

Vultures, their population status and some ecological aspects in an Indian stronghold

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Abstract

Indian vultures have important ecological and socio-economic functions and are increasingly studied, per their ecological role and recently, their catastrophic populations' decline. However, there are few studies of vultures in central India, a vulture stronghold. The present paper examined the presence, distribution per landcover variation, roosting and nesting habits of vultures in this region. Both quantitative (total count) and qualitative (questionnaire survey) methods of research were applied. The hypotheses were that vulture presence is higher in forested areas, unaffected by agricultural development (excepting the Egyptian vulture); as well as that vultures are more likely to roost and nest in large trees and on cliffs in open landcover. Vulture species recorded in summer and winter counts were the Long-billed vulture (*Gyps indicus*, Scopoli, 1786), Egyptian vulture (*Neophron percnopterus*, Linnaeus, 1758), White-rumped vulture (*Gyps bengalensis*, Gmelin, 1788), Eurasian Griffon vulture (*Gyps fulvus*, Hablizl, 1783), Red-headed vulture (*Sarcogyps calvus*, Scopoli, 1786), Cinereous vulture (*Aegypius monachus*, Linnaeus, 1766) and Himalayan Griffon vulture (*Gyps himalayensis*, Hume, 1869). Their average total abundance was of 7,028 individuals, maximum being Long-billed vulture (3,351) and minimum being Cinereous vulture (39). Thematic maps documented distributions in different agroclimatic regions and ecozones. Orography and forest structure influenced vulture presence, but human disturbance did not. Vulture protection, food monitoring and human-induced disturbances are manageable with critical, informed and flexible policies. These findings contribute to monitoring and management planning for vulture conservation in Central India and elsewhere.

Keywords: abundance; conservation; central India; habitat; vulture species

Introduction

Vultures are important for their scavenging role and socio-cultural and religious significance in India and elsewhere (Pain *et al.*, 2003; Ogada *et al.*, 2011; Moleon *et al.*, 2014; Campbell, 2015). *Gyps* vultures, especially Indian White-backed vultures and Long-billed vultures, were common in India, Nepal and Pakistan until the 1990s (Thakur and Kataria, 2012). Numbers of these vulture species declined strongly over most of their historical range, largely due to the impact of the veterinary drug Diclofenac (Shultz *et al.*, 2004;

Prakash *et al.*, 2007; Bonal and Prakash, 2014). This drug was later replaced with the less toxic compound Meloxicam, which influenced the stabilization of vulture populations in India and Nepal (Cuthbert *et al.*, 2011; Bowden, 2012).

Northern India hosts larger populations of the nine vulture species than the Southern subtropical region (Naoroji, 2006). Resident species frequent forest, mountainous cliffs and sometimes agricultural landcover. Central India (Madhya Pradesh = MP) has a large vulture population, due to the dual tropical and subtropical climates, suitable forest cover over plateaus, mountains and valleys, large cattle and wildlife populations. Vulture nests and roosts are on cliffs and in trees, the latter usually in open forests, sometimes near cultivated landcover. For example, the Griffon vulture is a colonial cliff nester (Campbell, 2015). Egyptian vultures are cliff nesters in heterogeneous landscapes (Mateo-Tomas and Olea, 2009). Cinereous vultures occur in open habitats, especially grassland, semi-desert, scrub and open forest in hilly and mountainous areas (Campbell, 2015).

The case study area (MP) is covered by subtropical wet and dry, tropical wet and dry, as well as semi-arid climates. It is divided into six ecozones, using geographical indicators: Bundelkhand, Central, Chambal, Malwa, Satpura and Vindhyan Ecozones (AR MPSBB, 2007-08). It also comprises 11 agro-climatic regions, based on soil, climatic and cropping variations (Bundelkhand, Central Narmada Valley, Chhattisgarh Plain, Gird Region, Jhabua Hills, Kymore Plateau and Satpura Hills, Malwa Plateau, Nimar Valley, Northern Hill Region of Chhattisgarh, Satpura Plateau and Vindhyan Plateau) (Sharma *et al.*, 2013).

The aim of the study was to generate reference data on Central India, which is a vulture stronghold (Jha, 2018). The data was derived by recording: (i) species richness and abundance of vultures; (ii) agro-climatic regions and ecozone distributions; (iii) correlations of past and current vulture populations; (iv) habitat frequencies of different vulture species; (v) breeding statuses of the resident vulture species; and (vi) local/seasonal movements of resident vultures.

Materials and Methods

Study site

Central India (MP, 21°6'-26°30' North and 74°00'-82°51' East) (Figure 1) is near the geographical center of India, contiguous with the former British Central Province, divided into several ecozones (Table 1). The tropical and sub-tropical climate is influenced by warm air masses from the Arabian Sea from the South and cold, high-altitude Himalayan air masses from North. The result is a mild subtropical climate, with a hot dry summer (March-June), monsoon rains (July-September) and a cool, relatively dry winter (October-February). Rainfall averages about 1,370 mm, decreasing from east (2,150 mm) to west (1,000 mm). Vegetation types are the dense tropical moist deciduous forest in the South, tropical dry deciduous forest in the middle and more open tropical thorn forests in the North, with undulating and hilly topography. The crown cover of these forests, respectively, are dominated by >70%, 40-70% and <40% density. Forests cover 28% of MP state, across varying topography, while 52 % of the state is under agricultural landcover.

Field survey

MP forest department is divided into forest circles and further into forest divisions (FDs) or district level administrative units. All the FDs were surveyed and workshops on census protocol, data collection pro forma and species identification were held. An identification booklet of vulture species in MP (Jha, 2015b) was circulated. Preliminary surveys located historical vulture distributions, whereas current roosting and nesting sites were identified and later revisited for data collection. The population estimation protocol was circulated, and two vulture counts were undertaken in winter (23/01/2016) and summer (14/05/2016). All sightings at pre-decided sites (ascertained during preliminary survey) were counted. Dates were fixed to avoid double counting from bird movements. Count times were fixed between 7:00 h - 9:00 h in winter and 6:00 h

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- 8:00 h in summer, to ensure full counts. Species, adults and juveniles were identified. Roosting, nesting and bathing sites were recorded using a GPS system.

