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Short Note

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Jack B Thorley* iD **and Tim Clutton-Brock**

Department of Zoology, University of Cambridge, Cambridge, UK
* Corresponding author, email: jbt27@cam.ac.uk

Vulture populations are experiencing rapid declines across the globe. While the declines have been most precipitous in Asia, recent reports suggest African populations are likewise imminently threatened. As the factors underlying these general population trends are multifaceted and will vary in their relative intensity spatially, it is imperative that monitoring data across different vulture populations is assimilated if targeted conservation action is to prove most effective. In this study, we highlight a medium-term decline in the African White-backed Vulture *Gyps africanus* population inhabiting the southern Kalahari, South Africa, using a long-term behavioural data set collected from a habituated population of meerkats *Suricata suricatta*. Meerkats emit an alarm call on sighting airborne vultures, which elicits a group-level response, such that the rates at which this behaviour is recorded in meerkats provides a high-resolution proxy for local vulture abundance. Although unconventional, this sampling method uncovered a steady decline over 17 years in White-backed Vulture numbers that mirrors the temporal decline recently documented in other southern African populations.

Déclin du Vautour africain dans le Kalahari, vu à travers les yeux des suricates

Tout autour du globe, les populations de vautours connaissent un déclin rapide. Alors que ce déclin s'est précipité au sein des populations d'Asie, de récents rapports suggèrent que les populations africaines sont au moins aussi menacées à court terme. Les facteurs qui influencent ces tendances démographiques générales ont plusieurs facettes et varient de manière spatiale dans leur intensité relative. Par conséquent, il est impératif de collecter et regrouper des données de surveillance sur différentes populations pour mettre en place des stratégies de conservation efficaces et ciblées. Dans cette étude, je souligne le déclin à moyen terme d'une population de Vautour africain (*Gyps africanus*) vivant dans la partie sud du Kalahari, en Afrique du Sud, en utilisant un jeu de données comportementales de long terme, récoltées sur une population de suricates (*Suricata suricatta*) habitués. Les suricates émettent une vocalisation d'alarme lorsqu'ils voient un vautour en vol, ce qui déclenche une réponse anti-prédateur au sein du groupe. La fréquence à laquelle ce comportement est observé et relevé chez les suricates représente un substitut fiable et de grande résolution pour attester de l'abondance locale de vautours. Bien que peu conventionnelle, cette méthode d'échantillonnage a mis en évidence une diminution constante du nombre de Vautours africains au cours de 17 dernières années, qui reflète le déclin récemment documenté dans d'autres populations d'Afrique australe.

Over recent decades, vulture populations globally have experienced rapid declines, with the sharpest downturns observed in south Asian *Gyps* populations (Ogada et al. 2012), where incidental diclofenac poisoning has brought many populations to the brink of extinction (Oaks et al. 2004; Shultz et al. 2004). In Africa the situation is little better: eight of the most widespread vulture species have similarly shown sharp declines (Ogada et al. 2016), six of which have occurred on a scale that has prompted their listing as Endangered or Critically Endangered (IUCN 2016). Despite the call to arms to abate or reverse the trends (Koenig 2006), which may be due to poisoning (Botha et al.

2015), changes in land use (Murn and Anderson 2008) or climate change (Simmons and Jenkins 2007), the intensity and quality of monitoring data varies geographically. In southern Africa, populations of Cape Vultures *Gyps coprotheres* and African White-backed Vultures *Gyps africanus* have both received reasonable attention (BirdLife International 2016a, 2016b; Ogada et al. 2016), but the speed at which breeding colonies or populations can crash demands ongoing assessment (Wolter et al. 2016), particularly if the threats facing vultures are spatially contingent.

In this paper, vulture trends at the southern edge of the Kalahari in the Northern Cape province of South Africa are

documented using a finely resolved time series of meerkat *Suricata suricatta* behaviour. Meerkats are small (<1 kg) desert-adapted mongooses inhabiting the arid regions of southern Africa. They are obligate cooperative breeders, living in groups of 2–50 individuals in which a dominant pair monopolise reproduction (Clutton-Brock et al. 1999). Living in open environments exposes meerkats to aerial and terrestrial predators. Meerkats mitigate this problem by exhibiting sentinel behaviour, wherein individuals periodically forgo foraging activities to scan the sky and ground for possible threats using exceptional eyesight (Supplementary Figure S1), at which point they emit alarm calls to inform the group. These calls vary according to the location (aerial or terrestrial) and urgency of the threat being posed, allowing context-specific group responses (Manser 2001). Vultures, although posing no threat to meerkats, also reliably elicit a 'low urgency, aerial threat' call and a coordinated group response. Therefore, the rate at which human observers note the response of meerkat groups to a vulture-induced alarm call acts as a good proxy for vulture abundance.

