# The Ecology and Management of a Critically Endangered Population of Bearded Vultures

**Sonja C Krüger**[a,b] **and Arjun Amar**[c], [a]Conservation Services Division, Ezemvelo KwaZulu-Natal Wildlife, Pietermaritzburg, South Africa; [b]Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa; [c]Department of Biological Sciences, FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence, University of Cape Town, Cape Town, South Africa





## Abstract

The Bearded Vulture *Gypaetus barbatus* is a Critically Endangered species in Southern Africa whose entire range in the Southern Hemisphere falls within the Maloti-Drakensberg mountains of South Africa and Lesotho. Here we synthesize 20 years of research on this population to quantify the decline in the species, investigate the potential drivers for this decline, and explore the most appropriate management actions necessary to recover this population. The population's breeding range and density have declined by at least 20%, and we estimate that there are now less than 400 individuals remaining. The densification of human settlements and associated infrastructure (e.g., power lines), together with human activities (e.g., poisoning) are the primary causes of mortality, and may also be contributing to the population's low productivity. Satellite tracking data of different age classes identified priority areas within the species' range to implement threat mitigation interventions. Conservation actions that have been implemented include supplementary feeding, power line mitigation, as well as risk models aimed at guiding developments. The need for population augmentation is discussed and assessed. Implementing the species management plan, specifically addressing the threat of poisoning, remains the priority to address the population decline and ensure that the unique ecological niche occupied by this imperiled species is maintained.

## Introduction

Avian scavengers have the highest percentage of extinction-prone species among all avian functional groups. Vulture populations are one of the fastest declining groups of birds, and populations across Africa have undergone massive declines, with seven species declining at a rate of >80% over three or more generations (Ogada et al., 2016). Similarly, in Southern Africa, the Bearded Vulture *Gypaetus barbatus* population has declined by at least 30% during recent decades and has been listed as regionally Critically Endangered (Krüger, 2015) with only approximately 100 pairs remaining.

Scavengers provide an important suite of ecosystem services and key ecological functions such as waste removal, disease control and nutrient recycling. The loss of obligate scavengers, such as vultures, can therefore have major ecological, social and economic

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consequences. Given the consequences of the ongoing and severe declines of vulture populations globally and in Africa, decisions on how to manage these threatened species are central to reduce their extinction risk and further loss of biodiversity. An understanding of the causes of decline is thus essential.

The African Vulture Crisis has been attributed mainly to their poisoning and their use in the traditional medicine trade (Ogada et al., 2016; Brink et al., 2021). Here, we detail research undertaken on the declining Bearded Vulture population in Southern Africa to assess the causes of decline in this population, identify remedial actions, and evaluate the successes of some of these actions. We discuss the likely limitations on population growth and reproductive success and describe what is known about the movement ecology of this population. Genetic variability was also investigated as a potential threat to the population and to explore whether augmentation (i.e., reintroductions) as a management scenario could assist population growth as well as improving genetic diversity. The demographic information obtained through this research was used to (i) model the population trend, (ii) identify the key demographic parameters driving this trend, and (iii) examine key interventions that could influence this trend. We explore several recommendations critical to the conservation of this population and discuss the effectiveness of those previously implemented.

### The Bearded Vulture in Southern Africa

The Bearded Vulture (Fig. 1) is a large, scavenging raptor that inhabits mountainous regions of Europe, Asia and Africa. In sub-Saharan Africa the species occurs in small geographically isolated populations in South Africa and Lesotho, and East Africa. The species is non-colonial, monogamous and sexually monomorphic and pairs occupy a territory containing one or more nests on high cliffs generally above 1800 m above-sea-level. The species occupies a unique avian trophic guild, whereby its diet consists almost exclusively of bones from the carcasses of wild and domestic ungulates. In Southern Africa, they forage along ridges and valleys in protected areas but also over communal rangelands and commercial farming areas (Abbass, 2021).

In Southern Africa, the drastic decline in both population number and range since the 1700s means the current population only occupies *c.* 20% of its historic range, being restricted to the Maloti mountains in the highlands of Lesotho and immediately adjacent Drakensberg mountains of South Africa (Fig. 2).

Historical research on the species by Christopher Brown during 1980–1983, and the results of our initial monitoring during 2000–2005, suggested limited success in addressing the species' decline since the early 1980s and that his conservation recommendations had not been implemented. Here we summarize the research and monitoring which has occurred since 2000. This research filled many of the information gaps and provides guidance on what is required to achieve a positive growth rate in the short term for this regional population.

## Investigating the decline of the Bearded Vulture population

### The status of the Bearded Vulture in Southern Africa

One of the first priorities in the conservation of a threatened species is to determine the current status and trend of the population. To this end, we first assessed territory occupancy, distribution and density of the Bearded Vulture population in Southern Africa between two time periods—former (1960–1999) and current (2000–2012)—to identify population trends.

Firstly, we obtained the location of former breeding territories from a variety of sources. We then conducted extensive ground and aerial helicopter surveys between 2000 and 2020, to determine the current occupancy status of those breeding territories, and identify any additional undiscovered territories. Data from these surveys were used to estimate the minimum and maximum number of breeding pairs, the population age ratio, and the overall population size.

