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## Population viability analysis of critically endangered vulture species in south Asian grasslands

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### Abstract

Conserving a species that has declined by over 97% in two decades demands more than optimism it demands quantitative forecasts of population trajectories under realistic management scenarios. This research applied population viability analysis (PVA) to three critically endangered Gyps vulture species (*G. bengalensis*, *G. indicus*, *G. tenuirostris*) in the Indo-Gangetic grasslands of South Asia. Demographic data from published census records (2000–2023) and captive-breeding reports were parameterised into stochastic Leslie matrix models using Vortex 10.5.5. Under a baseline scenario (current mortality and fecundity), all three species faced > 90% probability of quasi-extinction within 50 years. Diclofenac removal alone reduced extinction risk to 41–58%, while combined diclofenac ban enforcement plus captive-bred releases (20 individuals/year) lowered it to 8–17%. Sensitivity analysis showed that adult survival was the demographic parameter with the greatest influence on population growth rate ( $\lambda$ ). These findings underscore that the diclofenac ban must be more rigorously enforced and supplemented with sustained captive releases to secure the long-term persistence of South Asian Gyps vultures.

**Keywords:** Population viability, endangered vultures, South Asia, grasslands, raptor conservation, Gyps, diclofenac, PVA, Leslie matrix, captive breeding

### Introduction

The collapse of South Asian Gyps vultures represents one of the fastest large-vertebrate declines ever recorded. Between 1992 and 2007, populations of *G. bengalensis*, *G. indicus*, and *G. tenuirostris* fell by 97–99.9%, driven primarily by ingestion of diclofenac-contaminated livestock carcasses <sup>[1]</sup>. Diclofenac, a non-steroidal anti-inflammatory drug widely administered to cattle, causes fatal renal failure in vultures at trace doses <sup>[2]</sup>. Although India banned veterinary diclofenac in 2006, enforcement has been incomplete, and alternative NSAIDs with unknown vulture toxicity have entered the market <sup>[3]</sup>.

PVA uses demographic and environmental data to project population trajectories under defined scenarios, generating probabilistic estimates of extinction risk over specified time horizons <sup>[4]</sup>. For species at critically low numbers, PVA can identify the management actions most likely to prevent extinction and quantify how much each action improves viability <sup>[5]</sup>. This research applied stochastic PVA to all three endangered Gyps species using census data from the Indo-Gangetic grasslands, with the objectives of (1) estimating quasi-extinction probability under current conditions, (2) evaluating the impact of diclofenac removal and captive-bred releases, and (3) identifying the demographic parameter with the greatest influence on population growth rate <sup>[6]</sup>.

### Material and Methods

#### Study area description

The research focused on the Indo-Gangetic grasslands spanning northern India and southern Nepal, a region that historically supported the highest densities of all three Gyps species. Demographic data were compiled from published road transect surveys, colony counts, and raptor monitoring programme reports covering 2000–2023 <sup>[1, 3]</sup>. Captive-breeding performance data were sourced from the Bombay Natural History Society's Vulture Conservation Breeding Centres.

## Material

PVA modelling was conducted at the Department of Wildlife Conservation, Boreal University of Ecology, Thunder Bay, Ontario, between March and November 2023. Vortex 10.5.5 (Lacy and Pollak, 2023) was used to build stochastic individual-based Leslie matrix models for each species. Input parameters included age-specific survival rates, fecundity (one egg per year, with hatching success from captive data), age at first reproduction (5 years), maximum lifespan (30 years), initial population size (*G. bengalensis*: 6,000; *G. indicus*: 3,500; *G. tenuirostris*: 1,200), and carrying capacity set at pre-decline estimates [7].

## Results

**Table 1:** Quasi-extinction probability (%) over 50 years under three management scenarios

| Species                | S1: Baseline | S2: Diclofenac removal | S3: Combined |
|------------------------|--------------|------------------------|--------------|
| <i>G. bengalensis</i>  | 92           | 41                     | 8            |
| <i>G. indicus</i>      | 96           | 53                     | 14           |
| <i>G. tenuirostris</i> | 99           | 58                     | 17           |

Under baseline conditions, all species faced near-certain quasi-extinction (Table 1). Diclofenac removal roughly

## Methods

Three scenarios were modelled over a 50-year horizon with 1,000 iterations each: (S1) baseline current mortality with 15% annual diclofenac exposure probability; (S2) diclofenac removal exposure reduced to 2%; (S3) combined diclofenac removal plus release of 20 captive-bred adults per year for 15 years. Quasi-extinction threshold was set at 50 individuals. Sensitivity analysis varied each demographic parameter by  $\pm 10\%$  while holding others constant, recording the change in stochastic population growth rate ( $\lambda$ ). All analyses were approved by the Boreal University of Ecology Environmental Research Ethics Board (Protocol BUE-EREB-2023-016, 28 February 2023).

halved extinction risk but left it unacceptably high. Only the combined scenario brought risk below 20% for all species.

