conservation effort must lie with control, or preferably total exclusion of these species. Beyond developing increasingly sophisticated monitoring programmes to identify specific areas of Woylie ecology to target, the continuation of the Western Shield predator control programme forms the main focus of conservation effort. In their official conservation advice (Env. 2010), the Australian government also recommend reintroduction programmes and management of fire regimes to consider the importance of understorey cover for these and other ground dwelling species along with efforts to raise public awareness.

Population model

The population model will be concerned with the five areas of the Upper Warren region (Keninup, Balban, Warrup, Boyicup and Winnejup) and will assume an estimated starting population.
Data for inclusion in this model has been taken from the draft edition of the progress report from the Woylie Conservation Research Project; produced by the Science Division of the Department of Environment and Conservation (WCRP 2010). An online link to this document can be found in the bibliography below and page numbers within the progress report for specific data results can be found in the text. Research for this study was undertaken primarily at the five areas of the Upper Warren region of southwestern Australia, with a comparative population (Karakamia) located further North; 50km east of Perth. Decline rates vary across the Upper Warren regions with Balban still undergoing acute losses and Boyicup/Winnejup numbers at such low levels that they seem to have fallen below a density dependent effect on the decline vector. The comparative population at Karakamia shows no sign of declines and Woylie populations seem be at carrying capacity for this closed area (p.142).

a. Initial population and age demographics (WCRP 4.2, Demographics)

Even though the Upper Warren actually consists of semi-discrete populations undergoing differing survivorship/declines rates, it was considered, for the purposes of this model, as one area with an initial population suggested, based on an estimate of a post decline population for the region. It has been suggested that, pre-decline, there were approximately 20,000 individuals present in the Upper Warren (p.96); decline rates since 2001 give a median of 95% (p.2) therefore an initial population for the model was set at 1000 individuals across the region.

Age demographics are very difficult to ascertain from the Upper Warren trapping study, very few sub-adults were trapped over the year, e.g. 4.2% of trapped Woylies at Keninup, 10 individuals, Warrup 2 individuals and the remaining three areas none at all (p. 126), possibly influenced by the very short time taken from emergence to maturity (30-60 days). Therefore, given these low sample rates it was decided to distribute the initial population across an estimated life span of up to six years (p. 131) by considering the initial population of 1000 individuals as the area under a triangle and distribute them across six intervals.

b. Adult survival (WCRP 4.3, Survival and Mortality)

Adult survival rates of *B. penicillata* were investigated in the Upper Warren over the year between July 2006 and June 2007, carried out by a radio collar survey of 58 individuals. These collars were mortality sensitive and monitored every weekday, mainly from a fixed wing aircraft. 21 of these individuals were found to be dead by the end of the study giving an average adult survival rate across the region of 63.79% However, when the Kaplan-Meir survival function was applied to the figures, considering population density, it was found that areas still suffering the acute population declines had a higher mortality rate than areas which had already undergone significant declines. This indicated that vectors of the very high population declines were density dependent and ceased operating after those populations reached ~5% of their initial size. For the purposes of this model it is assumed that initial adult mortality would be taken at 66.67%; the Balban rate (which was still undergoing acute decline) and reduced to 22.22%; the Keninup rate (post decline) once numbers reach 5% of initial population (p. 142).

c. Numbers of females (WCPR, 4.2, Demographics)

Sex ratios within trapped samples proved to be area specific, the Upper Warren region showed the M/F ratio averaging 2.1:1 whereas the high density comparison site at Karakamia showed 0.7:1 (P. 126). It was considered that while this did provide some indication of gender demographics, sample sizes were very low at 2 of the Upper Warren sites and this bias may be indicating gender specific behaviour with respect to density and trapping success. Therefore, for the purposes of this model it was considered that M : F will be 1:1.

d. Numbers of pouch young (WCPR, 4.2, Demographics)

Reproduction rates remained high at all Upper Warren sites, an average of 89% of trapped females was found to be carrying pouch young and this was aseasonal across the year (p.129).

e. Survival of pouch young to maturity (WCPR, 4.2, Demographics)

Observations in this study were said to be in broad agreement with earlier studies (Christensen 1980) which showed a relatively high survival rate for pouch young up to the age of emergence (100-110 days), put at 82-91% but an extremely low rate of survival through to maturity once emerged from the pouch, 11-15% (p. 131). The model will consider averages of these values.

f. Numbers of offspring per year (WCPR, 4.2, Demographics)

While it is not uncommon for captive bred animals to produce twin offspring a single joey per breeding cycle is more usual in the wild though more than one cycle per year is the norm. Reproduction rates in the Upper Warren do not appear to be affected by seasonal variations as do the Karakamia populations whose reproduction rates drop significantly during the much hotter summer months. From birth to sexual maturity is assumed to be an average of 150 days; time spent in the pouch is between 100-110 days and from emergence to sexual maturity is between 30-60 days (p.131), giving the opportunity for at least 2 breeding cycles in each year. Assuming one offspring per cycle and aseasonal reproduction; the model incorporates 2 generations of offspring per adult per year with the first of these generations also having opportunity to breed in the same year. Again assuming 1:1 sex ratio in the offspring this gives 0.5*1st generation female with 89% of these likely to be breeding, therefore combined offspring going forward to next year = survival to maturity*2.45.