From January 1999 to December 2015, habituated meerkat groups at the Kuruman River Reserve, Vans Zyls Rus (26°58′ S, 21°49′ E), were visited by human observers approximately every 3 d in the morning (2–4 h) and the late afternoon (1–2 h) (see Russell et al. 2002 for details). Meerkats are largely foraging during these time periods, so observers recorded a large number of behaviours *ad libitum* into handheld organisers, including group responses to aerial threats (420.59 ± 6.69 h *ad libitum* data per month; Supplementary Figure S2). The proportion of observer time with meerkats in the late afternoon increased at the project from 2003 (Supplementary Figure S2) and, as vulture sightings are also lower in the afternoon, all analyses used data from mornings only. Observers would also note the species eliciting the response, but if unsure, observers did not specify or more broadly characterised the taxa (e.g. 'vulture'). From this data set we extracted rates of vulture sightings per month – the number of responses to vultures by meerkats in each month divided by the total amount of time observers spent with meerkats. In instances where vultures were seen soaring in groups, only a single record is made, so it must be assumed that the species noted was the most common in the group.

Rates of vulture sightings per month were subset into three time series (all vultures combined, White-backed Vultures, and Lappet-faced Vultures *Torgos tracheliotos*). Each time series was then seasonally decomposed into a seasonal component ('month of the year' effect), a trend component, and a residual component. The presence of a linear trend in each of the time series was first tested with a Mann–Kendall test. A more conservative approach was then performed by fitting generalised linear mixed models (GLMMs) in which the trend component of each decomposed time series (see Crawley 2007) was fitted against an indexed variable of time (indexed sequentially across the time series such that January 1999 = 1, February 1999 = 2…, January 2000 = 13, and so on). Year was set as a random effect to control for possible temporal autocorrelation. Assumptions for normality and homogeneity of variances were fulfilled throughout modelling mentioned in this paper, and the significance of the linear trend was

estimated from the likelihood ratio test on dropping the time index from the model. To compare the trends to other studies (Ogada et al. 2016), we also performed linear regressions of annual rates of vulture sightings per hour against year; these slopes were then used to estimate an annualised rate of change (*r*) over the study length (*t*) according to the formula in Ogada et al. (2016): $r = -(1 - (1 + C)\hat{}(1/t))$, where *C* is the overall change. A Mann–Kendall test was also performed on a monthly vulture sightings time series, and a monthly rainfall time series, the latter to investigate whether rainfall changed linearly over the study duration. Rainfall data were acquired from the meerkat project station, and all analyses were performed in R 3.2.3 (R Core Team 2015).

African White-backed Vultures were the predominant species on the ranch land in the southern Kalahari, Lappet-faced Vultures were frequently seen and Cape Vultures were rare (Figure 1). After accounting for the monthly seasonality of the 17-year time series, annual rates of total vulture sightings per hour, as indicated by meerkat behaviour, have declined (GLMM slope ± SE = −0.007 ± 0.003, $\chi^2_1 = 6.07$, $p = 0.047$; Mann–Kendall tau = −0.21, $p < 0.001$). This category includes vultures not identified to species level, but as White-backed Vultures account for the large proportion of vultures present in the study area, it is not surprising that a similar downward trend was seen with the restricted data set that only included vultures identified by human observers as White-backed Vultures (GLMM slope ± SE = −0.005 ± 0.002, $\chi^2_1 = 4.76$, $p = 0.03$; Mann–Kendall tau = −0.22, $p < 0.001$). Lappet-faced Vultures did not show a significant decline in the study area (GLMM slope ± SE = −0.0003 ± 0.0005, $\chi^2_1 = 0.31$, $p = 0.58$; Mann–Kendall tau = −0.01, $p = 0.84$). These slopes were similar to those estimated from the data on an annual basis (Figure 2), equating to a 46.9% absolute decline, or 3.65% average annual rate of decline in the case of all vulture sightings, and 45.3% absolute or 3.49% annual rate of decline for White-Backed Vultures. There was also a clear increase in sightings over winter (Figure 1), which coincides with breeding and might therefore reflect a local concentration of birds to nearby breeding locations when foraging ranges are reduced (Phipps et al. 2013).

