An updated account of mammal species and population status of ungulates in Keoladeo National Park, Bharatpur, Rajasthan

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This study documents the present status of mammals in Keoladeo National Park (KNP) and assesses the population structure of ungulates. It provides a comprehensive account of the mammal diversity of the park and aims to compare the change in mammalian species account ever since the park became a protected area. We employed line transect surveys for density estimation of ungulates. We report local extinction of eight species since 1966, and extant diversity of 34 mammalian species in KNP. The estimated densities of chital, feral cattle, nilgai, wild boar and sambar were 52.37, 33.66, 13.68, 3.21 and 0.32 individuals/km^2 respectively. Although blackbuck has become locally extinct and sambar density has significantly reduced, chital and nilgai as habitat generalists have increased in density in the last 25 years, which has contributed to an overall increase in ungulate population density in KNP. The mammalian diversity has changed substantially with local extinction of some carnivores and constant change in the habitat condition.

Keywords: Distance sampling, density, local extinction, mammal account, population dynamics, ungulates.

MONITORING and sporadic documentation of animal populations at landscape and global scales can advance our understanding of ecosystem responses towards any change[1]. A diverse habitat supports numerous species, while a dynamic habitat changes frequently through processes like vegetation succession, human activities and environmental variations, thus influencing the species occurrence[2]. Changes in habitat affect species richness[3,4], population abundance and distribution[5,6], thereby affecting the local distribution of species around the world. Understanding the social behaviour and demography of wild animals plays a major role in population monitoring and effective conservation planning[7,8]. Monitoring the population dynamics of herbivores, in particular, helps in comprehending various ecological processes at landscape and ecosystem levels[9]. Herbivores play a major role in forest ecosystems by influencing forest structure, composition, productivity, nutrient cycling and soil structure[10,11]. Herbivore biomass specifically contributes considerable proportion of prey base of any area and has been used to compare the carrying capacity of different habitats[12].

Understanding the response of different species towards changing habitat conditions over a period of time is crucial to manage the species or the habitat. In semi-arid areas with high human density, the forests are highly fragmented with minimal water resources resulting in increased dependency on restricted available resources[13,14]. Such sensitive ecosystems with localized wetlands buffered with vegetation cover are further vulnerable to disturbance due to high dependency on them by people, their livestock and wildlife[15]. The Keoladeo National Park (KNP) in India is one such wetland in the semi-arid zone designated as a world heritage site[14]. It is a 29 sq. km dynamic ecosystem with rich floral and faunal diversity[14]. Ever since the park's creation in 1956 it witnessed several changes in the ecosystem, eventually leading to alterations of the dependent wildlife. The major change in the habitat is primarily due to extensive invasion by *Prosopis juliflora* which not only replaced the native floral community but has vastly affected the large herbivore community that contributes to significant animal biomass of the area[16]. Cattle grazing is also one of the key reasons of altered ecosystem of the park[17]. There has been much debate about the reintroduction of cattle[18] in the park; especially domestic water buffaloes[18,19] which could control the spread of wild grass *Paspalum distichum*[19]. The idea is however flawed in the sense that the wild herbivores are already serving this function[20]. Such continuous habitat modifications and the associated change in species diversity if monitored periodically can help evaluate the success or failure of management action plans[21]. The present study aims to provide a comprehensive account of the mammal diversity of Keoladeo National Park, along with the present status of population structure of the ungulates of the area. The study also compares the

