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Quantifying the spatial distribution and trends of supplementary feeding sites in South Africa and their potential contribution to vulture energetic requirements

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Abstract

Old world vultures are the most threatened group of raptors globally. Supplementary feeding sites (SFS) are a popular conservation tool, widely used to assist vulture populations. Despite their popularity, the impact of SFS on vultures remains largely unstudied. A lack of knowledge on the number, distribution and management of SFS is a key factor hindering such research. In this study, we compile records of SFS in South Africa and conduct questionnaires with SFS managers to characterize SFS. We identify 143 currently active SFS. Our data suggest that SFS numbers have been stable over the last decade. The average provisioning rate for all SFS was 64.6 kg day^{-1}. Overall SFS provide an estimated 3301 tonnes of food to scavengers each year, the equivalent of 83% of the energetic needs of all vultures in the region. This contribution was highly skewed, however, with just 17% of active SFS sites providing 69% of all food. Furthermore, these resources were not equally distributed, with SFS in Limpopo, North West and Kwazulu-Natal provinces providing 83% of the total meat provisioned. The three most common meat types provided at SFS were beef (39%), pork (33%) and game (19%). Worryingly, we found that 68% and 28% of SFS managers were unaware of the potential harmful effects of lead and veterinary drugs, respectively, which highlights potential poisoning risks associated with SFS. Examining exposure to SFS by different vulture species, we found that whilst SFS are accessible across the distribution range of vultures with large home ranges (e.g. African white-backed and Cape vultures), those species with smaller home ranges have relatively poor accessibility. With this study, we demonstrate the potential importance, but also associated risks, of SFS to vultures in South Africa, and provide the information base to assess the impacts of this popular but as yet largely unassessed conservation tool.

Introduction

The decline of biodiversity often requires the implementation of intensive management actions (Butchart *et al.*, 2010; Barnosky *et al.*, 2011). Because of the inherent uncertainty in how biological systems will react to conservation interventions (Keith *et al.*, 2011), some management actions can cause unintended negative effects on target species or ecosystems (Cortés-Avizanda *et al.*, 2009; Wittmer, Elbroch, & Marshall, 2013). Validating the beneficial outcome of such interventions is thus a crucial role of conservation science. To facilitate such inquiry, responsible management should entail continuous monitoring and assessment. This is the only way in which to ensure that limited conservation resources are not wasted on ineffective or detrimental interventions (Santangeli & Sutherland, 2017).

Food supplementation is an intensive management intervention often meant to help threatened species. While its effects in a conservation context are in many cases unknown, unintended negative ecological effects of food supplementation have been reported (Robb *et al.*, 2008; Milner *et al.*, 2014). These include changes in social and movement behaviour (Duriez, Herman, & Sarrazin, 2012; Jones *et al.*, 2014; Fluhr *et al.*, 2017), predation and selection pressures (Schmidt & Hoi, 2002; Cortés-Avizanda *et al.*, 2009), interspecific relationships (Carrete *et al.*, 2010; Cortés-Avizanda *et al.*, 2012) sex ratios and reproductive performance (Clout, Elliott, & Robertson, 2002; Carrete, Donázar, & Margalida, 2006) and various health factors (Blanco, Lemus, & García-Montijano, 2011; Sorensen, van Beest, & Brook, 2014).

Almost seventy percent of old-world vulture species are threatened with extinction (IUCN, 2019), the most rapid population declines occurring in the vulture-rich regions of Asia and Africa (Ogada *et al.*, 2016). Over the last decade, the unnatural and accelerated mortality rates of vultures across Africa have led to the International Union for Conservation of Nature (IUCN), uplisting seven out of ten of the continent's vulture species to Critically Endangered and Endangered (Amar *et al.*, 2018). While this can be attributed to various threats (Anderson, Maritz, & Oosthuysen, 1999; Boshoff *et al.*, 2011; McClure *et al.*, 2018), the most prevalent of these is poisoning. This risk of poisoning include: direct poisoning – for traditional belief-based use of vulture parts (Mckean *et al.*, 2013), or "sentinel poisoning", whereby poachers target vultures as they provide rangers with a clear sign of poaching events (Ogada *et al.*, 2016), and indirect secondary poisoning – where vultures are the unintended victims of the poisoning of the so-called problem carnivores (Santangeli *et al.*, 2016). Similarly, vultures may be poisoned by feeding on livestock treated with veterinary drugs (Gilbert *et al.*, 2002; Oaks *et al.*, 2004), or lead contaminated carcasses (Bounas *et al.*, 2016; Garbett *et al.*, 2018), which may even lead to catastrophic population level impacts (Green *et al.*, 2004).

