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Catastrophic collapse of Indian white-backed *Gyps bengalensis* and long-billed *Gyps indicus* vulture populations

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Abstract

In 2000, we conducted a survey to quantify the declines in the populations of *Gyps bengalensis* and *G. indicus* across India since 1990–1993. Directly comparable data for the two periods were obtained from over 6000 km of road transect surveys carried out in protected areas, the regions around protected areas and linking highways across the country. An additional 5000 km were covered in 2000 in previously unsurveyed areas. Further data were collected from questionnaires circulated to ornithologists, wildlife experts and forestry officials. Massive declines in the populations of both species were apparent from all parts of the country, and exceeded 92% overall. The extent of declines did not differ between protected areas and elsewhere. Apparently sick birds, with drooping necks, were observed in all regions, and dead adult and juvenile vultures were frequently observed. Food availability did not decline greatly over this period. The patterns of declines and the presence of sick and dead birds indicate epidemic disease as a possible cause. If so, this is likely to be an agent to which the population is naïve, e.g. an introduced agent or one from which the species were previously isolated. Immediate steps are needed to confirm this and to identify measures that could be taken to stem the problem.

Keywords: Griffon; Vultures; Declines; India; Population; Conservation

1. Introduction

Nine or 10 species of vulture occur in India, many of them formerly common. Of these, four or five (depending on accepted taxonomy) are griffons, *Gyps*, a group of obligate scavengers that typically breed colonially or semi-colonially. *Gyps* vultures specialise in taking the soft tissues that make up the bulk of animal carcases and therefore comprise the majority of vultures numerically. In most African vulture populations, *Gyps* comprise around 90% of all vulture sightings and in India the figure used to be over 99% (Houston, 1983). However, marked declines have been noted in the Indian populations of at least two species of *Gyps*; the white-backed vulture (*G. bengalensis*), and the long-billed vulture (*G. indicus*). The latter probably comprises two distinct species, Indian vulture *G. indicus* and slender-billed vulture *G. tenuirostris* (Rasmussen and Parry, 2000) but is treated as one species here as the two forms were not differentiated during fieldwork.

Prakash (1999) recorded >95% declines in populations of each species between 1988 and 1999 in a national park in northern India, where populations of other genera of vultures remained unchanged. Prior to the declines in India, populations of *Gyps* vultures had declined or disappeared across huge areas of Peninsular Malaysia, Thailand and Indochina where they were formerly common (Thiollay, 1998; Satheesan, 2000; BirdLife International, 2001). However, these declines appear to have taken place over decades, particularly in the early–mid twentieth century, and were accompanied by similar declines in other scavenging species such as adjutant storks (*Leptoptilus* spp.), black kites (*Milvus migrans*), Brahminy kites (*Haliastur indus*) and other

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genera of vultures, such as the red-headed (*Sarcogyps calvus*) (BirdLife International, 2001). Declines in these countries are believed to have resulted from improvements in hygiene and concomitant reduction in food availability, persecution by humans and poisoning (BirdLife International, 2001).

G. bengalensis breeds in loose colonies or singly in tall trees, often near human habitation, whereas *G. indicus* nests colonially on cliffs (BirdLife International, 2001). Both feed at carcases, often in large groups. As recently as 1985, *G. bengalensis* was regarded as possibly the commonest large raptor in the world (Houston, 1985), with nest densities being recorded at 12/km^2 at Keoladeo National Park (Prakash, 1989) and nearly 3/km^2 in the city of Delhi (Galushin, 1971), where flocks of several thousand birds were present at carcass dumps. During the 1970s and 1980s, *G. indicus* was less common than *G. bengalensis* and more patchily distributed (Grubh, 1988). Both *G. bengalensis* and *G. indicus* were found throughout the subcontinent except in southernmost areas and Sri Lanka, and neither were considered to merit any conservation measures or to face any particular threats (Grubh, 1983; Grubh et al., 1990). Indeed numbers of *G. bengalensis* were considered unnaturally high because of the abundant carcases provided for their disposal around human habitation (Ali and Grubh, 1980; Grubh et al., 1990). Both species are now classified as "Critically Endangered", placing them among the world's bird species most threatened with global extinction (BirdLife International, 2000, 2001).

