Population viability analysis in urban wildlife management: modelling management options for Sydney's quarantined bandicoots

Peter B. Banks

School of Biological, Earth and Environmental Sciences, The University of New South Wales, Kensington, NSW 2052, Australia

Email: p.banks@unsw.edu.au

Tel: +612 9385 2066

Fax: +612 9385 1558

ABSTRACT

Managers of urban wildlife must make transparent, quantitative decisions about environmental impacts but are challenged by the complexity of these impacts, which can interact with environmental variability to cause long-term changes. Here I use population viability analysis (PVA) to exemplify its potential in urban wildlife management, modelling the endangered population of long-nosed bandicoots at North Head. An "off the shelf" software package, VORTEX, was used to model data on population size, animal life span, reproduction rates, litter size, and mortality rates to simulate the population's dynamics over time, taking into account fluctuations in these parameters due to environmental conditions. Various management options for the long-term recovery and potential impacts of urban development were then modelled by varying adult mortality and carrying capacity.

The bandicoot population was highly sensitive to increases in adult mortality. Under the basic model, with a 30% chance of fox arrival each year and the carrying capacity of the headland at 120 bandicoots, the population had a 10% chance of going extinct within 20 years due to chance events. When adult mortality was increased to 11%, 14% and 16% the probability of extinction by 2020 increased to 15%, 24% and 32% respectively. If the carrying capacity of the headland is increased (to 200 animals), elevated adult mortality had a much lower impact on the chances of extinction (6%, 9% and 15% for the 3 levels of mortality). However, if development reduces the carrying capacity (to 75 individuals on the headland), elevated adult mortality leads to increased chances of extinction in 20 years to 31%, 42% and 46% for the 3 levels. Hence the model showed that for bandicoots, managing the by-products of urbanisation, such as road kills or predation by pets is more immediately important than small changes in habitat availability, but the effects are additive. More generally, the exercise showed how PVA can be used to avoid subjective and short sighted assessment of management decisions to provide a quantitative comparison of a complex network of management options.

Key words: mammal conservation; demographic stochasticity; PVA; *Perameles nasuta;* VORTEX

Introduction

For several reasons, managers of urban wildlife face a difficult job understanding, predicting and managing the potential impacts of urban development. Firstly, impacts on basic population processes are difficult to quantify. For example, what will happen if an animal population loses habitat, and how much might be lost before the population will have a significantly reduced chance of persistence? Secondly, urban development typically causes multiple impacts. For example, clearing vegetation for housing causes habitat loss as well as potential increases in road kills and predation rates for any remaining wildlife caused by the cars and pets that future residents will bring. And thirdly, land managers must decide how these factors might interact with one-another and with natural environmental fluctuations in habitat quality. This final decision ultimately determines the fate of both the wildlife population and the development proposal. Due to this complex network of processes interacting in an unpredictable environment, assessment of the impacts of development have remained largely qualitative, and hence open to subjective interpretation and much debate.

This study takes an alternative approach by using population modelling to quantitatively assess development options for an urban bandicoot population. Managers of threatened species have long recognized the value of predictive modelling in species management. A variety of population modelling tools, or population viability analyses (PVA), have been developed with the specific purpose of understanding how threats or changes to conditions might affect population survival. These include programs such as RAMAS, SIMPOP, ALEX and VORTEX which model the interaction between population processes and stochastic conditions

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to simulate population trajectories over time (Brook *et al.* 2000). Importantly these tools allow managers to be proactive in their management of future threats, rather than simply reactive to change once it has occurred. The approach has been used to model management options for forest fauna (e.g. Possingham 1993; Lindenmayer and Possingham 1996) to reveal which options give the best prognosis of population persistence. However, this approach has rarely been applied to understanding potential negative impacts of urban developments.