**Fig. 1** An immature (left) and an adult (right) Bearded Vulture *Gypaetus barbatus* (photos by Sonja Krüger).

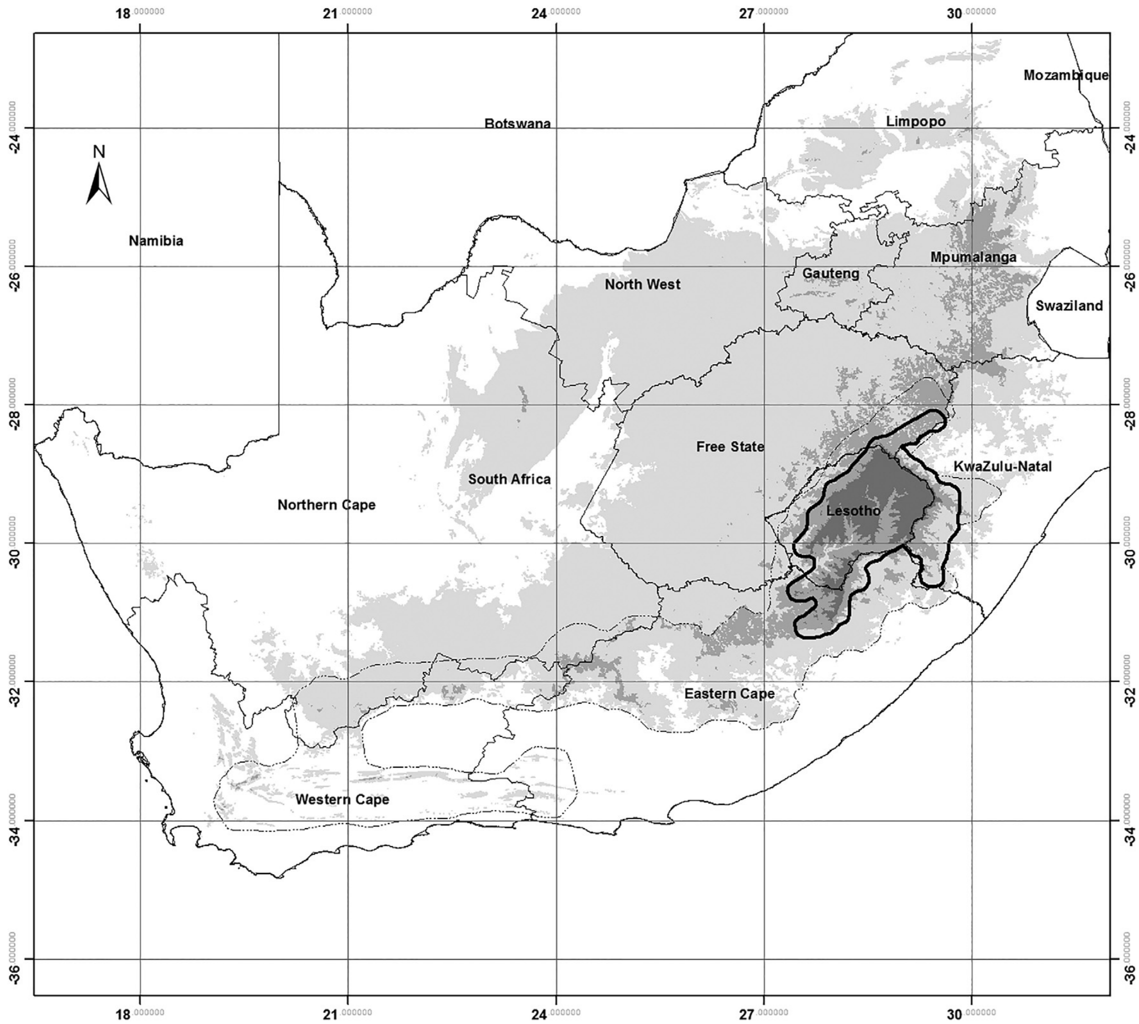


**Fig. 2** The past (..) and present (_) distribution range of the Bearded Vulture in Southern Africa, between 27°00"–30°00" E and 28°00"–31°40" S. Areas 1200–1799 m above sea level are depicted in pale grey, 1800–2199 m are medium grey and areas >2200 m are dark grey. Adapted from Krüger SC (2014) *An Investigation into the Decline of the Bearded Vulture Gypaetus barbatus in Southern Africa*. PhD Thesis, FitzPatrick Institute, University of Cape Town: South Africa, pp. 235.

We identified a total of 190 territories of which only 109 were currently occupied. These results indicated a breeding range reduction of 27%, restricting the birds to an estimated area of occupancy of 28,125 km$^2$ (Fig. 2). Breeding densities also decreased by 20%, declining from 4.9 to 3.9 pairs/1000 km$^2$, with inter-nest distances also increasing from 7.7 km to 9.0 km. In both periods, higher densities were recorded in the core of the range and inter-nest distances increased with distance away from the core of the range. We estimated that the population consisted of around 60% adults and 40% non-adults, comprising of between 352 and 390 individuals.

## The ranging behavior of the Bearded Vulture in Southern Africa

Knowledge of a species' movements is essential in designing effective conservation management strategies. The spatial and temporal use of the environment may differ according to an individual's age, sex or breeding status and knowledge of these differences may further contribute to ensuring that management actions are targeted appropriately.

We investigated Bearded Vulture movements in Southern Africa using data from satellite tags fitted to 18 individuals across four age classes (juvenile, immature, sub-adult and adult). The home range of each individual and the overall foraging range were obtained through kernel density estimations, and the extent of their movements (hereon referred to as range use) was quantified by determining the distance between hourly GPS fixes for individuals across all age classes. We also examined the ranging behavior of three fledglings fitted with satellite tags during the post-fledging dependence period and determined the onset of natal dispersal.