In this paper, we quantify the population declines of *Gyps* vultures in India, and determine whether there have been spatial patterns in the decline. We look for evidence of regional effects and assess whether declines have been lower in protected areas than outside, to try to identify possible causes of the declines. We also assess the hypothesis that declines have been caused by reductions in food availability.

2. Methods

2.1. Population assessments

Data for quantifying the decline in vulture populations were obtained from a number of sources.

(1) Detailed observations of vultures were made in Keoladeo National Park (Bharatpur) in the late 1980s and the mid-late 1990s. It was these observations that first detected evidence of decline (Prakash, 1999).

(2) We conducted repeat surveys of vultures across the country. Between 1991 and 1993 nationwide raptor surveys were conducted by the Bombay Natural History Society, supported by the US Fish and Wildlife Service (Samant et al., 1995). In these surveys, 6323 km of road transect surveys (64 transects ranging from 8 to 397 km in length) were carried out to assess the populations of all raptor species in the north, west and east of India. In most areas, transects were carried out between March and June. In a few areas (Ranthambore, Sariska and Keoladeo National Parks and surrounding areas in the north, and Desert and Little Rann National Parks and surrounding areas in the west) surveys were carried out in December and January. Numbers of birds recorded are likely to be higher between March and June (post-breeding) than in December and January (e.g. Prakash, 1999).

In the present study, these 6323 km of transect counts were repeated between April and June 2000, following the same routes as previous counts to allow direct comparison. One additional 32 km transect, for which previous data were available, was conducted for *G. bengalensis*. A further 5041 km of transects were included in our 2000 counts in regions for which there were no previous data. The same field staff and researchers were used for approximately two-thirds of the 1991–1993 and 2000 counts. In 2000, only *Gyps* vultures were counted along road transects, although Egyptian vulture (*Neophron percnopterus*) and *S. calvus* were counted in 13 national parks for which previous (1991–1993) counts were available.

In the 1990–1993 counts, both *Gyps* species were so common that only groups of five birds or more were counted, whereas in 2000 each individual bird was counted. The population declines apparent from direct comparisons of the two data sets are therefore likely to be underestimates. Declines are likely to be further underestimated for areas counted between December and January during the earlier transects. Road transects followed the methods of Fuller and Mosher (1981). Transects were driven at 10–20 km/h in protected and surrounding areas, and 50 km/h on highways, and birds recorded sitting or soaring within 500 m of the road. Road transects are a common method for counting conspicuous raptors (e.g. Hubbard, 1983; Viñuela, 1997). For this study, the North region comprises the States of Haryana, Punjab, Himachal Pradesh, Uttaranchal, Jammu and Kashmir, Uttar Pradesh and parts of eastern Rajasthan. The West region comprises the States of Gujarat, most of Rajasthan and west Maharashtra. The East region comprises the States of West Bengal, and Orissa. The Central region comprises the States of Madhya Pradesh and the rest of Maharastra.

During the road transects, vultures were counted at any carcases that were seen. Several carcass dumps were also revisited to assess vulture populations in these former hotspots. Any flocks of perched vultures found were scanned at 10-min intervals for at least half an hour to assess the proportion of birds exhibiting "neck-drooping" symptoms. During some transects (depending upon the expertise of surveyors), adults were distinguished from first year birds using plumage details.

(3) A third source of data was returns from over 5000 questionnaires sent to ornithologists, other wildlife experts and forestry officials across the country. These asked respondents to classify *Gyps* spp. vulture population trends between 1990 and 2000 in their area into one of five classes (''Increase'', ''No change'', ''Decline'', ''Severe decline'', ''Complete disappearance''). Respondents were also asked to provide details of the methods of carcass disposal most frequently used in their districts and to assess changes in the availability of carcases.

