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M. JAMSHED I. CHAUDHRY, DARCY L. OGADA, RIFFAT N. MALIK, MUNIR Z. VIRANI and MATTHEW D. GIOVANNI

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First evidence that populations of the critically endangered Long-billed Vulture *Gyps indicus* in Pakistan have increased following the ban of the toxic veterinary drug diclofenac in south Asia

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Summary

The cliff-nesting Long-billed Vulture *Gyps indicus* is one of four critically endangered Asian Vultures. In India, this species has declined catastrophically, but in Pakistan only small population declines have been recorded. Mortality of this species has been linked to poisoning by veterinary diclofenac, which was banned throughout south Asia in 2006. Between 2003 and 2012 we measured abundance of adult, sub-adult, juvenile, and dead vultures, and nest occupancy and productivity at the largest known Long-billed Vulture colony in Pakistan. We compared population parameters from before (2003–2006) and after (2007–2012) the ban on veterinary diclofenac. Our data and models indicate that vulture abundance, nest occupancy, and nest productivity declined 61%, 73%, and 95%, respectively, in the three years before the diclofenac ban, and then increased 1–2 years after the ban by 55%, 52%, and 95%. Furthermore, we observed 87% of total vulture mortalities prior to the diclofenac ban. Our results demonstrate for the first time since the onset of the Asian vulture crisis that the ban on veterinary diclofenac is an effective management tool for reversing Long-billed Vulture population declines.

Introduction

Through the early half of the 20th century, Long-billed Vultures *Gyps indicus* and White-rumped Vultures *G. bengalensis* were the most abundant vultures in South Asia (Thiollay 2000). In the 20–30 years following World War II, vultures disappeared from entire far east Asian countries (e.g. Malaysia, Laos, Cambodia and Thailand) and seriously declined in others (e.g. Burma and Bangladesh) (Thiollay 2000, Hla *et al.* 2011, Clements *et al.* in press). While there is some discrepancy over the health of vulture populations in Pakistan during the mid-20th century (Thiollay 2000 and Pain *et al.* 2003), they remained robust in India and Nepal until numbers began to plummet in the early 1990s due to poisoning by the veterinary drug diclofenac (Oaks *et al.* 2004, Green *et al.* 2004, Pain *et al.* 2008, Acharya *et al.* 2009, Das *et al.* 2011, Chaudhary *et al.* 2012). As a result, Asian vultures are amongst the most endangered birds in the world, and the Long-billed Vulture is one of four Asian species listed as “Critically Endangered” (BirdLife International 2011).

The rapid decline of Asian *Gyps* vulture populations was recorded over a 10-year period (1990–2000) when populations crashed by > 96% in Keoladeo National Park in northern India and by > 92% throughout the country (Prakash 1999; Prakash *et al.* 2003). Vulture populations in Pakistan remained stable through the mid-1990s, but rapid declines were first recorded in late 2000 (Gilbert *et al.* 2002; Khan *et al.* 2001). Gilbert *et al.* (2002) attributed rapid population declines of White-rumped Vultures to high mortality rates, and post-mortem analyses indicated the birds

died of renal failure that was subsequently linked to diclofenac residues found in livestock carcasses (Oaks *et al.* 2004). Diclofenac poisoning was further linked to the extirpation of two White-rumped Vulture colonies over three years and to a 54% decline in a third colony in eastern Pakistan (Gilbert *et al.* 2006).

While diclofenac had been in use in India since c.1990, veterinary use of diclofenac in Pakistan did not begin until 1998. After advocacy by the Bombay Natural History Society and the Royal Society for the Protection of Birds, the governments of India, Nepal, and Pakistan withdrew manufacturing licences for veterinary diclofenac in 2006 (Pain *et al.* 2008). Recent surveys in India indicate that the ban on veterinary use of diclofenac has markedly reduced its levels in livestock carcasses to almost half of what they were prior to and immediately after the ban (Cuthbert *et al.* 2011). Despite the reduction of diclofenac in carcasses, levels still remain sufficiently high to continue causing vulture population declines, estimated at 18% per year for the White-rumped Vulture in India (Cuthbert *et al.* 2011).