We found that the home range size and use of non-adults increased as they aged. However, the home ranges of adults were substantially smaller than those of non-adults. Adult average home ranges (286 km$^2$) were approximately 1% the size of the average

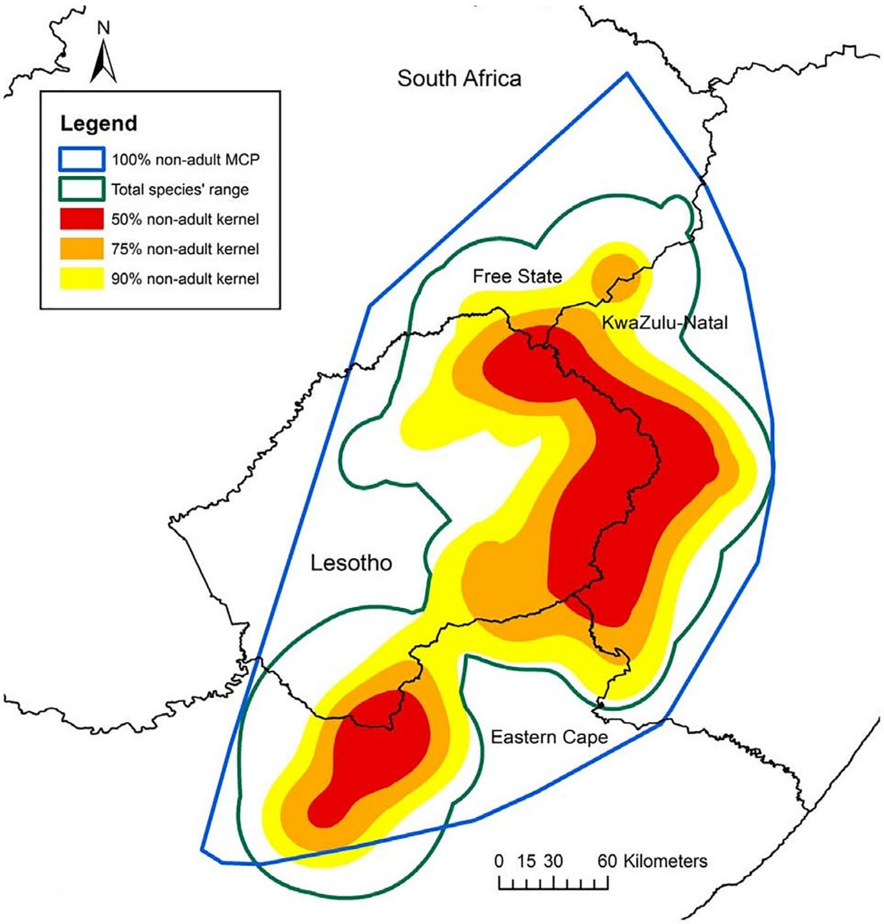


**Fig. 3** Minimum Convex Polygons (MCP) and 50%, 75% and 90% kernel home ranges in Southern Africa showing the total range collectively of non-adults in relation to the overall range for the species. Taken from Krüger SC, Reid T and Amar A (2014b) Differential range use and anthropogenic risk exposure between age classes of Southern African Bearded Vultures *Gypaetus barbatus*. *PLoS One* 9(12): e114920. doi: https://doi.org/10.1371/journal.pone.0114920.

foraging ranges of non-adults (10,540 $km^2$–25,985 $km^2$), with those of breeding adults being even smaller (95 $km^2$). Home ranges of breeding adults remained similar between seasons, but were utilized more intensively during breeding, with birds covering greater distances during the incubation and chick hatching period. Juvenile, immature, and sub-adult birds used different parts of the overall species' range, but their combined foraging range was 65% (33,636 $km^2$) of the overall range (Fig. 3). The overall foraging range of the population was estimated to be 51,767 $km^2$. Immatures and sub-adults had larger range sizes during winter, but their range use remained similar between seasons. Range size and use did not differ between the sexes in any of the age classes.

Fledglings were found to increase their home range size from an average of 9.13–11.47 $km^2$ within the first 6 months post fledging as they undertook pre-dispersive exploratory flights. They also increased the use of their home range as they aged with maximum daily distances travelled from the nest occurring between 98 days and 136 days post fledging, after which time they dispersed from their natal area.

## Identifying threats to the Bearded Vulture population in Southern Africa

Developing an effective conservation strategy for a critically endangered species relies on identifying the most pressing threats to the species and understanding which demographic factors are constrained. Based on the worrying trends observed in this population, we embarked on further studies to ascertain whether productivity or survival were limiting population growth, and whether anthropogenic influences were resulting in the abandonment of territories and individual mortalities, and driving the subsequent decline in numbers.