2.2. Statistical analyses

Population changes for each species and their confidence limits were estimated from the transect data using Generalised Linear Models (GLMs). The number of birds recorded in each transect during the second (2000) count was modelled using Poisson errors and a log link function. The natural logarithm of the number of birds (+ 1) recorded during the first count (1990–1993) was declared an offset, so the back-transformed model estimate was an estimate of the second count as a proportion of the first, allowing a percentage decline to be calculated. Transects were of greatly different lengths, so the counts of birds were significantly overdispersed. This was corrected by rescaling models to a value of Pearson's χ^2 divided by the residual degrees of freedom (Crawley, 1993). Factorial variables relating to geographical region and the type of transect (protected area, around protected area and between protected areas) were also fitted to assess differences in population change between either. The change in residual deviance brought about by adding either was compared with the χ^2 distribution to assess its significance. Sample sizes in analyses differed between within- and between-year comparisons as 5041 km of additional transects were covered in 2000.

3. Results

Although already reported (Samant et al., 1995; Prakash, 1999), we summarise and update these earlier studies here for comparative purposes with the present survey, and for the sake of completeness.

3.1. Counts and observations at Keoladeo National Park (KNP—Prakash, 1999 and subsequent unpublished observations)

Populations of *G. bengalensis* nesting in KNP fell hugely between the late 1980s and 2000, when the species disappeared as a breeding bird (Table 1). A decline of 57.5% between 1988 and 1996 suggests that the decline had already started by 1996, but the decline of 83.3% between 1996 and 1997 reflects the single largest fall. Nesting success in 1985–1986 was recorded at 82% ($n = 244$) but none of the 45 nests located in 1997–1999 produced young. Nesting attempts failed through failure to lay eggs, failure of eggs to hatch or death of young in the nest. *G. indicus* has never bred in KNP, being a cliff nester. However, counts of birds feeding in the park fell from a maximum count of 812 in 1985–1986 to a maximum count of 25 in 1998–1999, since when the species has become a rare visitor. Food availability and nesting habitat (for *G. bengalensis*) were assessed at KNP and had not changed over the period of decline (Prakash, 1999).

Table 1
Number of active nests of *Gyps bengalensis* at Keoladeo National Park, northern India (Prakash, 1999, and author's subsequent data)

Year	Count
1985/1986	244
1987/1988	353
1996/1997	150
1997/1998	25
1998/1999	20
1999/2000	0
2000/2001	0

3.2. Results of road transects

The total number of *G. bengalensis* recorded along the 6355 km of road transects undertaken both in 1991–1993 and 2000 fell from 20,974 (3.3 birds/km) in the first survey to 883 (0.14 birds/km) during the second. GLMs estimated a decline of 95.7% (95% CLs 93.2–97.3). Declines did not differ between protected and unprotected areas ($\chi^2 = 5.6$, df = 2, $P > 0.05$), but differed significantly between regions ($\chi^2 = 7.95$, df = 2, $P < 0.02$), estimated declines for North, West and East regions being 98.1, 91.0 and 96.3% respectively. Similar totals for *G. indicus,* along 6323 km road transects were 6546 (1.0 birds/km) and 517 birds (0.08 birds/km), GLMs estimating a decline of 92.2% (95% CLs 88.8–94.6). Geographic region or protection status had no significant effect on this estimate. There was no significant difference between the two species in estimated population declines ($\chi^2 = 3.15$, df = 1, $P > 0.05$). Declines were recorded in all transects in which birds were present in 1991–1993, representing a highly significant deviation from the null hypothesis of random population change (Wilcoxon paired sample tests, $P < 0.0001$ for both species). Numbers of birds and percentage declines are given in Table 2. It has recently been proposed that *G. indicus* comprises two species (*G. indicus* and *G. tenuirostris*—Rasmussen and Parry, 2000). Most of the birds recorded in west Bengal within the 'East region', will have been *G. tenuirostris*. Declines were similarly elevated in all areas (Table 2), indicating

Table 2
Numbers of *Gyps bengalensis* and *G. indicus* recorded in 1991–1993 and 2000 along transects in different areas of India