Different nest classifications have been used in the literature (Gilbert *et al.*, 2006; van Beest *et al.*, 2008; Bhusal, 2011; Joshi *et al.*, 2015 etc.). In the current research, there were active nests (with adults and juveniles/chicks/eggs), inactive nests (occupied/ surrounded only by adults) and abandoned nests (unoccupied). This estimated the breeding, potentially breeding and non-breeding vultures. It was assumed that every active and inactive nest supported one pair of resident breeding vultures. Therefore, breeders, potential breeders and non-breeders were assessed, respectively, by using the formula of: (i) twice the active nests, (ii) twice the inactive nests, and (iii) remaining population out of total population of residents.

Coordinates were recorded using GPS and binoculars and cameras were used for bird identification and counts. Microsoft Word and Excel, ArcGIS and PRESENCE software was used for data compilation, analysis and map generation. Thematic maps depicting roosting and nesting locations and species distribution were prepared by using geographical coordinates. ArcGIS 10.3.1 was used to convert GPS readings to spatial data layers (point features providing the location). Vulture locations were overlaid on the state map. Various thematic figures were designed using the retrieval function. A questionnaire survey was conducted targeting the villagers and the forest guards for their knowledge on vulture ecology.

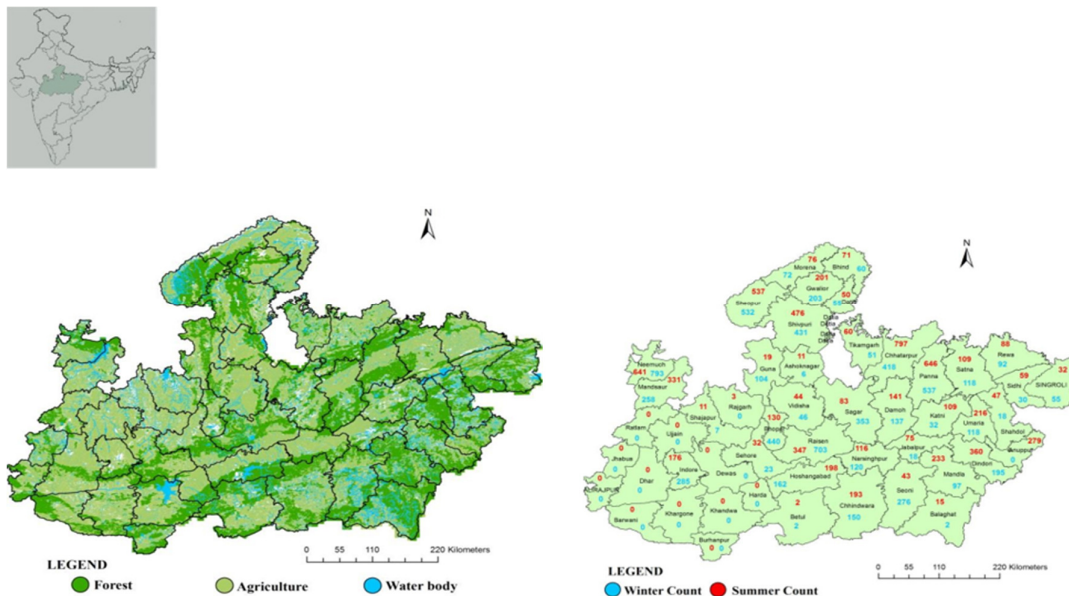


Figure 1. Location of the study area: Central India (Madhya Pradesh) with major Landcover; forest, agriculture and water bodies, on the left and numeric distribution of vultures in different districts, on the right. Inset gives relative position of the study area in India

Table 1. Climatic and physiographic characteristics of ecozones in the study area

Ecozones	Temperature (°C)	Rainfall (mm)	Elevation (m)	Forest type	River system
Bundelkhand	7.5 - 42.5	800-1,400	150-450	Dry Deciduous	Ken, Sonar, Berma, Tons
Central	5.1 - 42.5	1,200-1,400	300	Moist/Dry Deciduous	Betwa, Narmada Tributaries
Chambal	1 - 47*	800-1,000	15-300	Dry Deciduous	Chambal, Kalisindh, Parvati
Malwa	1.5-45**	800-1,200	350-450	Dry Deciduous	Chambal, Mahi, Kshipra, Betwa, Parvati
Satpura	10 - 39	1,000-1,600	300	Moist/Dry Deciduous	Tawa, Wainganga, Johila, Denwa, etc.
Vindhyan	8 - 43	1,200-1,600	400-1,000	Moist/Dry Deciduous	Sone, Kanhar Tributaries

Note: elevation does not include peak height. * and ** are representative of Gwalior and Indore.

Vulture movement and sites

Vultures movements relate to food and water sources hence movement zones were classified into water use areas and foraging areas. Qualitative methods (interview and questionnaire survey) were used to determine foraging ranges. Based on the responses, movement distance range from roost/nest to waterbody was 0.1 km to 13 km (average 1.66 km; $n = 2,277$) and from forest fringe or nest/roost to food source was 1 km to 45 km (average 7.7 km; $n = 37$). Assuming that vultures travelled the same distance in all four directions, the figures were 11 km² (water use area) and 237 km² (foraging area). However, for convenience, sub-cells and cells of equal size, 10 km² and 250 km², respectively, were fixed to make a grid framework for the surface area of Madhya Pradesh (Figure 2) using fishnet tool of Arc GIS. The sub-cells were also considered as vulture sites embodying one to many sightings of roosts or nests with vultures within the area. Presence and absence of vultures during the census was recorded as 1 and 0, respectively in the sub grids and occupancy analysis was done using “PRESENCE” software.

