Ecological Questions 32 (2021) 3: 7–22 http://dx.doi.org/10.12775/EQ.2021.20

The Distribution, Nesting Habits and Status of Threatened Vulture Species in Protected Areas of Central India

Kaushalendra Kumar Jha[1,*], Radhika Jha[2], Michael O'Neil Campbell[3]

[1]Environmental Management of Ecosystems and Tropical Forests, Technical Forestry Faculty Area, Indian Institute of Forest Management, Nehru Nagar, PB No. 357, Bhopal, 462003 India
[2]Zoology Department, Lucknow University, UP, India 226007
[3]Simon Frazer University, 8888 University Dr, Burnabay, BC V5A 1S6, Canada
*corresponding author e-mail: jhakk1959@gmail.com

Received: 19 August 2020 / Accepted: 15 April 2021

Abstract. Protected Area (PA) establishment is one of the commoner strategies for wildlife conservation, but the effectiveness of these developments is rarely evaluated in terms of species' performance. This article assesses the effectiveness of PAs of Central India, using an assessment of threatened vulture species. These species may be considered as keystone species in this region. Relevant parameters considered for assessment comprised: (i) the presence and population density of vultures in PAs compared with those in unprotected forests and agricultural landscapes; (ii) counts of the breeding population, nesting preferences and environmental factors for such variables; and (iii) the impacts of policies designed to combat the effects of the deadly diclofenac drug on vulture populations. Quantitative (total counts of vultures and nests, transect surveys) and qualitative (semi-structured interviews, secondary data surveys) methodologies were used in data collection, to provide an adequate information base. White-rumped, Long-billed, Egyptian and Red-headed vultures (resident) and Cinereous Vulture, Eurasian Griffon and Himalayan Griffon (migratory) were recorded in PAs. The probability of vulture occupancy was significantly higher in PAs (44–51%), than in unprotected forest (17.6–17.8%) and agricultural areas (0.03%). The average vulture density in PAs (0.529 ±0.228 km^{-2}) was also much higher than in unprotected forest (0.014±0.012 km^{-2}) and agricultural areas. The presence of active, inactive and abandoned nests in PAs revealed favorable habitat conditions for breeding, potential breeding and floater vulture categories. Disturbance factors were insignificant. The statutory ban on diclofenac use had a significant impact on vulture populations within the PAs, but this factor was insignificant in surrounding areas. These findings indicate a positive role of PAs in conservation, with insignificant impacts of the diclofenac ban across different types of landcover. It is concluded that increased promotion of environmental education is important to ensure effective vulture conservation and the success of PAs.

Keywords: vulture occupancy, vulture population, vulture density, nesting habitat, nesting density, diclofenac use, National Park and Sanctuary.

1. Introduction

Protected areas (PAs) are almost synonymous with the conservation of biodiversity (Lewis et al., 2017) and assessment of conservation, whether conducted to assess the status of a species or a continuum of threats. Consequently, this form of conservation management is deemed by managers, policy makers, researchers, and stakeholders to be vital for sustainable ecological conservation (Stem et al., 2005). The global numbers and areas of conservation projects have grown exponentially over the past 25 years, especially less developed countries (LDCs) with high biodiversity (Naughton-Traves et al., 2005). PAs covered 15.4% of the world's terrestrial land surface by the second decade of the 21st century, with a target of 17% by 2020 (Convention on Biological Diversity, 2010; Juffe-Bignoli et al., 2014; Watson et al., 2014). Currently, the figure is 15.53% (Protected Planet, 2021). In India, PAs have been expanded, with the objective of managing forests and wildlife populations, with particular emphasis on endangered species. Central India (≡Madhya Pradesh) has a wide network of PAs (9 National Parks and 25 Wildlife Sanctuaries) covering more than 11% of forest area of the state (AAR, 2000). The existing PA network protects animal habitats from human-induced degradation and consequent biodiversity loss (Bruner et al., 2001; Rodrigues et al., 2004). Tiger conservation is the primary concern of PAs in Central India, but other related species and habitats are also considered (Jitendra Agrawal, Chief Wildlife Warden, MP, personal communication).

Vultures are important species for conservation management, because they are obligate scavengers at the top of the trophic structure, with vital functions in ecosystem services, especially the removal of decaying carcasses and the potential spread of diseases in animals and human beings (Markandya et al., 2008). Vulture populations, especially in India are however seriously threatened by many environmental and human-induced factors (Galligan et al., 2020; Jha & Jha 2020, 2021). Madhya Pradesh is considered as an Indian stronghold for vulture species, but other Indian provinces still have sizable populations of different vulture species (Jha, 2018). Vultures mostly survive in PAs, with less presence in reserve forest, and seriously declining populations in agricultural landcover (Prakash et al., 2017). Favored nesting sites are tall trees in forest stands, and cliffs of nearby hills (Jha, 2017). Cliff-nesting is hypothesized to offer unhindered movement possibilities in open spaces, refuges and protection from the harsh weather, etc. Resident vulture populations are dependent on these parameters for nesting and roosting, but migratory species only need roosting structures.

The decline of *Gyps* species, along with other vultures such as the Egyptian Vulture and the Red-headed Vulture, across the Indian subcontinent was attributed largely to the consumption of tissue from carcasses of individual cattle administered with the nonsteroidal anti-inflammatory drug diclofenac (Shultz et al., 2004; Galligan et al., 2014; Majgaonkar et al., 2018). Veterinary formulation of this drug was banned to protect the vulnerable, declining vulture populations in India and neighboring countries. However, six years after the ban of licensed veterinary diclofenac, and of the sale and use in India, Saini et al. (2012) identified a persistent black market for the drug, which was very widely available for unrestricted purchase. Ten years after the ban, Cuthbert et al. (2016) and Nambirajan et al. (2017) also reported that diclofenac has remained a significant cause of mortality for India's vultures.

Although the larger issue of PA establishment is one of the most common strategies for wildlife conservation worldwide (Ervin, 2003; Gaston et al., 2008), the effectiveness of such policies is rarely evaluated (Morales-Reyes et al., 2016). Several studies have emphasized the importance of vulture conservation outside PAs as they can represent a significant part of vulture home ranges, while vulture populations frequently occur inside PAs (Galvez et al., 2013; Phipps et al., 2013; Mdhlano et al., 2018). Since PAs are the cornerstone of conservation (Gaston et al., 2008; Coetzee et al., 2014), they play a critical role in safeguarding biodiversity and maintaining the crucial services provided by the natural system (Kolahi et al., 2013). PA management is defined as a leading approach for protection of keystone species within their borders. Such PAs in Central India shelter both resident and migratory vulture species, both of which may be regarded as keystone species (Markandaya et al., 2008; Buechley et al., 2018; Mdhlano et al., 2018). Such keystone species may indicate the health of the environment of PAs which, generally, have a higher abundance, richness and assemblage than surrounding landuse-landscape (Coetzee et al., 2014; Sweke et al., 2016). This article considers these issues in the PAs of Central India, with the following objectives, assessing: (i) the occupancy and density of vultures in PAs vis a vis forest and agriculture landscapes; (ii) the breeding populations, preferential nesting structures, and surrounding factors; (iii) and the impact of preventive measures against the diclofenac threat on vulture populations.

2. Study area

The selected major PAs (National Parks (Bandhavgarh: BDNP, Kanha: KHNP, Madhav: MDNP, Panna: PANP, Pench: PENP, Sanjay: SJNP, Satpura: STNP) and Wildlife Sanctuaries (Gandhisagar: GSWS, Nauradehi: NDWS, Kuno-Palpur: KPWS) of Central India ≡ Madhya Pradesh (21° 6'– 26° 30' N and 74° 00'– 82° 51' E) for the present study are shown in Figure 1 (Red and maroon polygons).

There are three types of forests in the state – dense tropical moist deciduous forest in the south of the province, tropical dry deciduous forest in the middle, and more open tropical thorn forests in the north, with undulating and hilly topography – amongst which these PAs are interspersed. The climate of the province is subtropical, with a hot dry summer (March-June), monsoon rains (July–September) and a cool, relatively dry winter (October- February). Rainfall averages about 1370 mm, decreasing from east (2150 mm) to west (1000 mm) (Jha et al., 2020).

