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Recent trends in populations of Critically Endangered *Gyps* vultures in India

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Summary

This paper reports results from the eighth of a series of road transect surveys of *Gyps* vultures conducted across northern, central, western, and north-eastern India since the early 1990s. Populations of the White-rumped Vulture *Gyps bengalensis*, Indian Vulture *G. indicus*, and Slender-billed Vulture *G. tenuirostris* declined rapidly, beginning in the mid-1990s. The principal cause of the declines was poisoning due to widespread veterinary use of the non-steroidal anti-inflammatory drug (NSAID) diclofenac on cattle. The results of the current survey suggest that, while populations of all three species of vulture remain at a low level with no signs of recovery, they appear to have been approximately stable since veterinary use of diclofenac was banned in the mid-2000s. Population trends in India, where the illegal use of diclofenac and legal use of other toxic NSAIDs continues, are compared with more positive trends in Nepal, where the veterinary use of toxic NSAIDs appears to have been reduced to a low level.

Introduction

Rapid population declines since the mid-1990s of three species of vultures endemic to South Asia, White-rumped Vulture (*Gyps bengalensis*), Indian Vulture (*G. indicus*), and Slender-billed Vulture (*G. tenuirostris*), led to them all being listed as "Critically Endangered" on the IUCN Red List (BirdLife International 2021). Veterinary use of the non-steroidal anti-inflammatory drug (NSAID) diclofenac on cattle has been identified as the main and probably the only cause of these population declines. Evidence comparing the importance of diclofenac in causing the declines with that of other potential causes is of several types and has been presented in detail elsewhere (Oaks et al. 2004; Green et al. 2004; Shultz et al. 2004). Diclofenac-induced kidney failure causes the death of *Gyps* vultures if they ingest tissue from the carcass of an ungulate that has died soon after being dosed with the drug (Oaks et al. 2004; Swan et al. 2006; Green et al. 2006).

A ban on the veterinary use of diclofenac in India was announced in 2006. The official completion of the banning process was a gazette notification in 2008. Before the ban, in 2004–2005, the proportion of carcasses of domesticated ungulates sampled in India that were contaminated with diclofenac and the concentration of the drug in their tissues were sufficient to have caused vultures to decline at the rapid rates observed (Green et al. 2007). After the ban, both the prevalence and the concentration of diclofenac in cattle carcasses sampled in India declined (Cuthbert et al. 2014), and the rate of population decline of White-rumped Vultures slowed approximately to the extent expected from the predicted consequent reduction in annual death rate from diclofenac poisoning (Prakash et al. 2012). Prakash et al. (2019) reported results from counts of the three *Gyps* vulture species on road transects in northern India in seven comparable surveys between 1992 and 2015. The study indicated that the rapid population declines of all three species up to 2002 had slowed since 2003. In this paper, we report results from another in this series of counts, which was conducted in 2022.

Methods

Survey methods

Vultures were counted in 2022 on road transects widely distributed across northern, western, and central India in the following 13 states: Rajasthan, Gujarat, Maharashtra, Haryana, Punjab, Uttar Pradesh, Uttarakhand, Bihar, Madhya Pradesh, West Bengal, Assam, Meghalaya, and

Arunachal Pradesh. Transect locations and methods followed those of similar surveys conducted in 1991–1993, 2000, 2002, 2003, 2007, 2011, and 2015, as described previously (Prakash et al. 2007, 2012, 2019). The initial surveys in this series were conducted in one of the three years 1991–1993. For the purpose of the present analysis, we treated them all as having been conducted in 1992, the mid-point of that period. Over time, some of the initial survey routes ceased to be surveyed and some new routes were introduced, but once a route was initiated the same route was followed in subsequent survey years. Nesting colonies and cattle carcass dumps were not included on transect routes. The numbers of transects surveyed in 1992, 2000, 2002, 2003, 2007, 2011, 2015, and 2022 were 92, 98, 159, 149, 165, 154, 154, and 152, respectively. The total length of transect routes driven in 2022 was 16,427 km, which was similar to the length of transects covered during 2015 (15,517 km). Lengths of individual routes in 2022 ranged from 4 km to 1,542 km. A map showing transect locations is given in Green et al. (2007).

