

Effect of rehabilitation on survival rates of endangered Cape vultures

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Abstract

The rehabilitation of injured or poisoned birds, including raptors, is widely practiced even though its conservation value is not well understood. In this study, the survival rate of rehabilitated Cape vultures (*Gyps coprotheres*) released back into the wild was compared with that of wild-caught birds at a breeding colony in South Africa. The program MARK was used to model survival based on age, sex and whether they were rehabilitated or wild-caught for 405 individual birds. Despite receiving treatment, rehabilitated birds suffered significantly lower survival rates when compared with wild conspecifics of identical age. Annual survival rates (\pm SE) of rehabilitated and wild-caught birds were 74.8% (\pm 8.1%) and 91.3% (\pm 6.3%), respectively. In addition, a population dynamics model was developed to predict future trends based on varying proportions of rehabilitated and wild-caught birds. The population growth rate (λ) for a wild population (i.e. without any rehabilitated individuals) was greater than one or increasing, whereas that for an entirely rehabilitated population was less than one or declining. A stable growth rate, $\lambda = 1$, occurred when approximately 50% of the adults were rehabilitated. Together, our results underscore the importance of tackling the causes of these injuries to Cape vultures before rehabilitation becomes necessary.

Introduction

The number of bird species facing the threat of extinction has been increasing in the past few decades (Butchart *et al.*, 2010), placing pressure on successful implementation of conservation activities. A major problem is that the effectiveness of many conservation actions has yet to be assessed. One such conservation activity that is particularly widely practiced for birds is rehabilitation of injured, poisoned or otherwise harmed birds, which are then released back into the wild. Although rehabilitation of compromised birds as a conservation tool may be appealing (Naidoo *et al.*, 2011; Finkelstein *et al.*, 2012), few studies have actually tested the efficacy of the technique. After all, if rehabilitated birds are unable to survive in the wild, then the technique can hardly be called a conservation tool (Sharp, 1996).

The impact of rehabilitation on birds has best been examined in oiled seabirds, where survival of rehabilitated birds typically is significantly lower than that of non-oiled birds (Anderson, Gress & Fry, 1996; Sharp, 1996; Goldsworthy *et al.*, 2000; Golightly *et al.*, 2002). Notable exceptions are African penguins (*Spheniscus demersus*; Underhill *et al.*,

1999, Whittington, 1999) and Cape gannets (*Morus capensis*; Altwegg *et al.*, 2008). In contrast, very few studies have compared survival rates of rehabilitated raptors with wild (non-rehabilitated) birds (Sweeney, Redig & Tordoff, 1997).

Captive-bred Mauritius kestrels (*Falco punctatus*) had similar survival rates compared with wild-bred birds (Nicoll, Jones & Norris, 2004). Similarly, survival of captive-bred adult Griffon vultures (*Gyps fulvus*) after 1 year post-release was similar to that of wild-born adults (Sarrazin *et al.*, 1994). However, in general, captive-bred birds will not have experienced a traumatic or injurious event, in contrast to rehabilitated birds. The effects of rehabilitation on raptor survival are poorly understood and the handful of existing studies either suffer from very small sample size (e.g. Hamilton, Zwank & Olsen, 1988) and/or did not conduct robust survival analysis (e.g. Sweeney *et al.*, 1997; Fajardo, Babiloni & Miranda, 2000) where recaptures and survival are separately estimated such as is done in the program MARK (White & Burnham, 1999).

Many vulture and raptor populations have experienced serious declines (Thiollay, 2007; Pain *et al.*, 2008; Virani *et al.*, 2011) and most Old World vulture species are now

listed on the IUCN Red List (IUCN, 2012). Factors contributing to these declines include poisoning, electrocution, persecution and collision with power lines, and bush encroachment affecting their foraging ability (Anderson, 2000; Piper, 2005; Bamford, Monadjem & Hardy, 2009a). The Cape vulture (*G. coprotheres*) is a southern African endemic that has been declining in range (Robertson *et al.*, 1998; Boshoff, Piper & Michael, 2009) as well as numbers of breeding pairs (Benson, 2004), and is currently considered 'endangered' (IUCN, 2012) owing to the above causes. Individual birds range over large areas (Bamford *et al.*, 2007), making them susceptible to deliberate (Ogada, Keesing & Virani, 2012), indirect [notably from consumption of lead ammunition (Finkelstein *et al.*, 2012)] and accidental (e.g. see Swarup *et al.*, 2007) poisoning, even if the poisons are used at only a few localities (Green *et al.*, 2004). Poisoned and injured birds regularly show up at rehabilitation centers in South Africa (Naidoo *et al.*, 2011), where they receive medical attention and, if they recover, may be released. Previously, the efficacy of such treatments has been quantified on whether the birds have recovered from the injury or poisoning (Naidoo *et al.*, 2011). However, the longer term effects on the survival of these rehabilitated individuals have not been assessed.

This study aims to compare the survival rates of rehabilitated Cape vultures with wild-captured individuals in the Magaliesberg, South Africa. We predict that rehabilitated birds will have survival rates lower than those of healthy wild-captured birds since we suspect that the injury or poisoning that brought the bird into a rehabilitation center may occasionally (or even frequently) cause permanent damage to the animal. We also develop a population dynamics model by investigating the effect different proportions of rehabilitated birds will have on the future trends of the Magaliesberg colony.