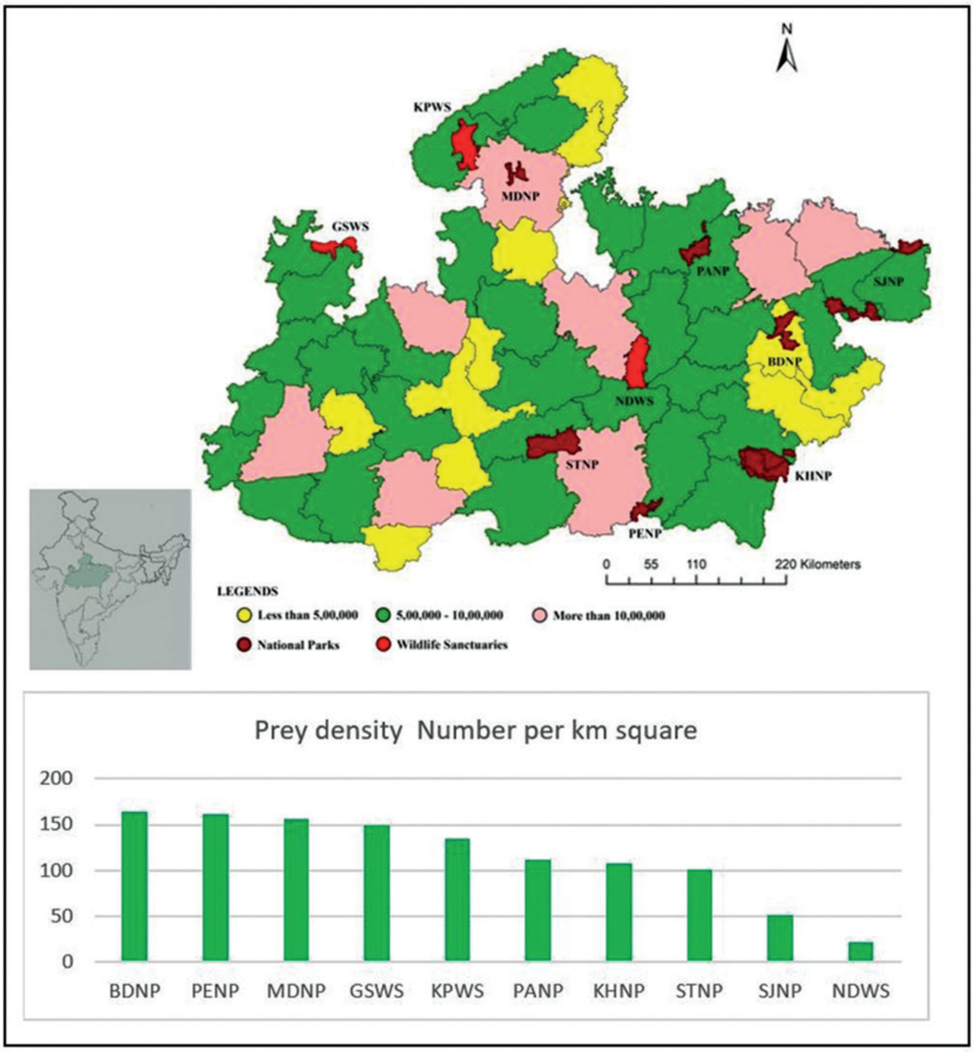

Figure 1. Top: Location of PAs in Central India-MP. Maroon polygons are the National Parks (BDNP: Bandhavgarh, KHNP: Kanha, MDNP: Madhav, PANP: Panna, PENP: Pench, SJNP: Sanjay, STNP: Satpura) and red polygons are the wildlife Sanctuaries (GSWS: Gandhisagar, NDWS: Nauradehi, KPWS: Kuno-Palpur). Yellow (low), green (moderate) and pink (high) polygons around the PAs are districts with different livestock availability or potential food for vultures outside the PAs. Bottom: Bar chart indicates ungulate density (number km^{-2}) within the PAs. Inset gives location of study area, Central India

3. Materials and Methods

Methods adopted for the estimation of the population of vultures, characterization of nesting habitat and diclofenac use survey are described in following paragraphs under different sub-sections.

3.1. Population Distribution in PAs

The total vulture count was done in winter (January) and summer (May) season of 2016 in all the PAs, besides reserve forest, and agriculture areas following protocols detailed in Jha (2018). Species-wise individuals (adult and juvenile) and their nests (active, inactive and abandoned) were also counted in these areas.

Rapid population assessment was also done in 2018, following a road transect survey that is a common method of measuring vulture density and estimating vulture populations (Prakash et al., 2007, 2017; Acharya et al., 2009, 2010; Virani et al., 2011; Subedi et al., 2018). For the present study three transects were selected to give sufficient representation to agricultural landscapes, forest areas outside PAs and Protected Areas (Fig. 2). The survey was done during the months of June, August and September 2018.

Approximately 2% transect area covered ca. 70% state area and traversed through the above-mentioned PAs and major corridors. For logistic convenience, these three transects (i. Bhopal-Nauradehi-Mukki-Karmajhiri-Delakhari-Bhopal; ii. Bhopal-Shivpuri-Gwalior-Sheopur-Gandhisagar-Bhopal; iii. Bhopal-Orchha-Panna-Tala-Sidhi-Singrauli-Damoh-Sagar-Bhopal) were kept circular without overlap. The origins and destinations of these surveys were our research headquarters in Bhopal. The distances covered on these routes were 1535 km, 1688 km and 2089 km, respectively (total 5312 km).

Vulture density (individual km^{-2}) was calculated using transect areas of 1 km width (500 m on either side of the road) and number of the vultures sighted along the survey routes. Vulture sighting was done by two observers concentrating on two different sides of the road from a moving vehicle at 50-60 km h^{-1} speed outside the forest and 20 km^{h-1} speed inside the forest or PAs. Vulture species sitting on the ground or tree or flying/soaring in the sky within half a kilometer distance on either side of the road were identified and counted. The observers practiced the methodology before starting the survey to estimate the 500 m distance by marking an object with known distance. Garmin GPS, Olympus Binocular (10x50 DPS I, field 6.5°) and Lumix Camera (FZ100, 24x Opt Zoom, 14 mega pixels) were used to record the coordinates of the sight, and to identify and capture the vulture species.

Occupancy estimation: The study area was divided into sub-cells and cells of equal size, 10 km^2 and 250 km^2, respectively, using the fishnet tool of ArcGIS 10.5. The sub-cells were treated as vulture sites or water use area embodying one to many sightings of roosts or nests with vultures within the area while cells as foraging area (Jha et al., 2020). Presence of vultures during census was recorded in the sub grids and occupancy analysis was done using PRESENCE software.

3.2. Breeding population and Nesting suitability

Roosting and nesting sites with different physical features were categorized as Forest and Agriculture (land use) habitat. Forest habitat was further sub-grouped as Vegetated and Hilly tracts as the trees and cliffs were used by different species for nesting and roosting. Breeding populations and

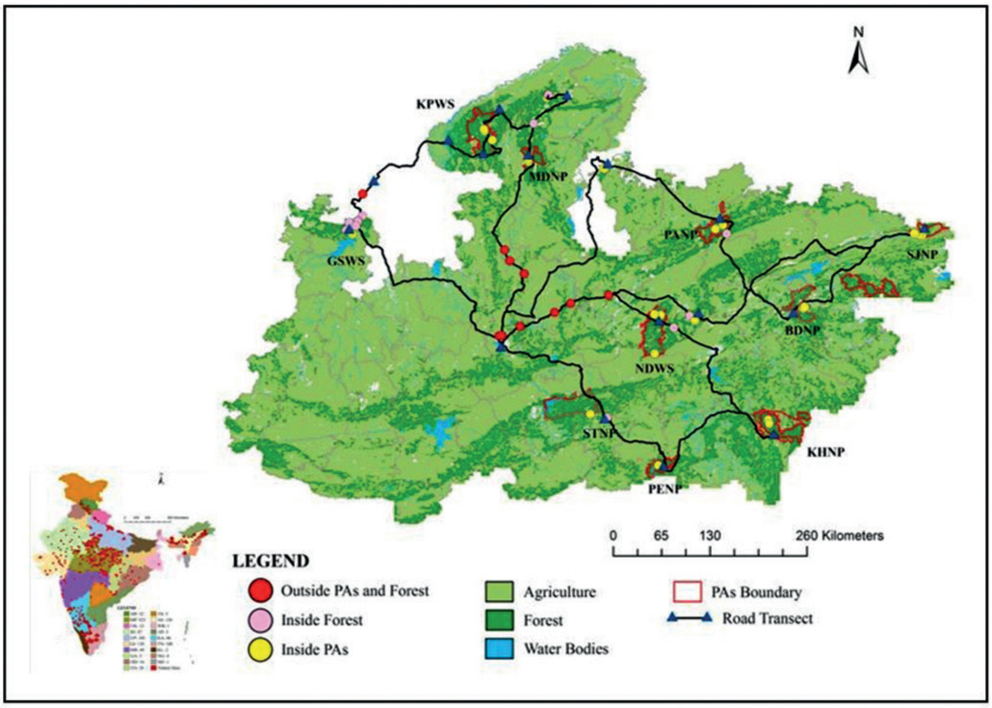

Figure 2. Routes of transect survey covering major Protected Areas – National Parks (BDNP: Bandhavgarh, KHNP: Kanha, MDNP: Madhav, PANP: Panna, PENP: Pench, SJNP: Sanjay, STNP: Satpura) and Wildlife Sanctuaries (GSWS: Gandhisagar, NDWS: Nauradehi, KPWS: Kuno-Palpur) and corridors through different landcovers in Central India-Madhya Pradesh. The coloured circles denote vulture sighting in different land cover. The same routes were followed for diclofenac survey covering major towns not far from the PAs. Inset depicts number of locations (red spots) of vultures in different provinces, indicating central India as a stronghold (Adopted from Jha, 2018)

potential breeders were calculated indirectly by using the hypothesis of number of active nests used by a pair and possibility of number of inactive nests to be used by another pair, respectively.