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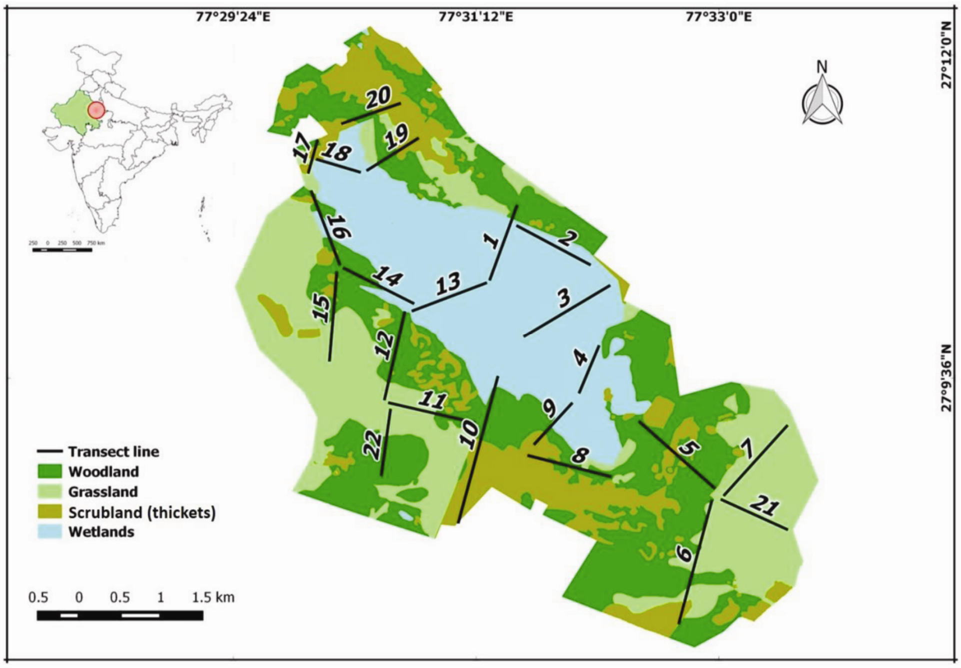

Figure 1. Transects used for density estimation of the ungulate species in Keoladeo National Park, India.

change in mammalian species account ever since the park was declared a protected area.

Material and methods

Study area

The Keoladeo National Park (KNP; 27°7.6′–27°12.2′N and 77°29.5′–77°33.2′E), a world heritage as well as ramsar site[15] is a 29 sq. km walled reserve, divided into 15 management blocks and surrounded by around 14 villages. The park, an artificially maintained refuge for waterfowls, was developed in 1966 through controlled management of water level[16,17]. It is a flat area with a mild slope towards the centre that creates a depression, thus forming a wetland spanning 8.5 sq. km. The terrestrial area is covered with thick alluvial soil with saline patches. The temperature of the area varies from 0.5°C to 50°C (ref. 22) with annual average rainfall being 655 mm over the past 100 years (ref. 15). It is covered with dry mixed deciduous forest type with a mixture of xerophytic and semi-xerophytic plant species[23]. KNP has a mosaic of habitats that comprises wetland, woodland (dominated by mature trees of *Acacia nilotica*, *Mitragyna parvifolia*, *Prosopis cineraria*, *Syzygium cumini* and *Zizyphus mauritiana*), scrub forest (dominated by thickets of *Salvadora persica*, *S. oleoides*, *Capparis sepiaria*, *C. decidua* invaded by *P. juliflora*) and grassland (dominated by *Desmostachya bipinnata*, *Saccharum munja*, *S. spontaneum* and *Vetiveria zizanioides*) that support diversity of plant and animal species. KNP, popularly known as a 'bird paradise', is also rich in flora and fauna, with more than 350 species of birds, 27 mammals, 13 reptiles, 7 amphibians, 40 fish and 375 species of angiosperms[23]. In the past few decades, the park is combating serious pressures of environment degradation due to frequent droughts and threats from three major invasive species including *Eichorrnia crassipes*, *Paspalam disticum* and *P. juliflora*[24]. In view of these issues, several management plans have been laid out by both government[25] and non-government agencies including regulating the seasonal water level important for maintaining the ecological serial stages, and forming ecodevelopmental communities (EDCs) for reviving the local natural heritage through frequent plantation programmes and regular eradication of invasive species[26].

Field methods

Mammal richness

A checklist of mammals in the park was developed based on sightings and captures in the camera traps during the study in addition to previously published records[18,27–31] and evidences obtained from forest department in the form of confiscated animals and skins of animals.

Density estimation and population structure

The study was conducted between October 2014 and June 2015. We used line transect surveys[32,33] to estimate the density of ungulate species namely, nilgai (*Boselaphus tragocamelus*), chital (*Axis axis*), sambar (*Cervus