The high mobility and wide ranging behaviours of vultures make conserving them challenging because conventional conservation measures, such as protected areas, may be insufficient (Santangeli *et al.*, 2019). In South Africa, there has been a strong emphasis on providing additional food through supplementary feeding sites (SFS; often also referred to as "vulture restaurants", Cortés-Avizanda *et al.*, 2016). These measures have been implemented because providing such food is typically assumed to reduce poisoning risk (Gilbert *et al.*, 2007), with some evidence indicating it can also increase breeding success and survival (González *et al.*, 2006; Oro *et al.*, 2008). However, such effects are not ubiquitous and in some cases SFS show no effects (Krüger, Simmons, & Amar, 2015; Oppel *et al.*, 2016a). SFS therefore remain a debated conservation tool (Oppel *et al.*, 2016b*b*).

Anderson and colleagues (2005) previously estimated that there were around 140–145 active SFS in South Africa, with an annual increase of 9% per year. The majority of SFS is established informally by land managers, particularly as an easy and inexpensive form of carcass disposal (Mundy *et al.*, 1992; Piper, 2004b). Therefore, many SFS are potentially operated without following best-practice guidelines (Piper, 2004a). Essential information on the number, status (active – providing food, or closed), location and provisioning rate of SFS is lacking and not collated into a systematic centralized database. This hinders investigations on the effects of SFS on vultures in Africa (e.g. Kane *et al.*, 2014), which is essential to understand the conservation outcomes of SFS. The first step in quantifying the effectiveness of SFS is thus to systematically gather this information.

Here, we aim to fill this knowledge gap in South Africa and lay the basis for future studies on this common, yet unassessed conservation tool. Specifically, we aim to (1) determine the current and historical number and distribution of active SFS in South Africa; (2) quantify the amount and type of food resources being provisioned at these SFS; (3) estimate the contribution of SFS resources towards filling the energetic needs of the different vulture species based on their potential access to SFS.

Materials and methods

Ethics statement

This study was approved by the Faculty of Science Research Ethics Committee at the University of Cape Town (Approval code: FSREC 83 – 2017). Participants provided informed verbal consent, as approved by the ethics committee.

Supplementary feeding site data

We used existing datasets on SFS from three organizations in South Africa which are extensively involved in vulture conservation (VulPro, The Endangered Wildlife Trust and Ezemvelo KwaZulu-Natal Wildlife). These datasets were outdated to various extents and the information they contained had not been verified during recent years. We consolidated all three databases.

We conducted a survey with the managers or affiliated persons of each SFS. The survey was conducted by a single interviewer (CWB) over the telephone or email, using an open-ended questionnaire (see Data S1). Surveys were conducted between November 2017 and October 2018. Respondents were asked to provide a range of information regarding their SFS, most notably coordinates of the site, the status of the SFS (whether the site was active, that is, provisioning food, or closed and no longer provisioning) their provisioning rates (tonnes per year), type of carcasses used, their date of establishment and closure and reasons for establishment and closure. SFS managers were also presented with a multiple-choice question regarding whether they believed that lead from spent ammunition or veterinary drugs present in carcasses could have any potential harmful effects on vultures.

Provisioning rate calculations

Respondents were asked to specify, as accurately as possible, the type and quantity of food (a combination of whole carcasses and offal) that they provide at their SFS within a given time unit. When respondents provided weights per carcass or specified the amount of offal in kilograms (the parts of an animal carcass that is discarded after butchering or dressing), these amounts were used. In cases where respondents provided a quantity range, the mid-point of this range was used to calculate provisioning rate. However, when livestock carcass weights were not provided but only the numbers of carcasses, we used the body mass of animals from the literature averaged across breeds within a specific livestock type (Cloete & De Villiers, 1987; Cloete *et al.*, 2000; Wells & Krecek, 2001; Sheridan, Ferreira, & Hoffman, 2003; Scholtz, 2010; Snyman, 2014a,*b,c,d,e*; A. Tucker unpubl. data).