During the 2018 survey, the randomly selected nests of the 2016 census in the PAs were revisited and characterized by recording certain features such as: i) elevation of nesting point; ii) distances of nearest village, metaled road, railway lines, waterbody; iii) overhead crown coverage; iv) cliff aspect; and v) nest condition etc. in order to know the nesting (habitat) suitability.

These vultures have a single food source which is ephemeral and partially predictive in time and space (Ruxton & Houston, 2004; Cortes-Avizanda et al., 2014; Alarcon & Lambertucci, 2018). They survive primarily on the carcasses of herbivores and ungulates found within forested landcover and human dominated landscapes. Corresponding secondary data were procured from the Wildlife wing of the Forest Department (SFRI, 2016) and the Veterinary Department, respectively (Fig. 1).

3.3. Diclofenac threat survey in and around PAs

A qualitative research methodology was adopted during the study period, June 14 to October 21, 2018. We interviewed eleven veterinary experts (including two retired veterinary officers), who were both freelance practitioners and government hospital doctors. Medical shops and pharmacies were covered along the routes chosen for transect survey mentioned above. A total of 35 towns and 116 on way shops dealing in human or veterinary medicines were randomly selected. Diclofenac vials were purchased during the interviews of the chemists (counter managers). To encourage cooperation from the respondents, receipts were not recorded. Anonymity was assured to get free, frank and fair information from generally the hesitant shopkeepers due to banned status of diclofenac. Within the PAs non-relocated villagers and frontline staff (n=28) were interviewed for use of diclofenac for cattle treatment.

4. Results

4.1. Population distribution

Vultures used space for shelter (roost/nest), water and nutritional requirements, areas of which were small, large and larger in scale, respectively. The vultures showed movement around and away from the shelter and ranged in all directions. Fishnet sub-cells (10 km^2) and cells (250 km^2) corresponded with shelter and water-use, and foraging areas, respectively (Jha et al., 2020). Seasonal vulture populations (Table 1) showed that the naïve estimate or psi (ψ) value varied little in the different seasons. However, they varied considerably in different landuse-landcover. Probability of occupancy (ψ) was maximum in PAs followed by forest and agriculture. Probably, 44–51% of PAs was occupied by vultures as compared to 17.6–17.8% of forest and 0.03% of agriculture areas.

During the road transect survey, 352 vultures of four species were sighted on three transects totaling a distance of 5312 km, which were covered in 19 days of field work during clear days of the post summer season. Only resident vultures were sighted outside and inside the forest and PAs. Migratory vultures were absent as expected, as the survey was conducted outside the winter migration period. Interestingly, on a shorter transect line in PAs (354 km) we encountered 181 vultures. Consequently, the average density (km^{-2}) of all vultures together was low (0.065 ±0.004) statewide, compared with that in the PAs (0.529 ±0.22). The relative proportions of vulture species on the full transect was 61.6% (Long-billed Vulture), 22.4% (Egyptian Vulture), 15.3% (White-rumped Vulture) and 0.7% (Red-headed Vulture).

The population distribution of vultures in selected PAs of Central India is presented in Table 2. The total population in PAs (2932) was 45% vultures confined to 5% of the forest area out of 87% vultures in 95% of forests in Central India. Thirteen percent of the recorded vultures were located in agriculture landscapes, which covered approximately double the forest area (Jha et al., 2020). Vulture populations estimated by transect and total count methods varied in

Table 1. Occupancy analysis of Vultures in Central India-MP

Analytical parameter	Winter			Summer		
	PAs	Forest	Agriculture	PAs	Forest	Agriculture
Naïve estimate	0.4454	0.1105	0.0114	0.3866	0.1252	0.0114
Psi (ψ) value (standard error)	0.5155 (0.0539)	0.1769 (0.0178)	0.0378 (0.0194)	0.4405 (0.0520)	0.1784 (0.0160)	0.0378 (0.0194)
95% confidence interval	0.4107–0.6189	0.1447–0.2144	0.0136-0.1007	0.3423–0.5436	0.1492–0.2118	0.0136–0.1007

different PAs but the total population was similar in both cases. PA category-wise population density and nest density differed, in that the former was lower in the National Park (0.47) while the latter was lower in the Wildlife Sanctuary (0.08). Vulture density estimated from the road transect survey (Table 3) varied on different tracks or regions and the landuse-landcover. It was highest in PAs (0.529 ±0.228) followed by whole state (0.065 ±0.004) and the mixed forest and agricultural landcover outside the PAs (0.033 ±0.019). However, vulture density just outside PAs in surrounding forest divisions was very low (0.014±0.012 km^{-2}).

4.2. Nesting (habitat) suitability

Observations were made on randomly chosen nests (n=56) in the selected PAs. Four vulture species were observed nesting on cliffs (Long-billed and Egyptian vultures) or trees (White-rumped and Red-headed vultures). Nesting site variables concerning safety from predators and positioning of disturbance-causing factors are recorded in Table 4. Nests were mostly located at lower altitudes but 55% of them were situated above 100 m. Large trees of different species (Arjun *Terminalia arjuna*, Peepal *Ficus religiosa*, Saj *Terminalia tomentosa*, Kaim *Mytragyna parviflora*, Mahua *Madhuca latifolia*, Baheda *Terminalia belerica*, Sal *Shorea robusta*, Sagaun *Tectona grandis* etc.) hosted vulture nests in relatively open forests (canopy cover 40–60%). Such trees were generally either isolated or dominant in the area. Ledges or caves on generally vertical cliffs were used for nesting, usually facing south or south west direction. Waterbodies, paved roads, and villages ranged from close to distant from nesting trees or cliffs. No railways were near the PAs.

Table 2. Vulture population and density in different PA categories in Central India-MP

Protected Areas	Area (km^2)	Population		Nests (Total count)	Density (km^{-2})	
		Transect method*	Total count		Population	Nesting
Bandhavgarh NP	448.85	237	171	36	0.38	0.08
Kanha NP	940.00	497	132	32	0.14	0.03
Madhav NP	375.22	198	356	55	0.94	0.14
Panna NP	542.67	287	811	226	1.49	0.41
Pench NP	292.85	155	40	0	0.001	0.00
Sanjay NP	466.88	247	54	23	0.11	0.04
Satpura NP	585.17	309	180	139	0.30	0.23
Total/Average NP	3651.64	1930	1744	511	0.47	0.14
Gandhisagar WS	368.62	195	628	111	1.70	0.30
Kuno WS	344.68	182	361	37	1.04	0.10
Nauradehi WS	1194.67	632	199	21	0.16	0.01
Total/Average WS	1907.97	1009	1188	169	0.62	0.08
Total/Average PA	5559.61	2939	2932	680	0.527	0.12

*Area x Density (0.529 km^{-2}); NP = National Park, WS = Wildlife Sanctuary

Table 3. Density estimation of Vultures in Central India-MP through road transect method

	Transect I	Transect II	Transect III	Average	StDev
Survey dates	14-21/06/ 2018	05-09/08/ 2018	21-26/09/ 2018		
Total Track Distance km	1535	1688	2089		
Vultures along track	93	117	142		
Track distance in PAs (km)	172	86	96		
Vultures along PAs track	73	32	76		
Vulture %age in PAs	78.4	27.3	53.5	53.1	±25.574
Density in State (km^{-2})	0.060	0.069	0.067	0.065	±0.004
Density in PAs (km^{-2})	0.424	0.372	0.791	0.529	±0.228
Density outside PAs (km^{-2})	0.014	0.053	0.033	0.033	±0.019

The total number of nests varied from 21 to 226 in different PAs (Table 2). Although Pench NP had a vulture population, nests were not detected in the 2018 survey or

Table 4. Habitat variables characterizing nest sites in PAs of central India

Variables	Average	SD (±)	Range
Cliff height of nests from the ground (m)	51	67	12-250
Tree height from the ground (m)	18	6	10-25
Elevation, Altitude (m)	109	36	56-169
Distance of nearest waterbody (km)	1.17	1.86	0.1-6
Distance of nearest village (km)	4	4	0.2-20
Distance of nearest metaled road (km)	6	5	0.1-20
Distance of nearest Railway station (km)	63	46	6-150

2016 counts. The highest number of nests were seen in Panna NP followed by Satpura NP, Gandhisagar WS etc. The classification of nests into active (parents with chick/juvenile), inactive (adults without chick/juvenile) and abandoned (deserted nest) nests in two different seasons are given in Table 5. Eight out of 10 PAs had all the three types of nests (Fig. 3) but Kanha NP had only inactive nests and no nests were recorded in Pench NP.