A driver and observer followed transect routes in a vehicle between 06h30 and11h00 and again between 15h00 and 19h00 local time at 10–20 km/hour in and near protected areas and ~50 km/hour between protected areas. Vultures observed on the ground, in trees, on cliffs, or flying and judged to be within 500 m on either side of the transect were recorded, but the distance between the transect route and the bird was not recorded. Vultures are large (c.5 kg body weight) and easy to detect within 500 m without optical equipment, but the identification of species required the use of binoculars. Vultures were identified using plumage characters as White-rumped Vulture, Indian Vulture, and Slender-billed Vulture from 2002 onwards. Indian Vulture and Slender-billed Vulture were not considered to be different species until 2001 (Rasmussen and Parry 2001), so the surveys in 1992 and 2000 recorded both taxa together as Long-billed Vultures. Surveys were conducted between March and July, which avoids the part of the monsoon season with most rain. Extreme conditions of rain and wind were avoided. This period is at the end of breeding season, when juveniles had fledged and adults were not confined to their nesting sites. Hence, at this time, numbers of free-ranging birds were close to their highest level during the year.

Calculation of annual population indices

We only analysed data from transects that were surveyed more than once during the study period and on which vultures of the focal species or species group had been recorded at least once. We called these informative transects. Not all of the informative transects were covered in every survey because some were added to the set after 1991–1993, whilst others were temporarily or permanently omitted from the survey. However, the mean number of surveys per informative transect across the eight surveys conducted from 1992 to 2022 was 6.9 for White-rumped Vulture and 7.0 for Indian and Slender-billed Vultures combined. For the six surveys between 2002 and 2022 in which Indian and Slender-billed Vultures were recorded separately, the mean number of surveys per informative transect was 5.6 for Indian Vulture and 5.8 for Slender-billed Vulture. Hence, the percentage completeness of survey coverage of informative transects was in the range 87–96%. To allow for these missing values, we fitted regression models to allow for the effects of the changing composition of the sample of transects in which count was the dependent variable, and transect and survey year were both fixed-effect factors with numbers of levels set to the number of informative transects and the number of surveys included, respectively. Models were fitted in GLIM 4 (Aitken et al. 2005), with a Poisson error term and a logarithmic link function. The form of the model was

$$C_{ij} = \exp\left(k_i + p_j\right),$$

where C_{ij} is the count for the j^{th} transect in the i^{th} year. Site effects are represented by the fitted regression coefficients p_j. The coefficients k_i represent the year effects and are the logarithms of the abundance of vultures in i^{th} year, allowing for site effects, expressed as a proportion of the abundance of vultures in the first year of the series in the study period. Hence, $\exp(k_i)$ provides an index of population density in the i^{th} year, relative to that in the first survey. We obtained 95% confidence intervals for the population index values using a non-parametric bootstrap method. In a period in which there were m informative transects eligible for analysis for a species or species group, we took random bootstrap samples of m transects, with replacement, from the m transects available. We then fitted the log-linear Poisson regression model for this bootstrap sample and recorded the value of $\exp(k_i)$ for each of the survey years. This procedure was repeated 1,000 times, the bootstrap estimates ranked, and the bounds of the central set of 950 estimates taken to define the 95% confidence interval of each of the population indices.

Calculation of mean annual population multiplication rate and changes in population trend over time

We estimated the mean annual rate of population change for White-rumped and Indian Vultures from the regression model results described above. We calculated the mean annual population multiplication rate λ during the interval between each pair of consecutive surveys conducted at times t_1 and t_2 as

$$\lambda = \exp((k_2 - k_1)/(t_2 - t_1)).$$

We obtained bootstrap estimates of λ for the intervals between each pair of consecutive surveys from each of the 1,000 bootstrap replicates described above and took the bounds of the central 950 bootstrap values as the 95% confidence limits for λ. The number of informative transects was much lower for Slender-billed Vulture than for the other two species (Table 1) and therefore we consider the use of this bootstrap method for calculating confidence limits to be unreliable to use for this species (Manly 1997).