To determine provisioning rate of game animals, the average mass of game species was derived from the 2016 South African hunting statistics (available from the Department of Environmental Affairs) and published weights (Stuart & Stuart, 2015). When respondents indicated an amount provisioned during the hunting season, we assumed that this was provided over the average winter hunting season, which is three months in duration.

To calculate the amount of offal provided, we used averaged dress out percentages (ratio of slaughtered and vicerated carcass to live weight) from the literature for each animal group. This was only needed for the game and pork category as all other livestock offal amounts were indicated in weights. South African dress out percentage for a range of ungulate species falls within a 52–61% of body weight (Von La Chevallerie, 1970; Hoffman, 2000; Van Zyl & Ferreira, 2004; Hoffman & Wiklund, 2006; Hoffman *et al.*, 2009; Swanepoel *et al.*, 2016). Offal thus accounts for between 39 and 48% of live weight. We used the conservative measure of 40% of live weight for our calculations of offal weight as some offal is commonly used for human consumption. Dressing weights for domestic pigs were between 72 and 84% (Warriss *et al.*, 1990; Virgili *et al.*, 2003; Latorre *et al.*, 2009; Boler *et al.*, 2012), thus for pigs we used 20% as percentage offal of live weight. QGIS was used for all spatial analyses (QGIS, 2019).

Calculation of vulture energetic needs

To contextualize the total amount of food being provided by SFS, we calculated the total annual food requirements of all vultures in South Africa, Lesotho and eSwantini region (Appendix S1). We used adult vulture population estimates, indications of the proportion of the population that are adults, and daily food requirements from the literature to do these calculations (Appendix S1). In addition to the SFS within South Africa, provisioning rates from two verified SFS in Lesotho and two in eSwatini were included in this calculation. The species evaluated included the IUCN critically Endangered African white-backed vulture, *Gyps africanus*, the endangered Cape vulture, *Gyps corprotheres*, the Endangered lappet-faced vulture, *Torgos tracheliotos*, the Near Threatened bearded vulture, *Gypaetus barbatus*, the critically Endangered hooded vulture, *Necrosyrtes monachus* and the critically Endangered white-headed vulture, *Trigonoceps occipitalis* (IUCN, 2019).

Coverage of species range by SFS

Adult vultures often have smaller home ranges than non-adults and thus their access to SFS is more restricted (e.g. Krüger, Reid, & Amar, 2014). For this reason, we focused this analysis on adults only. We quantified the proportion of each species' distribution range that is accessible to SFS in the following way. First, we collated home range estimates for each species from the literature (Krüger, Reid, & Amar, 2014; Kane *et al.*, 2016; Garbett, 2018; Reading *et al.*, 2019). Such estimates were unavailable for adult African white-backed vultures, but as evidence suggests, they display similar movement behaviour as lappet-faced vultures (Spiegel, Getz, & Nathan, 2013), we thus used lappet-faced vulture estimates as a proxy. The average across all species was used for white-headed vultures for which data were also unavailable. Assuming uniform circular home ranges, we converted these species-specific home range estimates to minimum and maximum buffers for each species. We used 95% Kernel Density Estimates (KDE), 90% in the case of bearded vultures, for the calculation of the maximum buffer radiuses and 50% KDE for the minimum buffer radius of each species.. These species-specific radi were then used to create buffers around each active SFS in the region. Finally, we calculated the proportion of each vulture species' range covered by the minimum and maximum buffer surrounding SFS in the region. This yielded a minimum and maximum proportion of species range coverage by SFS. We repeated the above analyses using only SFS with high provisioning rates (>40 kg day^{-1}).

Results

We were able to contact 92.4% of the SFS for which we had working contact details. The remainder either refrained from responding to all attempts at communication or had closed so long ago that no relevent respondent could be found. Of those we did contact, 72.4 % participated in the study beyond just simple verificaion of the status of their SFS. Among verified and currently active SFS, we had a response rate of 94.3%.

State of SFS in South Africa

We verified the status of 232 SFS records in South Africa, including 25 new sites (i.e. not present in the three original datasets) that were mentioned by respondents and verified on an ad hoc basis. Among verified SFS, 143 were active (Fig. 1), and 89 were closed. Ninety entries remained unverified, due to outdated contact information. Given the age of the databases and their entries, these were assumed to be closed.