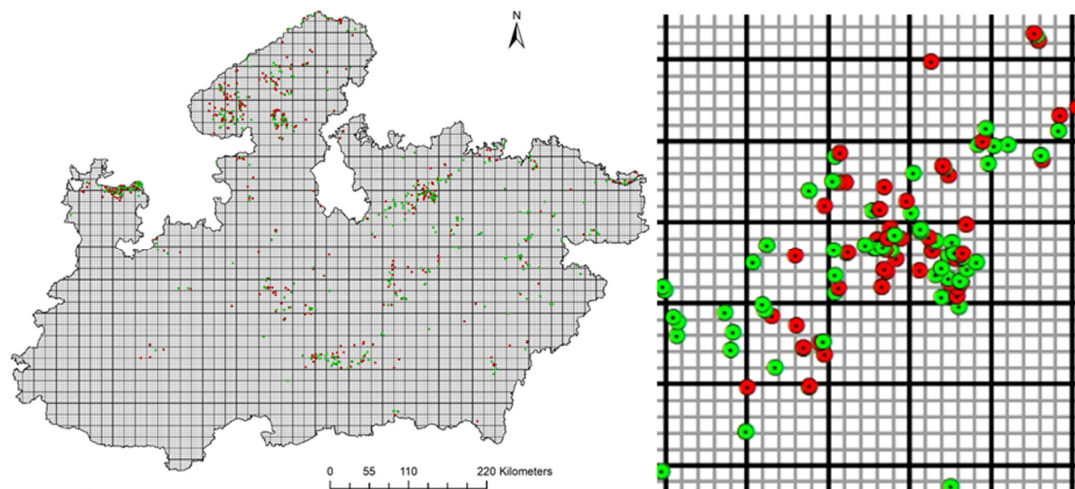


Figure 2. Small area extracted from the state on left is magnified fishnet on the right showing red and green circles are winter and summer sighting points of vultures. Black squares are grids of 250 km² and grey squares are sub-grids of 10 km². These grey and black squares are assumed shelter sites and foraging sites in the study area

Results

The questionnaire survey and quantitative work, recorded people's observations and understanding of vulture ecology, while recording sites, nests and vulture presence, as listed below.

Questions concerned vulture species type, nesting tree species, reasons for vulture decline etc. Respondents returned 2,103 completed questionnaires, out of 2,275 expected ones (92.4% return). Data analysis revealed the respondents identified vulture species with indicators. Firstly, while 20% of the respondents saw no vultures, 39%, 15%, 10%, 9%, 5% and 1% each identified Long-billed vulture (LV) *Gyps indicus*, Egyptian vulture (EV) *Neophron percnopterus*, White-rumped vulture (WV) *Gyps bengalensis*, Red-headed vulture (RV) *Sarcogyps calvus*, Cinereous vulture (CV) *Aegypus monachus*, Himalayan griffon (HG) *Gyps himalayensis* and Eurasian griffon (EG) *Gyps fulvus*, respectively. Secondly, 91% of the respondents acknowledged the local vulture population had either declined or become extinct. Thirdly, a majority (51%) blamed the use of diclofenac, 24% blamed food scarcity, 16% cited deforestation and 9% gave other reasons (aircraft collisions, natural disaster, sun radiation). Hearsay, rather than scientific information, dominated perceptions on diclofenac. Fourth, the respondents ranked vulture habitats as trees (28%), cliffs/mountains

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(25%), water bodies (13%), agricultural fields (8%), slaughter houses/dump yards (3%), old-monuments (2%) and towers (21%). Fifth, the respondents cited relevant tree species used by vultures. These were Peepal (*Ficus religiosa*) (25%), Banyan (*Ficus benghalensis*) (20%), Arjun (*Terminalia arjuna*) (14%), Semal (*Bombax ceiba*) (12%), Tamarind (*Tamarindus indica*) (7%), Haldu (*Haldina cordifolia*) (5%) and both Sheesham (*Dalbergia sisso*) and Mango (*Mangifera indica*) (1%). The remaining respondents (13%) identified other trees, including Chitwan (*Alstonia scholaris*), Keekar (*Acacia nilotica*), Saja (*Terminalia tomentosa*), Palash (*Butea monosperma*), Sagaun (*Tectona grandis*) and Eucalyptus (*Eucalyptus globulus*). Sixth, the respondents listed carcass disposal methods as outside the village boundary (79%), burial of carcasses (11%), sale to slaughter houses (6%) and railway tracks, roadsides or in the forest (4%). Seventh, respondents identified competing scavengers as dogs (44%), crows (41%) and other species (15%) (e.g. egrets, jackal, myna, hyena, foxes, kites etc.).

Vulture locations and occupancy

Vultures were absent from some expected locations (65 in winter, 55 in summer). However, they were recorded in 923 locations in 2016 in both winter and summer counts. These included 832 winter locations, 91 new summer locations and 120 abandoned winter locations. Seasonal occupancy analysis results are given in Table 2. Naïve estimate or Psi (ψ) values varied minimally in different seasons. However, they varied considerably in different land use-landcover. Probability of occupancy (ψ) was maximum in forest followed by agriculture. Probably 17.6-17.8% forest was occupied by vultures as compared to just 0.03% agriculture area. State occupancy was 0.18 to 0.19 %. Nevertheless, out of possible 30,825 shelter sites (fishnet sub-cells = 10 km²) in the state, vultures occupied only 454 in winter and 408 in summer. Among these sub-cells 230 were common, while 178 and 224 were new in summer and winter, respectively. Similarly, out of 1,409 cells, 312 partial and 1,097 full (fishnet cells, 250 km² = foraging sites) in the state, they occupied 216 in winter and 200 in summer.

Table 2. Results of occupancy analysis of vultures in Central India

Analytical parameter	Winter			Summer		
	State	Agriculture	Forest	State	Agriculture	Forest
Naïve estimate	0.1526	0.0114	0.1105	0.1437	0.0114	0.1252
Psi value (standard error)	0.1922 (0.0127)	0.0378 (0.0194)	0.1769 (0.0178)	0.1842 (0.0127)	0.0378 (0.0194)	0.1784 (0.0160)
95% confidence interval	0.1685- 0.2184	0.0136- 0.1007	0.1447- 0.2144	0.1605- 0.2105	0.0136- 0.1007	0.1492- 0.2118

Richness and abundance

Figures 1 and 3 depict the vulture count and species distribution. Landcover selection by vultures favored forest (87%), followed by agricultural landcover (13%) shown in Figure 3. Seven vulture species were reported: Cinereous Vulture (CV), Egyptian Vulture (EV), Eurasian Griffon (EG), Himalayan Griffon (HG), Long-billed Vulture (LV), Red-headed Vulture (RV) and White-rumped Vulture (WV). The average recorded was 7,028 (6,999 in winter and 7,057 in summer). In decreasing numbers, the species counts were LV (3,351), EV (1,874), WV (1,522), EG (95), RV (93), CV (53) and HG (39). Only HG was not reported during the summer (Table 3). The Slender-billed vulture and Bearded vulture were not found in any count in the study area.