Results

Annual population indices

The total numbers of White-rumped Vultures, Indian Vultures, and Slender-billed Vultures counted on informative transects in 2022 were 106, 299, and 11, respectively, compared with 102, 139, and 12 in 2015. Considering the 30-year period covered by all eight surveys, the annual population indices declined rapidly between 1992 and 2007 for White-rumped Vulture and for Indian and Slender-billed Vultures combined, but there was no evidence of a consistent trend in either case between 2007 and 2022 (Table 1, Figure 1). Population index values for both of these species groups during 2007–2022 remained far lower than the 1992 level, being about one 500th of the 1992 level for White-rumped Vulture and about one 50th of the 1992 level for Indian Vulture and Slender-billed Vulture combined. Too few Slender-billed Vultures have been counted per survey to quantify a reliable trend for this rare

Table 1. Indices of population size for White-rumped, Indian, and Slender-billed Vultures in northern India. Indices are populations relative to those of the first year of the period indicated in each row. Also shown are 95% bootstrap confidence intervals for each index value (in brackets) and the number of informative transects used in each analysis.

Species	Period	Informative transects	2000	2002	2003	2007	2011	2015	2022
White-rumped Vulture	1992–2022	124	0.0368	0.0208	0.0041	0.0014	0.0019	0.0019	0.0020
			(0.0183–0.639)	(0.0116–0.0336)	(0.0015–0.0084)	(0.0003–0.0037)	(0.0001–0.0054)	(0.0002–0.0051)	(0.0006–0.0050)
Indian and Slender-billed Vultures	1992–2022	114	0.0735	0.0652	0.0269	0.0258	0.0229	0.0112	0.0211
			(0.0586–0.1236)	(0.0498–0.1119)	(0.0161–0.0563)	(0.0182–0.0527)	(0.0163–0.0445)	(0.0078–0.0242)	(0.0152–0.0402)
Indian Vulture	2002–2022	49	–	–	0.4159	0.3968	0.3379	0.1636	0.3247
					(0.2871–0.7603)	(0.3147–0.7256)	(0.2200–0.9550)	(0.1170–0.3776)	(0.2155–0.8708)
Slender-billed Vulture	2002-2022	14	–	–	0.2189	0.3684	0.8948	0.4737	0.6253
					(0.1024–0.9408)	(0.1251–1.7993)	(0.6154–3.1424)	(0.2728–1.7143)	(0.4087–1.8042)

species separately, but the index values obtained since they were first counted separately in 2002 suggest an initial decline between 2002 and 2003 and possible increase since 2003 (Table 1).

Changes over time in annual population multiplication rate

Considering only the period 2002–2022 during which White-rumped Vulture, Indian Vulture, and Slender-billed Vulture have been counted separately, the annual population multiplication rate λ was significantly below one (i.e. significant decline) for White-rumped Vulture and Indian Vulture in the one-year interval between the 2002 and 2003 surveys (Figure 2). In the next interval (2003–2007), λ was significantly less than one (0.771; 95% confidence limits 0.697–0.965) for White-rumped Vulture, but λ was close to one (1.073, 1.002, and 1.009, respectively) for this species in the three subsequent intervals between pairs of surveys after 2007. The 95% confidence limits for λ for this species overlapped one in all three of these intervals. Hence, the population index for White-rumped Vulture has been approximately stable since 2007 (Figure 2). For Indian Vulture, λ was close to one in the first two of the intervals between pairs of surveys after 2003 (2003–2007, λ = 0.988; 2007–2011, λ = 0.961), and the 95% confidence limits of λ overlapped one for both of these intervals. In the interval 2011–2015, λ appeared to be low (0.834), suggesting that a decline might have occurred, but the 95% confidence limits of this estimate overlapped one (0.752–1.125), so this possible change was not statistically significant. In the interval 2015–2022, λ for Indian Vulture was significantly greater than one (1.103) and the 95% confidence limits of this estimate did not overlap zero (1.038–1.350), indicating a significant increase in the population index of Indian Vulture between 2015 and 2022 (Figure 2).

Discussion

The recent population trend estimates we obtained for all three vulture species are moderately encouraging in that the substantial declines recorded for all species up to 2003 appear to have ceased. The survey results for 2015 suggested that the Indian Vulture population might have begun to decline again having been approximately stable since 2003. However, the apparent decline was not statistically significant and the data for 2022 suggested that approximate stability or a slow increase has resumed. Too few Slender-billed Vultures were recorded on the transects to give a robust estimate of trend, but there is no evidence of decline of this rare species since 2003.