Trend and motivations of SFS establishment

We gathered information on establishment and closure dates of 104 currently active and 39 closed SFS. The earliest reported establishment date was 1933. From 1975 numbers of active SFS increased sharply, but have remained relatively constant since around 2009 (Fig. 2).

The main motivation for establishing an SFS was for conserving vultures (65% of 159 total responses) and for the cleaning benefits vultures provide (26%). Other reasons were the personal pleasure of running an SFS (12%) and ecotourism (11%).

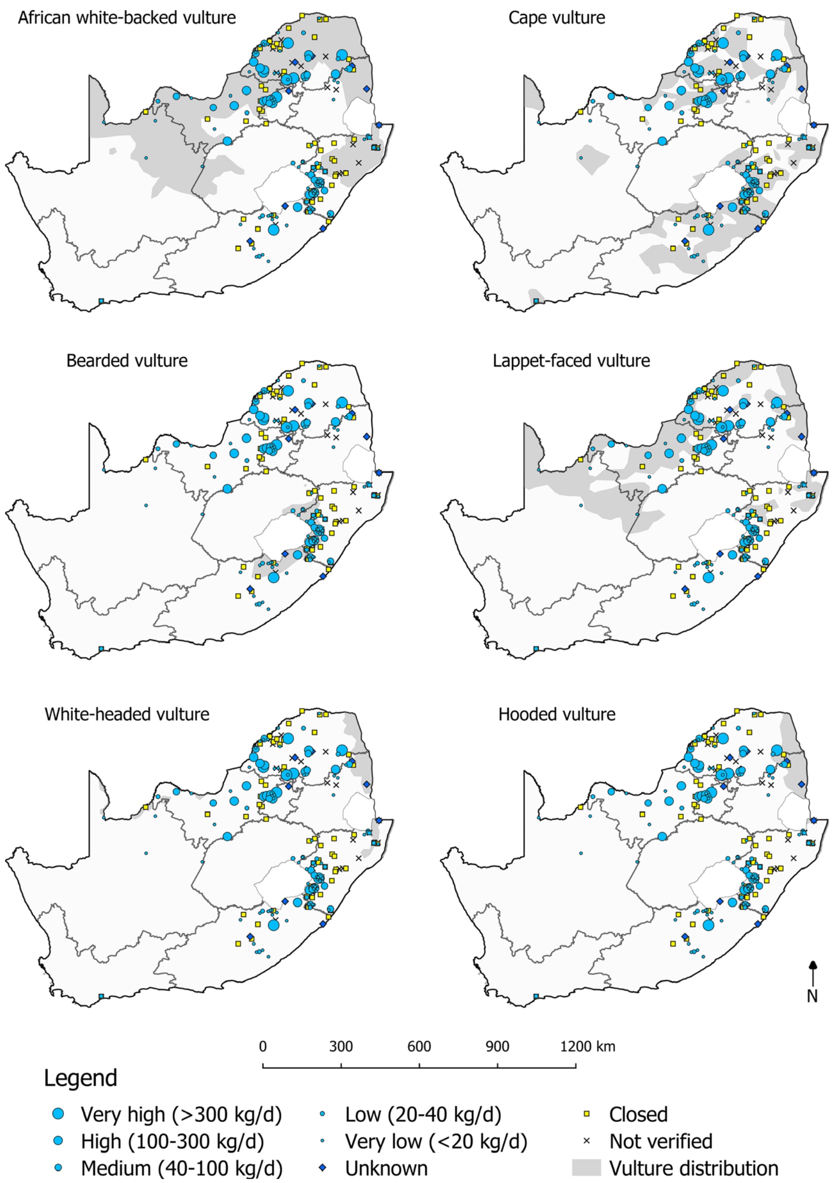

Figure 1 The distribution and status of vulture supplementary feeding sites in South Africa as verified by this study. Active (circles and diamonds), closed (sqaures) and unverified (crosses) supplementary feeding sites are indicated. The average daily food provisioning rate category of active sites is indicated by the size of the green circles, green diamonds indicate active supplementary feeding sites that have unknown provisioning rates. The distribution of each of six vulture species occurring in South Africa is shown in dark grey (data obtained from BirdLife International and Handbook of the Birds of the World (2017)

Reasons for closing SFS were as follows: managers moving away (22% out of 55 responses), low vulture visitation rates (13%), relocation of SFS (11%), carcass contamination concerns and lack of control regarding dumping by general public (11%), lack of carcasses for provisioning (7%) and occurrence of powerline mortalities (7%).