In response to vulture population declines in India, we measured the largest known breeding colony of Long-billed Vultures in Sindh Province, Pakistan from 2003 to 2012. Our objectives were to estimate 1) nest occupancy, 2) nest productivity, 3) relative abundance of juvenile, sub-adult, and adult vultures, and 4) relative abundance of vulture carcasses to assess the impact of the ban on demographics.

Methods

Study area

The Long-billed Vulture breeding colony was located on a series of cliffs in the Karunjhar Hills (24°22'N, 70°43'E) in Sindh Province, Pakistan. Situated on the extreme south-eastern border of Pakistan, Karunjhar is a 19 km-long range of large and small granite hills (305 m) surrounding the city of Nagar Parkar. The area is within the greater Thar Desert where temperatures range from 50°C in summer to 12–15°C in winter. Average annual rainfall is 200 mm and occurs mainly during the monsoon season from June to September. Due to the arid climate and lack of water to irrigate crops, livestock grazing is the major land use. The habitat is largely bushy scrub with occasional trees such as *Prosopis cineraria* occurring in the landscape (Chaudhry 2004).

Sampling

The Long-billed Vulture breeding season spans consecutive calendar years because the majority of egg-laying begins in November, while fledging occurs in mid-March to mid-May (Gilbert *et al.* 2006). One observer surveyed nest sites with binoculars and spotting scope from approximately 200 m for 6–14 days during November and March to count the number of birds in each age class and the number of occupied nests (at least one adult on a nest), unoccupied nests, and fledglings. We used age-specific plumage characteristics to count juveniles (< 1 year), sub-adults (> 1 year but with lanceolate feathers and lacking full adult plumage), and adults. We counted for five minutes at each observation point during early morning and late afternoon, which are periods of maximum activity for cliff-nesting *Gyps* vultures (Xirouchakis 2007). We determined nest status by descending cliffs when necessary. We photographed nest sites, recorded spatial coordinates with a GPS, and labelled nest photographs with unique alpha-numeric codes to confirm nest locations in subsequent surveys.

We repeated surveys in March to count nests with nestlings. We assumed maximum production of one fledgling per nest because large vulture species generally produce one nestling per breeding attempt. We assumed that failed breeding attempts prior to our initial visit and initiated subsequent to our second visit would have negligible influence on our estimates of nest occupancy and productivity. We also counted vulture carcasses at nest sites and along cliff bottoms, and collected and verified reports of carcasses from local citizens to minimise our rate of false absences.

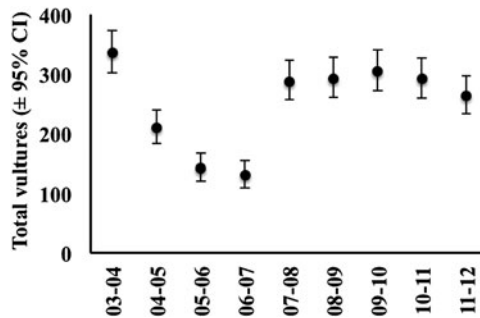


Figure 1. Relative abundance of Long-billed Vultures *Gyps indicus* at a breeding colony in the Karunjhar Hills, Sindh Province, Pakistan, 2003–2012.

We acknowledge potential biases in estimating abundance by counting vultures at nesting cliffs, including 1) non-breeding birds were undercounted, 2) pairs could have been double-counted if they changed nest locations within breeding seasons, and 3) we could not account for emigration and immigration (Margalida *et al.* 2011). To minimise these potential biases, we standardised our methods and conducted sampling with the same observer throughout the 8-year study.