Model Parameters

Estimates of demographic survival rates

Age Distribution *Initial population of 1000 individuals*

1 yr = 305.57	4 yrs = 138.90
2 yrs = 250	5 yrs = 83.35
3 yrs = 194.45	6 yrs = 27.76

Adult Survival

Initial = 33.33%

Post population decline to 5%, survival = 77.78%

Numbers of females

Surviving adults / 2

Pouch young

Females*89% (assuming one joey per breeding cycle)

Survival to maturity

(Pouch young*86%)*13%

Combined reproduction

(Survival to maturity)*2.45

Results

Population Model 1

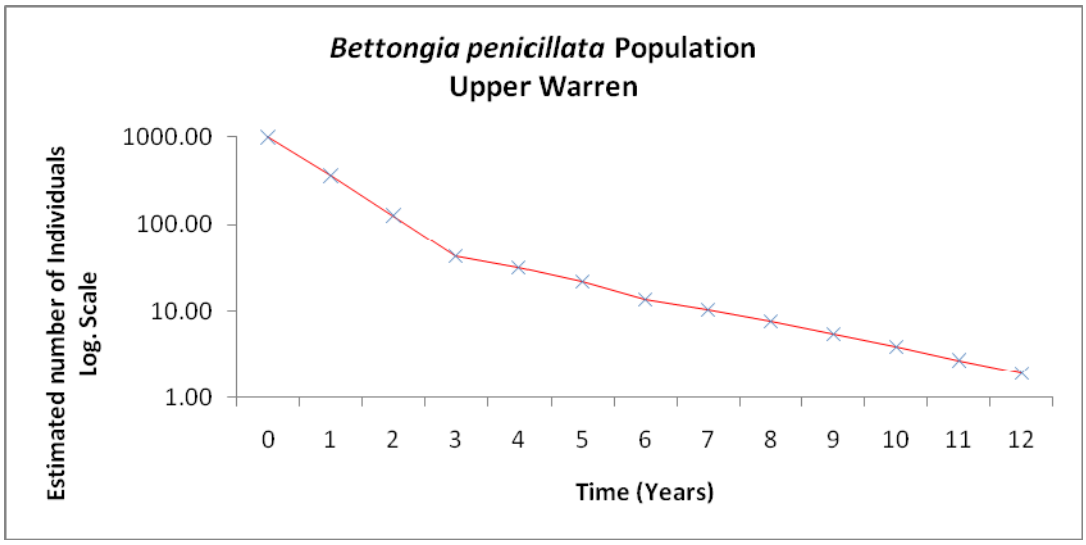

Figure 3 ***Starting population 1000 individuals, population decline average 38% / annum until local extinction after 12 years.***

Initial population of 1000 individuals declined at 65.11% until reaching density dependence of decline vector at three years, then slowing to 29% / annum until numbers fall below two after 12 years.

Population Model 2

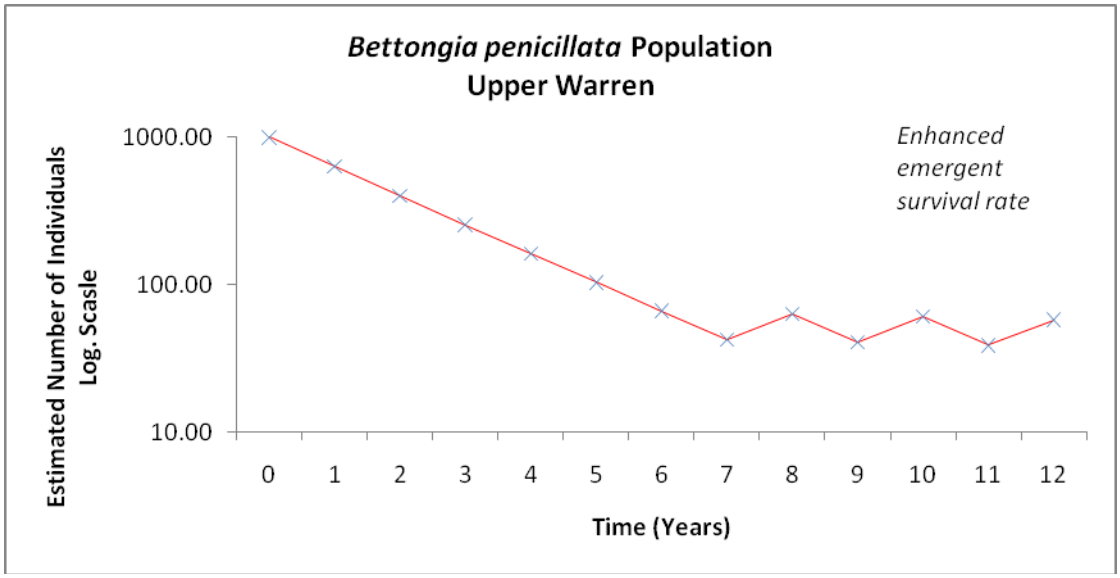

Figure 4 ***Starting population 1000 individuals, emergent survival rate enhanced to 100%***

Population declines at an average of 36.36% / annum until stabilising around decline vector density dependence after 6 years; average 53 individuals.