Materials and methods

Study site and species

Vultures were captured and tagged at 12 localities, 10 of which are in close proximity to each other (Fig. 1a). These 10 sites are all situated in the Magaliesberg mountain range and are covered by savanna, much of it recently transformed by humans. Vulture restaurants (*sensu* Piper, 2007) were established at some of these localities. Carcasses or parts thereof were put out for vultures several times a week at VulPro and the Rhino and Lion Park restaurants. The amount varied according to availability, but vultures were generally observed each day. In the past decade, approximately 300–400 pairs of Cape vultures have bred annually at the three colonies in the Magaliesberg range (Wolter, Whittington-Jones & West, 2007), which is slightly down from the maximum of 436 breeding pairs recorded in 1983 (Tarboton & Allan, 1984).

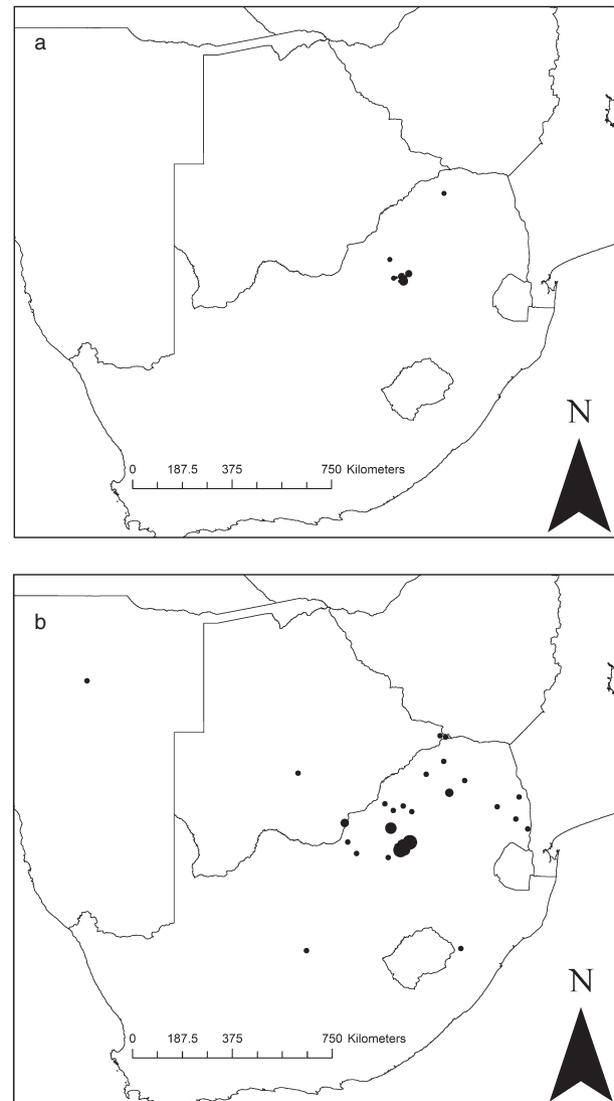


Figure 1 (a) The distribution localities where Cape vultures (*Gyps coprotheres*) were captured, tagged and released. The size of the circle is proportional to the numbers of birds released at each locality. (b) The distribution of localities where Cape vultures, tagged during this study, were resighted. The size of the circle is proportional to the numbers of birds resighted at each locality.

Data collection

Vultures were captured in a specially designed walk-in trap (Diekmann *et al.*, 2004; Bamford *et al.*, 2009b) that was built at the vulture restaurant at VulPro and the Rhino and Lion Park. Sick, injured or poisoned birds were either brought in to the center or collected by a staff member. Birds were captured and released, or rehabilitated birds released, between November 2005 and May 2012. A total of 163 rehabilitated birds were tagged and released. Rehabilitated birds were generally brought in singly and were released once fully recovered throughout the study period.

A total of 242 wild caught birds were captured, tagged and released. Wild birds were captured on 22 occasions where on average 9.0 birds (range, 1–32) were caught, tagged and released per capture session.

Captured birds were aged and had their wing length measured. Ageing was based on plumage characteristics (based on Piper, Mundy & Vernon, 1989; Mundy *et al.*, 1992) and birds were assigned to one of three age classes: juveniles (1st year birds), immatures (2nd–4th year birds), and adults (≥ 5 th year birds). Although sexing of Cape vultures is possible on external features (Naidoo *et al.*, 2011), not all the birds were assigned a sex in the field, and therefore, sex was dropped in subsequent analyses. Each bird was fitted with a metal ring issued by AFRING (Animal Demography Unit, University of Cape Town) and a patagial tag. Patagial tags were fitted according to the standard protocol adopted for this practice in southern Africa (Botha, 2007), which involves the use of a double set of standard cattle tags engraved with a unique number, which was fitted to the patagium on each wing of each bird using a tag applicator. This method was extensively assessed prior to this study and found not to be detrimental to the birds' health or inhibiting their ability to forage (Botha, 2007). All tagged vultures were released unharmed and immediately after processing each individual, which took, on average, 6 min per bird.

Injured and sick birds brought in for rehabilitation were examined closely to allow the cause of the injury to be determined. However, in most cases, it was not possible to establish the actual cause, even though the injury was evident. The number of days that each bird spent in captivity was recorded for some, but not all birds.

A dedicated resightings program was established, specifically at known vulture restaurants with hides and/or camera traps which are frequently visited by Cape vultures in the Gauteng and North West Provinces of South Africa. Media, both written and verbal, were also used to get buy-in and support from the general public, landowners, vulture restaurant managers and bird clubs to encourage them to report their tagged resightings to VulPro. In addition, a vulture restaurant monitoring protocol was also developed to standardize monitoring at the various vulture restaurants. The majority of the resightings came from vulture restaurants, which may lead to biases. For example, rehabilitated and wild-caught birds (or birds of different ages) may use these restaurants in different proportions and therefore have different resighting rates. However, the fact that all tagged birds in this study were released at vulture restaurants should reduce this resighting bias. In support of this assertion, the proportion of rehabilitated and wild-caught birds that were resighted at vulture restaurants (as opposed to being resighted away from the restaurants) was similar. For rehabilitated birds, 187 resightings were at restaurants compared with 18 elsewhere ($n = 62$ tagged birds); for wild-caught birds, 711 resightings were at restaurants compared with 32 elsewhere ($n = 172$ tagged birds).