Region	Protected areas				Adjacent areas				Roads			
	km	1991–1993[a]	2000	% Decline[b]	km	1991–1993[a]	2000	% Decline	km	1991–1993[a]	2000	% Decline[b]
North (*G. bengalensis*)	1021	4315	141	97	328	138	0	100	973	5200	38	99
North (*G. indicus*)	1021	3318	346	90	328	25	0	100	973	1080	22	98
West (*G. bengalensis*)	269	1371	135	90	226	455	110	76	2540	4350	270	94
West (*G. indicus*)	237	162	15	91	226	33	15	55	2540	1375	110	92
East (*G. bengalensis*)	400	1140	116	90	273	705	53	92	325	3300	20	99
East (*G. indicus*)	400	41	0	100	273	72	3	95	325	440	6	99

Adjacent areas cover a 25 km radius of protected areas, and Roads are the highways between protected areas. See text for definitions of each region.
[a] Samant et al. (1995) and authors' data.
[b] % Declines are based on actual numbers, not GLMs.

that *G. tenuirostris* and *G. indicus* have probably declined to a similar extent.

Counts (measured as birds per km of transect) of both *Gyps* species were strongly positively correlated between the two species during the initial survey ($r_{64}=0.8$, $P<0.001$). The percentage decline in counts of both species was also significantly correlated within transects ($r_{57}=0.34$, $P<0.01$). However there was no correlation between the initial counts of birds of either species and the subsequent percentage decline (*G. bengalensis* $r_{63}=-0.1$, $P>0.4$; *G. indicus* $r_{58}=-0.17$, $P>0.2$).

Although road transects were carried out in central parts of India only in 2000, counts of birds along road transects did not differ from those recorded in the same year in North, West and East regions combined ($F_{1,83}=0.24$, $P>0.6$) suggesting that similar declines had taken place there too.

3.3. Carcass availability

Counts of vultures at carcass dumps support the findings from road transects, with *Gyps* populations having declined by over 87% since 1990/1991 (Table 3). Only a small proportion of carcasses found during road transects had attendant vultures, ranging from 3.6% in the West to 13.3% in the East (Table 4).

3.4. Population trends of other vultures

Counts of *N. percnopterus* and *S. calvus* were available for 1991–1993 and for 2000 in 13 national parks (Table 5). The results of GLMs indicated that *N. percnopterus* did not decline significantly between count periods ($P=0.44$), but *S. calvus* did ($P=0.031$).

3.5. Population structure

When first year birds and adults could be clearly identified, the age structure of vulture populations was assessed. The ratios of adults to first year birds differed markedly between West India and other regions, with a far higher adult to juvenile ratio in the West (Table 6).

3.6. Observations of "neck-drooping" at colonies

The proportion of birds showing "neck-drooping" behaviour is given in Table 7. For *G. bengalensis*, a higher proportion of birds exhibited this behaviour in the North than in other regions. The proportion of birds exhibiting this behaviour was generally higher in *G. bengalensis* than in *G. indicus* despite the fact that both species suffered similar declines.

3.7. Observations of dead birds

Although dead birds were not searched for systematically during counts, dead adult and juvenile vultures have been recorded during and since the 2000 surveys in all regions. For example, dead vultures are found throughout the season at Bayana, Rajasthan, where a colony is being constantly monitored (authors' unpublished observations); the remains of 15 dead vultures

Table 3
Counts of *Gyps* vultures at three carcass dumps in northern India, 1990–1991 and 2000

Site	*G. bengalensis*			*G. indicus*		
	1990–1991	2000	% Decline	1990–1991	2000	% Decline
Hapur	>5000	0	100	15	2	87
Gazipur	>4000	15	>99	–	0	–
Chatta	300	8	97	5	0	100

Table 4
Numbers of livestock carcasses located in various regions during the survey

Regions	Protected areas	Adjoining areas	Highways	Number of carcasses with attendant vultures (%)
West	147	40	35	8 (3.6)
North	6	3	16	2 (8.0)
East	2	3	10	2 (13.3)

Table 5
Changes in number of Egyptian vulture (*Neophron percnopterus*) and Red-headed vulture (*Sarcogyps calvus*) in 13 protected areas and their environs between 1991–1993 and 2000