### *Causes of abandonment of Bearded Vulture territories in Southern Africa*

To elucidate the threats to the population, we investigated whether territorial abandonment was influenced by either; human impacts, food availability or climate change, or a combination of these. Three variables were used to explore *Human Impacts*: density

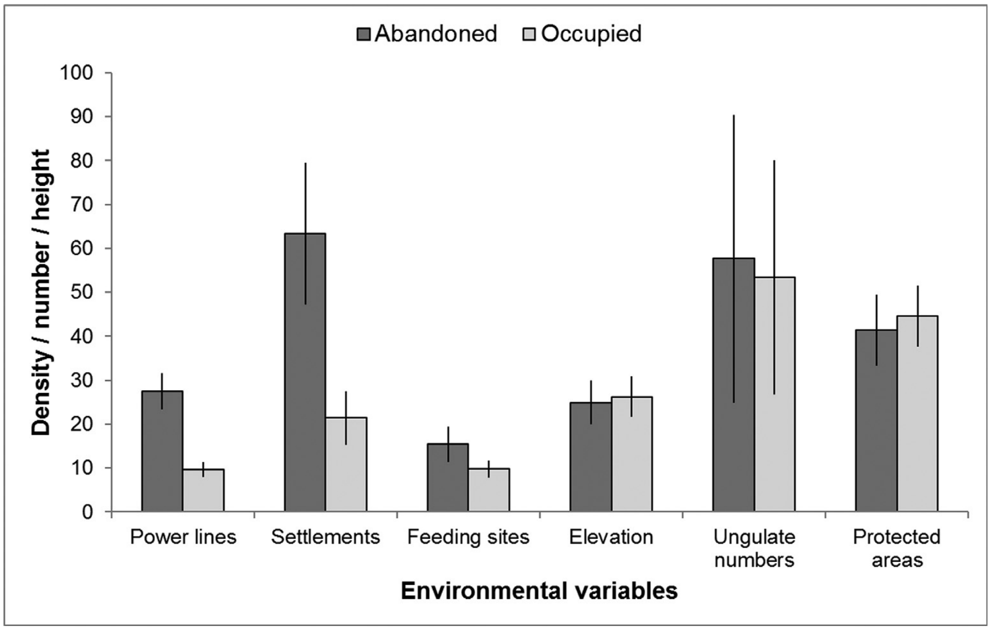


**Fig. 4** Comparison between the average (mean ± SE) density of human impacts, feeding site proximity, altitude, number of ungulates and percentage of area protected within a 10 km radius around nest sites of abandoned and occupied territories indicating that abandoned sites had a higher density of human impacts, higher feeding site proximity index and lower percentage of area protected. Values have been adjusted for display purposes (settlements x 0.1; feeding sites x 10,000; altitude x 0.1; ungulate numbers x 0.001). Taken from Krüger SC, Wesche PL and Jansen van Vuuren B (2015) Reduced genetic diversity in Bearded Vultures *Gypaetus barbatus* in Southern Africa. *Ibis* **157**: 162–166.

of human settlements (1), density of power lines (2) and area under formal protection surrounding each territory (3). Two variables were used to explore *Food Availability*: proximity and number of supplementary feeding sites (4) and numbers of ungulates surrounding each territory (5), assuming a positive relationship between the numbers of ungulates and availability of carcasses. Two variables were used to examine evidence for *Climate Change*: nest aspect (6) and nest altitude (7).

These seven variables, within a 10 km radius (314 $km^2$) surrounding each nest, were explored in relation to territorial abandonment. We found that human impacts were most closely associated with abandonment, with territories more likely to have been abandoned if they had more power lines and higher densities of human settlements (Fig. 4). Power line density and settlement density were more than twice as high surrounding abandoned territories compared with occupied ones. Additionally, within Lesotho, there was some support for the food shortage hypothesis, with territories more likely to have remained occupied where they had a greater access to supplementary feeding sites. This analysis provided no support for the climate change hypothesis, with no associations found between abandonment and either nest aspect or altitude. These results suggest that conservation measures should focus on limiting the development of further human settlements and power lines within 10 km of occupied territories and applying mitigation measures to existing developments, such as power lines.

### *Habitat selection and use of adult Bearded Vultures in Southern Africa*

To further understand the effects of human settlements on the Bearded Vulture population, Abbass (2021) explored habitat selection, and whether the species actively avoided human settlements as suggested above. This study used data from nine GPS satellite tagged adult Bearded Vultures to explore habitat selection in relation to various topographic (slope, elevation, roughness and ruggedness) and habitat variables (including the proportion of, and distance to, human settlements). Abbass's (2021) results indicated that adult Bearded Vultures are unlikely to select areas with a high proportion of built-up land cover and avoided areas close to these types of habitat, with the probability of use increasing by 50% at 5 km from a built-up area. Breeding adults also selected areas with grassland and avoided areas with forest.

These results suggest that Bearded Vultures are selective and prone to the negative impacts of changing land use within their home range. In addition to territorial abandonment and mortalities being linked to human settlements and human activities (e.g., poisoning or collisions with power lines), Abbass (2021) suggested that high levels of human settlements surrounding a nest site can reduce the quality of the habitat for foraging, and may contribute to increasing territorial abandonment. This information further assists conservation managers and planners to manage developments in the distribution range of the species.

### *Anthropogenic risk exposure between age classes of Southern African Bearded Vultures*

We examined the exposure to anthropogenic risks or benefits between four age classes of Bearded Vulture in Southern Africa to determine which age class was most affected. The negative influences (i.e., risk factors) we thought to have a potential influence on age-specific survival, were density of human settlements (number of houses per $km^2$); density of power lines (sum of the lengths of

11, 22 and 132 kV lines in km per $km^2$) and the density of roads (km of road per $km^2$). The positive influences (i.e., benefits) which were compared between age classes; included the percentage of formally protected land within a home range, and the density of feeding sites (number per $km^2$), plus the total number of feeding sites within a home range. The risks and benefits were identified in each of the 18 satellite tagged individual's 90% kernel home range previously determined (see above).