The population modelled here is a vestige of the long-nosed bandicoot *Perameles nasuta* at North Head, Manly at the opening to Sydney Harbour. The population is a small isolate of a once Sydney-wide distribution that has eroded and now shows all the symptoms of a fragmented population in danger from predation, road kills and disease. These bandicoots have persisted in and around the historical Quarantine Station where immigrants to Australia during the 1800's and 1900's were held to prevent foreign infectious diseases from entering the human population. However the bandicoots are themselves now "quarantined" from all other populations, cut-off by the urban development at Manly. Research into the ecology of the population over five years (Chambers 1991; Chambers and Dickman 2002) suggested that it was small and potentially declining (Scott 1995a; Scott, *et al.* 1999). Because this North Head population represents one of the few remaining populations of *P. nasuta* in the Sydney region, it has become an important conservation icon in Sydney. As such, the long-nosed bandicoot at North Head was the first Endangered Population listed under the NSW *Threatened Species Conservation Act 1995*. Mortalities from cars and predation by feral predators were listed as two key threats but their impact had not been quantified.

This paper presents a simple PVA to model the potential impact on bandicoots of various development scenarios at the headland. Bandicoot habitat covers 360ha of various land tenures and abuts some of Sydney's most valuable real estate and most sought after locations. This habitat includes National Park (160ha), defence land (72ha), residential lands (40ha), council reserves (25ha) St Patrick's Estate (25ha), a sewage treatment plant (25ha), Manly hospital (15ha) and a Police School (3ha). None of this tenure is free from potential development impacting upon bandicoots and major changes in land use are already underway. So to avoid a "death by a thousand cuts" scenario, a long-term management plan for the population is essential.

The key population biology data needed for a PVA of the north head bandicoots were available from National Parks and Wildlife Service (NPWS) trapping surveys and research by Chambers (1991), Miller and Puddephatt (1996) and Scott *et al.* (1999). These data were first used to model the dynamics of the populations under current conditions in order to estimate persistence probabilities. Parameters in the model were then varied to simulate different management options. These included negative effects of urban development, such as habitat loss and increased adult mortality, and positive effects, such as predator control and habitat augmentation. The impacts of development modelled here are not meant to simulate any particular development planned for North Head, but rather to simulate generic urban impacts. Changes in the population's survival prospects under different scenarios are compared to assess the sensitivity of the bandicoots to different management options.

Methods

This study employs a simple approach by using an "off-the-shelf" PVA package to demonstrate that the basics of PVA can be a useful tool to urban land managers. The package VORTEX 8.4 (Lacy 1993) is used to model bandicoot population dynamics as it is ideally suited to closed, single populations where stochastic events need to be modelled in the context of risk of catastrophes, inbreeding and environmental variations (Brook *et al.* 2000). SIMPOP, the precursor of VORTEX, was earlier used to model the viability of the eastern barred bandicoot *P. gunnii* at Hamilton in Victoria (Lacy and Clark 1990) and reliably predicted its fate (Clark *et al.* 1995). Importantly, retrospective analysis of declining populations has shown that VORTEX predictions are robust for a range of species (Brook *et al.* 2000). Nevertheless PVA's can produce unreliable estimates of net survival probabilities and hence are best used to compare the effects of changing input parameters (McCarthy *et al.* 2000; Coulson *et al.* 2001), which is the approach adopted here.

The basic PVA model

The basic model used data from ecological studies performed on the bandicoot population (Chambers 1991; Scott 1995a; Miller and Puddephatt 1996; Scott *et al.* 1999) and more recent NPWS trapping (Banks and Powell 2002; NPWS unpublished data) (Table 1). The basic scenario considered a population size of 100 animals with a mean total carrying capacity (K) of the headland of 120 individuals allowing some scope for disease and natural mortality to hold the population below the carrying capacity. It was assumed that the population had an even sex ratio (Scott *et al.* 1999) and a stable age distribution, and also that all adult males were able to breed in the polygynous breeding system.

The basic model included 25% standard deviation (SD) due to environmental variation (EV). An understanding natural environmental variation in K relies upon comparison of annual indices of population size, which is limited for the *P. nasuta*. Interannual variation in trap success at North Head from 1991-1996 shows an EV of 26% (Miller and Puddephatt 1996). Direct comparison of trapping with consistent methods in 1991 and 1996 showed EV of 44% for heath and 45% for open habitats, although these are based on very small sample sizes. Mallick *et al.* (2000) reported EV's of 47% and 34% for two Tasmanian populations of the eastern barred bandicoot. Environmental variation has great potential to influence the likelihood of persistence of a population modelled in PVA; EV's of >30% of the carrying capacity will in some years mean that the carrying capacity is very low and populations will be unlikely to persist (Lacy and Clark 1990; Lacy 1993). Nevertheless, bandicoot populations are typically variable and their r-selected life history strategy of rapid reproduction, high fecundity and short life span, suggest that they have evolved to exploit highly unpredictable conditions. To account for such uncertainty in EV, various models were run using values of 20%, 25% and 30% EV.