Table 1. Checklist of the mammals found in Keoladeo National Park

Species	Scientific name	IUCN status	Present status	Year of last seen
Ungulates				
Blackbuck	*Antilope cervicapra*	NT	A (PR)	1992 (ref. 18)
Chital	*Axis axis*	LC	P (S)	
Nilgai	*Boselaphus tragocamelus*	LC	P (S)	
Sambar	*Rusa unicolor*	VU	P (S)	
Wild boar	*Sus scrofa*	LC	P (S)	
Feral cattle	*Bos indicus*	LC	P (S)	
Domestic water buffalo	*Bubalus bubalis*	EN	A(PR)	1981 (ref. 18)
Hog deer	*Axis porcinus*	EN	P (S)	
Carnivores				
Tiger	*Panthera tigris*	EN	A (PR)	2011 (ref. 42)
Leopard	*Panthera pardus*	NT	A (PR)	2016 (ref. 41)
Golden jackal	*Canis aureus*	LC	P (S)	
Striped hyaena	*Hyaena hyaena*	NT	P (S)	
Indian fox	*Vulpes bengalensis*	LC	A (PR)	1966 (ref. 28)
Jungle cat	*Felis chaus*	LC	P (S)	
Fishing cat	*Prionailurus viverrinus*	EN	P (S)	
Leopard cat	*Prionailurus bengalensis*	LC	A (PR)	1992 (ref. 27)
Rusty spotted cat	*Prionailurus rubiginosus*	NT	P(S)	
Small Indian civet	*Viverricula indica*	LC	P (S)	
Common palm civet (Toddy cat)	*Paradoxurus hermaphrodites*	LC	P (S)	
Indian grey mongoose	*Herpestes edwardsii*	LC	P (S)	
Smooth coated otter	*Lutrogale perspicillata*	VU	A (PR)	1995 (ref. 54)
Bats				
Fulvous leaf-nosed bat[31]	*Hipposideros fulvus*	LC	P	
Short-nosed fruit bat[30]	*Cynopterus sphinx*	LC	P	
Asiatic greater yellow house bat[29]	*Scotophilus heathii*	LC	P	
Asiatic lesser yellow house bat[29]	*Scotophilus kuhlii*	LC	P	
Hares				
Indian hare	*Lepus nigricollis*	LC	P (S)	
Rufous-tailed hare	*Lepus nigricollis ruficaudatus*	LC	P (S)	
Pangolins				
Indian pangolin	*Manis crassicaudata*	EN	P (S)	
Primates				
Rhesus macaque	*Macaca mulatta*	LC	P (S)	
Hanuman langur	*Semnopithecus entellus*	LC A	(PR)	1992 (ref. 27)
Shrews				
House-shrew	*Suncus murinus*	LC	P (S)	
Hedgehog				
Indian hedgehog	*Paraechinus micropus*	LC	P (S)	
Rodents				
Indian crested porcupine	*Hystrix indica*	LC	P (S)	
Three-striped palm squirrel	*Funambulus palmarum*	LC	P (S)	
Five-striped palm squirrel	*Funambulus pennantii*	LC	P (S)	
Indian gerbil	*Tatera indica*	LC	P (S)	
House mouse	*Mus musculus*	LC	P (S)	
Little Indian field mouse	*Mus booduga*	LC	P (S)	
House rat	*Rattus rattus*	LC	P (S)	
Greater bandicoot rat	*Bandicota indica*	LC	P (S)	
Indian mole rat	*Bandicota bengalensis*	LC	P (S)	
Indian bush Rat	*Golunda ellioti*	LC	P (S)	
Indian gerbil	*Tatera indica*	LC	P (S)	

C, Least concerned; VU, vulnerable; NT, near threatened; EN, endangered; P, present; A, absent; PR, previously reported; S, Sighted.

unicolor), wild boar (*Sus scrofa*) and feral cattle (*Bos indicus*). The study involved visual counts of animals[9,21], an extensively used method for estimating abundance. A total of 22 transects (Figure 1) were randomly laid across all four major habitat types of the park. The total length of transect lines was 23.96 km. Each transect was monitored 8 times at dawn (05 : 00–09 : 00 h) and dusk (16 : 00–19 : 00 h), at a speed of 1 km/h totalling 176 surveys of 22 transects. For each sighting (detection of a 'cluster') of a species, we recorded the identity of the species, number of individuals sighted, age and sex of the individuals, observer–animal distance (r) using Nikon forestry pro range finder and sighting angle (θ) using Suunto compass.

Analytical methods

Density estimation and population structure

The encounter rate of all ungulate species was obtained by dividing the number of animals sighted by the length of transects (animals per kilometer). Generalized linear model (GLM)[34] with Poisson distribution was performed to compare differences of encounter rate between ungulate species and habitat types. GLM was run with number of individuals of each species in each transect as response variable with log transformed transect length as offset parameter. The analyses were done using *R* statistical language V 3.3.2 with *R* studio 1.0.4 (ref. 35). For group size, Kruskal Wallis *H* tests were performed to compare the group size of each ungulate species between habitat types. The average group size of ungulates for each transect was used for analysis. We also grouped each ungulate species in different group size-class, age-sex categories and ratios, i.e. percentages of adults and young ones, male per female and young ones per female.