National park	Egyptian vulture		Red-headed vulture	
	1991–1993[a]	2000	1991–1993[a]	2000
Desert NP	36	36	5	4
Little Rann	15	0	2	0
Similipal NP	0	0	0	0
Sanjay Gandhi NP	1	0	0	0
Buxa Tiger Reserve	0	0	0	0
Mahananda WS	0	2	0	0
Jaldapara WS	0	0	0	0
Kanha NP	1	0	2	0
Nawegaon NP	1	0	0	0
Corbett NP	9	8	13	5
Ranthambore NP	4	4	10	2
Sariska NP	0	7	4	5
Keoladeo NP	25	15	8	7
Totals	92	72	44	23
% Decline		21.7		47.7

NP = National Park, WS = Wildlife Sanctuary.
[a] Samant et al. (1995) and authors' data

Table 6
Ratio of first year to adult birds in different regions (excluding nestlings and birds of indeterminate age, i.e. juveniles not in their first year)

Region	White-backed vultures		
	Adults	First years	Ratio
North	203	31	6.5:1
West	288	11	26:1
East	100	20	5:1
Central	92	16	6:1

were found at Ranthambore in 2000 (authors' unpublished observations); 28 freshly dead vultures were collected from a range of areas by the authors in 2000 and 2001 for post-mortem examination (Cunningham et al., 2001). Other researchers monitoring colonies around the country have also reported dead vultures over the last few years (see vulture monitoring reports on www.vulturedeclines.org). These observations exclude birds that have died of an obvious cause.

Table 7
Percentage of *Gyps bengalensis* and *G. indicus* observed with 'neck-drooping' behaviour during surveys

Region	Percentage neck-drooping ('*n*' observed)	
	Gyps bengalensis	*Gyps indicus*
North	44 (177)	8 (508)
West	21 (259)	21 (66)
Central	14 (42)	10 (40)
East	8 (234)	No birds seen

3.8. Results of questionnaires

One-thousand nine-hundred and twenty completed returns were received from all parts of the country. Ninety-four percent of respondents reported a decline, a severe decline or the total disappearance of vultures from their regions between 1990 and 2000 (Table 8). Only 6% of respondents thought that vulture numbers had not changed or had increased, and these were all from two of the five regions (Central and Eastern). This was reflected in contingency analyses of the data matrix (Table 8).

Although there were regional differences (Table 9), nearly 80% of respondents indicated that the dumping of carcasses in the open remains the predominant form of disposal. There was an indication that carcass availability may have decreased between 1990 and 2000 (Table 10) but over 60% of all respondents indicated that carcases remained fairly or very common in their areas in 2000.

4. Discussion

4.1. Evidence of declines

The results of this synthesis demonstrate that there has been a catastrophic decline in numbers of *G. indicus* and *G. bengalensis* throughout India since the early 1990s. Although *S. calvus* had also undergone a significant population reduction, the declines in *Gyps* species are far more severe (> 92%). The speed and severity of the declines of *Gyps* spp. exceeds anything previously recorded in common and widespread birds of prey.

The large disparity in adult to first year ratios between different regions (Table 6) suggests particularly low rates of reproduction and/or high mortality of young birds in the West, raising the possibility that declines may have started in this region. However, *G. bengalensis* declined significantly more in the North (98.1% decline)

Table 8
Number (with % in parentheses) of questionnaire respondents classifying vulture population trends between 1990 and 2000 into one of five categories, broken down by region

Zone	Increase	No change	Decline	Large decline	Disappeared completely
West	0 (0)	0 (0)	87 (38)	106 (46)	37 (16)
North	0 (0)	0 (0)	212 (32)	224 (34)	224 (34)
East	11 (3)	22 (6)	83 (23)	115 (32)	130 (36)
Central	12 (2)	70 (12)	209 (36)	197 (34)	93 (16)
South	0 (0)	0 (0)	40 (44)	30 (33)	20 (23)
Total	23 (1.2)	92 (4.8)	631 (32.9)	672 (35.0)	504 (26.2)

There was a significant difference between regions in the distribution of different responses ($\chi^2 = 226.3$, df = 16, $P < 0.0001$)

Table 9
Number (with % in parentheses) of questionnaire respondents classifying carcass disposal methods into one of five categories, broken down by region