Table 1. Population parameters used in the PVA for the long-nosed bandicoot population at North Head, Manly NSW with values for variants used under different scenarios.

Vortex Input	Basic Model	Variants	References
Carrying Capacity (K)	120	75, 200	1, 5, 6, 7, 9
Environmental Variation in K	25	20, 30	2, 6, 9
Starting population size	100	75, 80, 200	1, 4, 5, 7, 8
Trend in carrying capacity	none	-	
Sex ratio at birth	0.5	-	10
Breeding system	polygynous	-	10
Age at first breeding	6 months	-	6, 10
% Females producing			10, 11
1-2 offspring	13.2	-	
3-4 offspring	50	-	
5-6 offspring	26.3	-	
7-8 offspring	10.5	-	
Maximum age	2 years	-	10, 11
Catastrophes: Fox			11
chance fox arrival	30% each year	-	
impact on survival	20% killed	-	
impact on reprod.	0	-	
Juvenile mortality	80% (EV 5%)	-	10, 11
Adult mortality	10% (EV 1%)	11,12,14, 16, 20	1, 5, 6, 9, 10, 11

[1](Chambers 1991), [2](Clark *et al.* 1995b), [3](Lacy and Clark 1990b), [4](Manidis Robert Consultants 2000b), [5](Miller 1997), [6](Miller and Puddephatt 1996b),[7](Minta *et al.* 1990), [8](Ravallion 2000), [9](Scott 1995b), [10](Scott *et al.* 1999), [11](Banks and Powell 2002)

Female fecundity is considered high with 85% of female *P. nasuta* breeding each year and females are able to breed at six months of age (Scott *et al.* 1999). A 5% SD due to environmental variation was used for both parameters (Lacy 1993). Female fecundity is considered to be typically very high during the breeding season, regardless of EV, and most females breed each year in the long-nosed bandicoot and eastern barred bandicoot (Lacy and Clark 1990; Dufty 1991; Scott *et al.* 1999; Mallick *et al.* 2000). Almost all individuals of breeding size (>450g) were recorded as breeding during the NPWS study (28/36 captured over three periods: NPWS unpublished data). Age at first reproduction can be as early as four months, and some very young animals have been recorded with pouch young during recent trappings. However, a more conservative value of six months is used here (see also Lacy and Clark 1990) which is when most females will be pregnant or with pouch young.

Juvenile mortality was considered high at 80% as typical for bandicoot species (Mallick *et al.* 2000). Scott *et al.* (1999) reported that only eight sub-adults were captured from >80 pouch young recorded. Lacy and Clark (1990) used estimates of 90% juvenile mortality of young until the age of sexual maturity. Based on fecundity estimates from Scott *et al.* (1999), the 45 females in a total population of 100 animals with 90% of the females breeding would produce 197 offspring each six months, most of which seem not to survive. A standard deviation due to EV of 5% was used because juvenile mortality probably always exceeds 70% (two standard deviations) regardless of annual conditions.

Adult survival was considered high, with 10% adult mortality every six months, based on the mortality register held by NPWS. At North Head, adult bandicoots are killed by cats, dogs and native predators (birds of prey), potentially by starvation, and by cars. Scott (1995a) and Chambers (1991) reported three predator kills and no road-kills from 28 radiocollared animals inhabiting areas with very low car activity. But Miller (pers comm.) reported two road-kills from ten adults tracked over four months; both animals killed on the main access road (Darley Road). The mortality register of dead bandicoots mainly reports road-kills, and every six months from January 1998 – January 2002, on average 5.25 bandicoots were found that had been killed by cars along public access roads. All deaths were of adult animals, with an approximately even number of males and females (8:6 where sex was reported). This figure represents a mortality rate of approximately 5.5% considering a population of 100 adults on the headland. Rates of mortality from other sources (e.g. toxoplasmosis or tick infestation) are not known for this bandicoot population. For the eastern barred bandicoot at Hamilton, 25% of adults were killed by cars each year (Minta *et al.* 1990). The results of these studies suggest that mortality from sources other than road-kills are low. Thus adult mortality was included as double the known deaths due to road trauma, which accounts for those individuals hit by cars but escape to die elsewhere as well other minor sources of mortality.