Population Model 3

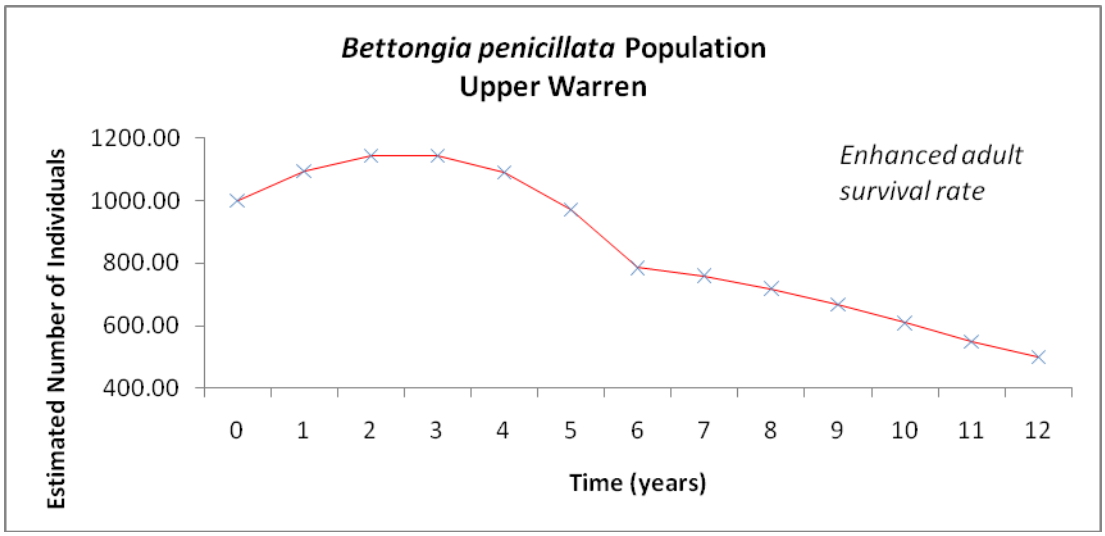

Figure 5 ***Starting population 1000 individuals, enhanced adult survival rate to 100%***

Population declines by an average of 9.2% / annum after 4 years and is less than 50% of start population after 12 years.

Population Model 4

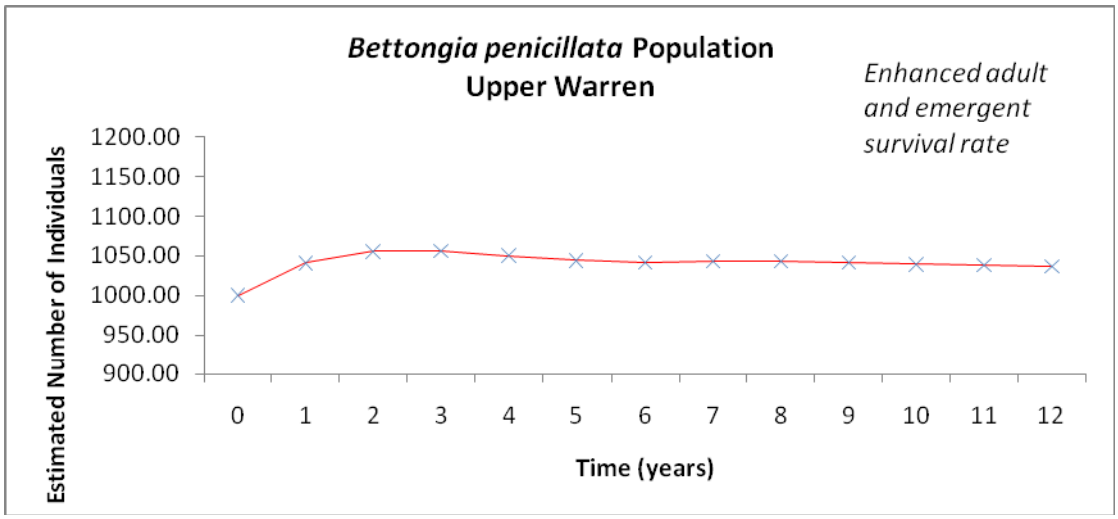

Figure 6 ***Combined minima for increased population after 12 years, adult survival = 77.78%, emergent survival = 39%***

With adult survival at an estimated rate independent of the acute decline pressures (77.78%), emergent survival needs to be raised to 39% to produce an increased population after 12 years. However, the population still shows a gradual decline of 0.13% / annum over the last five years.

Discussion

It must be remembered that these linear models are fairly simplistic in relation to real life scenarios. They rely entirely on assumptions based on research data, often incompletely available and, in the case of a species down to such low numbers, increasingly difficult to obtain. Age demographics have been particularly difficult to assess with the Woylies, time spent as sub-adults is very short and their lack of representation in the trapping data makes it difficult to ascertain trends in survivorship from emergence to maturity. Stochasticity is inherently difficult to incorporate into these models but, as populations fall towards minimum viability, this is likely to take on a higher significance in a population's continuation. With declines to such an extent as seen in these areas severe selection pressure is likely to have been imposed on these populations, coupled with greatly reduced migration opportunities; this is likely to lead to much reduced genetic diversity within populations and may seriously affect future population dynamics. However, given these limitations, these simple models may give a useful indication of future trends and could prove helpful in sensitivity analysis of variable factors.