The distance data was analysed using 'DISTANCE' software v. 6.0.3 (ref. 36) and the density was computed separately for each species. The animal detection data from the replicated transects were pooled and treated as a single sample (transect) for each species (sample size = 22 transects). The measure of parsimony among competing models for each dataset was examined using Akaike's information criterion (AIC) values[37] that give an agreement between the quality of fit and the number of model parameters to achieve the model, generated by the program DISTANCE. The best possible model with lowest AIC values was then selected[38,39]. We estimated encounter rate (n/l), average probability of detection ($\hat{p}$), cluster density ($\hat{D}g$), cluster size ($\hat{Y}$) and animal density ($\hat{D}$) using the selected model in 'Distance'. Depending on the outliers, the detection distances for each species were truncated to achieve the best fitted model as AIC cannot be used to choose between models that have different truncation distances[33,39]. Outliers are truncated to fit the best fit line to achieve the best estimate[33]. Density estimated for each ungulate species was then used to calculate biomass using the live weights of different ungulates[12,40].

Results

Mammal richness

A total of 43 mammals have been reported from KNP (Table 1). Tiger (*Panthera tigris*), leopard (*Panthera pardus*), blackbuck (*Antilope cervicapra*), smooth-coated otter (*Lutrogale perspicillata*), leopard cat (*Prionailurus bengalensis*), Indian fox (*Vulpes bengalensis*) and Hanuman langur (*Semnopithecus entellus*) were reported in the past, but are now locally extinct from the area. Fishing cat (*Prionailurus viverrinus*) was thought to be locally extinct from the area, until occasional sightings occurred during the study period. Hog deer (*Axis porcinus*) was also sighted in 2016 from the region in which it was earlier considered locally extinct. A solitary rusty-spotted cat *Prionailurus rubiginosus* was also camera-trapped for the first time from the region. Indian pangolin (*Manis crassicaudata*) was sighted occasionally from the region. According to the nominal distribution of the bats in this region[30], four species of bats, fulvous leaf-nosed bat (*Hipposideros fulvus*), short-nosed fruit bat (*Cynopterus sphinx*), Asiatic greater yellow house bat (*Scotophilus heathii*) and Asiatic lesser yellow house bat (*Scotophilus kuhlii*) are expected to be present in KNP.

Encounter rate and population characteristics of large herbivores

The total encounter rate was significantly higher for chital (9.74 ± 21.93; Walds $Z = 98.22$, $P < 0.001$) and feral cattle (9.67 ± 21.84) followed by nilgai (5.92 ± 17.96), wild boar (0.29 ± 0.94) and sambar (0.20 ± 0.85). Across all habitat types (Table 2), the encounter rate for feral cattle was higher in wetland (19.57; Walds $Z = 19.27$, $P < 0.001$) than woodland (5.87), scrubland (4.39) and grassland (4.02). The encounter rate for nilgai was higher in wetland (16.30; Walds $Z = 15.982$, $P < 0.001$), followed by scrubland (3.61), woodland (1.54) and grassland (0.81). The encounter rate for chital was significantly higher in wetland (14.94; Walds $Z = 9.22$, $P < 0.001$), followed by woodland (8.69), grassland (7.61) and scrubland (5.22). The encounter rate for wild boar was significantly lower in grassland (0.17) than wetland (0.41; Walds $Z = 2.35$, $P = 0.02$) but was not different from woodland (0.28) and scrubland (0.16). There was no difference in encounter rate of sambar across different habitats.