The impact of fox predation is modelled as a catastrophe or chance event that can be ameliorated by intensive fox control rather than being an on-going source of mortality. Foxes have been recorded twice on the headland in the past seven years. Scott (1995b) reported fox presence and noted that 30% of 12 radio-collared adult bandicoots were killed. In May 2000,one fox killed 15 adult animals, and probably injured many others. Hence, the model uses a 30% chance of a fox arriving in any given year with no effect on reproduction but a 20% impact on adult survival. This assumes that intensive and successful fox control efforts will be undertaken as soon as foxes are detected on site. Other persistent sources of predation, such as from local cats or dogs or birds of prey, are included in estimates for adult survival.

Inbreeding was not considered in the PVA because data on the genetic health of the population are lacking. Similarly, the impacts of wildfire could not be modelled because the likelihood or impact of fire at North Head is highly unpredictable making it too difficult to simulate realistic scenarios, despite its ever present threat. Hence this PVA should be considered an optimistic scenario. The population was considered not to be harvested or undergoing a decline in carrying capacity.

Modelling management options

Vigilant monitoring of fox activity and a rapid response to their arrival on the headland, although costly, may reduce the long-term impact of foxes on the bandicoots. Fox impact as a catastrophe is, therefore, removed from the basic model to determine benefits of such vigilance.

Table 2. Probabilities of population persistence for the long-nosed bandicoots at North Head under various scenarios of carrying capacity (K), environmental variation (EV) and adult mortality (AM). Values represent the proportion of 1000 simulated populations that persist at 10-year periods from 2000 when population parameters were determined from field data. Other parameters are presented in Table 1. Also presented are probabilities of persistence where catastrophic fox arrival is excluded from the PVA (No Fox).

ID Code	K	EV	AM	2000	2010	2020	2030	2040	2050
AM11	120	25	11	1	0.97	0.85	0.71	0.56	0.46
AM14	120	25	14	1	0.96	0.76	0.57	0.42	0.31
AM16	120	25	16	1	0.94	0.68	0.45	0.31	0.20
EV20AM11	120	20	11	1	0.98	0.88	0.75	0.66	0.56
EV20AM14	120	20	14	1	0.97	0.8	0.61	0.47	0.36
EV20AM16	120	20	16	1	0.95	0.72	0.50	0.34	0.23
EV30AM11	120	30	11	1	0.95	0.79	0.63	0.47	0.37
EV30AM14	120	30	14	1	0.92	0.7	0.47	0.32	0.21
EV30AM16	120	30	16	1	0.91	0.58	0.36	0.22	0.12
K200AM11	200	25	11	1	0.99	0.94	0.87	0.75	0.70
K200AM14	200	25	14	1	0.99	0.91	0.75	0.62	0.51
K200AM16	200	25	16	1	0.99	0.85	0.65	0.49	0.35
K200EV20AM11	200	20	11	1	0.99	0.97	0.91	0.84	0.77
K200EV20AM14	200	20	14	1	0.99	0.92	0.81	0.69	0.59
K200EV20AM16	200	20	16	1	0.99	0.87	0.70	0.53	0.39
K200EV30AM11	200	30	11	1	0.97	0.88	0.77	0.67	0.58
K200EV30AM14	200	30	14	1	0.97	0.85	0.67	0.51	0.38
K200EV30AM16	200	30	16	1	0.96	0.78	0.55	0.36	0.24
K75AM11	75	25	11	1	0.93	0.69	0.51	0.38	0.28
K75AM14	75	25	14	1	0.90	0.58	0.37	0.22	0.14
K75AM16	75	25	16	1	0.87	0.54	0.30	0.16	0.10
K75EV20AM11	75	20	11	1	0.96	0.79	0.63	0.46	0.34
K75EV20AM14	75	20	14	1	0.92	0.66	0.43	0.29	0.18
K75EV20AM16	75	20	16	1	0.89	0.54	0.32	0.19	0.11
K75EV30AM11	75	30	11	1	0.89	0.63	0.42	0.28	0.2
K75EV30AM14	75	30	14	1	0.86	0.51	0.3	0.18	0.1
K75EV30AM16	75	30	16	1	0.83	0.43	0.21	0.09	0.05
No Fox	120	25	10	1	0.99	0.97	0.96	0.95	0.94
No Fox A11	120	25	12	1	0.99	0.99	0.97	0.94	0.92
No Fox A14	120	25	16	1	0.99	0.94	0.87	0.81	0.75
No Fox A16	120	25	20	1	0.98	0.87	0.71	0.6	0.50