Our results provided no clear indication of a consistent population recovery for any species since 2003. The ratios of the means of the five population index values for 2003–2022, relative to the 2002 value, are 0.3278, 0.5162, and 0.1087 for White-rumped, Indian, and Slender-billed Vultures, respectively, indicating average declines of 67%, 48%, and 89%, respectively, relative to 2002. None of the five annual index values for 2003–2022 exceeded the 2002 index value for any of the three species. These population deficits relative to 2002 come on top of the population declines between 1992 and 2002, which were 98% for White-rumped Vulture and 93% for Indian and Slender-billed Vulture combined. The means of estimates of absolute population size in India for 2003, 2007, 2011, and 2015 given by Prakash et al. (2019) were 6,200, 23,900, and 1,400 individuals for White-rumped Vulture, Indian Vulture, and Slender-billed Vulture, respectively. It

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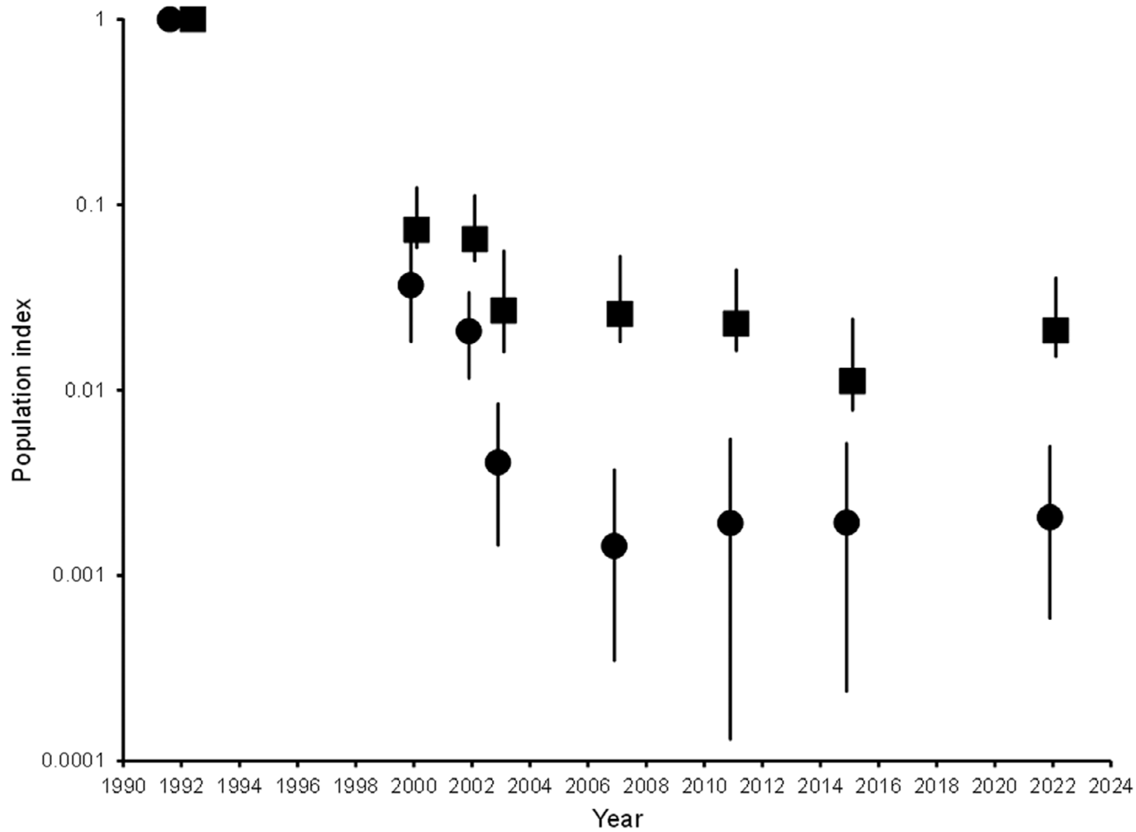

Figure 1. Indices and trends of populations of White-rumped Vulture (circles) and of Indian and Slender-billed Vultures combined (squares) in northern India. Points show indices of population relative to that in 1992, estimated by log-linear Poisson regression performed on data from eight road transect surveys in northern India. Vertical lines show 95% bootstrap confidence intervals. The vertical axis is logarithmic but the population index values given on it are untransformed.

appears that these precariously small populations have not increased substantially since then.