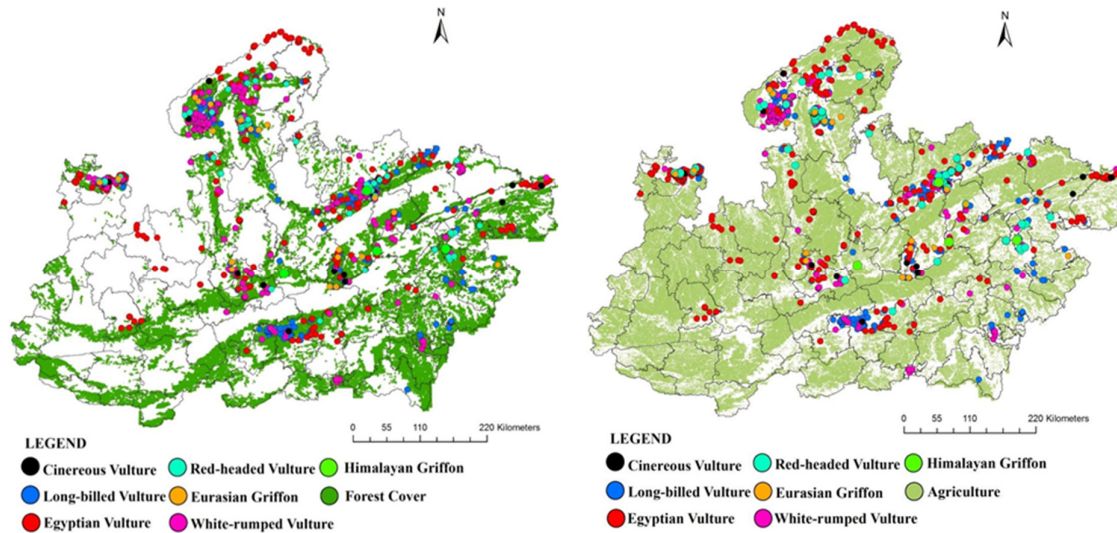


Figure 3. Spatial distribution of vulture species in the study area. Circular spots are the roosting or nesting locations of winter and summer combined. Note that almost all sites (87%) are in forested area (left), while very few (13%) in agriculture land use area (right)

Table 3. Population of different vulture species in Central India as per 2016 counts

Vulture species	Summer		Winter		Average	
	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile
Cinereous vulture	18	0	85	3	52	2
Egyptian vulture	1,082	179	1,894	595	1,488	387
Eurasian Griffon	42	2	181	6	112	4
Long-billed vulture	3,479	346	2,724	152	3,102	249
Red-headed vulture	102	7	76	0	89	4
White-rumped vulture	1,668	132	1,146	98	1,407	115
Himalayan Griffon	0	0	38	1	38	1
Total	6,391	666	6,144	855	6,288	762
	7,057		6,999		7,028	

Agroclimatic region and ecozone distribution

Figure 4 shows vulture records in agro-climatic regions and ecozones. For the agro-climatic regions, top records were 1,702 in Vindhyan plateau during winter and 1,391 in Gird region during summer. Among the ecozones, the highest population was in Chambal (1,463) in winter and in Bundelkhand (1,503) in summer. Table 3 shows the vulture counts according to species, depicting the average counts for adults and juveniles, and the counts in summer and winter. For example, out of 7,028 vultures, adults numbered 6,268 and juveniles 760 (6,144 adults and 855 juveniles in winter; 6,391 adults and 666 juveniles in summer). The commonest was LV, which recorded 3,102 adults and 249 juveniles (2,724 adults and 152 juveniles in winter; 3,479 adults and 346 juveniles in summer). The rarest was HG, which recorded 38 adults and 1 juvenile in only winter season. For the ecozones, the average adult and juvenile populations are presented in Figure 4. All the ecozones recorded vultures, in decreasing order: Chambal, Bundelkhand, Malwa, Central, Satpura and Vindhyan. However, only 9 of 11 agro-climatic regions recorded vultures (Bundelkhand, Central Narmada Valley, Chhattisgarh Plain, Gird Region, Kymore Plateau and Satpura Hills, Malwa Plateau, Northern Hill Region of Chhattisgarh, Satpura Plateau and Vindhyan Plateau); the remaining two (Jhabua Hills and Nimar Valley) did not.

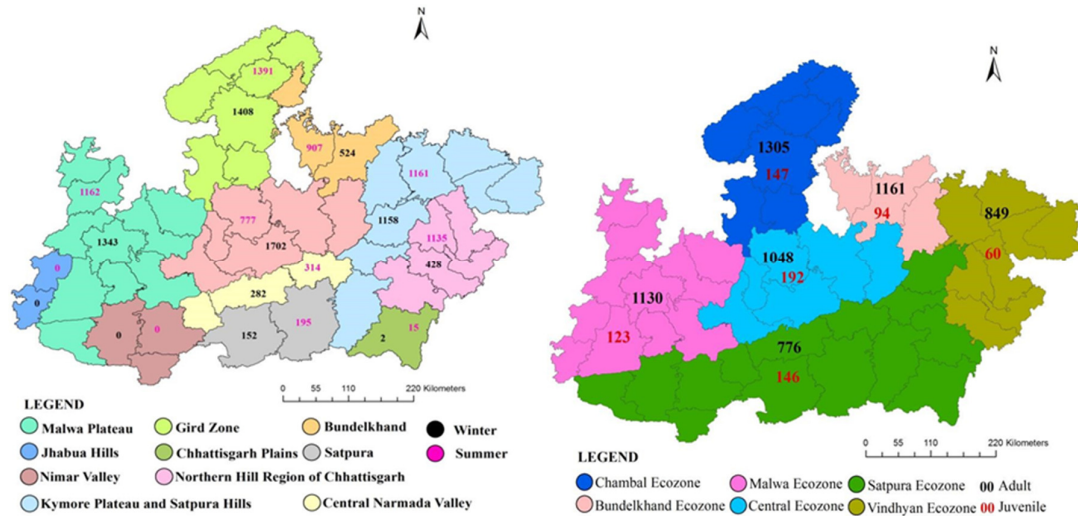


Figure 4. Winter and summer distribution of vultures population in different agro-climatic regions (left) and adults and juveniles spread in different ecozones of the study area. The Eastern side of the state has lower population (wetter areas with moist deciduous and dense forests) than the drier areas with dry deciduous and open forests

The South-Eastern part of the state (subtropical wet and dry climatic region of India) recorded fewer vultures than the Northern part (subtropical climatic region of India). The South-Western part of the state (tropical wet and dry climatic region of India) had almost no vultures, but the North-Western part of the state (semi-arid climatic region) recorded many vultures.