Possible impacts of increased traffic flow associated with urban development were also modelled. Environmental Impact Statements (EISs) typically document predicted flow increases caused by development, and these values can be extrapolated to give estimates of changes in bandicoot mortality, assuming that there is a linear relationship between traffic flow and probability of an individual being killed. Thus, increases in traffic flow of 10% to 60% resulting in associated adult mortality rates changing from 10% to 11, 14 and 16%. Although these proportional increases in traffic flow rates are high, the current traffic is mostly non-residential with very little evening traffic flow on either access roads or on the headland itself (Manidis Robert Consultants 2000). These values were then used in the basic model to predict the likely impacts on the chances of population extinction.

Declines in the carrying capacity (K) of the headland may also result from development because of increased visitor pedestrian traffic, lighting or loss of foraging habitat from removal of open spaces or vegetation. Increases in K may also be achievable with the construction of bandicoot friendly habitat, such as increasing foraging habitat. Thus a range of possible changes in K were modelled, including a reduction from 120 to 75 and an increase to 200, in order to determine how sensitive the population is to habitat loss.

Results

Under the basic model (i.e. the current situation), which includes a 30% chance of fox arrival causing 20% adult mortality, the long-nosed bandicoot population had a 10% chance of extinction in the next 20 years, where there are no changes to the carrying capacity or basic adult mortality. Excluding the risk of fox predation from the basic model reduces this chance of extinction to 3% (Table 2).

The long-nosed bandicoot population also proved to be very sensitive to changes in adult mortality with mild effects for 11% adult mortality, but substantial increases in the likelihood of extinction for 14% adult mortality (Figures 1-4). Probabilities of extinction within 20 years increased from 10% in the basic model (K=120) to 15%, 24% and 32% when adult mortality increased to

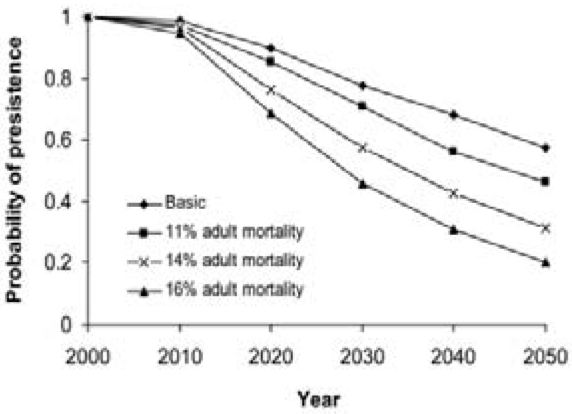

Figure 1. The effects of changes in adult mortality (AM) for the long-nosed bandicoot population at North Head, for values of AM at 10% (basic model), 11%, 14% and 16%. Data represent probabilities of persistence over 50 years modelled using PVA.

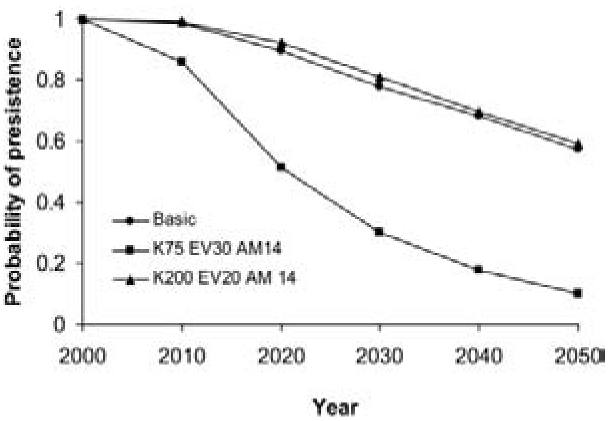

Figure 2. The effects of changes in carrying capacity (K) for the long-nosed bandicoot population at North Head for values of K as 120 (basic model), 75 and 200. Data represent probabilities of persistence over 50 years modelled using PVA under different levels of carrying capacity. Impacts of such changes on the effects of adult mortality (AM) are also shown.