There was no difference in group size (Table 2) between habitats for feral cattle ($\chi^2 = 2.54$, d$f = 3$, $P = 0.47$) and chital ($\chi^2 = 2.09$, d$f = 3$, $P = 0.55$). For nilgai, group size was significantly higher in scrubland

Table 2. Encounter rate of ungulate species and group sizes in different habitat types in Keoladeo National Park

	Wetland	Woodland	Scrubland	Grassland	Results
No. of transect	8	8	2	4	
Mean length of transect	0.96 ± 0.27	(0.60–1.32)	1.09 ± 0.38	(0.51–1.75)	
(km) ± SD (min–max)	1.46 ± 0.82	(0.88–2.04)	1.18 ± 0.17	(0.93–1.31)	
Total effort (km)	61.17	69.53	23.36	37.64	
Encounter rate					GLM (Poisson) result
Feral cattle	19.57 ± 28.99	5.87 ± 13.81	4.39 ± 7.68	4.02 ± 8.10	Walds $Z = 19.27$, $P < 0.001$***
Nilgai	16.30 ± 27.30	1.45 ± 3.23	3.61 ± 3.30	0.81 ± 1.19	Walds $Z = 15.98$, $P < 0.001$***
Chital	14.94 ± 31.75	8.69 ± 15.02	5.22 ± 5.61	7.61 ± 11.73	Walds $Z = 9.22$, $P < 0.001$***
Sambar	0.44 ± 1.32	0.22 ± 0.15	0.21 ± 0.85	0.00	Walds $Z = 0.001$, $P = 1$
Wild boar	0.41 ± 1.01	0.28 ± 1.13	0.16 ± 0.32	0.17 ± 0.50	Walds $Z = 2.35$, $P = 0.02$*
Group size					Kruskal Wallis H tests result
Feral cattle (median)	10.85	7.31	6.16	4.99	$\chi^2 = 2.54$, d$f = 3$, $P = 0.47$
Nilgai (median)	2.88	1.43	3.90	1.45	$\chi^2 = 9.83$, d$f = 3$, $P = 0.02$*
Chital (median)	10.70	4.11	4.68	6.65	$\chi^2 = 2.09$, d$f = 3$, $P = 0.55$

*Significant at $P = 0.05$, ***$P = 0.001$ level.

Table 3. Frequency of detections of each ungulate species falling under different group size-class in Keoladeo National Park

Group size	Chital (%)	Nilgai (%)	Sambar (%)	Wild boar (%)	Feral cattle (%)
1–5	193 (73.66)	231 (84.31)	21 (100)	30 (96.77)	103 (59.88)
6–10	37 (14.12)	21 (7.66)	0	1 (3.23)	33 (19.19)
11–15	8 (3.05)	10 (3.65)	0	0	8 (4.65)
16–20	4 (1.53)	4 (1.46)	0	0	8 (4.65)
>20	20 (7.63)	8 (2.92)	0	0	20 (11.63)

(median = 3.9) and wetland (2.88), followed by woodland (1.43) and grassland (1.45; $\chi^2 = 9.83$, d$f = 3$, $P = 0.02$).

The herd size >80% of the herds of all species ranged between one and ten individuals, while few herds of chital, nilgai and feral cattle with a herd size >20 were also observed. The herd size of sambar and wild boar remained <10 animals (Table 3). The sex ratio in chital, nilgai, sambar and feral cattle was 61.9, 76.5, 75.0 and 52.4 males per 100 females, respectively (Table 4). The ratio of number of young individuals to 100 adult females was highest for wild boar (138.90), followed by feral cattle (25.60), chital (23.80) and nilgai (20.30), whereas the per cent of young in sambar was very low compared to other ungulates (Table 4).

Density of herbivore species

To estimate the density of different ungulate species, 'uniform key' was selected as the best fit model (Table 5). Cluster density (Table 6) of chital (10.41 clusters/sq. km) was estimated to be the highest with a mean cluster size of 6.78 followed by nilgai (7.67 clusters/km^2) with a mean cluster size of 2.12 while the lowest was of sambar (0.18 clusters/sq. km) with a mean cluster size of 1.78 (Table 6). The estimated density of individuals was 52.37 chital/sq. km, 33.66 feral cattle/sq. km, 13.68 nilgai/sq. km, 3.21 wild boar/sq. km and 0.32 sambar/sq. km (Table 6).