Data analysis

We used R v2.14.1 (R Development Core Team 2012) to model nest occupancy, nest productivity, and relative abundance of live and dead vultures for the years and periods (i.e. years pooled) before and after the 2006 diclofenac ban. We used GLMs with binomial distributions and logit link functions to model nest occupancy because the binomial distribution is appropriate for binary data containing 1s (occupied) and 0s (unoccupied) (Crawley 2005). Long-billed Vultures produce a maximum of one nestling per nesting attempt so we also used GLMs with binomial distributions and logit link functions to model nest productivity, here defined as the probability of nests containing a nestling. We used GLMs with Poisson distributions and log link functions to model relative abundance of live and dead vultures. We fitted two models for each population parameter; we specified “period” (pre-ban period 2003–2006, and post-ban period 2007–2012) as a categorical predictor/independent variable in the first set of models so we could estimate parameter effect size and predictions for years pooled in periods before and after the diclofenac ban. We then fitted a second set of models for each population parameter in which we specified “year” as categorical variable so we estimate year-specific predictions. We report model parameter estimates/regression coefficients (β s) and predictions with asymmetric 95% confidence intervals (95% CIs). We calculated CIs by multiplying parameter estimate standard errors by 1.96 on the logit (for binomial models) and log (for Poisson models) scales and then back-transforming to the scale of prediction for response variables. We considered β s strongly influential on response variables if 95% CIs did not overlap zero, and predictions different from one another if 95% CIs did not overlap (Crawley 2005, Schielzeth 2010).

Results

Relative abundance of Long-billed Vultures declined by an estimated 61% between the 2003/2004 breeding season (335, 95% CI = 301–373) and 2006/2007 breeding season (130, 95% CI = 109–154) ($\beta = -0.95$, 95% CI = -1.15 to -0.74), then increased 55% by 2007/2008 (287, 95% CI = 256–322), and largely did not vary since (Fig. 1). Abundance declined between 2003/2004 and 2006/2007 for adults (2003/2004: 215, 95% CI = 188–246, 2006/2007: 95, 95% CI = 78–116),

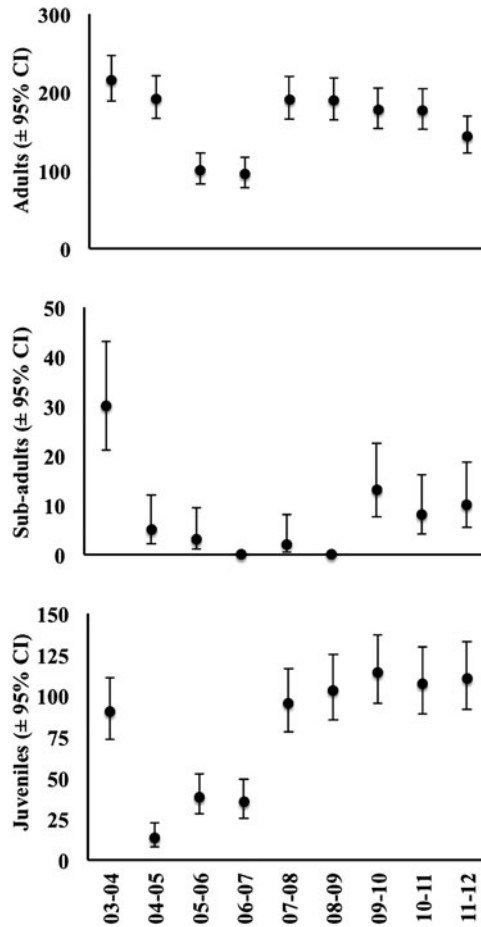


Figure 2. Relative abundance of three age classes of Long-billed Vulture *Gyps indicus* at a breeding colony in the Karunjhar Hills, Sindh Province, Pakistan, 2003–2012.

sub-adults (2003/2004: 30, 95% CI = 21–43, 2006/2007: 0.0), and juveniles (2003/2004: 90, 95% CI = 73–111, 2006/2007: 35, 95% CI = 25–49) (Fig. 2). Abundance increased from 2006/2007 to 2007/2008 for adults (2007/2008: 190, 95% CI = 165–219) and juveniles (2007/2008: 95, 95% CI = 78–116), but did not increase for sub-adults until 2009/2010 (13, 95% CI = 8–22) (Fig. 2). Between December 2003 and March 2011 we observed 16 dead vultures, of which 10 were adults and 6 were nestlings. Relative abundance of dead vultures declined from 7.0 (95% CI = 3.3–14.7) in the 2003/2004 breeding season to 0.0 in the 2008/2009 breeding season and beyond, but sample size and precision of predictions was low (Fig. 3).