Vulture habitats

Vulture habitats included woodland (with the most nests), mountain cliffs and agricultural areas. Some EV were recorded in the agriculture areas, while many LV were recorded near mountain cliffs and monuments. Landcover included trees, cliffs, dams, water bodies (drains, riversides, ponds, lakes), old building and monuments, electricity poles and agriculture fields. Most trees species listed in Table 4 were tall (10 - 25 m). In terms of percentage roosting use (relative frequency) *Boswellia serrata*, *Ficus religiosa*, *Terminalia arjuna*, *Dipterocarpus trubinatus*, *Madhuca indica*, *Lannea coromandelica* were the most important trees, having composed more than 5% of total host trees ($n = 1,025$). Species nesting habits are recorded in Table 5. Percentage nesting use (relative frequency) wise (Table 4) *Ficus religiosa*, *Boswellia serrata*, *Terminalia arjuna*, *Madhuca indica*, *Tectona grandis* were the most important trees having composed more than 5% of total host trees ($n = 492$).

Breeding status

At the 923 vulture locations, several nests were recorded (1,022 in winter, 1,631 in summer). There were 459 active nests (318 in winter, 601 in summer), 641 inactive nests (544 in winter, 739 in summer) and 225 abandoned nests (160 in winter, 291 in summer). Variants were nests occupied by adults with chicks/juveniles, those with adults without chick/juveniles and unoccupied nests. The locations of these nests are presented in Figure 5. Nest proportions were lower in unprotected area or the forests without specialized management for wild animals.

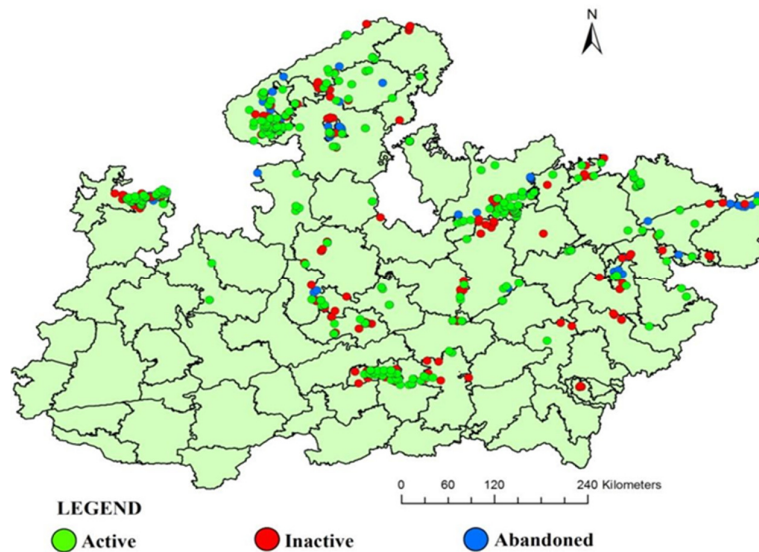
Table 4. Different tree species with their relative frequency of hosting the roost and nest of vultures

SN	Scientific name	Local name	Roost	Nest
1	<i>Acacia catechu</i>	<i>Khair</i>	0.5	0.4
2	<i>Acacia nilotica</i>	<i>Babool</i>	0.2	0.0
3	<i>Adina cordifolia</i>	<i>Haldu</i>	1.0	0.6
4	<i>Aegle marmelos</i>	<i>Bel</i>	0.6	0.2
5	<i>Albizia lebbek</i>	<i>Kala siras</i>	0.0	0.2
6	<i>Albizia procera</i>	<i>Safed Siris</i>	0.1	0.0
7	<i>Anogeisus latifolia</i>	<i>Dhawada</i>	2.3	3.3
8	<i>Anogeisus pendula</i>	<i>Kardhai</i>	0.9	1.0
9	<i>Anthocephalus kadamba</i>	<i>Kadam</i>	0.1	0.0
10	<i>Azadirachta indica</i>	<i>Neem</i>	1.4	1.0
11	<i>Bombax ceiba</i>	<i>Semal</i>	1.5	1.0
12	<i>Boswellia serrata</i>	<i>Salai</i>	13.9	11.8
13	<i>Butea monosperma</i>	<i>Palas</i>	2.8	0.0
14	<i>Casearia tomentosa</i>	<i>Chilla</i>	0.6	0.0
15	<i>Chloroxylon swietenia</i>	<i>Bhirra</i>	0.8	2.0
16	<i>Dalbergia paniculata</i>	<i>Dhobin</i>	1.4	1.8
17	<i>Diospyros melanoxylon</i>	<i>Tendu</i>	3.1	2.0
18	<i>Dipterocarpus trubinatus</i>	<i>Gurjan</i>	7.1	1.0
19	<i>Ficus benghalensis</i>	<i>Banyan</i>	1.5	2.8
20	<i>Ficus glomerata</i>	<i>Peepal</i>	0.0	0.6
21	<i>Ficus religiosa</i>	<i>Gular</i>	12.2	24.6
22	<i>Gmelina arborea</i>	<i>Khamber</i>	0.1	0.0
23	<i>Hardwickia binata</i>	<i>Anjan</i>	0.1	0.2
24	<i>Holoptelia integrifolia</i>	<i>Chirbul</i>	1.1	0.2
25	<i>Lagerstromia parviflora</i>	<i>Laidia</i>	0.2	0.0
26	<i>Lannea coromandelica</i>	<i>Gunja</i>	5.4	1.0
27	<i>Madhuca indica</i>	<i>Mahua</i>	5.8	5.9
28	<i>Mallotus philippinensis</i>	<i>Rohini</i>	0.1	0.0
29	<i>Mangifera indica</i>	<i>Mango</i>	0.8	1.8
30	<i>Miliusa tomentosa</i>	<i>Kari</i>	0.7	0.0
31	<i>Myrtagyna parviflora</i>	<i>Kaim</i>	2.5	4.5
32	<i>Pometia pinnata</i>	<i>Kasai</i>	0.2	0.0
33	<i>Prosopis juliflora</i>	<i>Prosopis</i>	0.4	0.0
34	<i>Pterocarpus marsupium</i>	<i>Bija</i>	0.1	0.0
35	<i>Schleichera oleosa</i>	<i>Kusum</i>	0.1	0.2
36	<i>Shorea robusta</i>	<i>Sal</i>	4.9	2.4
37	<i>Sterculia urens</i>	<i>Kullu</i>	1.4	0.0
38	<i>Sygygium cuminii</i>	<i>Jamun</i>	0.4	0.0
39	<i>Tamarindus indica</i>	<i>Tamarind</i>	1.1	1.2
40	<i>Tectona grandis</i>	<i>Sagaun</i>	4.2	5.9
41	<i>Terminalia arjuna</i>	<i>Arjun</i>	8.0	10.6
42	<i>Terminalia belerica</i>	<i>Baheda</i>	4.1	3.5
43	<i>Terminalia chebula</i>	<i>Harra</i>	0.1	0.0
44	<i>Terminalia tomentosa</i>	<i>Saaj</i>	4.5	7.1