In the first model current estimates are considered and local extinction (assuming no outside interference) is seen after 12 years, even though density effects on the decline vectors reduce the mortality rate after only three years; therefore, scenarios that would significantly affect this prognosis within those 12 years were considered. Since individuals remain fecund and have a high reproduction rate it seems likely that survivorship is likely to be the main consideration rather than recruitment numbers themselves. Two variables are considered for analysis, adult survival rate and survival from pouch emergence to maturity. In model 2, emergent survival rate is increased to 100% (all else as model 1), this is still seen to result in an acute decline, though at a lesser rate. The population is seen to stabilise at about 50 individuals, around the density dependence of the decline vectors. Whether these vectors would in fact immediately take effect again in the real world as populations recover beyond this point is unclear. Model 3, similarly, considers adult survival rate at 100%, in this scenario decline rates are far slower though the population is still less than 50% after the 12 years. Model 4 shows the most successful scenario for an increase over the time scale. In this a combination of the two variables is considered; the adult survival rate is enhanced to the estimated survival rate without the decline pressure (77.78%) and emergent survival is raised to the minimum required for an increased population after 12 years (39%).

These results would seem to agree broadly with the main conservation effort to exclude and control predators as these seem to have by far the biggest impacts on survivorship, both through the spread of disease and predation. The intention to continue and enhance Western Shield would certainly seem the most effective mechanism for Woylie recovery. Genetic bottlenecks must be considered and relocation programmes are proposed with thought given to genetic sources of introduction. More emphasis seems to have been placed in the report on adult survival though model 3 would suggest that this alone would not be enough. Survivorship to sexual maturity must also be enhanced considerably, though as we have seen this presents particular difficulties. Research is proposed to carry out more sophisticated data analysis and monitoring to gain a better understanding of age class demographics. The development of an inoculation programme, if possible, might be desirable, particularly if a vaccine that passed antibodies from the mother to the offspring were available. The unaffected population at Karakamia demonstrates that predator proof barriers do prove effective in preventing these acute declines but they also restrict movement of what would naturally be a highly mobile species; with implications for genetic management and the production of somewhat artificial populations. Recommendations for increasing public awareness and involvement are particularly important, especially where programmes to eradicate invading species are considered; public support and understanding is often essential to the success of any conservation effort.

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Appendix

Population Model 1

Current estimates of demographic survival rates
Average population decline = 38% / annum
Local extinction after 12 years

Age	Yr 0	Av. Adult surv	Breeding fema	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 1	Av. Adult surv	Breeding fema	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 2	Av. Adult surv
1yr	305.57	101.85	50.92	45.32	5.07	12.41	40.63	13.54	6.77	6.03	0.67	1.65	14.82	4.94
2yr	250.00	83.33	41.66	37.08	4.15	10.16	101.85	33.95	16.97	15.11	1.69	4.14	13.54	4.51
3yr	194.45	64.81	32.41	28.84	3.22	7.90	83.33	27.77	13.89	12.36	1.38	3.39	33.95	11.31
4yr	138.90	46.30	23.15	20.60	2.30	5.64	64.81	21.60	10.80	9.61	1.07	2.63	27.77	9.26
5yr	83.35	27.78	13.89	12.36	1.38	3.39	46.30	15.43	7.72	6.87	0.77	1.88	21.60	7.20
6yr	27.76	9.25	4.63	4.12	0.46	1.13	27.78	9.26	4.63	4.12	0.46	1.13	15.43	5.14
Totals	**1000.03**	333.31	166.65	148.32	16.58	40.63	**364.68**	121.55	60.77	54.09	6.05	14.82	**127.11**	42.36

Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 3	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 4	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matur
2.47	2.20	0.25	0.60	5.16	4.02	2.01	1.79	0.20	0.49	4.02	3.13	1.56	1.39	0.16
2.26	2.01	0.22	0.55	4.94	3.84	1.92	1.71	0.19	0.47	4.02	3.12	1.56	1.39	0.16
5.66	5.03	0.56	1.38	4.51	3.51	1.76	1.56	0.17	0.43	3.84	2.99	1.49	1.33	0.15
4.63	4.12	0.46	1.13	11.31	8.80	4.40	3.92	0.44	1.07	3.51	2.73	1.37	1.22	0.14
3.60	3.20	0.36	0.88	9.26	7.20	3.60	3.20	0.36	0.88	8.80	6.84	3.42	3.05	0.34
2.57	2.29	0.26	0.63	7.20	5.60	2.80	2.49	0.28	0.68	7.20	5.60	2.80	2.49	0.28
21.18	18.85	2.11	5.16	**42.39**	32.97	16.48	14.67	1.64	4.02	**31.39**	24.41	12.21	10.86	1.21