Our analyses suggested that non-adults aged between 4 and 6 years faced the greatest exposure to risk factors due to their larger range size and use (distances travelled), but also benefited by having better access to more feeding sites. Information on home range size and use and the approaches used to assess age-specific impacts of anthropogenic influences should enable more targeted management planning, education and conservation action in core areas (see Fig. 3) within the species' range.

### Productivity of the Southern African Bearded Vulture population

We assessed the population's productivity to determine whether lower recruitment could theoretically be a factor in the population's decline with suboptimal territories being abandoned as shown above, and less recruits being available to replace lost pairs.

The breeding parameters of the population were assessed during 2000–2016. We found that only around 54% of pairs attempted to breed each year, and although nesting success for pairs attempting to breed was relatively high ($0.75 \pm 0.22$; 95% CI: 0.44–1.00), this resulted in a low productivity of only $0.42 \pm 0.65$ (95% CI: 0.28–0.67) young per pair per year. These results suggest that many pairs do not attempt to breed each year. Understanding the factors influencing a pair's decision on whether to initiate a breeding attempt or not could be useful to guide conservation actions.

Food limitation, which may compromise a female's ability to get into breeding condition, is a possible explanation for the low breeding rate seen in this population, although our previous analyses did not find strong evidence to support the idea that food limitation was important in explaining territorial abandonment. Experimental provisioning of food to pairs during the pre-laying period could be used to test this explanation, since Abbass (2021) found that adult habitat use was influenced by the presence of feeding sites. An alternative explanation is that these low breeding rates are linked to elevated mortality rates. Losses of territorial birds would mean a high turnover of individuals within pairs, which can influence breeding performance. It may also mean that in some years, lack of breeding activity could be due to the territory not being occupied or being occupied by only one bird if the partner had died. If this is indeed the explanation for the low breeding rates, any conservation actions aimed at reducing adult mortality may also indirectly benefit productivity.

### Causes of mortality of the Bearded Vulture in Southern Africa

Based on the studies described above, the population decline appears to be driven by human impacts (high densities of settlements and power lines) and low productivity. Furthermore, research aimed to confirm these environmental constraints by exploring the primary causes of mortality. We collated all available information on the causes of mortality of Bearded Vultures found dead during 2000–2020, including mortalities of both tracked and non-tracked birds.

During 2007–2012, we tagged 24 Bearded Vultures with satellite tags, from which two experienced transmitter failures, six birds dropped their transmitters after an average period of 5 years (range = 10–126 months), the fate of three individuals was unknown, and 13 individuals were found dead between 2007 and 2020. A further 12 birds were reported dead during this period. We tested individuals found dead for lead (Pb) levels in their bones since the extent of the threat of lead poisoning to the population was unknown. We also examined the concentrations of lead in blood and tissue samples collected during the capture and tagging of individuals. Lead poisoning is an important threat to some raptor species, and the primary source of lead is through the ingestion of carcasses that have been shot with lead ammunition, making scavengers, such as vultures, particularly vulnerable.

Human activities (72%) and power line collisions (16%) were the primary mortality factors of birds found dead ($n = 25$), with poisoning (including lead poisoning) alone accounting for 85% of tagged birds found dead ($n = 13$). Blood lead levels ($0.62 \pm 0.81$ μg $dL^{-1}$) from six live birds tested in 2017 indicated only background levels of exposure to lead. Similarly, five live birds tested in 2009, using a less sensitive method, all had blood lead levels $<3$ μg $dL^{-1}$. However, bone lead levels from eight birds that had died indicated considerable lead exposure and accumulation over time ($11.79 \pm 8.34$ μg $g^{-1}$), suggesting that lead may have contributed to their deaths.

Our results also showed unusually high adult mortality rates from marked birds (31%), and a high overall percentage of adults found dead during the study period (24%), relative to those of other large raptors, which would have a significant negative effect on the population growth. Mortality rates from power line collisions are likely to be higher than recorded because of the expanding transmission and distribution networks and the fact that mortalities are likely to be under-reported because of the difficulty in finding carcasses in the rugged mountainous terrain, the high likelihood of scavengers removing the carcasses and the reluctance of landowners to report dead birds on their properties. Furthermore, based on other research from different species, individuals with high lead levels may be more susceptible to threats such as collisions with power lines.

We conclude that unnatural mortalities, poisoning in particular, are likely to be having a considerable effect on survival in this small and declining population.

### Population genetics of the Bearded Vulture

Information on the genetic diversity and differentiation among populations is required to inform conservation management of this species and to provide guidelines for captive breeding and translocations should populations continue to decline. Globally, the species occurs as small and dwindling population fragments with limited genetic differentiation among populations, suggesting that the species might globally be managed as a single entity. Previous genetic assessments of the species have mainly focused on

European and Asian populations with limited representation of the geographically isolated Southern African population. Krüger et al. (2015) studied mitochondrial DNA to determine the genetic variation within, evolutionary placement of, and connectivity among sub-Saharan African populations. Mitochondrial DNA fragment analyses detected little to no differentiation between populations in Ethiopia and Southern Africa, with reduced haplotype diversity in Southern Africa compared with populations in the Northern Hemisphere.