Data analysis

Model selection and estimation of demographic parameters

Survival and recapture were computed, using a combined 'live encounter-dead recovery' approach (Burnham, 1993; Lebreton *et al.*, 1995) in the program MARK (White & Burnham, 1999; White, 2008) using resightings (alive) and recoveries (dead) of Cape vultures. This model is appropriate since some tagged vultures were recovered dead. The model calculates 'S' (the probability of surviving the interval), 'r' (the probability of being found dead and reported), 'F' (the probability of remaining in the sample), and 'P' (the probability of recapture, conditional on being alive and in the sampling region). A goodness-of-fit test was used to test whether the general model (full-time dependence for all parameters) violated the underlying assumptions of MARK, using the median \hat{c} procedure and the bootstrap method, both implemented in MARK. The goodness-of-fit test showed that (at least) one of the four basic assumptions of MARK had been violated, $\hat{c} = 1.371$, $SE = 0.0194$ ($P = 0.003$). These assumptions are: (1) every marked animal present in the population at time (i) has the same probability of recapture (pi); (2) every marked animal in the population immediately after time (i) has the same probability of surviving to time ($i + 1$); (3) marks are not lost or missed; (4) all samples are instantaneous, relative to the interval between occasion (i) and ($i + 1$), and each release is made immediately after the sample. The loss of tags from birds have been reported from other recent studies using similar patagial tags (Monadjem, Botha & Murn, 2012a; Monadjem *et al.*, 2012b), and this is thought to be the case in this study as well. Since there is no reason to suspect that the rate of tag loss would differ between rehabilitated and wild-caught birds, any errors in estimation of survival rates should equally affect both groups.

A variety of survival models that included rehabilitation, time dependence and age were developed. These models were developed on the basis of biological sensibility and were hypothesis driven as opposed to ones derived from a data dredge. Models were ranked using Akaike's Information Criterion (AIC; Burnham & Anderson, 2002). The model with the lowest AIC_c was deemed the best model; where ΔAIC_c (the difference in AIC_c between models) for any two (or more) models was < 2.0 , they were both deemed to be equally good.

Projection of population growth rate

We created an age-based deterministic population dynamics model to explore the effect that different proportions of rehabilitated birds would have on the population trend of the Cape vultures. All of our population dynamics models were created and analyzed in the statistical programming language R. Statistical analyses were carried out in R 2.13.1 (R Development Core Team, Vienna; <http://www.r-project.org>) using the popbio package (Stubben, Milligan &

Nantel, 2012). Specifically, the model used here is based on a Leslie Matrix. The top row represents the fecundity values and the other values show survival probabilities from fledgling, s_0 to adult, s_{4+} , together these values are the so called vital rates of the matrix (Borkhataria *et al.*, 2008).

$$\begin{bmatrix} 0 & 0 & 0 & f_3 & f_{4+} \\ s_0 & 0 & 0 & 0 & 0 \\ 0 & s_1 & 0 & 0 & 0 \\ 0 & 0 & s_2 & 0 & 0 \\ 0 & 0 & 0 & s_3 & s_{4+} \end{bmatrix}$$

The matrix assumes a birth pulse, post-breeding census. This is suitable for birds because they typically have a set breeding season. We used the mean value of fecundity (0.69) based on 29 studies on Cape vultures contained in Piper (1994). Such a model only takes females into account, so fecundity values were halved accordingly. Further, given this is based on a post-breeding census, the survival probabilities of the birds at stage x are multiplied by the fecundity values of the stage $x + 1$ because they must survive the year in order to reproduce (see Beissinger *et al.*, 2006 for details). In our matrix, this is moving from stage 4 to stage 5 and above.

The completed matrix is multiplied by a vector, which contains the numbers of the birds for each stage present at time zero. This is iterated over a specified period of time, in this case, years, upon which the population growth rate can be determined. These values are the dominant eigenvalue and dominant eigenvector respectively. The growth rate is designated as lambda λ ; a value >1 signifies a population increase, a value <1 a decrease and when $\lambda = 1$, the population is stable.

We created models that assumed a best-case scenario whereby there were no rehabilitated adults in the population and a worst-case scenario whereby all the adults were rehabilitated. Then, we considered the intermediate case which had a 50:50 split of wild and rehabilitated adults. The new values for the survival rates were a function of this new proportion. For instance, a survival rate for adults in a 50:50 mix population would be $(0.7479 + 0.9130)/2 = 0.83045$. The fecundity values were updated concomitantly. We used the mean survival rate and the upper and lower confidence intervals in our models. The proportion that gave a lambda approximately equal to one could be considered the tipping point below which the population would decline. Our survival data for first year birds far exceeds the estimates of Piper, Boshoff & Scott (1999). Considering our sample size for this age class was relatively small, we decided to incorporate the survival rate from Piper *et al.* (1999) into this matrix. We feel that this is a better estimate of first year survival especially since the latter study reported an increase in first year survival rate when supplementary feeding sites became available to the vultures (Piper *et al.*, 1999), a situation similar to that of the Magaliesberg colony.

The initial population vector contained 400 individuals for the adult stage, the upper estimate from Wolter *et al.* (2007) and the models were iterated for 40 years, the life

expectancy of the closely related Eurasian griffon (Carey & Judge, 2000; note this is maximum life expectancy, data are unavailable for wild species but may be shorter).