Provisioning rates

We obtained information on provisioning rates from 132 of the 143 active SFS. Of these, 24 provided both livestock and game, 82 provided livestock only and 26 provided game only. Eight SFS that only provided game, indicated that their SFS was solely active during the hunting season. There was high variability in the provisioning rate among SFS, with a mean ± S.D. of 23.58 t/y ± 38.84 (range: 0.32–208.57 t/y), equivalent to 64.61 kg day^{-1} ± 106.42. Across all SFS for which data were collected, we estimated that 3113 tonnes of food are provided each year. If extrapolated across sites with unknown provisioning rates, using the average of similar types of sites in the same province (or across the entire country in the case of Nature and Game Reserves), then

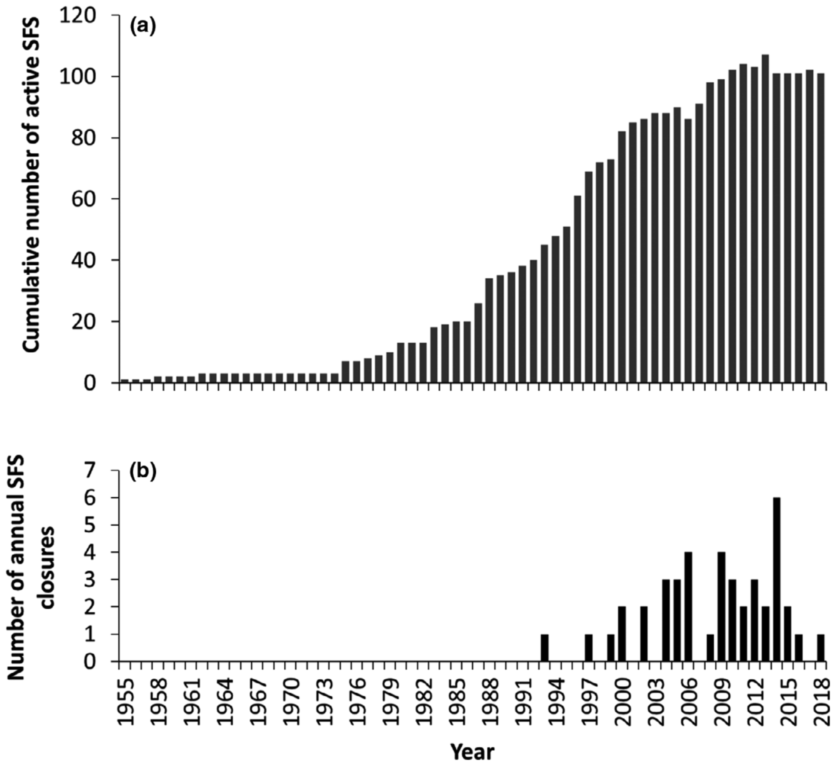

Figure 2 (a) Cumulative number of active SFS over time in South Africa, and (b) the number of annual SFS closures. This is based on information of opening and closing dates obtained from 143 SFS. We start the timeline at 1955 for brevity, because between 1933 and 1955 only a single SFS was reported as active. Sites that did not provide this information were excluded here

3301 tonnes of food are provided across all known active SFS.

The contribution of food provisioned was highly skewed, with just 17% of active sites providing 69% of reported total annual provisioned food (Appendix S2). Sites with the highest provisioning rates are generally affiliated with intensive livestock farms, abattoirs or Non-Governmental Organisations (NGO) who source carcasses from such operations. Sites that provided little food annually are represented more often by small-scale livestock farms. We report high variation in resource contribution by SFS across South Africa, with Limpopo, KwaZulu-Natal and North West provinces providing the majority of food resources (Fig. 3). Across South Africa, most of the total food provisioned consisted of beef (39.2%), pork (33.3%) and game (19.4%, Appendix S3). Less common meat sources included sheep (3.6%), horses/donkeys (2.2%), chicken (1.0%) and goat (0.2%).