Cmbnd Offs	Yr 5	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 6	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 7	Av. Adult surv
0.38	2.98	2.31	1.16	1.03	0.12	0.28	2.07	1.61	0.80	0.71	0.08	0.20	1.30	1.01
0.38	3.13	2.43	1.22	1.08	0.12	0.30	2.31	1.80	0.90	0.80	0.09	0.22	1.61	1.25
0.36	3.12	2.43	1.21	1.08	0.12	0.30	2.43	1.89	0.95	0.84	0.09	0.23	1.80	1.40
0.33	2.99	2.32	1.16	1.03	0.12	0.28	2.43	1.89	0.94	0.84	0.09	0.23	1.89	1.47
0.83	2.73	2.12	1.06	0.95	0.11	0.26	2.32	1.81	0.90	0.80	0.09	0.22	1.89	1.47
0.68	6.84	5.32	2.66	2.37	0.26	0.65	2.12	1.65	0.83	0.74	0.08	0.20	1.81	1.41
2.98	**21.79**	16.95	8.47	7.54	0.84	2.07	**13.69**	10.65	5.32	4.74	0.53	1.30	**10.29**	8.01

Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 8	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 9	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu
0.50	0.45	0.05	0.12	0.98	0.76	0.38	0.34	0.04	0.09	0.72	0.56	0.28	0.25	0.03
0.62	0.56	0.06	0.15	1.01	0.79	0.39	0.35	0.04	0.10	0.76	0.59	0.30	0.26	0.03
0.70	0.62	0.07	0.17	1.25	0.97	0.49	0.43	0.05	0.12	0.79	0.61	0.31	0.27	0.03
0.74	0.65	0.07	0.18	1.40	1.09	0.54	0.48	0.05	0.13	0.97	0.76	0.38	0.34	0.04
0.73	0.65	0.07	0.18	1.47	1.14	0.57	0.51	0.06	0.14	1.09	0.85	0.42	0.38	0.04
0.70	0.63	0.07	0.17	1.47	1.14	0.57	0.51	0.06	0.14	1.14	0.89	0.44	0.40	0.04
4.00	3.56	0.40	0.98	**7.58**	5.89	2.95	2.62	0.29	0.72	**5.47**	4.25	2.13	1.89	0.21

Cmbnd Offs	Yr 10	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 11	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 12
0.07	0.52	0.40	0.20	0.18	0.02	0.05	0.37	0.29	0.14	0.13	0.01	0.03	0.26
0.07	0.56	0.43	0.22	0.19	0.02	0.05	0.40	0.31	0.16	0.14	0.02	0.04	0.29
0.07	0.59	0.46	0.23	0.20	0.02	0.06	0.43	0.34	0.17	0.15	0.02	0.04	0.31
0.09	0.61	0.47	0.24	0.21	0.02	0.06	0.46	0.36	0.18	0.16	0.02	0.04	0.34
0.10	0.76	0.59	0.29	0.26	0.03	0.07	0.47	0.37	0.18	0.16	0.02	0.05	0.36
0.11	0.85	0.66	0.33	0.29	0.03	0.08	0.59	0.46	0.23	0.20	0.02	0.06	0.37
0.52	**3.88**	3.02	1.51	1.34	0.15	0.37	**2.73**	2.12	1.06	0.94	0.11	0.26	**1.92**

Population Model 2

Emergent survival rate increased to 100%
Average decline of 36.36% / annum before stabilising around average of 53 individuals after 6 years

Age	Yr 0	Av. Adult surv	Breeding fems	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 1	Av. Adult surv	Breeding fems	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 2	Av. Adult surv
1yr	305.57	101.85	50.92	45.32	38.98	95.49	312.52	104.16	52.08	46.35	39.86	97.66	198.93	66.30
2yr	250.00	83.33	41.66	37.08	31.89	78.13	101.85	33.95	16.97	15.11	12.99	31.83	104.16	34.72
3yr	194.45	64.81	32.41	28.84	24.80	60.77	83.33	27.77	13.89	12.36	10.63	26.04	33.95	11.31
4yr	138.90	46.30	23.15	20.60	17.72	43.41	64.81	21.60	10.80	9.61	8.27	20.25	27.77	9.26
5yr	83.35	27.78	13.89	12.36	10.63	26.05	46.30	15.43	7.72	6.87	5.91	14.47	21.60	7.20
6yr	27.76	9.25	4.63	4.12	3.54	8.68	27.78	9.26	4.63	4.12	3.54	8.68	15.43	5.14
Totals	**1000.03**	333.31	166.65	148.32	127.56	312.52	**636.57**	212.17	106.09	94.42	81.20	198.93	**401.84**	133.93

Breeding fems	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 3	Av. Adult surv	Breeding fems	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 4	Av. Adult surv	Breeding fems	Pouch Your	Survl to Matur
33.15	29.51	25.37	62.17	125.58	41.86	20.93	18.63	16.02	39.24	79.49	26.49	13.25	11.79	10.14
17.36	15.45	13.29	32.55	66.30	22.10	11.05	9.83	8.46	20.72	41.86	13.95	6.98	6.21	5.34
5.66	5.03	4.33	10.61	34.72	11.57	5.79	5.15	4.43	10.85	22.10	7.37	3.68	3.28	2.82
4.63	4.12	3.54	8.68	11.31	3.77	1.89	1.68	1.44	3.54	11.57	3.86	1.93	1.72	1.48
3.60	3.20	2.76	6.75	9.26	3.09	1.54	1.37	1.18	2.89	3.77	1.26	0.63	0.56	0.48
2.57	2.29	1.97	4.82	7.20	2.40	1.20	1.07	0.92	2.25	3.09	1.03	0.51	0.46	0.39
66.97	59.60	51.26	125.58	**254.37**	84.78	42.39	37.73	32.45	79.49	**161.88**	53.95	26.98	24.01	20.65