45	<i>Wrightia tinctoria</i>	<i>Doodhi</i>	0.2	0.4
46	Not identified		2.0	0.6

Table 5. Resident vultures' nesting habits in central India

Vulture species	Trees	Other sites
Egyptian	Arjun, Dhawda, Kardhai, Peepal, Baheda, Banyan, Gurjan, Mahua, Aam, Neem, Gular, Saja, Sagaun	Cliffs, monuments, electric poles
Long-billed	Arjun, Baheda, Banyan, Saja, Kaim, Mahua, Aam, Neem, Peepal, Gular, Sagaun, Dhobin, Sal, Semal, Ghiriya, Tendu, Dhawda	Cliffs, monuments
Red-headed	Dhawda, Dhobin, Gurjan, Kaim, Mahua, Peepal, Sal, Sagaun, Ghiriya, Mahua and Tendu	None recorded
White-rumped	Arjun, Anjan, Dhawda, Baheda, Banyan, Bel, Peepal, Gurjan, Kaim, Kardhai, Mahua, Aam, Neem, Sal, Sagaun, Ghiriya, Tamarind and Tendu	Cliffs

**Figure 5.** Spatial distributions of different categories of vulture nests found in Central India. Active nests (please note larger clusters of green circles) are mostly concentrated in Wildlife Protected Area

Discussion

Vultures are very cautious creatures, sensitive to disturbance and reluctant to alight near a carcass if there is too much noise or disturbance (Mundy *et al.*, 1992). During diclofenac use, while not denying the death or decline in population from millions, it was possible that the vultures avoided farms as they perceived a poisoning threat. This also takes the clue from the respondents ($n=57$) as just four percent of them saw the dead bodies of vultures in their surroundings (Pers. Comm. one case of train accident killing several WV, Amita Kanaujia, a conservation biologist and another case of heat stroke to LV near forest area, Ajit Dixit, a veterinary surgeon). Further, the protected forests especially the national parks, wildlife sanctuaries and tiger reserves have sufficient ungulate population in MP and they are the diclofenac-safe habitat. Prakash *et al.* (2012) speculated that the slowdown (indirect enhancement in population) might be due to the remaining vultures confining themselves to areas where much of the birds' food comprised uncontaminated carcasses of

wild ungulates. Jha (2015a) also reported very high concentrations of all the vultures except EV, in protected wildlife areas (national park and sanctuaries) as compared to neighboring forests and agriculture area.

Forests recorded higher vulture presence (87% in the 28% of the state under forest) than agricultural landcover (13% in the 52% of state under agricultural landcover). The highest and lowest records (in the Chambal ecozone and Vindhyan ecozone, respectively) may correlate with ecozone parameters (rainfall, temperature, orography, forest canopy covers etc.; see Table 1) as suggested by others. For example, rainfall (Virani *et al.*, 2012), high temperature (Chaudhry, 2007; Simmons and Jenkins, 2007), high-density cover and orography are important for vulture presence and breeding (Campbell, 2015). It can be speculated that agroclimatic regions are less significant than Ecozones as regards the vulture habitation.

Population factors

As recorded in MP, resident (LV, WV, RV and EV) and migratory (EG, HG and CV) vulture species were also reported in other parts of the country such as Rajasthan (Saran and Purohit, 2012; Purohit and Saran, 2013), Uttar Pradesh (Jha, 2015a), Gujrat (Kamboj *et al.*, 2016), Himachal Pradesh (Thakur and Narang, 2012), Karnataka (Subramanya and Naveein, 2006), Tamil Nadu (Ramakrishnan *et al.*, 2014), etc. Himalayan Griffon, EG, CV and RV have very low contribution (3-4%) in the total vulture population (6999-7057 individuals) of the study area. Other vultures like, EV, LV and WV have major contribution, for example, 18-36%, 41-54% and 18-26%, respectively. Among the low contributors to the population, all others except RV are practically nonresident (migrant or visitor). All the major contributors are resident vultures in MP and reported to breed satisfactorily (Naoraji, 2006).

Juvenile percentage is an indicator of population recruitment and annual breeding success (Campbell, 2015). Adult and juvenile proportions (juveniles per hundred adults: jpha) or fresh recruitment (juvenile percentage in total population: jptp) may be used as indicators of population growth. Juvenile proportions and fresh recruitment in the present study averaged 12 jpha and 11 jptp, respectively, for all vultures in the state. This is encouraging in the light of previous prediction. However, such parameters are highly variable (3-26% and 3-21%, respectively). Among the resident and breeding vultures in MP, jptp indicated varied success of breeding in following order: EV (21%) > WV (8%) > LV (7%) and RV (4%). Average juvenile percentage in the population (10%) seems to be a satisfactory growth indicator. Although EV showed high juvenile percentages, juvenile increase in WV and LV is like annual population increase (7%) of vultures (LV, WV, RV, EV, EG, HG and CV) in arid regions (Khatri, 2013).