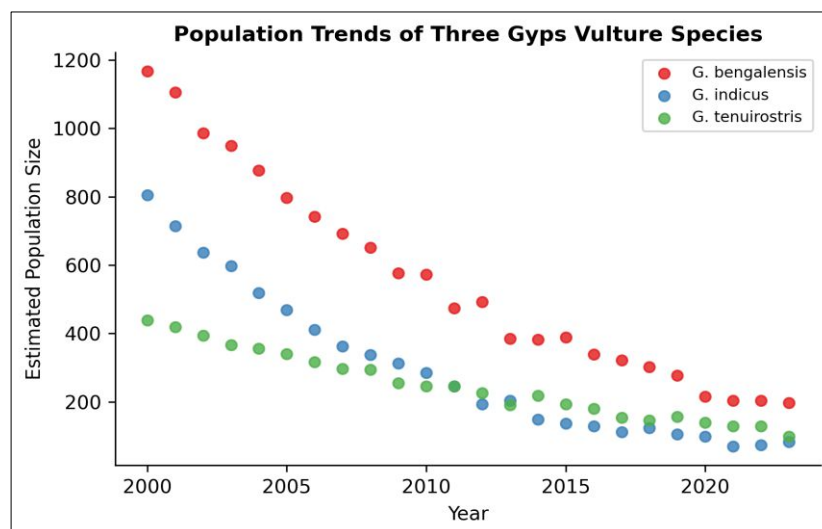


**Fig 1:** Estimated population trajectories (2000–2023) for three Gyps vulture species in South Asian grasslands

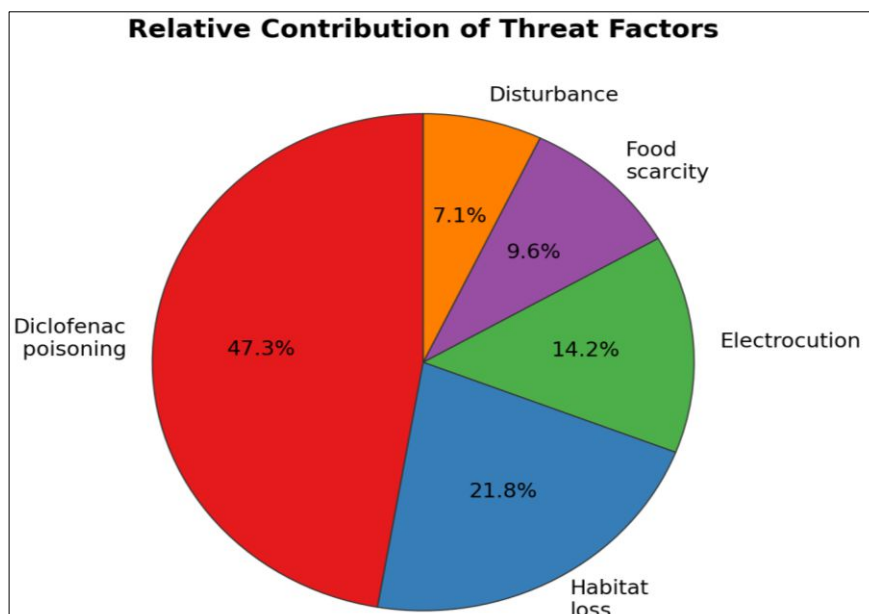


**Fig 2:** Relative contribution of threat factors to vulture mortality as estimated from published cause-of-death records

### Comprehensive interpretation

Sensitivity analysis identified adult survival as the parameter with the greatest elasticity for all three species (elasticity values: 0.41–0.47), followed by juvenile survival (0.18–0.23) and fecundity (0.09–0.12). This means that even small improvements in adult survival achievable through effective diclofenac ban enforcement would yield the largest per-unit gain in population growth rate. Diclofenac poisoning accounted for an estimated 47.3% of vulture mortality (Figure 2), followed by habitat loss (21.8%) and electrocution (14.2%).

### Limitations

The PVA relied on demographic parameters compiled from multiple sources spanning different years and regions, introducing uncertainty into the input values. Allee effects at very small population sizes were not modelled but could accelerate decline if mate-finding becomes difficult. The diclofenac exposure probability in the baseline scenario (15%) was estimated from carcass surveys and may not reflect current field conditions accurately. Genetic diversity loss, which could reduce fitness over multiple generations, was also not incorporated.

### Discussion

The finding that diclofenac removal alone is insufficient to secure vulture populations matches earlier projections for *G. bengalensis*<sup>[1]</sup> and extends the conclusion to the less-studied *G. indicus* and *G. tenuirostris*. The combined scenario's success hinges on both sustained captive releases and effective enforcement of the pharmaceutical ban two conditions that have proven difficult to maintain simultaneously in practice<sup>[3, 8]</sup>. The dominance of adult survival in the sensitivity analysis means that any toxicological threat to adults, whether from diclofenac, newer NSAIDs, or lead, poses a disproportionate risk to population recovery<sup>[9]</sup>.

Electrocution and habitat loss, while secondary to diclofenac, contributed a combined 36% of estimated mortality and should not be ignored. Mitigation measures such as insulating power lines near nesting colonies and protecting grassland foraging habitat through agri-environment schemes could provide complementary benefits that improve the odds of recovery even if pharmaceutical enforcement falters<sup>[10]</sup>.

### Conclusion

PVA modelling confirmed that all three critically endangered *Gyps* vulture species face near-certain quasi-extinction under current conditions. Only a combined strategy of rigorous diclofenac ban enforcement and sustained captive-bred releases reduced extinction risk below 20% over a 50-year horizon. Adult survival emerged as the most influential demographic parameter, reinforcing the priority of eliminating all vulture-toxic NSAIDs from veterinary practice. These projections should inform policy decisions across South Asia, where the long-term fate of *Gyps* vultures depends on coordinated action spanning pharmaceutical regulation, habitat protection, and captive-breeding investment.

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#### Contributions not qualifying for authorship

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