Streicher et al. (2021) extended this study by examining the phylogeography and genetic connectivity of global *G. barbatus* populations using a panel of 14 microsatellite loci. Firstly, the phylogeographic structure and genetic connectivity among *G. barbatus* populations across Africa and Europe was examined with the focus on determining if the geographically isolated Southern Africa population is genetically unique. This analysis revealed spatially correlated genetic differentiation between regional populations and low levels of gene flow between these population fragments. In contrast to the mitochondrial data, the microsatellite data support the management of genetically different populations as separate entities. Genetic depauperation and geographic isolation are known to adversely affect the evolutionary potential of a species in the long term. The high inbreeding found in the Southern African and, to a lesser extent, the North African population highlights the need for conservation programs to effectively manage populations of this species and maintain extant genetic diversity.

## Management of the Bearded Vulture in Southern Africa

### The viability of the Southern African Bearded Vulture population

Based our research, the Bearded Vulture was uplisted to regionally Critically Endangered in Southern Africa (Krüger, 2015); the population now faces an extremely high risk of extinction in the wild as a result of a reduction in population size and geographic range and the continuing threats to the species.

We examined the demographic parameters of this population including age structure, productivity and survival rates, and used these parameters to quantify the extinction risk of the population, identify the mechanisms responsible, and set conservation priorities to address the decline through a Population Viability Analysis (PVA).

We estimated age-specific survival rates from data of the 24 birds tagged between 2007 and 2012. Although there was considerable uncertainty in the confidence of the estimates at the time, we found that Fledglings (0–1 years) had the lowest survival estimates (57.14%), followed by 3–5 year old birds with survival estimates of between 57.89%–61.29%. Survival rates for adults were around 84%, which is very low compared to other raptor species with similar life histories. Model trajectories over 50 years starting in 2000, resulted in mean population sizes of $46 \pm 6$ individuals in 2050 with a $\lambda = 0.99$ and a 0.89 probability of extinction within the next 50 years, and a mean time to extinction of $18.74 \pm 0.41$ years.

Burke (2018) improved on our model by including genotypic information derived from 14 polymorphic microsatellite markers sampled from 52 individuals belonging to the population, and found that the population's growth rates would unlikely be largely altered by the addition of genetic data. All genetic indicators showed deterioration after 50 years. The number of alleles present and heterozygosity levels within the population were diminished, while inbreeding became more pronounced. Although the number of alleles remained low, incorporating the allelic frequencies as a parameter (with or without inbreeding), resulted in a controlled and linear decline in the number of alleles. However, Burke's (2018) results indicated that although the number of individuals in the population was low, there is still sufficient genetic variability to delay genetic erosion and the negative impacts this would have on demographic vital rates. Burke (2018) cautioned that these results should not lessen the urgency of actively conserving the species.

We identified that a positive growth rate could be achieved by reducing mortality by 40% across all age groups in combination with increasing productivity by 15% and supplementing the population.

### Risk models for proactive conservation action

Our data on Bearded Vulture movements provide an opportunity to develop habitat use models to be used as a planning tool to mitigate infrastructure developments aimed at reducing risks. For example, Reid et al. (2015) used the spatial analyses of Bearded Vulture movements to inform wind-turbine placement in Southern Africa.

Wind farms have been shown to cause bird mortality in many studies. Proposals for the development of wind farms in Lesotho, the core habitat for this population, are therefore of concern. Rushworth and Krüger (2014) used Bearded Vulture movement data to demonstrate that Southern African Bearded Vultures spend the majority of their time foraging in landscape zones typically chosen for wind farm development (active selection for ridge tops and upper slopes), and generally fly at heights within the rotor-sweep of a typical, modern wind turbine. They used a PVA to assess the potential impact of two specific wind farm development proposals on the population. Those results suggested that even under conservative assumptions, relatively small-scale wind farm developments in the Lesotho Highlands could accelerate population decline and the regional extinction of the species. Their recommendation for mitigation was to move the development sites off the ridge tops and upper slopes.

Reid et al. (2015) used the available movement data from tracked birds, and also incorporated flying heights at risk of collision, to predict important areas of use that may conflict with wind turbines. Adult and non-adult Bearded Vultures were found to use mostly areas with high elevations and steep and rugged topography in the core area; adults tended to use areas in relatively close proximity to their nest sites, whereas non-adult birds used areas dispersed over the entire species' range and were more likely to fly at risk-height in areas that were less used by adults. Altitudes of fixes of adults and non-adults showed that they spent 55% and 66% of their time, respectively, at heights that placed them at risk of collision. They demonstrated the value of habitat use models for identifying intensively used areas to guide the placement of wind turbines away from the most damaging locations.

The habitat use model developed by Reid et al. (2015) is a tool that operates at the scale of regional and national development plans and provides important supplementary assessments of site-specific development proposals. Although an extremely useful tool, the habitat use model, is currently in a format that cannot be easily interpreted and implemented by those without specialist Geographic Information System's knowledge. While this is being addressed, conservation authorities are able to use data from the 90%, 75% and 50% kernel ranges of the various age classes (Fig. 3) for management planning purposes, with the 50% kernel area representing the minimum area for the implementation of conservation action for non-adults and the entire home range of all identified breeding pairs.

We recommended an area of protection in a radius of 10 km from the nest site to be used during Environmental Impact Assessments. The commonly used approach of buffer circles centered on nest sites assumes that birds use the space around their nest in a uniform way, but few have evaluated the effectiveness of buffer circles at protecting a species' home range. Brink (2019) used movement data of the Southern African Bearded Vulture to evaluate the effectiveness of buffer circles to cover the ranging movements of adult birds throughout the year, as well as during their breeding and non-breeding season. This study revealed that buffer circles whose dimensions were based on the species' 95% kernel home range did relatively well at capturing a high proportion of individual GPS fixes, and thus our recommendations appear robust.