Region	Thrown out	Skinned and thrown out	Collected for disposal	Sent to processing units	Buried
West	99 (43)	124 (54)	7 (3)	0 (0)	0 (0)
North	198 (30)	284 (43)	125 (19)	13 (2)	40 (6)
East	198 (55)	54 (15)	36 (10)	36 (10)	36 (10)
Central	267 (46)	232 (40)	0 (0)	35 (6)	46 (8)
South	24 (27)	50 (55)	0 (0)	16 (18)	0 (0)
Total	786 (40.9)	744 (38.8)	168 (8.8)	100 (5.2)	122 (6.4)

There was a significant difference between regions in the distribution of different responses ($\chi^2 = 366.6$, df = 16, $P < 0.0001$).

than the West (91% decline). In general the data tend to suggest that the problem may be more severe in the North than elsewhere, as the declines were greatest, a higher proportion of *G. bengalensis* had neck droop in the North (44%), and all questionnaire respondents reported that vultures had declined since 1990, 68% of these reporting a large decline or disappearance in the North (Table 8). However, apart from *G. bengalensis* in the North, data from counts and questionnaires did not show any consistent regional patterns.

'Neck-drooping' has been reported to be a normal behaviour in Eurasian griffons *Gyps fulvus* under hot conditions in Spain (e.g. Camiña, 2001), although vulture researchers from Israel have reported that neck-drooping is almost universally a sign of a sick or weak bird (Bahat, O., cited in Katzner and Parry-Jones, 2001). This behaviour had never been observed in India by the authors before the period of decline, either because it was absent or infrequent. 'Neck-drooping' was first reported in Keoladeo National Park, where birds would exhibit this behaviour for protracted periods over several weeks before collapsing and falling out of trees, at the point of or just prior to death (Prakash, 1999). Protracted 'neck-drooping' appears to be a sign that birds are weak or clinically sick, possibly carried out to conserve energy. It is a very important behaviour to monitor, as it is the only obvious behavioural indication that birds are ill, and even where this is reported in healthy birds under hot conditions, it is likely that it will be recorded more frequently in populations with a higher proportion of sick or weak birds. As with many non-specific signs of sickness, this may be exacerbated by environmental conditions, such as excessive temperature, and in future surveys it is important that temperature and time of day are recorded. For example, Virani et al. (2001) reported a correlation between neck drooping and ambient temperature in a population of white-backed vultures in Pakistan, where large numbers of vultures are also reported to be dying.

The extent and rapidity of declines across India, along with the evidence that birds appear to be weakened and/or clinically ill, mirrors the declines documented by intensive monitoring at Keoladeo National Park (KNP—Prakash, 1999). Prakash (1999) evaluated hypotheses for the declines at KNP, including food availability, persecution, chemical contamination and disease, and concluded that disease and chemical contamination were the most likely causes.

Table 10
Changes in the abundance of carcases, 1990–2000, all regions combined, as assessed from results of questionnaires

	None	Rare	Fairly common	Very common
1990	4.5	20.0	39.0	36.5
2000	4.6	33.7	37.6	24.0

4.2. Causes

A decline in food availability does not appear to be a tenable explanation for the nationwide *Gyps* vulture declines. Livestock carcasses were found in all study areas, very few with attendant vultures (Table 4). Respondents to the questionnaire survey reported that a higher proportion of carcasses were disposed of in the open, thus available to vultures, in the West (97%) than other regions (Table 9), whilst a higher proportion of respondents (100%) reported vulture declines in the West and North regions than elsewhere (Table 8). However, about 10–15% of questionnaire respondents suggested that carcasses were less common in 2000 than in 1990. It is possible that, in the absence of disease, chemical contamination or any additional factor, populations of vultures and/or other scavengers would have been gradually declining in India because of some reduction in food supply and/or other factors. However, our results indicate that food reduction alone cannot explain the population crash seen in *Gyps*. spp in India. Although few data are available, the less severe decline of *S. calvus* suggests that this species may be affected by factors other than that/those affecting *Gyps* spp. There were no observations of unusually high mortality of non-*Gyps* species.

The rapidity of declines, i.e. over 90% in less than 10 years, is unprecedented in other raptors, and far more rapid than that of *Gyps* species and other scavengers elsewhere in south-east Asia, where declines were attributed to reduction in food availability, persecution and poisoning (BirdLife International, 2001). Declines were independent of protection status or geographical location of survey area, suggesting that persecution is an unlikely cause. Similarly, were contamination from industrial or agricultural chemicals responsible, regional differences would be highly likely.