Sensitivity and elasticity analyses

We then performed sensitivity and elasticity analyses to explore how changes in each vital rate value in our matrix (i.e. fecundity and survival rates) affected the population growth rate, λ . These analyses measure the absolute and relative impact, respectively (see Caswell, 2001).

Statistical analysis

An analysis of variance was used to test whether the length of time rehabilitated birds spent in captivity differed based on the injuries for which they were originally admitted into the rehabilitation center.

The location of resightings was plotted using ArcGIS 9.3 (Environmental Systems Research Institute, Redlands, CA, USA). All mean values are quoted with \pm SE.

Results

A total of 405 Cape vultures was fitted with patagial tags and released, of which 163 were rehabilitated birds. The causes of injuries were mostly unknown (Table 1). Of the 19 vultures with known causes of injury poisoning accounted for eight of them, followed by poaching (four birds), collision (two birds) and electrocution (two birds). The length of time spent in captivity was known for 92 of the rehabilitated birds and averaged 68 days, and did not differ statistically between birds with different injuries, that is, poisoning, poached, collision and electrocution ($F = 1.603$, $P = 0.194$, d.f. = 3, 8).

The age classes of these birds are shown in Table 2. Of these, 234 birds (58%) were resighted a total of 952 times between January 2006 and May 2012 (mean of 2.4 times per bird, range: 0–29). The locations of the capture sites and resightings are shown in Fig. 1. A summary of the dead recoveries and live recaptures is shown in Table 3.

Model selection and estimation of demographic parameters

The best model was represented by differential survival for rehabilitated and wild-caught birds and time dependence for

Table 1 The causes of injuries of the 163 rehabilitated Cape vultures (*Gyps coprotheres*) in this study

Cause of injury	# individuals
Poisoning	8
Poaching	4
Power line collision	2
Power line electrocution	2
Other	3
Unknown-grounded	38
Unknown-other	106

the parameters ‘*r*’, ‘*F*’ and ‘*P*’ (Table 4). The next two models had a $\Delta AIC_c \leq 0.2525$ and were hence indistinguishable from the best model. One was represented by differential survival and recapture rates based on condition (rehabilitated vs. wild-caught), whereas the other was represented by both differential survival for condition (rehabilitated vs. wild-caught) and age, with other parameters being time dependent (Table 4). The remaining models had $\Delta AIC_c \geq 2.0$ with declining AIC_c weights (Table 4), and were therefore discounted as best candidate models. Based on the best model, the survival estimates for rehabilitated

and wild-caught birds were 0.7479 ± 0.08189 and 0.9130 ± 0.06327 , respectively.

Projection of population growth rate

This matrix (below) contains vital rates of a wild population without any rehabilitated individuals,

$$\begin{bmatrix} 0 & 0 & 0 & 0.314985 & 0.314985 \\ 0.689 & 0 & 0 & 0 & 0 \\ 0 & 0.913 & 0 & 0 & 0 \\ 0 & 0 & 0.913 & 0 & 0 \\ 0 & 0 & 0 & 0.913 & 0.913 \end{bmatrix}$$

The projected population changes of the five matrix models are summarized in Fig. 2. The population growth rate for a wild population (i.e. without any rehabilitated individuals) is greater than one. By contrast the growth rate for an entirely rehabilitated population (i.e. with only rehabilitated individuals) indicates a decline. In our model, $\lambda = 1$, that is,

Table 2 The number of juvenile, immature and adult Cape vultures (*Gyps coprotheres*) marked and released in this study, either as rehabilitated or wild-caught birds

Age class	Rehabilitated	Wild-caught	Total
Juvenile (1st year)	37	39	76
Immature (2nd–4th year)	66	114	180
Adult (≥ 5 th year)	60	89	149
Total	163	242	405

Table 3 Number of Cape vultures (*Gyps coprotheres*) tagged in South Africa and subsequently resighted (alive) or recovered (dead) (in parentheses), by year

Year of ringing	Number ringed	Number of resightings (recoveries)								
		2005	2006	2007	2008	2009	2010	2011	2012	
2005	2	0 (0)	0 (1)	1 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	
2006	36		5 (3)	5 (0)	5 (0)	5 (0)	2 (0)	0 (0)	0 (0)	
2007	117			65 (2)	39 (1)	59 (0)	38 (0)	14 (0)	3 (0)	
2008	17				5 (0)	9 (0)	8 (0)	3 (0)	4 (1)	
2009	95					26 (0)	29 (0)	14 (1)	9 (0)	
2010	50						5 (0)	11 (0)	5 (0)	
2011	39							12 (0)	7 (2)	
2012	49								21 (0)	

Table 4 The candidate models used to estimate survival in rehabilitated and wild-caught Cape vultures (*Gyps coprotheres*) captured in South Africa