### Supplementary feeding sites as a conservation tool

Supplementary feeding sites are a popular tool widely used in vulture conservation, yet the contribution of these sites remains unquantified. Brink et al. (2020a) attempted to address this knowledge gap by quantifying the spatial distribution and trends of these sites in South Africa and assessing their potential contribution to vulture energetic requirements. The 143 sites they identified to be currently active, provided the equivalent of 83% of the energetic needs of all vultures in the region, with just 17% of active sites in only three provinces providing 69% of all the food provided. They also found that vulture species with smaller home ranges (such as the Bearded Vulture) have relatively poor access to these sites. Of further concern is that 68% and 28% of site managers were unaware of the potential harmful effects of lead and veterinary drugs, respectively, which highlights potential poisoning risks associated with these sites. Their study demonstrates the potential importance, but also associated risks, of feeding sites to vultures in South Africa, which need to be considered by those promoting them as a conservation tool.

Their results were substantiated in a second study (Brink et al., 2020b) focusing on the perceptions of feeding site managers and the management of their sites. Only 47% and 24% of managers, respectively, listed unintentional and intentional poisoning as potential threats to vultures, highlighting limited understanding of current vulture conservation issues. Although most managers (85%) vetted carcasses for provisioning suitability based on whether they had been treated with veterinary drugs, relatively few managers (10%) did the same for lead (Pb) contamination. Only 30% of managers considered threats to vultures (such as nearby power lines) when they decided on the location of their sites.

Both studies showed that vultures may be exposed to risks at many of these feeding sites, if they are not managed properly. There is, therefore, a need for increased interactions between site managers and conservation practitioners, to increase the flow of information on best management practices and enforce stringent and clear guidelines that minimize risks to vultures.

### Augmentation of the Bearded Vulture population in Southern Africa

In response to the ongoing decline in the Southern African population of Bearded Vultures, coupled with known or anticipated increases in some key threats (density of human settlement, power lines and wind farms), a decision was taken in 2015 to establish a captive population to serve as a genetic insurance in the event of extinction of the wild population and to allow for breeding and reintroductions within their historic range to reduce extinction risk.

The program was initiated by harvesting second eggs from the *in situ* population because (i) there was only one individual in captivity at the time, and (ii) we conservatively assumed a unique genetic status of the population, subsequently confirmed (Burke, 2018; Streicher et al., 2021), which highlighted the need to focus only on the Southern African population. The species exhibits cainism behavior, therefore this approach was assumed to have the lowest impact on the wild population, a key consideration when impacting upon a Critically Endangered species.

A pilot project was undertaken in 2015 to confirm harvest methods, following which the Bearded Vulture Breeding Program was established with a steering committee to guide the harvest process and management of the captive population. To ensure that the founder birds (those hatched from eggs harvested *in situ*) are behaviorally sound, they are puppet-raised with exposure to other chicks and the surrogate adult through protective barriers until fledging.

While no decision has been made on where releases will be undertaken, Brink et al. (2020c) modelled suitable nesting habitat, using our nest site data, to identify potential reintroduction sites within the species' historic range for consideration. They compared the suitability of these sites based on the quantification of various threats and benefits within each site. They then compared different release strategies using a PVA, to determine which approach would most likely be successful (defined as $>$34 individuals present after 30 years). Their models suggested establishing a captive breeding program and releasing four captive-bred young annually would have the lowest failure probability (25.5–49.8%), whereas the direct releases of wild-taken fledglings, without a supporting captive breeding program, had the highest probability of failure (78.3–95.7%). Their models also suggested that even in the presence of high mortality rates at the reintroduction site, a reintroduction project would still be worthwhile, because it would reduce the probability of extinction of the wider Southern African population by approximately 30% over a 50-year period.

The Brink et al. (2020c) model, developed in 2015, was based on a harvest of 5 second-eggs per year over a 6 year period to establish a founder population of approximately 30 birds. This target was used at the outset of the Breeding Program, also taking into account the number of chicks that the surrogate adult female in captivity could have simultaneous exposure to. However, after 6 years, the captive population currently comprises only seven individuals (aged between 1 and 6 years) fledged from eggs collected *in situ* (S. Hoffmann *pers. comm.*). The reality of limited resources for the full implementation of the program, extreme weather events, the proportion of unviable/infertile second-eggs (45%), nest site accessibility, as well as being limited to harvesting only the second egg, exacerbated latterly by travel restrictions due to the Covid-19 Pandemic, are some of the challenges that have prevented the program from achieving its target.

For the Bearded Vulture Breeding Program to be an effective conservation intervention in future, a more intensive monitoring and harvesting approach will be required.

## Management recommendations

### Addressing the threats to the Bearded Vulture population in Southern Africa

Vultures are protected in most African countries, including the Bearded Vulture in both South Africa and Lesotho, but enforcement of the legislation is poor. To address the potential 'African Vulture Crisis', the Vulture Specialist Group of the IUCN Species Survival Commission was established in 2011 to ensure the continued survival of vultures across the African continent. The Group aims to assess the population status of all African vulture species, identify threats, and implement appropriate conservation actions that effectively address the key threats to African vultures.

The conservation challenge is enforcing the legislation throughout the range and coordinating conservation efforts between the various authorities within the reality of fiscal and human resource constraints. Although the species has an important ecological role and is a transfrontier icon in Southern Africa, the reality of resource limitations makes the transition from management planning to conservation action particularly challenging.