Whilst pesticide use in India increased massively in the 1980s, official statistics indicate an overall decline in national pesticide consumption of over 40% between 1990 and 1999 (Directorate of Economics and Statistics, http://agricoop.nic.in/statistics/consum1.htm). Toxicological analyses of tissues from *G. bengalensis* from Pakistan, to which the problem appears to have spread and where clinical signs of sickness are similar, have found no biologically significant concentrations of pesticides or metals, despite broad-spectrum analyses (Oaks et al., 2001). Similarly, analyses of tissues from a small number of affected vultures from India conducted by two separate laboratories found no significant levels of pesticide or other chemical contamination (Rahmani and Prakash, 2000; unpublished data). Whilst some form of chemical contamination cannot be ruled out, there is currently no evidence to support such an hypothesis.

Finally, infectious disease has been a suggested cause. The rapidity and pattern of declines is consistent with an infectious disease hypothesis. It seems intuitive that infectious disease could spread rapidly in species that travel large distances, feed, breed and roost communally, and occur at high densities, as did *Gyps* vultures in India. Infectious diseases, especially viral, can exhibit genus specificity, and the clinical signs of sickness would be consistent with infectious disease (or chemical contamination). Evidence supporting an infectious disease hypothesis comes from post-mortem and histopathological studies of 28 carcasses of *G. bengalensis* and *G. indicus* collected from across India (Cunningham et al., 2001). At post-mortem examination, many birds showed evidence of visceral or renal gout, and similar findings have been reported from dead vultures in Pakistan (Oaks et al., 2001). This, and the presence of similar clinical signs of sickness, such as neck-drooping, make it highly probable that the same factor is affecting *Gyps* species irrespective of location.

We consider that the pattern of declines, absence of evidence for chemical contamination, and the presence of clinical signs and abnormally high mortality, suggest that infectious disease is currently the most tenable hypothesis for the declines. The pathological investigations conducted so far on vultures from two countries support this hypothesis. Although infectious disease does not appear to be a major cause of mortality in populations of *Gyps* vultures elsewhere in the world (e.g. Benson, 2000), its diagnosis in wild bird populations is rarely attempted, and the importance of disease as a population regulator remains poorly understood and probably greatly underestimated (Daszak et al., 2000; Friend et al., 2001). Other possibilities, however, cannot yet be ruled out as the cause of the declines of *Gyps* spp. vultures in India.

4.3. Conservation implications

4.3.1. For Gyps species

Declines of the extent and rapidity seen in *G. bengalensis* and *G. indicus* are unprecedented, and have already resulted in local extinctions. Vulture colonies are being monitored across India, but there is currently no indication that the declines have slowed or stopped (authors' unpublished observations). A repeat nationwide survey, underway in 2002, should provide further information. If the cause of declines is not identified soon, and remedial action taken, then it is possible that the affected species will become extinct.

If, as seems likely, the declines are caused by infectious disease, this may spread outside Asia. There is concern that *Gyps* spp. vultures in Pakistan and Nepal may already be suffering a similar fate to those in India, with birds in these countries exhibiting similar "neck drooping" behaviour and abnormally high mortality rates (Rahmani and Prakash, 2000; Oaks et al., 2001; Virani et al., 2001). *Gyps* spp. have a contiguous distribution

through much of the old world, and can travel long distances (e.g. Susic, 2000). Even where there are obvious gaps in distribution, mixing of *Gyps* species occurs (e.g. a Eurasian griffon was recorded feeding with Rüppell's griffons (*G. rueppellii*) in Kenya in 2000—Clark, 2000). Eurasian *G. fulvus* and Himalayan *G. himalayensis* griffons have small breeding and larger wintering populations in India (Ali and Ripley, 1983). Over the last few years, unusually large numbers of *G. fulvus* have been reported wintering in India, and feeding at carcass dumps previously attended primarily by the now-scarce *G. bengalensis* and *G. indicus* (e.g. 850 *G. fulvus* were observed at Jor Bir carcass dump in western Rajasthan in January 2002, unpublished authors' observation). The breeding origin of these birds is unknown, but is probably in the countries to the north and west of India, and these birds could potentially spread disease outside the Indian subcontinent.