Model	AICc	Delta AICc	AICc weights	<i>n</i>
<i>S</i> (condition), <i>P</i> (<i>t</i>), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1187.1064	0	0.43742	22
<i>S</i> (condition), <i>P</i> (condition), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1187.2139	0.1075	0.28152	18
<i>S</i> (condition + age2), <i>P</i> (<i>t</i>), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1187.3589	0.2525	0.26171	24
<i>S</i> (age2), <i>P</i> (<i>t</i>), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1190.0874	2.9810	0.09853	22
<i>S</i> (condition + age3), <i>P</i> (<i>t</i>), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1191.2596	4.1532	0.05198	26
<i>S</i> (condition), <i>P</i> (.), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1191.9462	4.8398	0.0389	17
<i>S</i> (age3), <i>P</i> (<i>t</i>), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1192.2037	5.0973	0.0342	23
<i>S</i> (condition), <i>P</i> (condition), <i>r</i> (condition), <i>F</i> (<i>t</i>)	1197.0221	9.9157	0.00209	12
<i>S</i> (condition + <i>t</i>), <i>P</i> (<i>t</i>), <i>r</i> (<i>t</i>), <i>F</i> (<i>t</i>)	1199.6142	12.5078	0.00084	33
<i>S</i> (<i>t</i>), <i>P</i> (.), <i>r</i> (.), <i>F</i> (.)	1199.8801	12.7737	0.00050	11
<i>S</i> (condition), <i>P</i> (.), <i>r</i> (.), <i>F</i> (<i>t</i>)	1199.9394	12.8330	0.00049	11
<i>S</i> (condition), <i>P</i> (condition), <i>r</i> (condition), <i>F</i> (condition)	1245.8147	58.7083	0	6
<i>S</i> (condition), <i>P</i> (.), <i>r</i> (.), <i>F</i> (.)	1247.4331	60.3267	0	5
<i>S</i> (.), <i>P</i> (.), <i>r</i> (.), <i>F</i> (.)	1270.3358	83.2294	0	4

Estimates of survival (*S*), recovery rate (*r*), site fidelity (*F*) and recapture (*P*) were modeled with time (*t*), and age class (age) and whether rehabilitated or wild-caught (condition). ‘age2’ refers to two age classes (1st years vs. and all other age classes), and ‘age3’ refers to three age classes (1st years, 2nd–4th years, and ≥ 5 years). The number of parameters is indicated by ‘*n*’. The models are arranged from best (top of table) to worst (bottom).

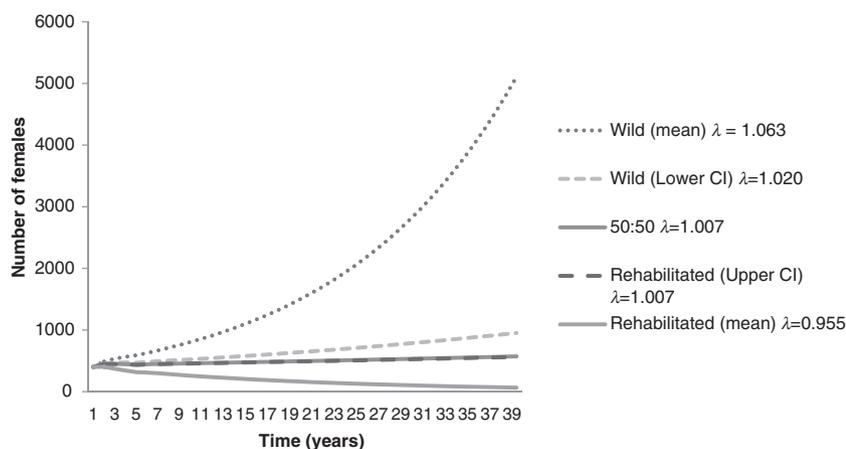


Figure 2 Graph showing predicted population trends over time for the various mixes of wild and rehabilitated birds in a colony of Cape vultures (*Gyps coprotheres*). Only the upper CI for rehabilitated birds and the lower CI for wild birds are graphed for ease of viewing. The 50–50 proportion and the upper CI for rehabilitated birds exhibit a similar trend.

Table 5 Elasticity and sensitivity values for the various vital rates in the Leslie Matrices. s_0, s_{4+} are the stage-specific survival rates, f_3, f_{4+} are the stage-specific fecundities

Vital rate		Elasticity	Sensitivity
s_0	Wild	0.099	0.153
	Rehab	0.131	0.182
	50:50	0.115	0.168
s_1	Wild	0.099	0.116
	Rehab	0.131	0.138
	50:50	0.115	0.128
s_2	Wild	0.099	0.116
	Rehab	0.131	0.138
	50:50	0.115	0.127
s_3	Wild	0.085	0.099
	Rehab	0.102	0.108
	50:50	0.094	0.105
s_{4+}	Wild	0.517	0.603
	Rehab	0.371	0.474
	50:50	0.445	0.540
f_3	Wild	0.014	0.047
	Rehab	0.029	0.087
	50:50	0.020	0.065
f_{4+}	Wild	0.085	0.288
	Rehab	0.103	0.381
	50:50	0.095	0.333

a stable growth rate, occurs when approximately 50% of the adults are rehabilitated.

Sensitivity and elasticity analyses

These analyses showed that for all models the survival rate of the adult stage was the most important component of the populations’ life histories (see Table 5).

Discussion

Our study demonstrates that the survival rate of rehabilitated Cape vultures was lower than that of wild-caught birds. This is a significant finding because it shows that, despite treatment received, the survival rate of rehabilitated

birds does not recover to the level of non-injured, wild birds. The difference in survival rates between rehabilitated and wild-caught birds is large enough to have serious conservation implications. It should be noted, however, that artificial feeding sites (such as vulture restaurants) may act to counter this to some extent. For example, Oro *et al.* (2008) showed that artificial feeding sites buffered the effects of illegal poisoning on the survival of immature and juvenile Bearded vultures (*Gypaetus barbatus*).

The negative impact that rehabilitated birds have on long-term population trends is a significant finding of this study. In this case, the tipping point between a declining population and a growing one occurs when the proportion of rehabilitated birds is approximately 50%. This results in a vital rate of survival of between 80 and 85% (the mean survival values for wild and rehabilitated birds were 91.3 and 74.8%, respectively). By coupling this data with accurate surveys on the size of the population, it will become clearer if and when such a tipping point is likely to manifest. It can be seen in Fig. 2 that a population of rehabilitated adults would drive the population below 70 females in 40 years (the estimated maximum life expectancy recorded in captivity) and ultimately to extinction in 100 years. Of course, this is better than not rehabilitating the birds at all, which would simply remove any potential breeders from the population and accelerate the time to extinction. Of further importance is the realization that the survival rate of the adult stage has the greatest effect on the population growth rate as revealed by the sensitivity and elasticity analyses (Table 4; Sæther & Bakke, 2000; Oro *et al.*, 2008).