Cmbnd Offs	Yr 5	Av. Adult surv	Breeding fems	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 6	Av. Adult surv	Breeding fems	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 7	Av. Adult surv
24.84	50.59	16.86	8.43	7.50	6.45	15.81	32.35	10.78	5.39	4.80	4.13	10.11	20.76	16.15
13.08	26.49	8.83	4.42	3.93	3.38	8.28	16.86	5.62	2.81	2.50	2.15	5.27	10.78	8.39
6.91	13.95	4.65	2.32	2.07	1.78	4.36	8.83	2.94	1.47	1.31	1.13	2.76	5.62	4.37
3.62	7.37	2.45	1.23	1.09	0.94	2.30	4.65	1.55	0.77	0.69	0.59	1.45	2.94	2.29
1.18	3.86	1.29	0.64	0.57	0.49	1.21	2.45	0.82	0.41	0.36	0.31	0.77	1.55	1.21
0.96	1.26	0.42	0.21	0.19	0.16	0.39	1.29	0.43	0.21	0.19	0.16	0.40	0.82	0.64
50.59	**103.51**	34.50	17.25	15.35	13.20	32.35	**66.43**	22.14	11.07	9.85	8.47	20.76	**42.47**	33.04

Breeding fems	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 8	Av. Adult surv	Breeding fems	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 9	Av. Adult surv	Breeding fems	Pouch Youn	Survl to Matu
8.07	7.19	6.18	15.14	30.97	10.32	5.16	4.59	3.95	9.68	19.80	15.40	7.70	6.85	5.90
4.19	3.73	3.21	7.86	16.15	5.38	2.69	2.39	2.06	5.05	10.32	8.03	4.01	3.57	3.07
2.19	1.95	1.67	4.10	8.39	2.80	1.40	1.24	1.07	2.62	5.38	4.19	2.09	1.86	1.60
1.14	1.02	0.88	2.15	4.37	1.46	0.73	0.65	0.56	1.37	2.80	2.17	1.09	0.97	0.83
0.60	0.54	0.46	1.13	2.29	0.76	0.38	0.34	0.29	0.72	1.46	1.13	0.57	0.50	0.43
0.32	0.28	0.24	0.60	1.21	0.40	0.20	0.18	0.15	0.38	0.76	0.59	0.30	0.26	0.23
16.52	14.70	12.64	30.97	**63.37**	21.12	10.56	9.40	8.08	19.80	**40.52**	31.52	15.76	14.03	12.06

Cmbnd Offs	Yr 10	Av. Adult surv	Breeding fems	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 11	Av. Adult surv	Breeding fems	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 12
14.44	29.55	9.85	4.93	4.38	3.77	9.24	18.90	14.70	7.35	6.54	5.63	13.78	28.21
7.53	15.40	5.13	2.57	2.28	1.96	4.81	9.85	7.66	3.83	3.41	2.93	7.18	14.70
3.92	8.03	2.68	1.34	1.19	1.02	2.51	5.13	3.99	2.00	1.78	1.53	3.74	7.66
2.04	4.19	1.40	0.70	0.62	0.53	1.31	2.68	2.08	1.04	0.93	0.80	1.95	3.99
1.06	2.17	0.72	0.36	0.32	0.28	0.68	1.40	1.09	0.54	0.48	0.42	1.02	2.08
0.56	1.13	0.38	0.19	0.17	0.14	0.35	0.72	0.56	0.28	0.25	0.22	0.53	1.09
29.55	**60.48**	20.16	10.08	8.97	7.71	18.90	**38.68**	30.09	15.04	13.39	11.51	28.21	**57.73**

Population Model 3

Adult survival rate increased to 100%

Population declines by average 9.2% / annum after 4 years.

Age	Yr 0	Av. Adult surv	Breeding fema	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 1	Av. Adult surv	Breeding fema	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 2	Av. Adult surv
1yr	305.57	305.57	152.79	135.98	15.20	37.25	121.89	121.89	60.95	54.24	6.06	14.86	133.37	133.37
2yr	250.00	250.00	125.00	111.25	12.44	30.47	305.57	305.57	152.79	135.98	15.20	37.25	121.89	121.89
3yr	194.45	194.45	97.23	86.53	9.67	23.70	250.00	250.00	125.00	111.25	12.44	30.47	305.57	305.57
4yr	138.90	138.90	69.45	61.81	6.91	16.93	194.45	194.45	97.23	86.53	9.67	23.70	250.00	250.00
5yr	83.35	83.35	41.68	37.09	4.15	10.16	138.90	138.90	69.45	61.81	6.91	16.93	194.45	194.45
6yr	27.76	27.76	13.88	12.35	1.38	3.38	83.35	83.35	41.68	37.09	4.15	10.16	138.90	138.90
Totals	**1000.03**	1000.03	500.02	445.01	49.75	121.89	**1094.16**	1094.16	547.08	486.90	54.44	133.37	**1144.18**	1144.18

Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 3	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 4	Av. Adult surv	Breeding fem	Pouch Your	Survl to Matur
66.68	59.35	6.64	16.26	139.46	139.46	69.73	62.06	6.94	17.00	139.53	139.53	69.77	62.09	6.94
60.95	54.24	6.06	14.86	133.37	133.37	66.68	59.35	6.64	16.26	139.46	139.46	69.73	62.06	6.94
152.79	135.98	15.20	37.25	121.89	121.89	60.95	54.24	6.06	14.86	133.37	133.37	66.68	59.35	6.64
125.00	111.25	12.44	30.47	305.57	305.57	152.79	135.98	15.20	37.25	121.89	121.89	60.95	54.24	6.06
97.23	86.53	9.67	23.70	250.00	250.00	125.00	111.25	12.44	30.47	305.57	305.57	152.79	135.98	15.20
69.45	61.81	6.91	16.93	194.45	194.45	97.23	86.53	9.67	23.70	250.00	250.00	125.00	111.25	12.44
572.09	509.16	56.92	139.46	**1144.75**	1144.75	572.37	509.41	56.95	139.53	**1089.83**	1089.83	544.91	484.97	54.22

Cmbnd Offs	Yr 5	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 6	Av. Adult surv	Breeding fema	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 7	Av. Adult surv
17.01	132.84	132.84	66.42	59.11	6.61	16.19	118.56	118.56	59.28	52.76	5.90	14.45	95.76	95.76
17.00	139.53	139.53	69.77	62.09	6.94	17.01	132.84	132.84	66.42	59.11	6.61	16.19	118.56	118.56
16.26	139.46	139.46	69.73	62.06	6.94	17.00	139.53	139.53	69.77	62.09	6.94	17.01	132.84	132.84
14.86	133.37	133.37	66.68	59.35	6.64	16.26	139.46	139.46	69.73	62.06	6.94	17.00	139.53	139.53
37.25	121.89	121.89	60.95	54.24	6.06	14.86	133.37	133.37	66.68	59.35	6.64	16.26	139.46	139.46
30.47	305.57	305.57	152.79	135.98	15.20	37.25	121.89	121.89	60.95	54.24	6.06	14.86	133.37	133.37
132.84	**972.67**	972.67	486.33	432.84	48.39	118.56	**785.66**	785.66	392.83	349.62	39.09	95.76	**759.53**	759.53

Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 8	Av. Adult surv	Breeding fema	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 9	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu
47.88	42.61	4.76	11.67	92.58	92.58	46.29	41.20	4.61	11.28	87.61	87.61	43.80	38.99	4.36
59.28	52.76	5.90	14.45	95.76	95.76	47.88	42.61	4.76	11.67	92.58	92.58	46.29	41.20	4.61
66.42	59.11	6.61	16.19	118.56	118.56	59.28	52.76	5.90	14.45	95.76	95.76	47.88	42.61	4.76
69.77	62.09	6.94	17.01	132.84	132.84	66.42	59.11	6.61	16.19	118.56	118.56	59.28	52.76	5.90
69.73	62.06	6.94	17.00	139.53	139.53	69.77	62.09	6.94	17.01	132.84	132.84	66.42	59.11	6.61
66.68	59.35	6.64	16.26	139.46	139.46	69.73	62.06	6.94	17.00	139.53	139.53	69.77	62.09	6.94
379.76	337.99	37.79	92.58	**718.74**	718.74	359.37	319.84	35.76	87.61	**666.88**	666.88	333.44	296.76	33.18

Cmbnd Offs	Yr 10	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 11	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 12
10.68	81.29	81.29	40.64	36.17	4.04	9.91	74.19	74.19	37.09	33.01	3.69	9.04	67.04
11.28	87.61	87.61	43.80	38.99	4.36	10.68	81.29	81.29	40.64	36.17	4.04	9.91	74.19
11.67	92.58	92.58	46.29	41.20	4.61	11.28	87.61	87.61	43.80	38.99	4.36	10.68	81.29
14.45	95.76	95.76	47.88	42.61	4.76	11.67	92.58	92.58	46.29	41.20	4.61	11.28	87.61
16.19	118.56	118.56	59.28	52.76	5.90	14.45	95.76	95.76	47.88	42.61	4.76	11.67	92.58
17.01	132.84	132.84	66.42	59.11	6.61	16.19	118.56	118.56	59.28	52.76	5.90	14.45	95.76
81.29	**608.63**	608.63	304.32	270.84	30.28	74.19	**549.98**	549.98	274.99	244.74	27.36	67.04	**498.46**

Population model 4

Combined minima for increased population after 12 years
Adult survival rate = 77.78% (estimated survival rate with no decline pressure), emergent survival rate increased to 39% (currently 13%)

Age	Yr 0	Av. Adult surv	Breeding fema	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 1	Av. Adult surv	Breeding fema	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 2	Av. Adult surv
1yr	305.57	237.67	118.84	105.76	35.47	86.91	284.43	221.23	110.61	98.45	33.02	80.90	295.98	230.21
2yr	250.00	194.45	97.23	86.53	29.02	71.10	237.67	184.86	92.43	82.26	27.59	67.60	221.23	172.07
3yr	194.45	151.24	75.62	67.30	22.57	55.31	194.45	151.24	75.62	67.30	22.57	55.31	184.86	143.79
4yr	138.90	108.04	54.02	48.08	16.12	39.51	151.24	117.64	58.82	52.35	17.56	43.02	151.24	117.64
5yr	83.35	64.83	32.41	28.85	9.68	23.71	108.04	84.03	42.02	37.39	12.54	30.73	117.64	91.50
6yr	27.76	21.59	10.80	9.61	3.22	7.90	64.83	50.42	25.21	22.44	7.53	18.44	84.03	65.36
Totals	**1000.03**	777.82	388.91	346.13	116.09	284.43	**1040.66**	809.42	404.71	360.19	120.81	295.98	**1054.98**	820.56

Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 3	Av. Adult surv	Breeding fem	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 4	Av. Adult surv	Breeding fem	Pouch Your	Survl to Matur
115.11	102.45	34.36	84.18	300.06	233.38	116.69	103.86	34.83	85.34	300.14	233.45	116.72	103.88	34.84
86.04	76.57	25.68	62.92	230.21	179.06	89.53	79.68	26.73	65.48	233.38	181.53	90.76	80.78	27.09
71.89	63.98	21.46	52.58	172.07	133.84	66.92	59.56	19.98	48.94	179.06	139.27	69.64	61.98	20.79
58.82	52.35	17.56	43.02	143.79	111.84	55.92	49.77	16.69	40.90	133.84	104.10	52.05	46.32	15.54
45.75	40.72	13.66	33.46	117.64	91.50	45.75	40.72	13.66	33.46	111.84	86.99	43.49	38.71	12.98
32.68	29.08	9.76	23.90	91.50	71.17	35.58	31.67	10.62	26.02	91.50	71.17	35.58	31.67	10.62
410.28	365.15	122.47	300.06	**1055.26**	820.78	410.39	365.25	122.50	300.14	**1049.75**	816.50	408.25	363.34	121.86

Cmbnd Offs	Yr 5	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 6	Av. Adult surv	Breeding fem	Pouch Your	Survl to Matu	Cmbnd Offs	Yr 7	Av. Adult surv
85.36	298.57	232.23	116.11	103.34	34.66	84.92	296.90	230.93	115.47	102.76	34.47	84.44	296.13	230.33
66.38	233.45	181.57	90.79	80.80	27.10	66.40	232.23	180.63	90.31	80.38	26.96	66.05	230.93	179.62
50.93	181.53	141.19	70.60	62.83	21.07	51.63	181.57	141.23	70.61	62.85	21.08	51.64	180.63	140.49
38.07	139.27	108.33	54.16	48.21	16.17	39.61	141.19	109.82	54.91	48.87	16.39	40.16	141.23	109.85
31.81	104.10	80.97	40.48	36.03	12.08	29.61	108.33	84.26	42.13	37.49	12.58	30.81	109.82	85.42
26.02	86.99	67.66	33.83	30.11	10.10	24.74	80.97	62.98	31.49	28.02	9.40	23.03	84.26	65.53
298.57	**1043.90**	811.94	405.97	361.31	121.18	296.90	**1041.19**	809.84	404.92	360.38	120.87	296.13	**1042.99**	811.24

Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 8	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 9	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu
115.17	102.50	34.38	84.23	296.65	230.73	115.37	102.68	34.44	84.37	296.46	230.59	115.29	102.61	34.42
89.81	79.93	26.81	65.68	230.33	179.15	89.58	79.72	26.74	65.51	230.73	179.46	89.73	79.86	26.79
70.25	62.52	20.97	51.37	179.62	139.71	69.85	62.17	20.85	51.09	179.15	139.34	69.67	62.01	20.80
54.92	48.88	16.40	40.17	140.49	109.27	54.64	48.63	16.31	39.96	139.71	108.66	54.33	48.36	16.22
42.71	38.01	12.75	31.23	109.85	85.44	42.72	38.02	12.75	31.24	109.27	84.99	42.50	37.82	12.69
32.77	29.16	9.78	23.96	85.42	66.44	33.22	29.56	9.92	24.29	85.44	66.45	33.23	29.57	9.92
405.62	361.00	121.08	296.65	**1042.35**	810.74	405.37	360.78	121.01	296.46	**1040.77**	809.51	404.75	360.23	120.82

Cmbnd Offs	Yr 10	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 11	Av. Adult surv	Breeding fem	Pouch Youn	Survl to Matu	Cmbnd Offs	Yr 12
84.32	296.01	230.24	115.12	102.46	34.36	84.19	295.53	229.86	114.93	102.29	34.31	84.05	295.11
65.62	230.59	179.35	89.68	79.81	26.77	65.58	230.24	179.08	89.54	79.69	26.73	65.48	229.86
50.95	179.46	139.59	69.79	62.12	20.83	51.04	179.35	139.50	69.75	62.08	20.82	51.01	179.08
39.74	139.34	108.38	54.19	48.23	16.18	39.63	139.59	108.57	54.28	48.31	16.20	39.70	139.50
31.08	108.66	84.52	42.26	37.61	12.61	30.91	108.38	84.30	42.15	37.51	12.58	30.83	108.57
24.30	84.99	66.11	33.05	29.42	9.87	24.17	84.52	65.74	32.87	29.25	9.81	24.04	84.30
296.01	**1039.07**	808.19	404.09	359.64	120.62	295.53	**1037.61**	807.05	403.53	359.14	120.45	295.11	**1036.43**