Long-term trends in populations of White-rumped and Indian Vultures in India have also been evaluated using a population index based upon the frequency of occurrence of records on checklists contributed by citizen scientists from the whole of India in the State of India's Birds project (SoIB 2020). These results show declines of 97% in the index for White-rumped Vultures and a 90% decline for Indian Vultures between the pre-2000 period and 2018. The frequency of occurrence trend results differ from our road transect results in finding continuing declines between 2003 and 2018 during a period when our road transect surveys in northern India indicated approximate population stability. A possible explanation for this apparent difference in trend is that the road transects surveys are concentrated in and near protected areas, whereas the citizen science checklists are more widely distributed. Previous analyses of the road transect data showed that vulture densities are higher close to national parks (Prakash et al. 2019), and also showed smaller declines near to parks (Prakash et al. 2012). Hence, the more widely dispersed checklist-based index might reflect changes further from protected areas, which may be more negative than those occurring close to them. Considering both types of information together, we conclude that only small proportions of the populations of all three species that existed in the early 1990s remain and that none of the species show any consistent signs of population recovery in India.

The absence of recovery so far of vulture populations in India contrasts with the situation in Nepal. Road transect surveys of White-rumped and Slender-billed Vultures in Nepal showed rapid declines for both species up to about 2013, followed by rapid increases for both species between 2013 and 2018 (Galligan et al. 2020). We compared the patterns of change in estimates of the population multiplication rate λ directly between Nepal and India for White-rumped Vulture in Figure 2. In the period 2002–2013, the White-rumped Vulture population index was declining significantly in Nepal at a mean rate similar to that for the species in India at approximately the same time. However, piecewise regression analysis of the Nepal data indicated a marked change in trend, beginning in about 2013. From 2013 to 2018, the White-rumped Vulture population index for Nepal showed a rapid mean rate of increase of 22% per year while the population in India showed no sign of recovery. The population index for Slender-billed Vultures in Nepal showed a similar pattern of change over time to that of White-rumped Vultures (Galligan et al. 2020), but results from India for this species are based upon too few data for a direct comparison of results for the two countries to be meaningful. For both White-rumped and Slender-billed Vultures, the mean annual rate of population increase in Nepal, estimated since the early 2010s, was significantly greater than the maximum rate of increase for a closed population, calculated according to the method of Niel and Lebreton (2005). Observed rates of increases for White-rumped and Slender-billed Vultures were 22% and 41% per year, respectively, compared with about 12% for the expected