Our survival estimates for the Cape vulture can be compared with two previous studies. The first estimates used ring recoveries (e.g. Piper, Mundy & Ledger, 1981) and have subsequently been shown to be seriously flawed (Anderson, Burnham & White, 1985). The second study was based on the resightings of color-ringed birds in an isolated (Potberg) population in southern South Africa, and reported high survival rates in subadults (Piper *et al.*, 1999). The survival rate of wild-caught birds in our study was 91.3%, which compares well with the survival of second year birds from the Potberg at 88.8% Piper *et al.* (1999). However, the best

model in our study did not include age as a parameter, whereas the best model in Piper *et al.* (1999) was one which separated birds into four age classes: first year, second year, third year and fourth year or older birds. At Potberg, first year Cape vultures had lower survival rates than second and third year birds, whereas the estimates for older birds was biased by ring loss (Piper *et al.*, 1999), which has been reported in other recent southern African studies involving patagial tags on vultures (Monadjem *et al.*, 2012a) and storks (Monadjem *et al.*, 2012b).

In our study, the best model for estimating survival of Cape vultures did not vary with age class (although the third best model did so). This is surprising (but see Oro *et al.*, 2008) since, in the wild, naïve and inexperienced juvenile birds typically have lower survival rates than adults (Sæther, 1989), something that has been established for several species of vultures (Sarrazin *et al.*, 1994; Monadjem *et al.*, 2012a), including the Cape vulture (Piper *et al.*, 1999). However, it has been shown that food supplementation may significantly increase the survival of birds including juvenile Cape vultures (Piper *et al.*, 1999; Oro *et al.*, 2008; Chauvenet *et al.*, 2012). The birds studied here breed at one of three colonies in the Magaliesberg mountain range, all within 43 km of VulPro where most of the captures and resightings pertaining to our study were made (Wolter *et al.*, 2007). This is easily within daily foraging distances of Cape vultures (Bamford *et al.*, 2007). These birds have received supplementary food at various vulture restaurants in the region for the past decade or more. In fact, telemetry studies of Cape vultures have shown that the Magaliesberg birds have significantly smaller foraging ranges than elsewhere in their range (Naidoo *et al.*, submitted). Furthermore, in contrast to a previous study (Bamford *et al.*, 2007); juvenile and adult foraging ranges were not significantly different in the Magaliesberg (Naidoo *et al.*, submitted). This suggests that vulture food is abundant and easily available to the birds in this region, and which may explain the very high survival rates of juveniles estimated in our study (see Piper *et al.*, 1999 for a similar result).

We were unable to factor the impact of type of injury (poisoning, electrocution, etc.) into the survival models because the injury of most (more than 80%) of the birds that were brought in for rehabilitation were unknown. However, the type of injury is likely to have a significant influence on how quickly the bird recovers and whether it suffers long-term effects. Future research is urgently needed to determine the impact of injury type on survival of rehabilitated vultures. Although we can conjecture that poisoning is the factor most responsible as has been reported in many other instances for other vulture species (for a detailed review see Ogada *et al.*, 2012).

In conclusion, we have shown that rehabilitated Cape vultures have significantly lower survival rates than wild (non-rehabilitated) birds. We have also shown that once the mix between rehabilitated and non-rehabilitated birds in a colony reaches 50:50, the colony will go into decline. Managers can use this to predict at which stage a particular colony is likely to go into decline.

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References

- Altwegg, R., Crawford, R.J.M., Underhill, L.G. & Williams, A.J. (2008). Long-term survival of de-oiled Cape gannets *Morus capensis* after the Castillo de Bellver oil spill of 1983. *Biol. Conserv.* **141**, 1924–1929.
- Anderson, D.R., Burnham, K.P. & White, G.C. (1985). Problems in estimating age-specific survival rates from recovery data of birds ringed as young. *J. Anim. Ecol.* **54**, 89–98.
- Anderson, D.W., Gress, F. & Fry, D.M. (1996). Survival and dispersal of oiled brown pelicans after rehabilitation and release. *Mar. Pollut. Bull.* **32**, 711–718.
- Anderson, M.D. (2000). Cape vulture. In *The Eskom red data book of birds of South Africa, Lesotho and Swaziland*: 73–75. Barnes, K.N. (Ed.). Johannesburg: BirdLife South Africa.
- Bamford, A.J., Diekmann, M., Monadjem, A. & Mendelsohn, J. (2007). Ranging behaviour of Cape vultures *Gyps coprotheres* from an endangered population in Namibia. *Bird Conserv. Int.* **17**, 331–339.
- Bamford, A.J., Diekmann, M., Monadjem, A. & Hardy, I.C.W. (2009b). Development of non-explosive based methods for mass capture of vultures. *S. Afr. J. Wildl. Res.* **39**, 202–208.
- Bamford, A.J., Monadjem, A. & Hardy, I. (2009a). The effect of vegetation density on carcass exploitation by vultures in an African savanna. *Ostrich* **80**, 135–137.
- Beissinger, S.R., Walters, J.R., Catanzaro, D.G., Smith, K.G., Dunning, J.B., Jr, Haig, S.M., Noon, B.R. & Stith, B.M. (2006). *Modeling approaches in avian conservation and the role of field biologists*. Ornithological Monographs.
- Benson, P. (2004). The status of the Kransberg and Manutsa Cape Vulture colonies *Gyps coprotheres* in (2003): causes of mortality, reasons for concern, research needs and recommendations. In *The vultures of Southern Africa – Quo Vadis? Proceedings of a workshop on vulture research and conservation in southern Africa*: 109–118. Monadjem, A., Anderson, M.D., Piper, S.E. & Boshoff, A.F. (Eds). Birds of Prey Working Group: Johannesburg.