The 3.49% annual rate of decline in White-backed Vulture groups we detect using meerkat behaviour lies within the range reported for African vulture populations using more orthodox sampling methods applied over three decades (Ogada et al. 2016), lending support for the methodology used in this paper as a representative means of assessing vulture population trends. If one specifically considers White-backed Vultures in southern Africa, the accumulated evidence does not provide a consistent picture across the region. For example, annualised rates of change in vulture numbers displayed a 2.5% annual decrease at the Kruger National Park (27-year period, aerial nest surveys; Murn et al. 2013), but a 3.1% annual increase in Swaziland (29-year period, aerial nest survey; Hitchins 1980; Bamford et al. 2009). A 22-year data set also documented a 72% increase in breeding pairs near Kimberley, South Africa (BirdLife International 2016b), but nonetheless, the overall consensus is that populations have undergone rapid declines (BirdLife International 2016b). This is backed
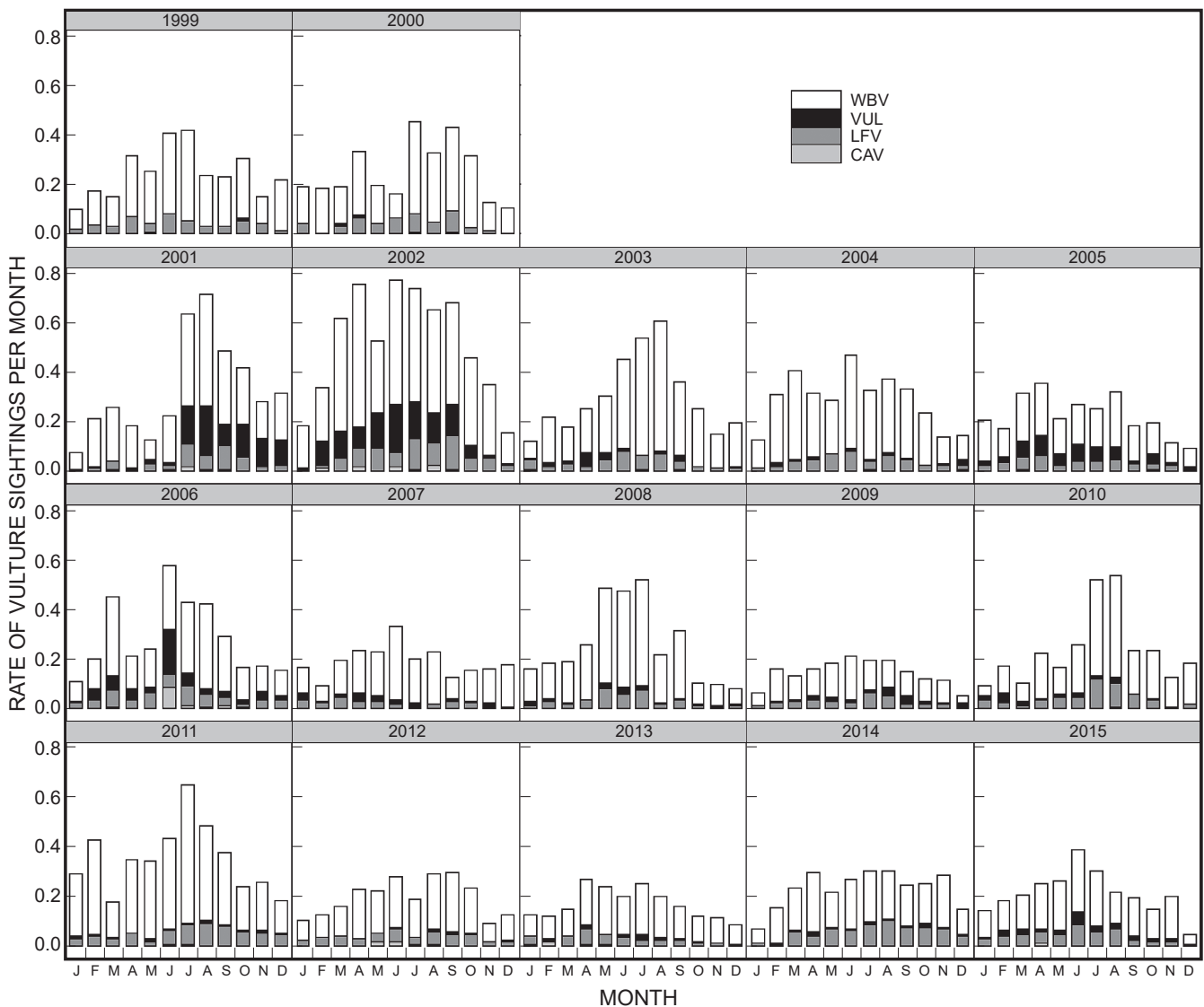
Figure 1: Monthly rates of vulture sightings by meerkats at the Kalahari Meerkat Project. CAV = Cape Vulture, LFV = Lappet-faced Vulture, VUL = Unknown vulture, WBV = White-backed Vulture

up by a comparison of reporting rates across each period of the South African Bird Atlas Project (Period 1: 1987–1992; Period 2: 2007–ongoing), which indicated a 23.8% decline. To derive this estimate, we extracted data from the Southern African Bird Atlas Project 2 (http://www.sabap2.adu.org.za; accessed 30 October 2016), only including data from one-quarter degree squares (QDS) that had recorded White-backed Vultures on at least one checklist in either period, and for which at least five or more full protocol checklists were present in both periods. Next, we specified a GLMM with binomial errors and logit link function, where the response variable noted the number of checklists with and without White-backed Vultures for each QDS in each atlas period. Period was fit as a two-level categorical covariate, and QDS was set as a random effect to account for the non-independence of sampling site.