Potential energetic contribution of SFS

We estimated that the extrapolated total provisioning rate of 3301 t/y, plus 16 t/y provided at SFS in eSwatini and Lesotho, is enough to potentially fulfil about 83 % of the annual food requirements for vultures in South Africa.

Food safety

Out of 111 respondents answering the question on the health risks posed to vultures from providing contaminated food, 32% of managers believed that lead from spent ammunition could be dangerous to vultures, 35% were not sure and 32% were convinced otherwise. For veterinary drugs, 72% believed that they could have harmful effects, 20% were unsure and 8% were convinced otherwise.

Vulture range coverage by SFS

The South African range of lappet-faced vultures, African white-backed vultures and Cape vultures had the highest accessibility to SFS, with 100% of their range being covered by any SFS, and 79% to 81% when considering only SFS providing more than 40 kg d^{-1} (Table 1). Conversely, hooded and bearded vultures had the lowest SFS range coverage (Table 1).

Discussion

Our study shows that use of SFS in South Africa is widespread, and they provide enough food to potentially fill almost all the energetic needs of the entire South African vulture population. Provisioned food was not distributed

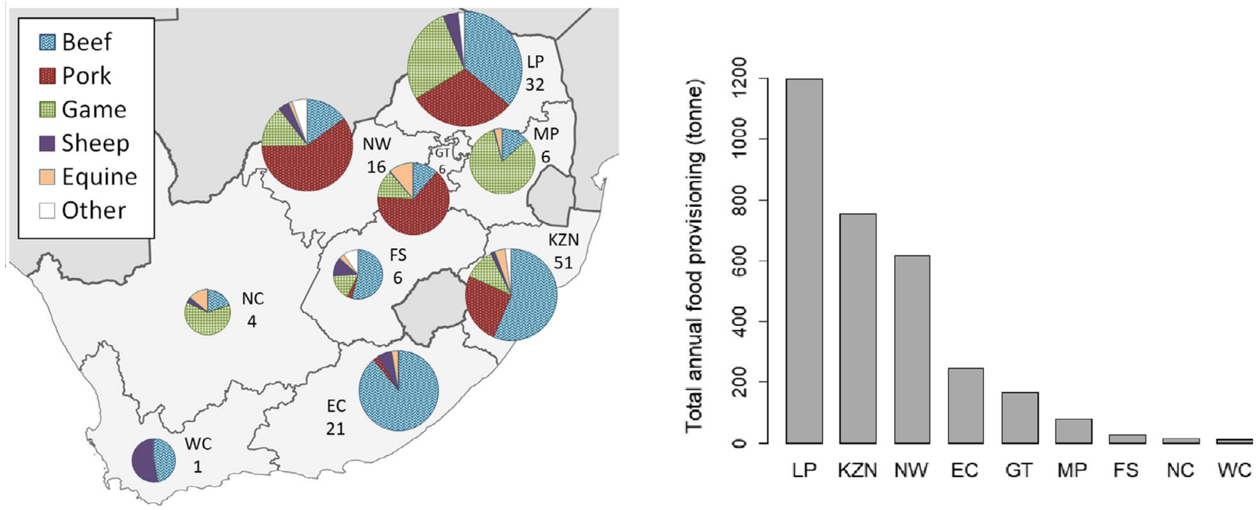

Figure 3 Proportional contribution of each meat type to the total food provisioned at supplementary feeding sites in each province in South Africa (shown by the pie charts within each region in the map). The size of each pie chart is proportional to the total amount of food provisioned in each province per year (log transformed to ease visualization). Numbers below the name of each province in the map indicate the number of active supplementary feeding sites in that province. The total amount of food provided at supplementary feeding sites in each province in tonnes per year is reported in the histogram to the right. LP, Limpopo, KZN, KwaZulu Natal, NW, North West, EC, Eastern Cape, GT, Gauteng, MP, Mpumalanga, FS, Freestate, NC, Northern Cape, WC, Western Cape

Table 1. The percentage area of vulture species' South African distribution range that is within adult vulture maximum (based on 95% Kernel Density Estimates, except for bearded vultures which is based on 90% Kernel Density Estimates) and minimum (based on 50% Kernel Density Estimates) home range distances from SFS and SFS with higher provisioning rates respectively