Addressing the threat of poisoning must be the priority intervention for this population. A multi-pronged strategy is required to address the impacts of poisoning throughout the species' range by directing attention to the causes of poisoning. In Lesotho, conservation efforts need to focus on addressing the direct poisoning of vultures for the traditional medicine trade and by herders that believe vultures are a threat to livestock. By contrast, in South Africa, vultures are the indirect targets of predator poison baits (Krüger et al., 2006; Brink et al., 2021). Throughout the range, conservation efforts must focus on (i) exploring alternative, effective and legal predator control measures (such as the use of guard animals), (ii) regulating the import, manufacture and use of agricultural chemicals and pharmaceutical products known to be lethal to vultures, (iii) stringent law enforcement measures to prosecute and impose harsh penalties on perpetrators of poisoning, (iv) outreach programs focused on educating the collectors and users of vulture parts, herders that believe vultures kill stock, and farmers using poisons illegally, and (v) banning hunting and culling with lead ammunition, which is the most likely source of lead in vultures.

A power line mitigation strategy is in place through a partnership between Eskom (South Africa's electricity utility) and the Endangered Wildlife Trust (an environmental NGO). This partnership is also engaging with the Lesotho Electricity Company to reduce bird collisions and electrocutions. The strategy, however, is a reactive one and as such there is an opportunity for the implementation of a project to identify power lines in high use areas modelled by Reid et al. (2015) and prioritize these for mitigation.

Measures aimed at improving productivity include reducing human activities, such as helicopter flights and mountaineering, close to nest sites at the beginning of the breeding season and placing supplementary food close to nest sites early in the breeding season. Supplementary food provision near nest sites will ensure that 'safe' food is provided to adults during the breeding season reducing the need to forage wider with reduced exposure to threats of poisoning. Although proximity to feeding sites was not found to be a major factor driving the abandonment of territories, that analysis used a potentially out-of-date database of supplementary feeding sites and the more recent analysis by Brink et al. (2020a), found that feeding sites influenced habitat use and therefore establishing additional responsibly managed feeding sites may benefit the population by improving productivity and reducing the risk of exposure to human persecution and poisoning incidents, particularly for immatures and sub-adults, identified as the high risk age classes. Feeding sites within the adult home range would also benefit fledglings in the post fledging dependency period.

To address the threat of ongoing human development and encroachment into the core range of the species, proposals for infrastructural development (e.g., houses, power lines, wind farms) and activities (e.g., helicopter flights, cable-way developments) must be; (i) rejected if the impacts cannot be adequately mitigated, or (ii) sited in the most appropriate location to avoid or minimize negative impacts, and (iii) constructed with acceptable (raptor friendly) mitigation measures. Existing unsafe infrastructure must be identified proactively and modified/mitigated accordingly.

Increasing public awareness at all levels of society (from schools to politicians) around the threats to vultures will engage their support in addressing these threats and obtaining the necessary economic resources to protect the species. An example of this is International Vulture Awareness Day which is held annually across the globe. The 'flagship' species approach of focusing conservation efforts on this charismatic and Critically Endangered species will also raise the profile of the species and its plight as well as benefitting mountain habitats and the other scavengers and raptors within them.

### Implementation of management plans

A conservation action plan was developed for the species following a Population and Habitat Viability Analysis workshop in 2006 by Krüger et al. (2006) aimed at undertaking a risk assessment and developing a species' management strategy. A conservation target was set for the species and priority conservation interventions required to achieve the target over a 10-year period were detailed. The plan was revised in 2011 and a Biodiversity Management Plan for the species was gazetted in South Africa in 2014 (Government Gazette No. 37620, 8 of May 2014) to provide a more formal mechanism to achieve the species' conservation objectives. The 2020 revision of the plan resulted in a Transfrontier Bearded Vulture Recovery Strategy and Action Plan for Southern Africa. The strategy aims to provide a mechanism to ensure the long-term survival of the species through halting the population decline and stabilizing the population at the current population size (approximately 100 breeding pairs) over the next 10 years and to start growing the population to a realistic carrying capacity (150 breeding pairs) in the future. The Bearded Vulture Task Force is the steering committee of the Recovery Program and is responsible for implementing the strategy and action plan. In addition, a National Vulture Task Force has been established in both Lesotho and South Africa to address country-specific vulture conservation needs. A Biodiversity Management Plan has been developed to address national concerns for all South African Vultures, including the Bearded Vulture.

## Conclusions

This chapter has attempted to synthesize 20 years of research on the Bearded Vulture population of Southern Africa to document its status and distribution and to achieve a better understanding of the factors that may be limiting population growth, their movement ecology, and the genetic diversity of the population. Recommendations for urgent intervention, in priority areas across the species' range, have been made to address the species' demise and to enable conservation action to be focused most effectively to improve the status of the species and gain support for its conservation among a host of other priority species or economic and development challenges.

The studies discussed in this chapter have provided the necessary information to enable conservationists to focus their interventions on specific issues and locations that will have the highest impact. In so doing they have also provided the evidence-base to justify the management recommendations. The research is timely in that it can add value to the international strategy for the management of the Bearded Vulture, the African Vulture strategy and the local management plans and strategies for the species. This is particularly important at a time when vulture population declines are increasingly being recognized as one of the most pressing issues in avian conservation globally and in Africa in particular.

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## Relevant Website

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