- Borkhataria, R.R., Frederick, P.C., Hylton, R., Bryan, A.L., Jr & Rodgers, J.A. (2008). A preliminary model of Wood Stork population dynamics in the southeastern United States. *Waterbirds* **31**, 42–49.
- Boshoff, A.F., Piper, S.E. & Michael, M.D. (2009). On the distribution and breeding status of the Cape Vulture *Gyps coprotheres* in the Eastern Cape Province, South Africa. *Ostrich* **80**, 85–92.
- Botha, A. (2007). A review of colour-marking techniques used on vultures in southern Africa. *Vulture News* **56**, 52–63.
- Burnham, K.P. (1993). A theory for combined analysis of ring recovery and recapture data. In *Marked individuals in the study of bird population*: 199–213. Lebreton, J.-D. & North, P.M. (Eds). Basel: Birkhäuser-Verlag.
- Burnham, K.P. & Anderson, D.R. (2002). *Model selection and multimodel inference. A practical information-theoretic approach*. 2nd edn. New York: Springer-Verlag.
- Butchart, S.H.M., Collar, N.J., Stattersfield, A.J. & Bennun, A. (2010). Conservation of the World's birds: the view from (2010). In *Handbook of the birds of the world. Vol. 15. Weavers to new world warblers*: 13–68. del Hoyo, J., Elliot, A. & Christie, D.A. (Eds). Barcelona: Lynx Edicions.
- Carey, J. & Judge, D. (2000). *Longevity records: life spans of mammals, birds, reptiles, amphibians and fish*. Odense Monographs on Population Aging. University Press of Southern Denmark.
- Caswell, H. (2001). *Matrix population models*. Sunderland: Sinauer Associates.
- Chauvenet, A.L.M., Ewen, J.G., Armstrong, D.P., Coulson, T., Blackburn, T.M., Adams, L., Walker, L.K. & Pettoerlli, N. (2012). Does supplemental feeding affect the viability of translocated populations? The example of the hihi. *Anim. Conserv.* **15**, 337–350.
- Diekmann, M., Scott, A., Scott, M. & Diekmann, J. (2004). Capture and fitting of satellite- and radiotelemetry equipment onto Cape griffon *Gyps coprotheres*, African white-backed *Gyps africanus* and lappet-faced *Torgos tracheliotos* vultures in the Waterberg area, Namibia, in 2004. *Vulture News* **51**, 34–45.
- Fajardo, I., Babiloni, G. & Miranda, Y. (2000). Rehabilitated and wild barn owls (*Tyto alba*): dispersal, life expectancy and mortality in Spain. *Biol. Conserv.* **94**, 287–295.
- Finkelstein, M.E., Doak, D.F., George, D., Burnett, J., Brandt, J., Church, M., Grantham, J. & Smith, D.R. (2012). Lead poisoning and the deceptive recovery of the critically endangered California condor. *Proc. Natl. Acad. Sci. USA* **109**, 11449–11454.
- Goldsworthy, S.D., Giese, M., Gales, R.P., Brothers, N. & Hamill, J. (2000). Effects of the Iron Baron oil spill on little penguins (*Eudyptula minor*). II. Post-release survival of rehabilitated oiled birds. *Wildl. Res.* **27**, 573–582.
- Golightly, R.T., Newman, S.H., Craig, E.N., Carter, H.R. & Mazet, J.A.K. (2002). Survival and behavior of western gulls following exposure to oil and rehabilitation. *Wildl. Soc. Bull.* **30**, 539–546.
- Green, R.E., Newton, I., Shultz, S., Cunningham, A.A., Gilbert, M., Pain, D.J. & Prakash, V. (2004). Diclofenac poisoning as a cause of vulture population declines across the Indian subcontinent. *J. Appl. Ecol.* **41**, 793–800.
- Hamilton, L.L., Zwank, P.J. & Olsen, G.H. (1988). Movements and survival of released, rehabilitated hawks. *J. Raptor Res.* **22**, 22–26.
- IUCN. (2012). IUCN Red List of Threatened Species. Version 2012.1. Available from: <http://www.iucnredlist.org>. Downloaded on 25 June 2012.
- Lebreton, J.-D., Morgan, B.J.T., Pradel, R. & Freeman, S.N. (1995). A simultaneous survival rate analysis of dead recovery and live recapture data. *Biometrics* **51**, 1418–1428.
- Monadjem, A., Botha, A. & Murn, C. (2012a). Survival of the African white-backed vulture *Gyps africanus* in north-eastern South Africa. *Afr. J. Ecol.* **51**, 87–93.
- Monadjem, A., Kane, A., Botha, A., Dalton, D. & Kotze, A. (2012b). Survival and population dynamics of the marabou stork in an isolated population, Swaziland. *PLoS ONE* **7**, e46434.
- Mundy, P.J., Butchart, D., Ledger, J.A. & Piper, S.E. (1992). *The vultures of Africa*. Randburg: Acorn books and Russel Friedman books
- Naidoo, V., Wolter, K., Espie, I. & Kotze, A. (2011). Vulture rescue and rehabilitation in South Africa: an urban perspective. *J. S. Afr. Vet. Assoc.* **82**, 24–31.
- Nicoll, M.A.C., Jones, C.G. & Norris, K. (2004). Comparison of survival rates of captive-reared and wild-bred Mauritius kestrels (*Falco punctatus*) in a re-introduced population. *Biol. Conserv.* **118**, 539–548.
- Ogada, D.L., Keesing, F. & Virani, M.Z. (2012). Dropping dead: causes and consequences of vulture population declines worldwide. *Ann. N. Y. Acad. Sci.* **1249**, 57–71.
- Oro, D., Margalida, A., Carrete, M., Heredia, R. & Donazar, J.A. (2008). Testing the goodness of supplementary feeding to enhance population viability in an endangered vulture. *PloS ONE* **3**, e4084.
- Pain, D.J., Bowden, C.G.R., Cunningham, A.A., Cuthbert, R., Das, D., Gilbert, M., Jakati, R.D., Jhala, Y., Khan, A.A., Naidoo, N., Oaks, J.L., Parry-Jones, J., Prakash, V., Rahmani, A., Ranade, S.P., Baral, H.S., Senacha, K.R., Saravanan, S., Shah, N., Swan, G., Swarup, D., Taggart, M.A., Watson, R.T., Virani, M.Z., Wolter, K. & Green, R. (2008). The race to prevent the extinction of South Asian vultures. *Bird Conserv. Int.* **18**, S30–S48.
- Piper, S.E. (1994). *Mathematical demography of the Cape vulture*. Cape Town: University of Cape Town.
- Piper, S.E. (2005). Cape Vulture. In *Roberts birds of southern Africa*: 489–491. 7th edn. Hockey, P.A.R., Dean, W.R.J. & Ryan, P.G. (Eds). Cape Town: Trustees of the John Voelcker Bird Book Fund.