Probability of nest occupancy declined from 0.90 (95% CI = 0.86–0.92) during the 2003/2004 breeding season to 0.21 (95% CI = 0.18–0.25) during the 2004/2005 breeding season, but then increased to 0.51 (95% CI = 0.43–0.58) during the 2006/2007 breeding season and did not vary thereafter (Fig. 4). Probability of nests containing a nestling declined from 0.56 (95% CI = 0.51–0.61) in 2003/2004 to 0.03 (95% CI = 0.01–0.05) in 2005, but then increased to 0.50 (95% CI = 0.43–0.57) by 2008 (Fig. 4). We did not obtain nestling data for 2006 and 2007.

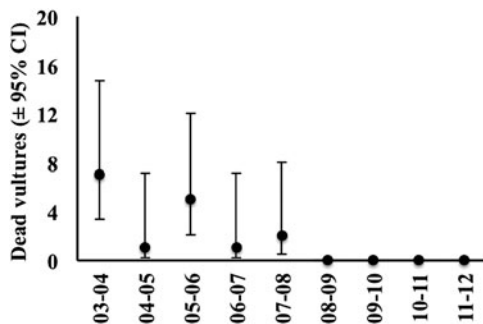


Figure 3. Relative abundance of dead Long-billed Vultures *Gyps indicus* at a breeding colony in the Karunjhar Hills, Sindh Province, Pakistan, 2003–2012.

Discussion

Given that we did not start measuring this population until 2003 and diclofenac had been in widespread use in Pakistan since 1998, it is likely that our 2003 estimates of population parameters are lower than in years prior to initiation of diclofenac use, such that we began monitoring during the population’s decline. Our data and models indicate that Long-billed Vulture abundance and nest occupancy and productivity were declining rapidly prior to the ban of veterinary diclofenac, and then increased and stabilised thereafter. However, while vulture abundance appeared to increase

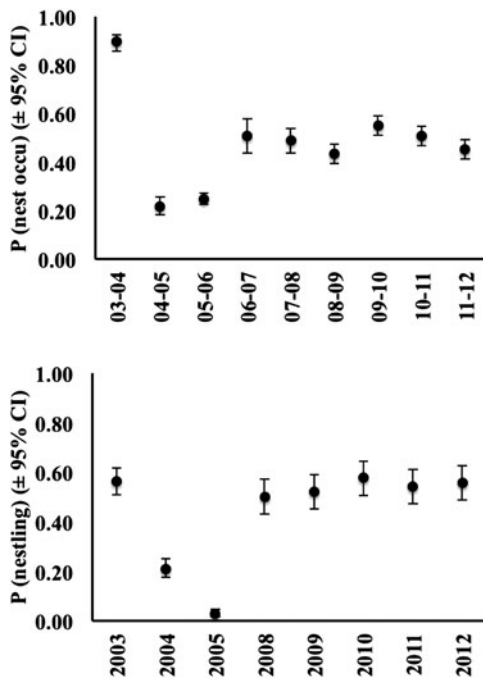


Figure 4. Probability of nest occupancy (P(nest occu)) and nestling occurrence (P(nestling)) for a Long-billed Vulture *Gyps indicus* breeding colony in the Karunjhar Hills, Sindh Province, Pakistan, 2003–2012.

and attain the pre-ban levels we observed in 2003/2004, nest occupancy (breeding effort) did not. Chhangani (2004) estimated ~90% nest occupancy for an apparently healthy population in north-west India, so our post-ban maximum occupancy estimate of 0.55 in 2009/2010 is relatively low. Numerous plausible and non-exclusive processes could explain why the breeding population attained its 2003 size following the diclofenac ban but not its nest occupancy and productivity. Perhaps first and foremost, the population's age structure changed over the 8-year study period, such that the ratio of breeding adults to sub-adults/juveniles was 1.8 in 2003 and 1.2 in 2012. Thus, lower nest occupancy would be expected from a population with a higher proportion of sub-adults and juveniles. A potential mechanism responsible for the shift in the population's age structure could be that breeding adults out-compete sub-adults and juveniles for what is the most readily available and therefore perceived to be highest quality food (i.e. livestock carcasses), but, in reality, was highly toxic. Thus, if adults consumed toxic livestock carcasses at higher rates while sub-adults and juveniles fed relatively less on livestock carcasses and more on wild animal carcasses, then mortality could have been exceptionally high for breeding adults, potentially producing the age structure shift and consequent lag period in recovery rates for breeding parameters (i.e. nest occupancy and productivity). Furthermore, local livestock producers may have changed their disposal methods for livestock carcasses following the vulture population decline, such that they buried or burned carcasses more frequently because of the lack of vultures. If locals then continued to bury or burn carcasses during growth of the vulture population, the habitat's carrying capacity would be diminished because of relatively less food availability. Despite relatively lower levels of post-ban nest occupancy compared to our 2003/2004 estimates and those of Chhangani (2004), post-ban increases in abundance, and nesting occupancy and productivity, and decreased abundance of dead vultures indicate that this population of Long-billed Vultures is experiencing population growth, documenting for the first time the effectiveness of implementing a diclofenac ban as a conservation strategy.