Several *G. fulvus* wintering in India have recently been reported as exhibiting neck drooping behaviour, and an individual sick *G. himalayensis*, caught outside Corbett National Park in North India with similar signs, subsequently died (Mr. N. Ghosh, Corbett Foundation; authors' unpublished observations). Consequently, the cause of *Gyps* vulture declines in India may threaten other *Gyps* spp. throughout Asia, Europe and Africa.

4.4. For people and wildlife

The ecological and economic implications of the declines are hard to determine at present—but ecological systems will undoubtedly be affected. Vultures are the primary removers of carrion in India and Africa. In Africa, they consume as much meat as all mammalian predators combined (Houston, 1983). In the Serengeti region of Africa, *Gyps* vultures consume around 370 kg of meat/km^2 annually, most of it from carcases undiscovered by mammalian predators or scavengers (Houston, 1983). Removal of a major scavenger will affect the equilibrium between populations of other scavenging species, and/or result in an increase in putrefying carcasses.

In India, the vulture declines have led to an obvious (but unquantified) increase in the number of putrefying animal carcases in some areas. This is particularly so around human habitation, which formerly held particularly high numbers of vultures, due to the disposal of livestock carcases by dumping outdoors rather than burial or incineration (see Table 9). In some areas, vultures appear to have been replaced by packs of feral dogs as the main scavengers of carcases. For example, the feral dog population at one carcass dump increased from around 60 in 1992 to over 1200 in 2001 (authors' unpublished observation).

Both increases in putrefying carcasses, and changes in scavenger populations, have associated disease risks for wildlife, livestock and humans. Carcasses need to be removed, incinerated or buried to limit the spread of livestock-borne diseases such as anthrax. Increases in feral dogs in India may pose an increased rabies problem. India already has half of the annual 60,000 human cases of rabies reported globally by the World Health Organisation, the great majority resulting from bites by dogs (e.g. see World Health Organisation online database http://www.who.int/whosis/).

The loss of vultures has also had serious cultural and religious implications. The ancient Parsee religion hold earth, fire and water sacred and, to avoid contaminating them, dispose of their dead by placing them in 'Towers of Silence', where vultures used to rapidly strip the bones of flesh (MacKenzie, 2000). Vulture numbers are now so low that human corpses are no longer being adequately disposed of by this method. The Parsees are urgently seeking a remedy to this problem (Parry-Jones, 2001).

5. Conclusions

We conclude that the decline of vultures in India has serious implications for the species themselves, and potentially for other wildlife and for human health. Specific conservation or management solutions cannot be identified until the causal agent(s) have been identified. Further research is urgently required, and disease investigations are underway. We recommend that other possible causes or contributing factors be investigated in parallel, for, although current evidence points to the involvement of an infectious agent, this may not be the case or, if so, it may only be part of the story. Agencies with appropriate expertise need to work together to this end as a matter of urgency.

Monitoring of vulture colonies should continue within India, and should be initiated in all *Gyps* spp. range states across Asia, Europe and Africa, to detect any evidence of a spread of this problem. The breeding origins of the large numbers of *G. fulvus* wintering in India should be identified through satellite-tracking, to enable monitoring and future management to be targeted at the most appropriate places, should the declines spread.

If the declines have resulted from infectious disease, this is likely to be something to which the birds were naíve, such as an agent either introduced to the species range (e.g. Daszak et al., 2000), or from which the birds were ecologically isolated in some way (e.g. Warner, 1968). There may be ways of stemming the spread of the problem and of helping populations undergo some degree of recovery. A captive care centre has already been developed in India to study the progress of this problem in sick birds and to investigate possible remedial measures.

If the spread of the problem cannot be stemmed, knowledge of the cause and rate of spread should enable the development of management strategies to minimise the impacts of vulture declines on wildlife and humans in other regions, such as Europe and Africa. At a minimum, identifying the cause, and its origin, should provide information to help prevent similar occurrences in future.

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