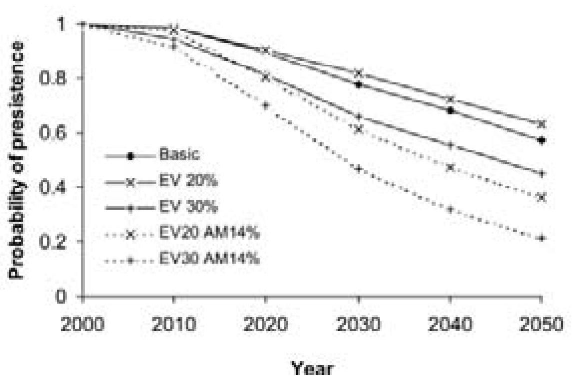

Figure 3. The effects of changes in environmental variation in carrying capacity (EV) for the long-nosed bandicoot population at North Head for values of EV as 25% (basic model), 20 and 30. Data represent probabilities of persistence over 50 years modelled using PVA under different levels of carrying capacity. Impacts of such changes on the effects of adult mortality (AM) are also shown.

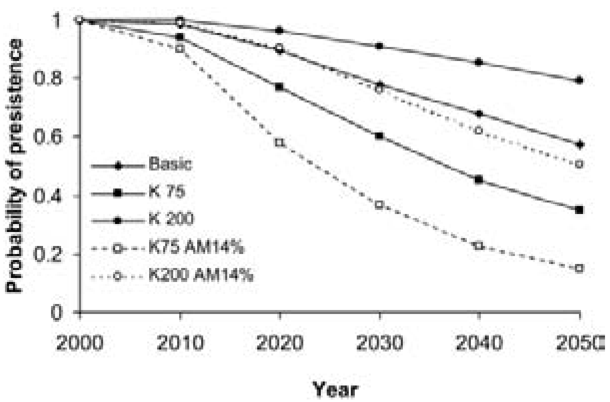

Figure 4. The effects of increased adult mortality (AM=14%) under the best and worst case scenarios of unknown parameters. Best case is the largest potential population size (K=200) and lowest potential EV (EV=20%); Worst case is the smallest potential population size (K=75) and highest potential EV (EV=30%).

11%, 14% and 16% respectively (Table 2). When K=75, extinction probability under the current conditions was 23%, and increased to 31%, 42%, and 46% with adult mortality at 11%, 14% and 16% (Table 2, Figure 2). When K=200, the base extinction risk at 4% increased to 5%, 9% and 34% under the three levels of potential adult mortality. Changes in EV had similar effects on the impacts of increased adult mortality, with a 20% EV leading to increased extinction probabilities within 20 years of 3% 18% and 27% for the three scenarios (Table 2). Conversely, higher EV at 30% led to a greater impact of higher adult mortality (Figure 3). In all scenarios, the magnitude of impact increased with time.

The combination of different levels of EV and K on the four levels of adult mortality is shown in Figure 4. Under the worst-case scenario, where EV = 30% and K=75, 10% adult mortality caused the population to have a 33% chance of extinction within 20 years; this increased to 57% where adult mortality is 16%. Under the best-case scenario where EV=20 and K=200, the effect is milder increasing from a 2% to 13% for 10% and 16% adult mortality respectively.

Discussion

Bandicoot responses to management options

The basic PVA model was sensitive to variations in carrying capacity and to underlying environmental variation. The chance of extinction within 20 years under the basic model was non-zero because fox predation was included as a chance catastrophe. The PVA therefore highlights the need for some action plan for the rapid response to fox arrival on the headland to prevent long term damage to the population.