Part of the challenge in assessing White-backed Vulture demography is their level of mobility, with recent work

highlighting that juveniles can travel upwards of 900 km in search of carcasses in a limited period of time (Phipps et al. 2013). In this regard, aerial surveys of nest counts provide the gold standard for assessing abundance of the tree-nesting vultures, but road transects are the most commonly employed method in practice. However, road transects are always intermittent, and are known to be prone to a number of factors that influence short-term vulture presence (discussed in Murn and Botha 2016). The data set used in this study might be prone to the same spatio-temporal factors on shorter time scales, but its temporal resolution far exceeds other long-term data sets examined to date, which would be expected to remove substantial bias induced by short-term local events. Even so, the sampling methodology employed in this paper could be adjusted to provide greater information content concerning vulture abundance. Notably, human observers could actively count the number of vultures seen at each recording event, rather
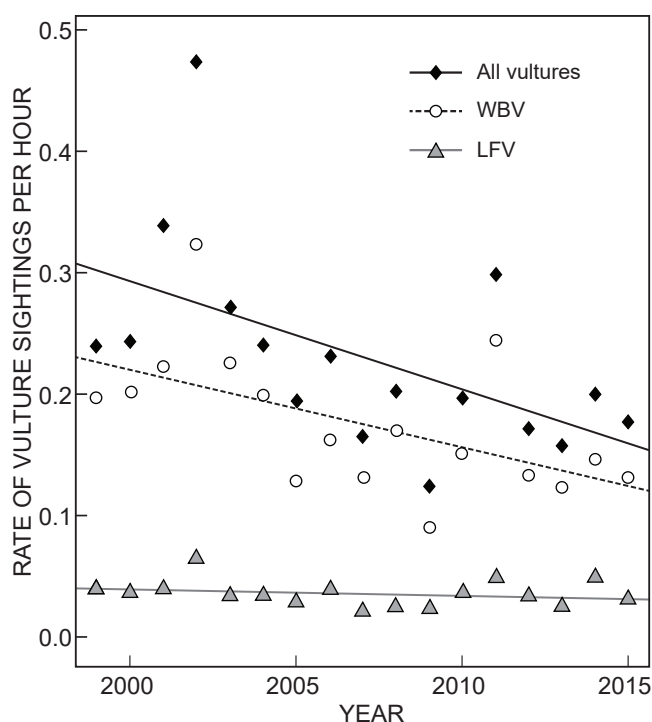
Figure 2: Vulture sighting rates linear trends. Lines of best fit estimated from linear regression (all vultures: slope $\pm$ SE = -0.0088 ± 0.0035, t_{15} =2.64, p = 0.025; White-backed Vultures: slope $\pm$ SE = -0.0064 ± 0.0024, t_{15} = 2.49, p = 0.018; Lappet-faced Vultures: slope $\pm$ SE = -0.00048 ± 0.00054, t_{15} = 0.89, p = 0.39). LFV = Lappet-faced Vulture, WBV = White-backed Vulture

than only document their presence, whilst more informed documentation of plumage characteristics could quantify annual changes in population age structure.

Aside from the absence of a correlation between rainfall and vulture sighting rates (r = 0.25, t_{15} = 1.01, p = 0.33), and no linear trend in annual rainfall over the duration of the study regardless (Mann–Kendall tau = -0.06, p = 0.22), we could only speculate on the causes of the vulture decline at the study site. It would, however, be informative to know how breeding success and juvenile mortality has changed in recent years at core local breeding sites for White-backed Vultures, such as in the Askham area and in the Kgalagadi Transfrontier Park, where large nesting trees become more frequent. Doing so would help start to understand at what geographic scale the decline is operating in the Northern Cape, as the aforementioned evidence suggests vulture trends are not consistent spatially.

Although easily regarded as unsavoury through human eyes, the importance of scavengers in recycling carcasses and preserving high energy flows in food webs cannot be understated (DeVault et al. 2003). It is with some irony that vultures, whose futures are globally imperilled, have been attributed the power of clairvoyance by several cultures (Cunningham and Zondi 1991; Mundy et al. 1992). In this paper, it is through the eyes of meerkats that a vulture population's downward trend is seen, in spite of the recent optimism and high conservation incentives to protect these raptors worldwide (Koenig 2006).

ORCID

Jack B Thorley   iD   http://orcid.org/0000-0002-8426-610X

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