Table 5. Distribution of Vulture nests in Protected Areas of Central India-MP

PAs	Winter			Summer			Average		
	Active	Inactive	Aband	Active	Inactive	Aband	Active	Inactive	Aband
Bandhavgarh NP	6	1	4	16	24	19	11	13	12
Gandhisagar WS	14	76	26	49	27	27	32	52	27
Kanha NP	0	28	0	0	0	36	0	14	18
Kuno WS	7	13	0	22	21	9	15	17	5
Madhav NP	15	22	6	8	36	23	12	28	15
Nauradehi WS	14	4	0	15	8	0	15	6	0
Panna NP	43	41	46	170	91	60	107	66	53
Pench NP	0	0	0	0	0	0	0	0	0
Sanjay NP	0	2	21	5	3	13	3	3	17
Satpura NP	22	82	25	64	64	20	43	73	23
Total	121	269	128	349	274	207	238	272	170

Aband = Abandoned, NP = National Park, WS = Wildlife Sanctuary

Figure 3. Vulture landscape and nesting. Top: An ideal landscape for vultures in Gandhisagar Wildlife Sanctuary, the vertical cliff and nesting trees on the table land and Chambal river in close proximity. Bottom left: Active nest of cliff nesting Long-billed vulture (an adult with a chick on the nest). Bottom centre: Inactive nest of White-rumped vulture (two adults without chick/juvenile on the nest). Bottom right: Abandoned nest without vulture occupancy in breeding season

4.3. Diclofenac survey

All the doctors interviewed knew that veterinary use of Diclofenac was banned by the government, as vultures were vulnerable to poisoning effects. They were also aware that Meloxicam was available as a safe substitute. This alternative drug was easily available in the surveyed hospitals and several shops. However, diclofenac sodium in small vials (1 ml to 3 ml) was available in almost all the shops, labelled with fourteen different trade names, including Voveran 1 ml. Sodium diclofenac pills for human use was also available in the market. There were also larger vials (30 ml) of diclofenac sodium (Fig. 4) with different names (D-25, Difenac, Diclofenac Sodium and Diclohim). Some of the vials had statutory cautions “Not for veterinary use and Not to be used in neonates” and some with only “Not to be used for neonates”. Such vials currently available in the market have valid periods of two to four years from 2015–17 to 2018–20.

Figure 4. Diclofenac NSAID: 30 ml vials available in the market for sale by different brand names (left). Manufacturing date (06/2015 and 03/2018) and Expiry date (05/2019 and 02/2020) may be noted on the vials on the right

Survey interviews revealed the ease of accessing these sources in the veterinary network. Human formulations were found to be frequently used and equally effective in animals. The multi-dose human diclofenac may have gradually replaced the veterinary formulation before declining in availability. Respondents noted that in some cases several smaller vials are combined to administer larger doses to cattle, when larger vials are unavailable. A retired official of the veterinary department argued that such human formulations, including multi-dose diclofenac is freely available in the market within easy reach of the veterinary network. This official disputed the opinions of others, some of whom stated that the diclofenac was banned and unavailable. One of the veterinary practitioners also revealed that Meloxicam was relatively unpopular, being found to be more painful to animals due to its oil-base nature and its greater cost.

5. Discussion

Given the ongoing vulture decline (save Prakash et al., 2017), it is essential to assess the relative importance of the factors that affect vulture population persistence and growth (Virani et al., 2011; Ogada et al., 2016). Many published sources suggest vultures are affected by threats such as poisoning, electrocution, collision with urban structures, direct persecution, changes in agricultural practices, landscape composition, and sanitary regulations that can reduce food availability (Oppel et al., 2016; Santangeli et al., 2019 etc.). However, vulture distribution and density, nesting habitat suitability and poisoning threats could be used as population persistence and growth indicators. The findings of the current research are evaluated in relation to the existing literature in the following sections.

5.1. Distribution and density

Vulture occupancy was largest in PAs, followed by forest and agricultural areas. However, it is interesting to note that vulture populations (all species together) estimated in PAs by two different methods (total count and road transect) have changed little over two years. This change might have been expected as a normal phenomenon during this time. Individual PAs have variable populations, with no evidence of a correlation between vulture population and increased area, so the lack of evidence of population change could be coincidental. The similar population densities of the PAs may also be coincidental. Normally, this should vary as the two methods have different detection probabilities which may be reflected in extrapolation.

The higher population density or proportion of population distribution in PAs as compared to forest indicated the greater habitat suitability of the PAs. One possible reason, *prima facie*, is the high level of protection or low level of anthropogenic disturbance in the PAs. Larger populations of ungulates in the PAs (22–101 animals km^{-2}) serve as additional food sources or at least as a safety-net. These localized findings are like those found at the broader, national scale (Prakash et al., 2017). A factor for this could be the species-specific management of PAs as the protection of umbrella species is expected to benefit a wide range of co-occurring species and their ecosystems (Roberge & Angelstam, 2004; Seddon & Leech, 2008; Caro, 2010; Maslo et al., 2016; Kalinkat et al., 2017). Most of the PAs (Bandhavgarh NP, Kanha NP, Panna NP, Pench NP, Sanjay NP, Satpura NP) under study are managed for the conservation of flagship umbrella species such as the Tiger and a few other PAs for secondary species. Our findings agreed with those of Prakash et al. (2017), who speculated that *Gyps* vultures may be more numerous in National Parks because of the greater availability of nesting and roosting sites, such as trees or cliffs, in the relatively undisturbed forests, woodlands and mountains within the parks. Another finding of our research, that PAs have a higher vulture density or abundance than surrounding unprotected area, concurred with Coetzee et al. (2014) and Sweke et al. (2016) but did not agree with high species richness in PAs. This disagreement may be because in the current study we worked only on the few, comparative rare keystone species of PAs.

5.2. Nesting habitat suitability

Raptor populations are limited by the availability of breeding habitat at the microscale level (Bevers & Flater, 1999). However, macrohabitat characteristics like, vegetation cover types, topography, human pressure, availability and accessibility of prey, etc. are important components in nesting habitat selection (Janes, 1985; Bosakowski & Speiser, 1994; McGrady et al., 2002; Sergio et al., 2004; Kudo et al., 2005; Rodríguez-Lado & Tapia, 2012).

Tree availability is a potential limiting factor (Newton, 2010), but some findings dispute this position for vultures and eagles (Kendall et al., 2017). However, mature (Poirazidis et al., 2004) and tall trees of >10m (Chomba & Simuko, 2013; Chomba et al., 2013) are critical for nest placement by vultures. In various studies (Mundy, 1982; Monadjem, 2003; Monadjem & Garcelon, 2005; Herholdt & Anderson, 2006; Thakur & Narang, 2012; Jha, 2015; Monadjem et al., 2016) average nesting height varied between 11 m and 18 m which corresponds to the present study (average 18 m ± 6). Most nests were observed on mature trees in the upper quarter of the tree, usually in tri-forked positions in lower canopy. Exceptions were some Red-headed and White-rumped vulture nests found on top of the tree crown. This finding is marginally different from those of Monadjem et al. (2016) for the Hooded vulture, where the mean nesting location is 72% of the tree height within the foliage but never in the canopy.

The presence of all three types of nests (active, inactive and abandoned) in PAs indicated favorable habitat, due to the presence of breeder (active nests), potential breeder (inactive nests) and floater category of vultures. Vultures without any nests in a PA (eg. PENP) belonged to the floater category, like raptors located far from the breeding grounds (Prommer et al., 2012; Tanferna et al., 2013; Zuberogoitia et al., 2013; Tapia & Zuberogoitia, 2018). However, the nesting density range in our PAs (1–41 nests 100 km^{-2}) was much lower than in the Masai Mara Game Reserve in Kenya (53.5 100 km^{-2}; Virani et al., 2010) and conservation area (18.8–58.2 100 km^{-2}) of Swaziland but was higher than in protected cattle ranches (3–8.9 100 km^{-2}) reported by Monadjem & Garcelon (2005). However, higher nesting densities in conservation areas than in protected cattle ranches and unprotected government ranches (Monadjem & Garcelon, 2005) supports our findings where forest (lesser protected area) and agriculture area (unprotected) showed much lower nesting density as compared to PAs (unpublished data).

The high numbers of active and inactive nests (75%) in the PAs indicate their healthy breeding rates and high habitat suitability. Concurrently, abandoned nests may reveal unsuitability, at least temporarily. Though the abandoned nests, *prima facie* appear useless, they should be observed and protected as vultures may reoccupy the nest sites even after a decade of absence (Del Hoyo et al., 1994; Hardey et al., 2009; Bamford et al., 2009; Tapia & Zuberogoitia, 2018).

Higher nesting density could be attributed to the prevailing geo-biotic resources as most of our PAs have undulating terrain, which provide cliff nesting for vultures. These PAs also contain forests of different density classes, such as Moist Peninsular Sal Forests, Moist and Dry Mixed Deciduous Forest, *Boswellia serrata* forest, *Anogeissus pendula* Forest, Tropical Moist and Dry Deciduous Teak etc. (Source: Working plans of different PAs; FSI, 2011). Just 2.15% of the total forest (28% of state area) is dense forest which, in principle, is not suitable for vultures (Sara & Di Vittorio, 2003; Campbell, 2017). Most of the state forests are either moderately dense (11.35%) or open (11.70%) supporting dominant and isolated trees of *Shorea robusta*, *Tectona grandis*, *Boswellia serrata*, *Anogeissus pendula* etc. which host safe vulture nests (ISFR, 2011). PAs also contain waterbodies such as rivers, streams and ponds, which ensure favorable roosting and nesting conditions to vultures.