- Piper, S.E. (2007). *The Sasol guide to vulture restaurants in Southern Africa*. Johannesburg: Endangered Wildlife Trust.
- Piper, S.E., Boshoff, A.F. & Scott, H.A. (1999). Modelling survival rates in the Cape Griffon *Gyps coprotheres*, with emphasis on the effects of supplementary feeding. *Bird Study* **46**, S230–S238.
- Piper, S.E., Mundy, P.J. & Ledger, J.A. (1981). Estimates of survival in the Cape Vulture, *Gyps coprotheres*. *J. Anim. Ecol.* **50**, 815–825.
- Piper, S.E., Mundy, P.J. & Vernon, C.J. (1989). An ageing guide for the Cape Vulture. *Madoqua* **16**, 105–110.
- Robertson, A., Jarvis, A.M., Brown, C.J. & Simmons, R.E. (1998). Avian diversity and endemism in Namibia: patterns from the Southern African Bird Atlas Project. *Bio-divers. Conserv.* **7**, 495–511.
- Sarrazin, F., Bagnolini, C., Pinna, J.L., Danchin, E. & Clobert, J. (1994). High survival estimates of griffon vultures (*Gyps fulvus fulvus*) in a reintroduced population. *Auk* **111**, 853–862.
- Sæther, B.-E. (1989). Survival rates in relation to body weight in European birds. *Ornis Scand.* **20**, 13–21.
- Sæther, B.-E. & Bakke, O. (2000). Avian life history variation and contribution of demographic traits to the population growth rate. *Ecology* **81**, 642–653.
- Sharp, B.E. (1996). Post-release survival of oiled, cleaned seabirds in North America. *Ibis* **138**, 222–228.
- Stubben, C., Milligan, B. & Nantel, P. (2012). Construction and analysis of matrix population models. <http://cran.r-project.org/web/packages/popbio/popbio.pdf>.
- Swarup, D., Patra, R.C., Prakash, V., Cuthbert, R., Das, D., Avari, R., Pain, D.J., Green, R.E., Sharma, A.K., Saini, M., Das, D. & Taggart, M. (2007). Safety of meloxicam to critically endangered *Gyps* vultures and other scavenging birds in India. *Anim. Conserv.* **10**, 192–198.
- Sweeney, S.J., Redig, P.T. & Tordoff, H.B. (1997). Morbidity, survival and productivity of rehabilitated peregrine falcons in the upper Midwestern U.S. *J. Raptor Res.* **31**, 347–352.
- Tarboton, W.R. & Allan, D. (1984). *The status and conservation of birds of prey in the Transvaal*. Pretoria: Transvaal Museum.
- Thiollay, J.M. (2007). Raptor population decline in West Africa. *Ostrich* **78**, 405–413.
- Underhill, L.G., Bartlett, P.A., Baumann, L., Crawford, R.J.M., Dyer, B.M., Gildenhuys, A., Nel, D.C., Oatley, T.B., Thornton, M., Upfold, L., Williams, A.J., Whittington, P.A. & Wolfaardt, A.C. (1999). Mortality and survival of African Penguins *Spheniscus demersus* involved in the Apollo Sea oil spill: an evaluation of rehabilitation efforts. *Ibis* **141**, 29–37.
- Virani, M.Z., Kendall, C., Njoroge, P. & Thomsett, S. (2011). Major declines in the abundance of vultures and other scavenging raptors in and around the Masai Mara ecosystem, Kenya. *Biol. Conserv.* **144**, 746–752.
- White, G.C. (2008). Closed population estimation models and their extensions in Program MARK. *Environ. Ecol. Stat.* **15**, 89–99.
- White, G.C. & Burnham, K.P. (1999). Program MARK: survival estimation from populations of marked animals. *Bird Study* **46**, 120–139.
- Whittington, P.A. (1999). The contribution made by cleaning oiled African penguins *Spheniscus demersus* to population dynamics and conservation of the species. *Mar. Ornithol.* **27**, 177–180.
- Wolter, K., Whittington-Jones, C. & West, S. (2007). Status of cape vultures (*Gyps coprotheres*) in the Magaliesberg, South Africa. *Vulture News* **57**, 24–31.