Nest-occupancy in the current research, recorded a 10-17% breeding population, 17-21% potential breeding population and non-breeders (62-74%, under-aged or over-aged vultures). Bird species commonly record adult non-breeders, partly due to sparse nesting areas (Campbell, 2015). Forests offered superior food and nesting sources than agricultural landcover, hence there were more vulture records in forest (87%) than agricultural landcover (13%). Possibly, there were fewer uninfected carcasses and undisturbed trees and cliffs in agricultural land. Tall forest trees (>10 m) and elevated ledges/caves/crevices (≤ 25 m) offered refuge from predators, and foraging platforms (Chhangani, 2003; Chomba and M'Simuko, 2013; Campbell, 2015). Smaller trees in agricultural landcover were utilized when tall trees were absent. This is in agreement with earlier reports of Kambale (2011) and Harris (2013).

Diclofenac use (Campbell, 2015) precluded its rapid withdrawal from the vulture food supply. The three *Gyps* species were almost extirpated (Campbell, 2015). Prakash *et al.* (2007) suggested that only one in 1000 *Gyps benghalensis* (99.9%) and three in 1000 *Gyps indicus* and *Gyps tenuirostris* (96.8%) survived. However, current species counts of *Gyps benghalensis* (1522) and *Gyps indicus* (3350) in MP may indicate a one thousand-fold decline over a decade is exaggerated. The population trend in MP is lacking, hence many experts are skeptical (*Pers. comm.* Jitendra Agrawal CWLW, MP). Data is scanty on the threshold level population for the extinction of resident vultures and diclofenac ban impact (Taggart *et al.*, 2007). Likely, diclofenac caused extinctions (Green *et al.*, 2004; Oaks *et al.*, 2004; Shultz *et al.*, 2004; Prakash *et al.*, 2012),

reported recoveries also appear exaggerated. Diclofenac abolition is uncertain (Taggart *et al.*, 2007); users cite availability and high potency over other NSAIDs (Saini *et al.*, 2012; Dama, 2014; Cuthbert *et al.*, 2016, for India, Phuyal *et al.*, 2016, for Nepal). As vultures are slow breeders (Campbell, 2015), the annual decrease in population in the state of UP was 3.2% (Jha, 2015a). The maximum population increase in a year could only be 2.5-3.45% (Changani and Mohnot, 2008). These figures may not be comprehensive, requiring further research. The two hypotheses, of extinction risk (Prakash *et al.*, 2007) and reduced population decline (Prakash *et al.*, 2012) may be based on untested or hypothetical models (Pavokivic and Susic, 2005).

Records of past vulture numbers is scanty or subjective (Thakur and Kataria, 2012; Thakur and Narang, 2012, etc.). Statements include 'several tens of millions of individuals' of *Gyps bengalensis* (Houston 1985 in Botha *et al.*, 2017). Baral *et al.* (2013), the only quantitative report, gives the WV population as 15000. More recently, Botha *et al.* (2017) gave global population of EV, RV, WV, and LV as 18000-57000, 3500-15000, 8000 and 12000, respectively. Therefore, for MP this corresponds to 3.3%, 0.6%, 19% and 27.9% of the global population. However, the jtp of the combined population ranged between 6.5% - 15.7% in different ecozones of MP. Vindhyan, Bundelkhand and Malwa require special care for conservation since they have a jtp of less than 10%. The lack of uninfected food and drought, malaria, storms, and habitat degradation exacerbate the diclofenac problem (Ramakrishnan *et al.*, 2014; Jha, 2015a; Paital, 2016).

Our findings dispute some media statements. For example, LV in MP constitute 28% of global population, but Saxena (2017) argued that MP has 40% of the global LV population. This quoted an expert, who doubted its veracity (*Pers. Comm.* Chris Bowden, a vulture expert). Another report citing 'vulture population increase in Charotar region (Anand district) of Gujarat in 2016 (Ruperal, 2016) may exaggerate local changes. Kamboj *et al.* (2016) reported *Gyps* populations decreased in the whole state as well as in central Gujarat, to which Anand and other districts belongs. The increase in Charotar could be only local, as in our study and that of Naoroji (2006).

Habitats and sites

Vulture presence decreased with forest density. Eurasian and African vultures have no sense of smell for carrion detection; hence their avoidance of closed canopies (Brown, 1985; Schulz, 2007; Campbell, 2015; Samson *et al.*, 2016). Roosting and nesting occurred on trees and cliffs, while water bodies were used for drinking. Other studies record use of similar tree species in other regions. These include *Tectona grandis*, *Bombax ceiba*, *Terminalia tomentosa*, *Dalbergia sissoo* in Uttarakhand (Das *et al.*, 2011); *Terminalia arjuna*, *Terminalia bellerica*, *Alstonia scholaris*, *Mangifera indica* in Maharashtra (Pande *et al.*, 2013); *Ficus benghalensis*, *Ficus religiosa*, in erstwhile East Bengal now Bangladesh (Khan, 2013) and in Tamil Nadu (Ramakrishnan *et al.*, 2014). Out of 44 tree species used by vultures for roosting, 14 (mostly shorter) trees were not used for nesting, indicating a preference for taller trees. Vulture species not included in the current study, including Eurasian Black vultures, Lappet-faced vulture (*Torgos tracheliotus*), White-headed vulture (*Trigonocepos cipitalis*) and White-backed vulture (*Gyps africanus*), are also tree nesters (Campbell, 2015).

Large trees (Chhangani, 2007; Dhakal *et al.*, 2014) provided predator avoidance, suitable microclimates (Campbell, 2015) and increased mobility (Wright *et al.*, 1986) for vultures. Nest elevation included those of the White-backed (-rumped) vulture at 16.6 m (Chomba and M'Simuko, 2013), 8 m - 28 m (Subedi and DeCandido, 2014), 14.8 m (Thakur and Narang, 2012), 18 to 36 m (Naoroji, 2006), above 21 m (Thompson *et al.*, 1990) and 25-30 m (Ramakrishnan *et al.*, 2014). Other species were recorded in smaller trees (*Mangifera indica*, *Acacia nilotica*, *Azadirachta indica*, *Prosopis cineraria*) in other regions such as arid Rajasthan and Maharashtra (Chhangani, 2007; Kambale, 2011; Khatri, 2013).