Human disturbance has been recognized as a prominent factor for vulture territory abandonment (Carrete et al., 2007; Zuberogoitia et al., 2014; Kruger et al., 2015). It can impact them directly (e.g., by persecution and harvesting) or indirectly, via effects on the quantity, quality, or configuration of the landscape and consequently on the habitats that it contains (Hollander et al., 2011; Kamp et al., 2016; Morant et al., 2018). While some authors suggest that vultures (Egyptian Vulture) are tolerant to human activities (Ceballos & Donazar, 1989), human disturbance would lead raptors (including old world vulture) to abandoning their nests and thereby reducing breeding success (Chomba & Simuko, 2013). The nesting of the Egyptian Vulture is particularly impacted by human presence as they clearly prefer to breed away from nearby villages, towns or roads (Sen et al., 2017). Therefore, management strategies aimed at preventing human disturbance to endangered species (Egyptian Vulture) is of paramount importance for effective conservation results (Zuberogoitia et al., 2014). The PAs in the current study have this factor covered as human settlements are generally reduced after being relocated outside the PAs. The operation is ongoing, the objective being the exclusion of human settlements from PAs in the future (RP Singh, Park Authority, MP, personal communication).

Disturbance creating factors (i.e., average distance of railway, metaled road and villages) were quite distant in the studied PAs (63,6 and 4 km, respectively). Internal traffic was also highly regulated. Consequently, their impact on vultures was minimal. However, nesting vultures are so sensitive to disturbance that even increased activity along roads may contribute to nest site desertion (Bridgeford & Bridgeford, 2003; Monadjem & Garcelon, 2005). By contrast, White-rumped and Egyptian vultures have been recorded foraging around human settlements (Thakur & Narang, 2012). Such associations have also been found for other species such as White-backed, Hooded and Egyptian vultures in different parts of the world (Henriques et al., 2018).

Sunshine and slope orientation appeared to be of low importance in the case of *Aegypus monachus* (Mihoub et al., 2013), but aspects of the cliff location play a role in nest site selection. For example, Eurasian Griffon Vultures generally prefer western and southern exposure due to larger amount of sunshine (Marinkovic et al., 2012). Although the present study revealed use of almost all the aspects for nest building, East and North were the least preferred aspects. As expected, more than half of the nests (51%) were seen on South and South western cliffs dominated by Long-billed vultures. In other studies (Vlachos et al., 1998; Liberatori & Penteriani, 2001; Sen et al., 2017), the southern aspect was preferred, possibly due to sunlight availability (Carlon, 1992). Published findings suggest that nest sites were influenced by cliff height for greater protection from predators (Pfeiffer et al., 2016). *Aegypus monachus* preferred elevations of 750 to 800 m (Mihoub et al., 2013) and at least 180 m in the case of *Gyps coprotheres* (Pfeiffer et al., 2016). However, in the current research Long-billed and Egyptian vultures showed preferences of 56–169 m. This indicated that elevation is linked to local topography rather than a species-specific requirement (Mihoub et al., 2013) and plays secondary role in nest site selection (Moran-Lopez et al., 2005).

In the current study, nesting distances of resident vultures from water bodies varied from a few meters to a few kilometers indicating the primary importance of vegetation suitability in preference to water proximity. This finding is supported elsewhere. African White-backed vultures are known to favor riparian vegetation for nesting (Monadjem, 2001; Monadjem & Garcelon, 2005) but this may vary when this vegetation type is scarce or absent (Tarboton & Allen, 1984; Monadjem & Garcelon, 2005). The strategy behind this appears to be the optimization of nest location guiding factors. The current study found many larger congregations near waterbodies and smaller populations distant from waterbodies.

5.3. Diclofenac threat

Many studies have reported diclofenac poisoning in vultures and the subsequent ban of the drug in the Indian subcontinent (Chaudhry et al., 2012; Paudel et al., 2016; Prakash et al., 2017 etc.). Our findings indicate the 2006 and 2015 diclofenac bans were being violated through the sale of forms of diclofenac manufactured for human use for veterinary purposes; this point also cited by Cuthbert et al. (2016). Published sources document the development of the diclofenac issue in India. The veterinary use of diclofenac was banned by the government of India on May 11, 2006 due to its impact on vulture populations (Taggart et al., 2007; DeVault et al., 2016). In 2008 it was made an offense to manufacture, retail or use of diclofenac for veterinary purpose (Richards et al., 2017). Later in July 2015, the Union Ministry of Health and Family Welfare banned multi-dose vials of this drug for human use (GSR 558(E) dated 17 July 2015) which was finally confirmed by the court in November 2017. This resulted in single dose vial packing for humans (The Wire, 2/04/2018). Recently the Drug Controller General of India (DCGI) has banned production and sale of a pain killer "Voveran 1ml", the diclofenac injection due to its negative impact on humans. The DGCI further ordered withdrawal of the drug's stock from the market (The Wire, 12/07/2018; Medical Dialogue, 13/07/2018). These actions impacted the pharmaceutical companies, with cascading effects on the economic links of the stakeholders in this industry. For example, there was a legal challenge by Laborate Pharmaceutical India Ltd. and Alpa Laboratories Ltd (Mandhani A. November 7, 2017, LiveLaw.in). Implementation of statutory provisions was also weak, leading to uncertainty as to its short-term effectiveness. This is supported by our findings, as the drug is still available in the market even as the writ petition (Laborate Pharmaceutical India vs Union of India) was dismissed by the court on 24/10/2017.

Even though licensed veterinary diclofenac manufacture, sale and use was banned in India, injectable human formulations have remained very widely available for unrestricted purchase (Saini et al., 2012). The threat to vultures still exists, as long as these other formulations could be used on the animals. Our findings, also supported by those of Cuthbert et al. (2017) and Galligan et al. (2020), suggested that despite the ban in 2006 and then in 2015, diclofenac drugs were still being used directly or indirectly on cattle even in October 2018, with consequent impacts on vultures. Any declaration that classifies the areas around PAs as vulture safe zones is therefore risky, unless the use of the drug is eliminated. As hinted by Taggart et al. (2007) the removal of both the veterinary diclofenac and the multi-dose human formulation from the market, quickly and effectively, is essential. This study also suggests the claim of vulture population recovery on account of ban on manufacture and sale of veterinary diclofenac (Galligan et al., 2014; Prakash et al., 2017) may be premature, and should be deferred until more definitive evidence of a total ban is derived. The authors could not trace the use of diclofenac among the remnant cattle population in PAs. However, the small towns where diclofenac was available are located less than 50 km from the PAs. The surrounding non-forest and settled areas, with dense cattle herds where stealthy use of the drug may create risks for the vultures of PAs.

It is evident from the study that statutory bans on drug use have been found to be insufficient on their own (Safford et al., 2019). Consumers as well as producers of the drug need to be counselled against the unethical practice, with explanations of the ecological externalities.

6. Conclusion

Vulture presence was higher in PAs than forest and agriculture areas. These findings may illustrate the healthy impact of conservation programs on this keystone species. Nesting and reproductive success was an indicator of the habitat suitability at the sites (Majgaonkar et al., 2018). Factors for success included the availability of tall trees, caves and ledges in the cliffs, minimized human made disturbance and nearby water sources. The PAs should be made inviolate at the earliest, potential nesting trees should be preserved and road traffic must be regulated to optimum level, as these habitat characteristics play important role in nesting choice in addition to protection (Bamford et al., 2009).

The PAs appear to have had a positive impact on vulture conservation. However, the indirect poisoning of vultures may hamper these impacts. The government aims to protect the vultures from poisoning, but manufacturing companies have continued producing diclofenac under the garb of court cases. Stealthy use of the drug continues, as pre-court decisions allow market availability until the expiry period of 02/2020. In simple words, diclofenac risk has not been eliminated even after12 years of efforts. Government strategy must be revamped to ensure absolute implementation of the ban to achieve complete and early success. Simultaneously, environmental education should be promoted in conservation programs, especially in the vultures' ranges (Nambirajan et al., 2017).

These findings contribute to knowledge of the relationship between PAs and vultures. However, further studies must examine vulture mortality rates and nesting successes at temporal scales, and the use and impact of other anti-inflammatory drugs etc. (Cuthbert et al., 2016). Such investigations may increase understanding of the hypothesis that PAs do play strong roles in vulture, keystone species, conservation (Thiollay, 2006; Murn et al., 2013, 2016).

Acknowledgements

The authors are thankful to the PCCF, and the CWLW MP Forest Department, Member Secretary, MP State Biodiversity Board, and the Director IIFM for supporting the Vulture Census Project in MP. Shri Ankit Sinha deserves thanks for his initial support in performing the task.

References

AAR, 2000, Annual Administrative Report. Bhopal: Forest Department, Government of Madhya Pradesh.

Acharya R., Cuthbert R., Baral H.S. & Chaudhary A., 2010, Rapid decline of the Bearded Vulture *Gypaetus barbatus* in Upper Mustang, Nepal. Forktail 26: 117–120.

Acharya R., Cuthbert R., Baral H.S. & Shah K.B., 2009, Rapid population declines of Himalayan Griffon *Gyps himalayensis* in Upper Mustang, Nepal. Bird Conservation International 19: 99–107. doi:10.1017/S0959270908007417.