Discussion

A comprehensive account on status of mammals in KNP is provided in the present article. At present, 30 species of mammals are known to be present in the park. Over a span of five decades, mammals including tiger, leopard, blackbuck, smooth-coated otter, leopard cat, Indian fox and Hanuman langur have even become locally extinct. However, in 2016 a leopard was camera-trapped again from the park after suspected sightings of the pug marks[41]. Among large mammals, ungulate species majorly contribute to the mammal diversity of the park. The present study also assessed the population structure of these ungulates. The total encounter rate of chital was significantly higher compared to other ungulates. Across all habitat types, the encounter rate of all ungulates except sambar was significantly higher in wetland. The group size of ungulates did not vary between different habitat types, except for nilgai whose median group size was higher in scrubland than in other habitats. The herd size of >80% of the herds of all the species ranged between 1 and 10 individuals. The sex ratio was skewed towards females in chital, nilgai, sambar and feral cattle

Table 4. Population structure of ungulate species in Keoladeo National Park

Species	Total individuals	Individuals classified (%)	Total adults	% Adults	% Young	Ratio Female	Male	Young
Chital	1875	1785 (95.20%)	1556	82.90	12.20	100	61.90	23.80
Nilgai	1135	1055 (93.00%)	946	83.40	9.60	100	76.50	20.30
Sambar	38	38 (100%)	35	92.10	7.90	100	75.00	15.00
Wild boar	55	53 (96.40%)	28	50.90	45.50	100	55.60	138.90
Feral cattle	1853	1677 (90.50%)	1436	77.50	13.00	100	52.40	25.60

Table 5. Details of detections, detection functions fit to data and model selection of ungulate species in Keoladeo National Park

	Detections			Detection functions and model selection				
Species	n	n/l	N	m	$\hat{p}$	$\hat{\mu}$ (m)	Selected model	Min. AIC
Chital	237	1.24	1607	140	0.42	59.36	Uniform	772.09
Nilgai	162	0.85	344	80	0.68	55.03	Uniform	646.13
Sambar	14	0.07	25	200	1.00	200.00	Uniform	58.22
Wild boar	27	0.14	47	60	0.57	34.73	Uniform	84.68
Feral-Cattle	139	0.73	1235	150	0.39	58.62	Uniform	429.27

n, No. of cluster detections (after truncation); n/l, Encounter rate of clusters; N, No. of individuals (observed); m, truncation width; $\hat{p}$, average detection probability between the transect and truncation distance; $\hat{\mu}$, effective strip width sampled.

Table 6. Density estimate of ungulate species and their biomass in Keoladeo National Park

	Density estimates					Biomass	
Species	$\hat{Y}$	$\hat{D}g$ (km^{-2})	$\hat{D}$ (km^{-2})	%CV ($\hat{D}$) (km^{-2})	95% CI	W (kg)	B (kg/km^2)
Chital	6.78	10.41	52.37	18.13	36.47–75.16	45.00[49]	2,356.65
Nilgai	2.12	7.67	13.68	13.04	10.53–17.77	180.00[49]	2,462.40
Sambar	1.78	0.18	0.32	46.47	0.13–0.81	135.50[49]	43.36
Wild boar	1.74	2.02	3.21	24.37	1.97–5.21	27.00[49]	86.67
Feral cattle	8.88	6.18	33.66	19.78	22.86–49.56	180.00[55]	6,058.80
Total							11,007.88

$\hat{Y}$, Mean cluster size; $\hat{D}g$, density of cluster; $\hat{D}$, density of individuals; %CV $\hat{D}$, percentage coefficient of variation; 95% CI, 95% confidence interval; W, average weight of individual; B, biomass of individual.

with 61.90, 76.50, 75.00 and 52.40 males per 100 females respectively. The ratio of young individuals to adult females was highest for wild boar (138.90), whereas the per cent of young ones in sambar was very less. The estimated density for chital, feral cattle, nilgai, wild boar and sambar was 52.37, 33.66, 13.68, 3.21 and 0.32 individuals/sq. km respectively.

A significant change in the mammalian diversity in KNP was observed in the last five decades. In 1964, leopard was exterminated from the area[27], but has recently been camera-trapped by the forest department in 2016 (ref. 41). Tigers have been reported twice from the area with first sighting in 1999 when a tigress ventured into the park but was later found dead. In 2010 a tiger came from Ranthambore National Park and stayed in the park for four months until it was relocated to Sariska tiger reserve[42]. The present study reports the first record of rusty-spotted cat which is the world's smallest cat and is listed as near-threatened on the IUCN Red List of Threatened species[43]. Blackbuck, smooth-coated otter, leopard cat, Indian fox and Hanuman langur which were earlier present in the park are now locally extinct. The disappearance of many of these species can be attributed to continuous modifications of both terrestrial and wetland habitat[16,25]. Other reasons like repeated drought, inter-specific competition, anthropogenic pressures like logging and cattle grazing, possibility of the presence of toxic chemicals in the water from the catchment area[16] and political pressures that often lead to irregular water supply to the region[44] have affected the equilibrium of park. Still, some of the larger and medium-sized ungulates have successfully established themselves in the continuously modifying habitat of KNP.