High cliff nesting averaged 25 m to 35 m elevation, generally inaccessible to humans from ground level or cliff top (Subramanya and Naveein, 2006). Cliff locations provided predator visibility, easier nest access and reduced human disturbances (Donazar *et al.*, 1993; Yamac, 2007). Some species favored cliffs (e.g. EV

and LV) and others favored trees (e.g. KV and WV), but there were also inter-species reversals (trees to cliffs and vice versa) in the current study and others (Navaneethan *et al.*, 2015). For example, while Ramesh *et al.* (2011) reported LV nesting on *Dalbergia lanceolaria* tree, Venkitachalam and Senthilnathan (2015) recorded LV nesting on rock cliffs. KV and LV were also observed roosting on *Albizzia procera* and *Shorea robusta* trees and EV *Butea monosperma* trees. Some vulture species, their habitats and companion scavengers in the study area are presented in Figures 6-13.



Figure 6. Tree nesting, critically endangered, resident White-rumped vulture *Gyps bengalensis* perched on a Sheesham tree, *Dalbergia sissoo*



Figure 7. A wake of vultures (Himalayan Griffon and White-rumped Vultures) feeding on cattle carcass. Companion scavengers like, dog and crows can also be seen competing for the carrion



Figure 8. A group of cliff nesting, Critically Endangered, resident Indian or Long-billed Vulture *Gyps indicus* resting on ledges near permanent roosting location



Figure 9. An ideal landscape for cliff nesting vultures. A Dry Deciduous Tropical Forest on plateau (cliff providing nesting ledges and crevices) cut by a meandering river (perennial water source)



Figure 10. A cliff nesting, Endangered, resident, Egyptian Vulture *Neophron percnopterus* perched on a hacked drying tree



Figure 11. A small group of vultures on mud flat of a river basking late afternoon sun. Himalayan Griffon *Gyps himalayensis* vulture is a Near Threatened and migratory



Figure 12. Treescape of a moist deciduous tropical forest having a silk cotton tree *Bombax ceiba* with red flowers. This is very common and one of the most favoured trees for nesting, generally by White-rumped vulture



Figure 13. Long-billed or Indian Vulture *Gyps indicus* revisits a foraging area while roaming in a barren field in search of food. An old cattle carcass skull can be seen in the foreground

Local movements

Vulture summer ranges varied from winter ranges, either towards denser, protected forest or varied landcover. This search for optimal feeding, nesting and roosting habitat is found among vultures and other species (Saran and Purohit, 2013). In the study area, movements responded to water and food availability, and temperature and humidity variability, as noted in other studies (Campbell, 2015; Saran, 2017). Naoroji (2006) and Bildstein (2006) record the LV, WV and CV as irruptive and locally migratory. For example, other studies record similar results for the Cinereous vulture in other continents, with seasonal changes in home ranges, and sometimes overlaps in the home ranges during the breeding and non-breeding periods (Campbell, 2015).

Competing scavengers

Several competing scavengers were seen on the carcass at a time but feral dogs dominated scavenging, possibly due to declining vulture populations as also recorded by Markandya *et al.* (2008). Other competitors in the study area included the common raven (*Corvus corax*), house crow (*Corvus splendens*), cattle egret (*Bubulcus ibis*), drongo (*Dicrurus macrocercus*), jackal (*Canis aureas*) and wild pig (*Sus scrofa*). They were reported in the same region by Navaneethan *et al.* (2015). These concur with findings in other regions of India (Purohit and Saran, 2013; Chhangani and Mohnot, 2008; Jha, 2015a). Moleon *et al.* (2015) hypothesized that larger carcasses attracted more species and scavenger numbers, was observed in the current study as well.

Conservation policy

The findings of the current study make important contributions to the literature on conservation policy and management action (Jha, 2015a). Important points concern vulture dependence on forested areas, the low relevance of agricultural land use (except for Egyptian vultures), high usage of open landcover is favored for roosting and nesting, and preferences cliffs and large trees for roosting and nesting. These indicate that ecological knowledge is vital for endangered species and orography and forest structure influence vulture

presence as also reported by Sutherland and Green (2004) and Campbell (2015). Human disturbance was insignificant for vulture presence, is contrary to the findings of Bamford *et al.* (2009) and Chomba and M'Simuko (2013). Recovery from the diclofenac event was evident. Like others, our findings support nest protection (Pande *et al.*, 2013), tree protection (those used for nesting and roosting, and cattle) (Poirazidis *et al.*, 2004; Chhangani, 2007; Yamac, 2007; Forest Survey of India, 2011), ungulate protection, diclofenac bans (Hla *et al.*, 2010), restriction of human activities in breeding months (Jha, 2015a) and minimum buffers of 500 m (Margalida *et al.*, 2011) between nests and disturbance source (Chomba and M'Simuko, 2013).

The large trees of preferred species for roosting and nesting in the forest, even though commercially important, must be excluded from felling so that the current and future sites remain intact. Inclusion of such provisions in forest management plans will minimize the conflict between forest exploitation and vulture conservation (Poirazidis *et al.*, 2004; Yamac *et al.*, 2006). Also, branch lopping of trees as suggested by Chhangani (2007) must be banned.

Finally, prey abundance, a key factor for vulture presence (Kendall *et al.*, 2014) may be supported by traditional pastoralism, especially the relationship between vultures and migrating livestock populations as suggested by Mateo-Tomas and Olea (2009) in Malwa and Chambal ecozones with minimal wild ungulate populations.

Conclusions

The present study provided for the first-time count data of different species of vultures, which could be used for future monitoring and conservation strategies. Further studies may apply the present hypotheses to other regions. For example, (i) Vultures rely heavily on forested area and agriculture does not have much impact except in the case of Egyptian vultures, (ii) Comparatively drier area with open canopy are more suitable as roosting and nesting habitat, (iii) Interspecies differences in nesting choices (cliff or trees) and (iv) Human presence do not affect vulture colonizing in forest. The current findings provide sufficient support for enhanced conservation actions for vultures: (i) The nests identified so far (active or inactive or abandoned) must be safeguarded for current and future breeding of population. Branch lopping of trees must be banned, (ii) Large trees of preferred species for roosting and nesting must be excluded from felling, so that the sites remain intact. Inclusion of such provisions in forest management plans will minimize the conflict between forest exploitation and vulture conservation (Poirazidis *et al.*, 2004; Yamac *et al.*, 2006), and (iii) Prey abundance and their mortality should be ensured through traditional pastoralism or migrating livestock populations in areas with low ungulate populations.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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