Alarcon P.A.E. & Lambertucci S.A., 2018, A three-decade review of telemetry studies on vultures and condors. Movement Ecology 6: 13. https://doi.org/10.1186/s40462-018-0133-5.

Bamford A.J., Monadjem A. & Hardy I.C.W., 2009, Nesting habitat preference of the African White-backed Vulture *Gyps africanus* and the effects of anthropogenic disturbance. Ibis 51: 51–62.

Bevers M. & Flather C.H., 1999, The distribution and abundance of populations limited at multiple spatial scales. Journal of Animal Ecology 68: 976–987.

Bosakowski T., & Speiser R., 1994, Macrohabitat selection by nesting northern goshawks: implications for managing eastern forests. Study of Avian Biology 16: 46–49.

Bridgeford P. & Bridgeford M., 2003, Ten years of monitoring breeding Lappet-faced Vultures *Torgos tracheliotos* in the Namib-Naukluft Park, Namibia. Vulture News 48: 3–11.

Bruner A. G., Gullison R.E., Rice R.E. & Fonseca G.A.B., 2001, Effectiveness of parks in protecting tropical biodiversity. Science 291: 125–128.

Buechley E.R., McGrady M.J., Çoban E. & Şekercioğlu Ç.H., 2018., Satellite tracking a wide-ranging endangered vulture species to target conservation actions in the Middle East and East Africa. Biodiversity & Conservation 27(9): 2293–2310. DOI:10.1007/s10531-018-1538-6.

Campbell M.O., 2017, The conservation biology of vultures, [in:] M.O. Campbell (ed.), Biological Conservation in

21st Century: A Conservation Biology of Large Wildlife. Nova Science Publishers, New York.

Carlon J., 1992, Breeding phenology of the Egyptian vulture, World Working Group on Birds of Prey and Owls. Newsletter 16/17: 12–13.

Caro T., 2010, Conservation by proxy: indicator, umbrella, keystone, flagship, and other surrogate species. Island Press, Washington, DC.

Carrete M., Grande J.M., Tella J.L., Sanchez-Zapata J.A., Donazar J.A., Dıaz-Delgado R. & Romo A., 2007, Habitat, human pressure, and social behavior: Partialling out factors affecting large-scale territory extinction in an endangered Vulture. Biological Conservation 136(1): 143–154.

Ceballos O. & Donazar J.A., 1989, Factors influencing the breeding density and nest site selection of the Egyptian vulture. Journal of Ornithology 130: 353–359.

Chaudhry M.J.I., Ogada D.L., Malik R.N., Virani M.Z. & Giovanni M.D., 2012, 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, Bird Conservation International 22: 389–397. DOI:10.1017/S0959270912000445

Chomba C., M'simuko E. & Nyirenda V., 2013, Patterns of nest placement of lappet faced vulture (*Torgos tracheliotos*) in Lochinvar National Park, Kafue Flats, Zambia. Open Journal of Ecology 3(6): 431–437. http://dx.doi.org/10.4236/oje.2013.36049

Chomba C. & Simuko E.M., 2013, Nesting patterns of raptors; White backed vulture (*Gyps africanus*) and African fish eagle (*Haliaeetus vocifer*) in Lochinvar National Park on the kafue flats, Zambia. Open Journal of Ecology 3(5): 325–330.

Coetzee B.W.T., Gaston K.J. & Chown S.L., 2014, Local Scale Comparisons of Biodiversity as a Test for Global Protected Area Ecological Performance: A Meta-Analysis. PLoS ONE 9(8): e105824. DOI:10.1371/journal.pone.0105824

Convention on Biological Diversity, 2010, Strategic plan for biodiversity 2011–2020 - COP 10, decision X/2. Montreal, Canada.

Cortes-Avizanda A., Jovani R., Donazar J.A. & Grimm V., 2014, Bird sky networks: how do avian scavengers use social information to find carrion? Ecology 95: 1799–808.

Cuthbert R.J., Taggart M.A., Saini M., Sharma A., Das A., Kulkarni M.D., Deori P., Ranade S., Shiringarpure R.N, Galligan T.N. & Green R.E., 2016, Continuing mortality of vultures in India associated with illegal veterinary use of diclofenac and a potential threat from nimesulide. Oryx 50(1): 104–112. DOI:10.1017/S003060531500037X

Cuthbert R.J., Dave R., Chakraborty S.S., Kumar S., Prakash S., Ranade S.P. & Prakash V., 2017, Assessing the ongoing threat from veterinary non-steroidal anti-inflammatory drugs to Critically Endangered *Gyps* vultures in India. Oryx 45(3): 420–426. DOI:10.1017/S0030605311000135

Del Hoyo J., Elliot A. & Sargatal J., 1994, Handbook of the birds of the world, New world vultures to guineafowl, Vol 2. Lynx Edicions, Barcelona.

DeVault T.L., Beasley J.C., Olson Z.H., Moleon M., Carrete M., Margalida A. & Sanchez-Zapata J.A., 2016, Ecosystem Services Provided by Avian Scavengers, [in:] C.H. Şekercioglu, D.G. Wenny, C.J. Whelan (eds), Why Birds Matter: Avian Ecological Function and Ecosystem Services. University of Chicago Press, Chicago, pp. 235–270.

Ervin J., 2003, Protected area assessments in perspective. BioScience 53: 819–822.

FSI., 2011, Atlas: Forest Types of India. Forest Survey of India, Dehradun.

Galligan T.H., Amano T., Prakash V.M., Kulkarni M., Shringarpure R., Prakash N., Ranade S., Green R.E. & Cuthbert R.J., 2014, Have population declines in Egyptian Vulture and Redheaded Vulture in India slowed since the 2006 ban on veterinary diclofenac? Bird Conservation International / FirstView Article / April 2014, pp. 1–10. DOI: 10.1017/S0959270913000580.

Galligan T.H., Mallord J.W., Prakash V.M., Bhusal K.P., Alam A.B.M.S., Anthony F.M., Dave R., Dube A., Shastri K., Kumar Y., Prakash N., Ranade S., Shringarpure R., Chapagain D., Chaudhary I.P., Joshi A.B., Paudel K., Kabir T., Ahmed S., Azmiri K.Z., Cuthbert R.J., Bowden C.G.R. & Green R.E., 2020, Trends in the availability of the vulture-toxic drug, diclofenac, and other NSAIDs in South Asia, as revealed by covert pharmacy surveys. Bird Conservation International (2020), page 1 of 17. DOI:10.1017/S0959270920000477

Galvez N., Hernandez F., Laker J., Gilabert H., Petitpas R., Bonacic C., Gimona A., Hester A. & MacDonald D.W., 2013, Forest cover outside protected areas plays an important role in the conservation of the Vulnerable guiña *Leopardus guigna*. Oryx 47: 251–258.

Gaston K.J., Jackson S.F., Cantu-Salazar L. & Cruz-Pinon G., 2008, The ecological performance of protected areas. Annual Review of Ecology Evolution and Systematics 39: 93–113.

Hardey J., Crick H., Wenham C., Riley H., Etheridge B. & Thompson D., 2009, Raptors. A field guide for surveys and monitoring. The Stationery Office, Edinburgh.

Henriques M., Granadeiro J.P., Monteiro H., Nuno A., Lecoq M., Cardoso P., Regalla A., Catry P., 2018, Not in wilderness: African vulture strongholds remain in areas with high human density. PLOS One 13(1): e0190594. https://doi.org/10.1371/journal.pone.0190594

Hollander F.A., Van Dyck H., San Martin G. & Titeux N., 2011, Maladaptive habitat selection of a migratory passerine bird in a human-modified landscape. PLoS One 6: e25703.

ISFR, 2011, India State Forest Report. 9.15 Madhya Pradesh. Forest Survey of India, Dehradun.

Janes S.W., 1985, Habitat selection in raptorial birds, [in:] M.L. Cody (ed.), Habitat selection in birds. Academic, San Diego, pp. 159–188.

Jha K.K., 2017, Vulture Atlas – Central India, MP. Indian Institute of Forest Management, Bhopal, India.

Jha K.K., 2018, Mapping and Management of Vultures in Indian stronghold, [in:] M.O. Campbell (ed.), Biological Conservation and Geomatics. NOVA Science Publisher, New York, pp. 45–75.

Jha K.K., Campbell M.O. & Jha R., 2020, Vultures, their population status and some ecological aspects in an Indian stronghold. Notulae Scientia Biologicae 12(1): 124–142. DOI:10.15835/nsb12110547.

Jha K.K. & Jha R., 2020, Habitat suitability mapping for migratory and resident vultures: A case of Indian stronghold and species distribution model. Journal of Wildlife and Biodiversity 4(3): 91–111.