				All SFS		Higher provisioning rate SFS (>40 kg d^{-1})	
Species	Maximum buffer radius (km)	Minimum buffer radius (km)	South African distribution range (km^2)	Percentage area within maximum home range distance (%)	Percentage area within minimum home range distance (%)	Percentage area within maximum home range distance (%)	Percentage area within minimum home range distance (%)
Lappet-faced vulture	249	94	243 927	100	84	79	45
African white-backed vulture	249	94	399 801	100	81	81	46
Cape vulture	187	56	285 533	100	72	80	41
White-headed vulture	120	41	34 717	92	41	56	5
Hooded vulture	35	10	37 888	33	5	14	2
Bearded vulture	10	4	35 898	24	6	7	2

evenly, with some species having low access to SFS through their range. Therefore, vultures in the area are exposed to varying amounts of provisioned meat quantities and types, and the associated risks of provisioned food of which many SFS managers remain unaware. The numbers of active SFS have remained stable over the past decade.

SFS trends

The initial increase in SFS from the 1970s onwards can likely be ascribed to various awareness campaigns promoting the establishment of SFS to local landowners and the general public (Mundy *et al.*, 1992). Combined with increased awareness of vulture declines, this may have accounted for the growing adoption of SFS by landowners. If the growth rate of SFS remained consistent since that of 2002, then today there would be 430 active SFS in South Africa (Anderson, Piper, & Swan, 2005). Our results show a similar increase up to the year 2002, but a reduction in this rate afterwards, with SFS numbers plateauing in 2009.

Adherence to best practices

Livestock dominates the food provisioned by SFS in most areas. Due to widespread use of veterinary drugs in livestock production, many scavenger species may be exposed to these substances (Blanco *et al.*, 2016; Blanco, Junza, & Barrón, 2017) in a similar way as reported for Asian vultures (Shultz *et al.*, 2004). Other veterinary drugs such as antibiotics may have unidentified long-term sub-lethal effects that can influence the fitness of scavengers (Pitarch, Gil, & Blanco, 2017). Game meat was provisioned at 34% of SFS and mostly originates from hunting activities. This provisioned meat may therefore contain lead fragments from spent lead ammunition. This is problematic as the harmful effects of lead on avian taxa are well documented (Haig *et al.*, 2014). Lead is known to accumulate in vultures in southern Africa and a worrying amount of individuals display lead levels consistent with subclinical to severe clinical effects (Garbett *et al.*, 2018; Krüger & Amar, 2018; van den Heever *et al.*, 2019). Ingestion of lead fragments in carcasses have been indicated as the most likely cause of these elevated lead levels as these elevated levels were not found in non-scavenging species and were also associated with hunting season and areas (Garbett *et al.*, 2018; van den Heever *et al.*, 2019).

The safety of the food provided at SFS depends on how aware managers are of threats, and how seriously they take them. In South Africa, our survey suggested that 28% of SFS managers were unaware of potential harmful effects of veterinary drugs and 68% were unaware of the harmful effects of lead. Consequently, carcasses provided at many SFS could be contaminated with these harmful substances, which could have a negative impact on the vultures that consume them. Another indication that best practice is not always followed is illustrated by the small percentage of SFS that are providing poultry carcasses, potentially exposing vultures to avian influenza (Ducatez *et al.*, 2007). Some respondents also reported powerline-associated mortalities at their sites which represents a main contributing factor for the closure of 7% of SFS. This indicates that some SFS may potentially increase the collision and electrocution risks to vultures. We suggest that conservation practitioners should work more in connection with SFS managers in order to increase their awareness of these unintended consequences and reduce their likelihood through promoting best management practices. In cases where negligent management practices are resulting in mortalities of endangered species, the relevant authorities should intervene.

Temporal variation in SFS provisioning: a paradox

Our updated information on distribution and food provision of SFS in South Africa will allow in-depth analyses of how SFS may influence space use of vultures. Vultures have historically evolved to use temporally variable and unpredictable food resources (Monsarrat *et al.*, 2013). Conversely, regular feeding at SFS associated with intensive livestock farming operations, could lead to the development of routine behaviours and dependence (Fluhr *et al.*, 2017). Within an African context, limited information exists on this potential impact of SFS on vulture behaviour. Anecdotal knowledge in Southern Africa suggests this may be species-specific. For example, dependence on SFS seems low for the Cape vulture (Kane *et al.*, 2016), but high for non-adult bearded vultures (Reid *et al.*, 2015).