Although rapid population declines of White-rumped Vultures have been documented in Pakistan (Gilbert *et al.* 2002, 2004, 2006, Arshad *et al.* 2009), there is little evidence for similar declines of Long-billed Vulture populations in Pakistan, despite catastrophic declines of this species throughout neighbouring India (Prakash *et al.* 2003, 2007). There may be two plausible explanations for this. The first is that because of their large number, proximity to livestock areas in central Pakistan and dominance at livestock carcasses, White-rumped Vultures were more vulnerable to the lethal effects of diclofenac-contaminated carcasses than Long-billed Vultures that occurred in remote and economically poor areas of Pakistan. Secondly, although diclofenac has been found to cause mortality in all species of *Gyps* vultures, there may be dose-level toxicity differences between the two species associated with levels of diclofenac consumed. These need to be further investigated. In Rajasthan Province of northwest India, which is contiguous with Sindh Province, surveys of a resident population of Long-billed Vultures indicated that it remained relatively stable during 1995–2001 (Chhangani 2004).

Mortalities in our study were caused by visceral gout caused by diclofenac residues in livestock carcasses (Arshad *et al.* 2009), which was a primary food source for our study population. Interviews with livestock and veterinary officers in Nagar Parkar indicated that diclofenac was commonly used to treat livestock in the area (Chaudhry 2004, 2009). However, Arshad *et al.* (2009) speculated that Long-billed Vultures may have lower exposure to diclofenac residues due to the relative scarcity of livestock in this desert region as well as the remoteness and poverty levels of locals who may not be able to afford veterinary drugs. Though the lower rates of decline in this population are presumably due to lower consumption of contaminated carcasses, the exact mechanism(s) by which this is occurring have yet to be determined. Additional research should track movements of Long-billed Vultures to identify foraging locations and estimate diet composition, feeding rates, and concentration levels of diclofenac in livestock carcasses, ultimately providing data to estimate adult mortality and identify its causes. Our mortality data should be interpreted with caution as we found relatively few dead vultures and given their large home range size, it is possible that mortality rates could have been higher than our results indicate.

Conclusions

While Long-billed Vulture populations in Pakistan have declined, the extent of decline has been less than that of Long-billed Vultures in India and White-rumped Vultures throughout South Asia (Gilbert 2002, 2004, 2006, Arshad *et al.* 2009, Prakash 2003, 2007). The 2006 ban on veterinary diclofenac appears to have caused an increase in population size and growth, which is the first time this has been documented in *Gyps* vultures since the onset of the Asian vulture crisis over a decade ago. We are observing similar increases in nest occupancy for White-rumped Vultures in Nepal and Long-billed Vultures in central India, but we need more data to confirm the trends with higher certainty. This population of Long-billed Vultures in Pakistan may grow to the pre-diclofenac size if adult mortality remains low, nesting continues to generate population recruits, and food availability is sufficient.

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M. JAMSHED I. CHAUDHRY^{1,2}, RIFFAT N. MALIK²

¹WWF-Pakistan, Ferozepur Road, PO Box 5180, Lahore, 54600, Pakistan.

²Environmental Biology Laboratory, Department of Plant Sciences, Quaid-i-Azam University, Islamabad 46000, Pakistan.

DARCY L. OGADA^{3,4}, MUNIR Z. VIRANI^{*3,4}, MATTHEW D. GIOVANNI³

³The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, Idaho 83709, USA.

⁴National Museums of Kenya, Ornithology Section, Box 40658, 00100 Nairobi, Kenya.

*Author for correspondence; email: tpf@africaonline.co.ke

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