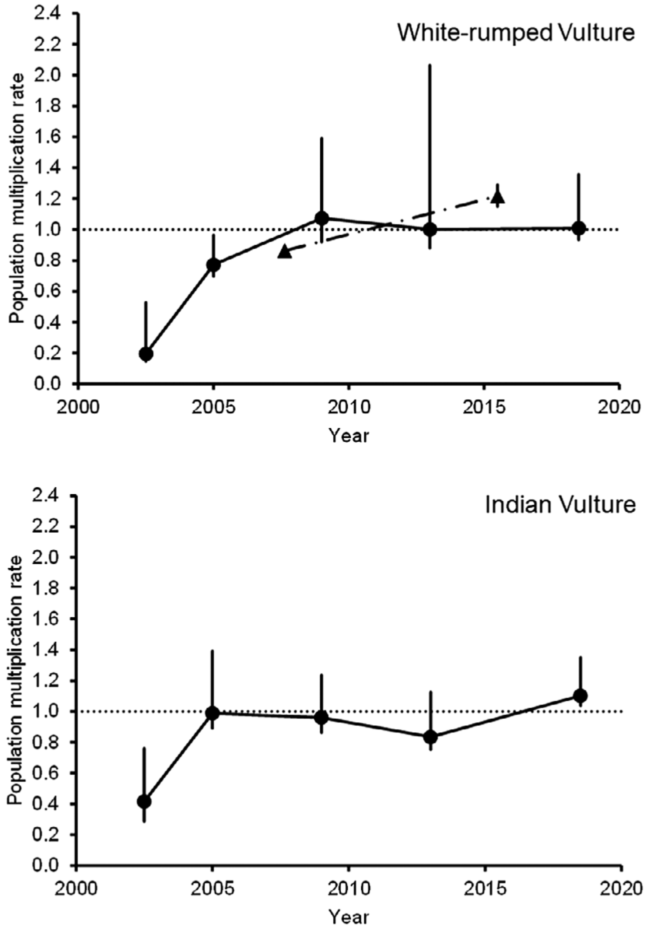

Figure 2. Annual population multiplication rates λ for populations of White-rumped Vulture in northern India (circles) and Nepal (triangles), and Indian Vulture in northern India. For India, rates were averaged for intervals between each consecutive pair of surveys (1–7 years apart) and are plotted at the midpoint of each interval. Vertical lines show 95% bootstrap confidence intervals. For Nepal, the estimates of λ and its 95% confidence limits are for two periods (2002–2013 and 2013–2018) and are from a piecewise quasi-Poisson regression model of annual road transect counts (see Figure 3 of Galligan *et al.* 2020). The horizontal dashed line indicates stable population size (λ = 1).

maximum rate. This suggests that vulture populations in Nepal might recently have been supplemented by net immigration from adjacent parts of India (Galligan et al. 2020). Net immigration on a sufficient scale seems feasible for *Gyps* species, given their large home range sizes (Gilbert et al. 2007) and social attraction to conspecifics, including social facilitation of food finding (Jackson et al. 2008).

A possible cause of the difference in recent vulture population trends between India and Nepal is the difference between the two countries in the degree to which nephrotoxic NSAIDs have continued to be in veterinary use. The prevalence and concentration of the toxic NSAID diclofenac in cattle carcasses available to vultures in India decreased substantially after veterinary use of the drug was banned in 2006, but its prevalence still remained at a substantial level (Cuthbert et al. 2014). Undercover surveys of the availability of veterinary NSAIDs in pharmacies in India showed that the availability of diclofenac has declined in some Indian states, but has remained high in others (Galligan et al. 2021). In addition, whilst the NSAID meloxicam, which is not toxic to vultures, had largely replaced diclofenac in some Indian states, the replacement drugs in other states were other nephrotoxic drugs including ketoprofen, nimesulide, and aceclofenac, which had not yet been banned (Galligan et al. 2021). This situation with veterinary NSAIDs in India contrasts markedly with that in Nepal, where a public-awareness programme to create a Vulture Safe Zone has been effective. Since about 2012, the availability of veterinary diclofenac in pharmacies in a large part of Nepal has declined to very low levels and the drug has largely been replaced by meloxicam (Galligan et al. 2020, 2021)

In conclusion, following the catastrophic population declines of White-rumped, Indian, and Slender-billed Vultures in India and elsewhere in South Asia since the mid-1990s, our results indicate that rapid declines have ceased in India. However, unlike in Nepal where NSAID use has largely switched to the safe alternative meloxicam, there are no indications yet of population recovery. The Government of India's action plan (MoEFCC 2020), the Convention on Migratory Species Raptors MoU Multi-species Action Plan (Botha et al. 2017), and the SAVE Blueprint (SAVE 2021) have all emphasised the importance of further measures to make the ban on veterinary use of diclofenac ban more effective and to regulate the veterinary use of the other drugs in veterinary use that are known to be nephrotoxic to vultures. These other drugs are aceclofenac, ketoprofen, and nimesulide (Naidoo et al. 2010; Cuthbert et al. 2016; Galligan et al. 2016; Nambirajan et al. 2021; Chandramohan et al. 2022). In July 2023, the Health Ministry and Central Drugs Standards Control Organisation (CDSCO) of the Government of India recommended a ban on veterinary use of aceclofenac and ketoprofen in response to a vulture conservation petition submitted to the New Delhi High Court by the advocate Gaurav Kumar Bansal. The government rapidly adopted this recommendation and gazetted the bans in August 2023. If the bans are effective, this is a positive step, although the vulture-toxic drug nimesulide has not yet been banned.

There are no regulatory processes in place in India or any other South Asian vulture range state that require evidence to be produced of the safety to vultures of new-to-market veterinary drugs before their manufacture and use are approved and licensed. Hence, the global populations of White-rumped, Indian, and Slender-billed Vultures remain at risk from illegal use of diclofenac, aceclofenac, and ketoprofen and the legally approved nephrotoxic NSAID nimesulide, and potentially from new toxic drugs which might be introduced in future without any safety testing. The maintenance of self-sustaining captive populations of these three vulture species will continue to be an essential precaution until these threats are controlled more effectively (Bowden et al. 2012).

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