Paradoxically, while foraging naturally, vultures may have an increased risk to come into contact with carcasses that have been laced with poison (Monadjem *et al.*, 2018). Regular and copious provisioning of safe food at SFS could thus lead to a reduction in poisoning risk. Initially, SFS were only viewed as a temporary means to 'buy time' for addressing the ultimate threats that are causing vulture declines. Unfortunately, after 40 years since the introduction of SFS, the threat of poisoning is still high, and SFS have become an established tool for general application.

Expansion of the SFS network

Many conservation organizations promote the establishment of SFS (Birds of Prey Programme, 2007). They do so based on different unverified assumptions, for example, that SFS reduces localized poisoning risk and SFS can divert vultures from areas of high risk and in the absence of SFS, vulture populations experience food shortages. In order for the expansion of the existing SFS network to be evidence-based, such assumptions first need verification through scientific investigation. Once evidence for a measurable net positive impact on vulture demographic parameters has been obtained, then this tool can be considered on a case-by-case basis. Given the current lack of such evidence, decisions on SFS establishment are made in the dark (Cook, Hockings, & Carter, 2010).

Future research

Parts of the SFS database were already being used in research prior to this study and thus prior to our verification (e.g. Krüger, Simmons, & Amar, 2015; Kane *et al.*, 2016). A visual comparison of the results of this study and the locations used by Kane *et al.* (2016) suggests that roughly 22% of the 110 SFS included in their study were miscategorized. Their study also omitted at least 70 active SFS. One of the aims of this study is therefore to provide up to date information that can assist future analyses exploring the influence of SFS on vulture behaviour or demographics.

Future studies need to verify the basic assumptions on the demographic effects of SFS on vulture populations. In addition, research should focus on quantifying the role of SFS in reducing poisoning risk to vultures, for example, by studying impacts on ranging behaviours. For example, it may be that SFS could be strategically located to divert vulture movements away from areas with a high threat of poisoning or wind turbine collision (Reid *et al.*, 2015). Finally, the effects of different feeding methods (regular vs. irregular feeding, whole carcasses versus small food parcels) on the above factors and the structure and functioning of the South African scavenger guild could be assessed. In Europe, increased predictability of resources at SFS favoured more dominant species to the detriment of less competitive and often more threatened vulture species (Cortés-Avizanda *et al.*, 2012).

Feeding methods could thus play an important role when SFS are aimed at supporting a particular species in a particular area.

Although we hope this study can assist in future research, SFS security is a concern. There are fears that if SFS locations are made freely available, they could be exploited by poachers for vulture harvesting, or that provided carcasses would be taken for human consumption. Parties interested in using this data for research or management planning are therefore encouraged to contact the authors directly so relevant data agreements can be arranged.

Conclusion

To assess the effectiveness of conservation interventions, it is crucial to know where, when and how such interventions are implemented. A lack of this information prevents such assessments, ultimately leading to a potential waste of scarce conservation resources that, in the case of vulture SFS, may even have counterproductive effects. In this study, we provide the necessary information to enable such research and provide conservation managers with an updated view of the South African SFS network.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. South African population size and total annual food requirement estimates for six vulture species.

Appendix S2. Supplementary feeding sites (SFS) ranked according to their annual provisioning rates, from highest to lowest, in relation to the cumulative contribution of each additional site, to the national total annual provisioning rate (expressed as a percentage).

Appendix S3. Summary of the composition and distribution of the 3113 tonnes of annually provided food, at 143 verified active SFS, across all South African provinces. LP, Limpopo, KZN, KwaZulu Natal, NW, North West, EC, Eastern Cape, GT, Gauteng, MP, Mpumalanga, FS, Freestate, NC, Northern Cape, WC, Western Cape.

Appendix S4. Vulture species home range sizes used for the calculation of SFS range coverage. The maximum buffer radius corresponds to the 95% Kernel Density Estimates (KDE) for the given species. Only a 90% KDE was available for bearded vultures. For the minimum buffer size, 50% KDE was used.