As expected, the long-nosed bandicoot population model was extremely sensitive to adult mortality. Mild increases in mortality rates from 10-11% generally only result in mild increases in the probability of extinction. However, increases in adult mortality to 14% or 16% resulted in much greater increases in the chances of extinction under all EV's and K values used. Adult mortality is a key factor influencing the persistence of many bandicoot populations. It was a key reason for initial declines of the eastern barred bandicoot at Hamilton that sent the remnant population into a spiral of further declines from which it never recovered (Maguire *et al.* 1990; Minta *et al.* 1990; Clark *et al.* 1995). Mortality rates approaching 25% were enough to cause the rapid extinction of the eastern barred bandicoot where K=150 individuals (Clark *et al.* 1995). At North Head, where K=120 and EV=25%, increases in road kills from 10 to 16% resulted in a 320% higher chance of extinction within 20 years, and much lower prospects of longer term survival. A rate of 16% adult mortality represents just one additional bandicoot killed each month due to the increased traffic flow where the population is approximately 100 individuals. Such a high level of adult mortality is possible if traffic moves directly through the bandicoot's core habitat when animals are most active and most likely to cross roads (N. Hughes and P. Banks unpublished data). Unlike other road developments where most local resident bandicoots are killed soon after the road opens, after which road deaths subside; increased mortality at the Quarantine station could be prolonged because it is such attractive habitat for breeding bandicoots. However, the PVA here indicates that this mortality rate is severely detrimental to the population in the long term, despite the high reproductive output of the species. Where K=200, the impact of 16% adult mortality was lower at 15% but still represents a more than three fold increase in the chances of extinction. Predictably, environmental variability also had a big impact on long term persistence. This suggests that, despite its high fecundity, the population will suffer from a series of poor years, e.g. due to drought. Active management may, therefore, be needed to arrest further population declines when weather conditions are unfavourable.

Persistence to 10 years did not vary greatly between scenarios (Table 2), and the effects of different adult mortalities become most apparent at greater than 20 years. By this time there is a greater likelihood of several catastrophic fox events, which compounds the impact of greater adult mortalities, and the forces of demographic stochasticity to put the population under greater stress. Whatever management plans are put in place to control foxes, the risk of fox arrival to the headland cannot be excluded from consideration of threats to the population.

General use of PVA in urban wildlife management

For reliable results, PVA's require considerable inputs of quality data, including variation in key population parameters caused by environmental conditions. The results obtained here are considered robust because population data for the population were extensive and relevant to the population at question. The nearly 10 years of student research has given important key information on population biology, such as fecundity, sources of mortality and age at breeding. Where parameters were poorly known, information was sought from populations of the eastern barred bandicoot as a closely related bandicoot with a similar life history. However, uncertainty in data quality can undermine a PVA's accuracy, and here the exact values of quasi extinction rates under various scenarios may not reflect real chances of extinction or population trajectory (Coulson *et al.* 2001). Validation of PVA predictions is also desirable, but a quantitative validation this model was not possible because long-term population data are lacking. The relative change in the chances of extinction suffers far less from uncertainty in parameter estimation, and can be considered instructive in balancing management options (Lindenmayer and Possingham 1996). But to use the approach advocated here, conservation managers must critically assess the quality of their data for urban populations and use PVA judiciously, and should seek advice from population ecologists if in doubt.

Nevertheless, this example has highlighted how PVA is useful for managing urban wildlife because it revealed the longer-term sensitivity of the population to different environmental changes. The model dealt with general management scenarios based on realistic impacts, but other PVA's could use exact details provided in EISs; habitat modification can be incorporated into changes in carrying capacity; traffic flows or pet predation can be included as increases in adult mortality, and ameliorative measures could also be included. Indeed, modelling the consequences of conservation options for wild populations is well established (e.g. Possingham 1993; Hamilton and Moller 1995; Todd *et al.* 2002). In this example, small increases in traffic flow and adult mortality had a far greater impact on bandicoot persistence than would small changes in habitat area. Even minor increases in road-kills can increase the chances of extinction within 20 years up to 5 fold. Attempts to ameliorate this impact via creation of small of amounts of habitat would not compensate for the effects of adult mortality; therefore greatest attention should be given to reducing road kills or predation by pets. Nevertheless, larger declines in habitat availability (expressed as a substantial drop in K) that results from the cumulative impact of several small developments also had a large negative influence on population persistence that was exaggerated under increased adult mortalities. Importantly, the PVA quantified these impacts, allowing an objective comparison of options. This analysis contrasts with traditional, qualitative impact assessment, which rarely considers possible interactions between impacts and environmental variation, and seldom takes a long-term view. PVA therefore offers a rigorous alternative for urban wildlife managers to distinguish among multiple management options.

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