Jha K.K. & Jha R., 2021, Study of Vulture Habitat Suitability and Impact of Climate Change in Central India Using MaxEnt. Journal of Resources and Ecology. 12(1): 30–42. DOI: 10.5814/j.issn.1674-764x.2021.01.004

Juffe-Bignoli D., Burgess N.D., Bingham H., Belle E.M.S., de Lima M.G., Deguignet M., Bertzky B., Milam A.N., Martinez-Lopez J., Lewis E., Eassom A., Wicander S., Geldmann J., van Soesbergen A., Arnell A.P., O'Connor B., Park S., Shi Y.N., Danks F.S., MacSharry B. & Kingston N., 2014, Protected planet report 2014. UNEP-WCMC, Cambridge, England.

Kalinkat G., Cabral J.S., Darwall W., Ficetola G.F., Fisher J.L., Giling D.P., Gosselin M.-P., Grossart H.-P., Jahnig S.C., Jeschke J.M., Knopfe K., Larsen S., Onandia G., Patzig M., Saul W.C., Singer G., Sperfeld E. & Jaric I., 2017, Flagship umbrella species needed for the conservation of overlooked aquatic biodiversity. Conservation Biology 31(2): 481–485. DOI: 10.1111/cobi.12813

Kamp J., Koshkin M.A., Bragina T.M., Katzner T.E., Milner-Gulland E.J., Schreiber D., Sheldon R., Shmalenko A., Smelansky I., Terraube J. & Urazaliev R., 2016, Persistent and novel threats to the biodiversity of Kazakhastan's steppes and semi-deserts. Biodiversity Conservation 25: 2521–2541.

Kendall C.J., Rubenstein D.I., Slater P.L. & Monadjem A., 2017, An assessment of tree availability as a possible cause of population declines in scavenging raptors. Journal of Avian Biology 48: 001–008. DOI: 10.1111/jav.01497.

Kolahi M., Sakai T., Moriya K., Makhdoum M.F. & Koyama L., 2013, Assessment of the Effectiveness of Protected Areas Management in Iran: Case Study in Khojir National Park. Environmental Management 52: 514–530. DOI 10.1007/s00267-013-0061-5

Kruger S.C., Simmons R.E. & Amar A., 2015, Anthropogenic activities influence the abandonment of Bearded Vulture (*Gypaetus barbatus*) territories in southern Africa. Condor 117: 94–107.

Kudo T., Ozaki K., Takao G., Sakai Yonekawa H. & Ikeda K., 2005, Landscape analysis of northern goshawk breeding home range in northern Japan. Journal of Wildlife Management 69: 1229–1239.

Lewis E., McSharry B., Juffe-Bignoli D., Harris N., Burrows G., Kingston N., & Burgess N.D., 2017, Dynamics in the global protected-area estate since 2004. Conservation Biology 33: e32529. https://doi.org/10.1111/cobi.13056

Liberatori F. & Penteriani V., 2001, A long-term analysis of the declining population of the Egyptian vulture in the Italian peninsula: distribution, habitat preference, productivity and conservation implications. Biological Conservation 101: 381–389.

Majgaonkar I., Bowden C.G.R. & Quader S., 2018, Nesting success and nest-site selection of white-rumped vultures (*Gyps bengalensis*) in western Maharashtra, India. Journal of Raptor Research 52(4): 431–442.

Mandhani A., November 7, 2017 (LiveLaw.in). https://www.livelaw.in/madras-hc-upholds-ban-multiple-dosage-diclofenac-save-vultures-read-order/

Marinkovic S.P., Orlandic L.B., Skoric S.B. & Karadzic B.D., 2012, Nest-Site Preference of Griffon Vulture (*Gyps fulvus*) in Herzegovina. Archives of Biological Science, Belgrade 64 (1): 385–392.

Markandya A., Taylor T., Longo A., Murty M.N., Murty S. & Dhavala K., 2008, Counting the cost of vulture decline – An appraisal of the human health and other benefits of vultures in India. Ecological Economics 67(2): 194–204. https://doi.org/10.1016/j.ecolecon.2008.04.020

Maslo B., Leu K., Faillace C., Weston M.A., Pover T. & Schlacher T.A., 2016, Selecting umbrella species for conservation: A test of habitat models and niche overlap for beach-nesting birds. Biological Conservation 203: 233–242.

McGrady M.J., Grant J.R., Bainbridge I.P. & Mcleod D.R.A., 2002, A model of golden eagle (*Aquila chrysaetos*) ranging behavior. Journal of Raptor Research 36(Suppl): 62–69.

Mdhlano S.F., Gandiwa, E., Muboko N. & Mashapa C., 2018, Local knowledge and perceptions of vulture conservation in communities living adjacent to the northern Gonarezhou National Park, Zimbabwe. Vulture News 74. http://dx.doi.org/10.4314/vulnew.v74i1.1

Mihoub J-B., Jiguet F., Lecuyer P., Eliotout B. & Sarrazin F., 2013, Modelling nesting site suitability in a population of reintroduced Eurasian black vultures *Aegypius monachus* in the Grands Causses, France. Oryx 48(1): 116–124. DOI: 10.1017/S0030605312000634

Monadjem A., 2001, Observations on the African White-backed Vulture *Gyps africanus* nesting at Mlawula Nature Reserve, Swaziland. Vulture News 45: 3–10.

Monadjem A., 2003, Nest site selection by African White-backed Vulture in Swaziland. Vulture News 48: 24–26.

Monadjem A. & Garcelon D.K., 2005, Nesting distribution of vultures in relation to land use in Swaziland. Biodiversity and Conservation 14: 2079–2093. DOI: 10.1007/s10531-004-4358-9

Monadjem A., Wolter K., Neser W. & Bildstein K., 2016, Hooded Vulture *Necrosyrtes monachus* and African White-backed Vulture *Gyps africanus* nesting at the Olifants River Private Nature Reserve, Limpopo province, South Africa. Ostrich 87(2): 113–117. DOI: 10.2989/00306525.2016.1179690

Morales-Reyes Z., Perez-Garcia J.M., Moleon M., Botella F., Carrete M., Donazar J.A., Cortes-Avizanda A., Arrondo E., Moreno-Opo R., Jimenez J., Margalida A. & Sanchez-Zapata J.A., 2016, Evaluation of the network of protection areas for the feeding of scavengers in Spain: from biodiversity conservation to greenhouse gas emission savings. Journal of Applied Ecology 54: 1120–1129. DOI: 10.1111/1365-2664.12833

Moran-Lopez R., Guzman J.M.S., Borrego E.C. & Sanchez A.V., 2005, Nest-site selection of endangered cinereous vulture (*Aegypius monachus*) populations affected by anthropogenic disturbance: present and future conservation implications. Animal Conservation 9: 29–37. DOI:10.1111/j.1469-1795.2005.00003.x

Morant J., Zabala J., Martınez J.E. & Zuberogoitia I., 2018, Out of sight, out of mind? Testing the effects of overwinter habitat alterations on breeding territories of a migratory endangered species. Animal Conservation 21(6): 465–473. DOI:10.1111/acv.12412

Mundy P., 1982, The Comparative Biology of Southern African Vultures. Vulture Study Group, Johannesburg, South Africa.

Murn C., Combrink L., Ronaldson G.S., Thompson C. & Botha A., 2013, Population estimates of three vulture species in Kruger National Park, South Africa. Ostrich 84: 1-9.

Murn C., Mundy P., Virani M.Z., Borello W.D., Holloway G.J. & Thiollay J.M., 2016, Using Africa's protected area network to estimate the global population of a threatened and declining species: a case study of the Critically Endangered white-headed vulture *Trigonoceps occipitalis*. Ecology and Evolution 6: 1092–1103.

Nambirajan K., Muralidharan S., Roy A.A. & Manonmani S., 2017, Residues of Diclofenac in Tissues of Vultures in India: A Post-ban Scenario. Archives of Environmental Contamination and Toxicology 74(2): 292–297. https://doi.org/10.1007/s00244-017-0480-z

Naughton-Treves L., Holland M.B. & Brandon K., 2005, The role of protected areas in conserving biodiversity and sustaining local livelihoods. Annual Review of Environment and Resources 30: 219–52. DOI: 10.1146/annurev.energy.30.050504.164507

Newton I., 2010, Population ecology of raptors. Poyser Monographs, Bloomsbury Publishing, London.

Ogada D., Shaw P., Beyers R.L., Buij R., Murn C., Thiollay J-M., Beale C.M., Holdo R.M., Pomeroy D., Baker N., Krüger S.C., Botha A., Virani M.Z., Monadjem A. & Sinclair A.R.E., 2016, Another continental vulture crisis: Africa's vultures collapsing toward extinction. Conservation Letter 9: 89–97.

Oppel S., Dobrev V., Arkumarev V., Saravia V., Bounas A., Manolopoulos A., Kret E., Velevski M., Popgeorgiev G.S. & Nikolov S.C., 2016, Landscape factors affecting territory occupancy and breeding success of Egyptian Vultures on the Balkan Peninsula. Journal of Ornithology 158: 443-457. DOI: 10.1007/s10336-016-1410-y

Paudel K., Bhusal K.P., Acharya R., Chaudhary A., Baral H.S., Chaudhary I.P., Green R.E., Cuthbert R.J. & Galligan T.H., 2016, Is the population trend of the Bearded Vulture *Gypaetus barbatus* in Upper Mustang, Nepal, shaped by diclofenac? Forktail 32: 54–57.

Pfeiffer M.B., Venter J.A. & Downs C.T., 2016, Cliff characteristics, neighbour requirements and breeding success of the colonial Cape Vulture *Gyps coprotheres*. Ibis 159: 26–37.

Phipps W.L., Willis S.G., Wolter K. & Naidoo V., 2013, Foraging ranges of immature African white-backed vultures (*Gyps africanus*) and their use of protected areas in southern Africa. PLoS One 8(1): e52813.

Poirazidis K., Goutner V., Skartsi T. & Stamou G., 2004, Modelling nesting habitat as a conservation tool for the Eurasian black vulture (*Aegypius monachus*) in Dadia Nature Reserve, northeastern Greece. Biological Conservation 118: 235–248.

Prakash V., Galligan T.H., Chakraborty S.S., Dave R., Kulkarni M.D., Prakash N., Shringarpure R.N., Ranade S.P. & Green R.E., 2017, Recent changes in populations of Critically Endangered *Gyps* vultures in India. Bird Conservation International 29(1): 55–70. DOI: 10.1017/S0959270917000545

Prakash V., Green R.E., Pain D.J., Ranade S.P., Saravanan S., Prakash N., Venkitachalam R., Cuthbert R., Rahmani A.R. & Cunningham A.A., 2007, Recent changes in populations of resident Gyps vultures in India. Journal of the Bombay Natural History Society 104(2): 129–135.

Prommer M., Bagyura J., Chavko J. & Uhrin M., 2012, Migratory movements of central and eastern European

Saker falcons (Falco cherrug) from juvenile dispersal to adulthood. Aquila 119: 111–134.

Protected Planet, 2021, Discover the world's protected areas. Retrieved from https://www.protectedplanet.net/en

Richards N.L., Gilbert M., Taggart M. & Naidoo V., 2017, A Cautionary Tale: Diclofenac and Its Profound Impact on Vultures. Encyclopedia of the Anthropocene, pp. 1–10. http://dx.doi.org/10.1016/B978-0-12-409548-9.09990-5

Roberge J-M. & Angelstam P., 2004, Usefulness of the umbrella species concept as a conservation tool Conservation Biology 18: 76–85.

Rodrigues A.S.L., Andelman S.J., Bakarr M.I., Boitani L., Brooks T.M., Cowling R.M., Fishpool L.D.C., da Fonseca G.A.B., Gaston K.J., Hoffmann M., Long J.S., Marquet P.A., Pilgrim J.D., Pressey R.L., Schipper J., Sechrest W., Stuart S.N., Underhill L.G., Waller R.W., Watts M.E.J. & Yan X., 2004, Effectiveness of the global protected area network in representing species diversity. Nature 428: 640–643.

Rodriguez-Lado, L. & Tapia L., 2012, Suitable breeding habitat for golden eagle (*Aquila chrysaëtos*) in a border of distribution area in northwestern Spain: advantages of using remote sensing information vs land use maps. Vie et Milieu 62: 77–85.

Ruxton G.D. & Houston D.C., 2004, Obligate vertebrate scavengers must be large soaring fliers. Journal of Theoretical Biology 228: 431–436.

Safford R., Andevski J., Botha A., Bowden C.G.R., Crockford N., Garbett R., Margalida A., Ramírez I., Shobrak M., Tavares J. & Williams N.P., 2019, Vulture conservation: the case for urgent action. Bird Conservation International 29: 1–9. DOI: 10.1017/S0959270919000042

Saini M., Taggart M.A., Knopp D., Upreti S., Swarup D., Das A., Gupta P.K., Niessner R., Prakash V., Mateo R. & Cuthbert R.J., 2012, Detecting diclofenac in livestock carcasses in India with an ELISA: A tool to prevent widespread vulture poisoning. Environmental Pollution 160: 11–16.

Santangeli A., Girardello M., Buechley E., Botha A., Di Minin E. & Moilanen A., 2019, Priority areas for conservation of Old World vultures. Conservation Biology 33(5): 1056–1065. DOI: 10.1111/cobi.13282

Sara M. & Di Vittorio M., 2003, Factors influencing the distribution, abundance and nest-site selection of an endangered Egyptian vulture (*Neophron percnopterus*) population in Sicily. Animal Conservation 6: 1–12. DOI: 10.1017/S1367943002004000

Seddon P.J. & Leech T., 2008, Conservation short cut, or long and winding road? A critique of umbrella species criteria. Oryx 42: 240–245.

Sen B., Tavers J.P. & Bilgin C.C., 2017, Nest site selection patterns of a local Egyptian Vulture *Neophron percnopterus* population in Turkey. Bird Conservation International 27: 568–581. DOI: 10.1017/S0959270916000411

Sergio F., Marchesi L. & Pedrini P., 2004, Integrating individual habitat choices and regional distribution of a biodiversity indicator and top predator. Journal of Biogeography 31: 619–628.

SFRI, 2016, Status Report: Tigers. Co-predators and prey in protected areas of Madhya Pradesh. State Forest Research Institute, Jabalpur, MP, India.

Shultz S., Baral H.S., Charman S., Cunningham A.A., Das D., Ghalsasi G.R., Goudar M.S., Green R.E., Jones A., Nighot P., Pain D.J. & Prakash V., 2004, Diclofenac poisoning is widespread in declining vulture populations across the Indian subcontinent. Biology Letters 271: 458–460.

Stem C., Margoluis R., Salafsky N. & Brown M., 2005, Monitoring and evaluation in conservation: a review of trends and approaches. Conservation Biology 19: 295–309.

Subedi T.R., Virani M.Z., Gurung S., Buij R., Baral H.S., Buechley E.R., Anadon J.D. & Sah S.A.M., 2018, Estimation of population density of bearded vultures using line-transect distance sampling and identification of perceived threats in the Annapurna Himalaya range of Nepal. Journal Raptor Research 52(4): 443–453.

Sweke E.A., Assam J.M., Chande A.I., Mbonde A.S., Mosha M. & Mtui A., 2016, Comparing the Performance of Protected and Unprotected Areas in Conserving Freshwater Fish Abundance and Biodiversity in Lake Tanganyika, Tanzania. International Journal of Ecology Volume 2016, Article ID 7139689, 7 pp. http://dx.doi.org/10.1155/2016/7139689.

Taggart M.A., Senacha K.R., Green R.E., Jhala Y.V., Raghavan B., Rahmani A.R., Cuthbert R., Pain D.J. & Meharg A.A., 2007, Diclofenac residues in carcasses of domestic ungulates available to vultures in India. Environment International 33: 759–765.

Tanferna A., Lopez-Jimenez L., Blas J., Horaldo F. & Sergio F., 2013, Habitat selection by black kite breeders and floaters: implications for conservation management of raptor floaters. Biological Conservation 160: 1–9.

Tapia L. & Zuberogoitia I., 2018, Breeding and Nesting Biology in Raptors, [in:] J.H. Sarasola, J.M. Grande, J.J. Negro (eds), Birds of Prey. Springer International Publishing AG, part of Springer Nature 2018, pp. 63–94. https://doi.org/10.1007/978-3-319-73745-4_3

Tarboton W.R. & Allan D.G., 1984, The Status and Conservation of Birds of Prey in the Transvaal. Transvaal Museum Monograph 3, Pretoria, South Africa.

Thakur M.L. & Narang S.K., 2012, Population status and habitat-use pattern of Indian White-backed vulture (*Gyps bengalensis*) in Himachal Pradesh, India. Journal of Ecology and the Natural Environment 4(7): 173–180.

Thiollay J.M., 2006, The decline of raptors in West Africa: long-term assessment and the role of protected areas. Ibis 148: 240–254.

Virani M., Kirui P., Monadjem A., Thomsett S. & Githiru M., 2010, Nesting status of African White-backed Vultures *Gyps africanus* in the Masai Mara National Reserve, Kenya. Ostrich 81(3): 205–209.

Virani M.Z., Kendall C., Njoroge P. & Thomsett S., 2011, Major declines in the abundance of vultures and other scavenging raptors in and around the Masai Mara ecosystem, Kenya. Biological Conservation 144: 746–752.

Vlachos C.G., Papageorgiu N.K. & Bakaloudis D.E., 1998, Effects of the feeding station establishment on the Egyptian Vulture *Neophron percnopterus* in Dadia Forest, north eastern Greece, [in:] B.U. Meyburg, R.D. Chancellor (eds), Holarctic birds of prey. WWGBP, London, UK.

Watson J.E.M., Dudley N., Segan D.B. & Hockings M., 2014, The performance and potential of protected areas. Nature 515: 67–73.

Zuberogoitia I., Gonzalez-Oreja J.A., Martínez J.E., Zabala J., Gomez I. & Lopez-Lopez P., 2013, Foraging movements of Eurasian griffon vultures (*Gyps fulvus*): implications for supplementary feeding management. European Journal of Wildlife Research 59: 421–429.

Zuberogoitia I., Zabala J., Martinez J.E., Gonzalez-Oreja J.A. & Lopez-Lopez P., 2014, Effective conservation measures to mitigate the impact of human disturbances on the endangered Egyptian vulture. Animal Conservation 17: 410–418.