Across all habitat types in KNP, ungulates were most dominant in the wetland habitat. Nilgai, known to occur in smaller groups[8], was usually found solitary or in small groups of not more than six individuals mostly comprising females along with fawn and yearlings in KNP. They

Table 7. Comparison of the age-sex ratios of the ungulate species between study of 1989 and the present study in Keoladeo National Park

	Ratio (1989)[15]			Ratio (2015)		
Ungulate species	Female	Male	Young	Female	Male	Young
Chital	100	34.20	17.20	100	61.90	23.80
Nilgai	100	80.60	21.50	100	76.50	20.30
Sambar	100	82.00	18.20	100	75.00	15.00
Wild boar	NA	NA	NA	100	55.60	138.90
Feral cattle	100	37.90	21.70	100	52.40	25.60
Blackbuck	100	66.70	25.00	AB	AB	AB

AB, Absent; NA, not analysed.

Table 8. Comparison of estimated densities (km^{-2}) of animal species in different Indian forests

Location	Chital	Nilgai	Sambar	Wild boar	Gaur	Muntjac	Hanuman langur	Chinkara	Blackbuck	Feral cattle	Biomass (kg/km^2)
Nagarhole[40]	50.60	AB	5.50	NA	9.60	4.20	23.80	AB	AB	NA	9,273.65
Bandipur[56]	20.10	AB	5.60	NA	7.00	0.70	NA	AB	AB	NA	5,873.80
Bhadra[9]	4.51	AB	0.89	NA	1.48	3.64	22.60	AB	AB	NA	1,672.94
BRT[57]	13.96	AB	6.01	NA	5.08	3.70	6.34	AB	AB	NA	4,660.17
Pench[58]	80.70	0.40	6.10	2.60	0.70	NA	NA	AB	AB	NA	5,020.25
Kanha[59]	49.70	NA	1.50	2.50	NA	0.60	NA	AB	AB	NA	2,516.25
Ranthambore[50]	31.00	11.4	17.15	9.80	AB	AB	21.75	5.60	AB	NA	6,555.72
Ranthambore[51]	38.40	6.60	10.70	3.61	AB	AB	NA	1.20	AB	NA	4,490.92
Gir[52]	50.80	0.40	2.00	2.10	AB	AB	NA	2.10	AB	NA	2,734.00
Mudumalai[60]	25.03	AB	6.61	NA	0.50	NA	NA	AB	AB	NA	2,322.00
Anamalai[61]	20.54	AB	6.54	NA	12.34	0.28	NA	AB	AB	NA	9,218.67
KMTR[47]	NA	AB	7.00	NA	3.60	NA	9.90	AB	AB	NA	3,286.70
Sariska[53]	27.62	5.19	8.44	1.64	AB	AB	14.13	AB	AB	NA	3,619.34
Keoladeo[62]	9.80	7.00	0.70	2.24	AB	AB	AB	AB	0.76	35.34	9,219.23
Keoladeo	52.37	13.68	0.32	3.21	AB	AB	AB	AB	AB	33.66	11,007.88

AB, Absent; NA, not analysed; KMTR, Kalakad–Mundanthurai Tiger Reserve; BRT, Biligiri Rangaswamy Temple Wildlife Sanctuary.

Table 9. Comparison of density and biomass of all ungulate species between previous study (1989) and present study in Keoladeo National Park

	Density		Biomass density	
Species	1989 (ref. 15)	2015	1989 (ref. 15)	2015
Chital	9.79	52.37	441.00	2,356.65
Nilgai	7.00	13.68	1,451.80	2,462.40
Sambar	0.75	0.32	94.85	43.36
Wild boar	2.24	3.21	60.48	86.67
Blackbuck	0.76	nil	28.62	nil
Feral cattle	35.34	33.66	6,361.20	6,058.80
Total	55.88	103.24	9,219.23	11,007.88

were however seen congregating in larger herds in wetland and adjacent scrubland areas, possibly due to the large resources available. Similarly, chital was seen to be gregariously present in smaller groups of 8–15 individuals in all the habitats of KNP similar to several other regions, e.g. Nagarahole[40] and Gir[8]. However, large herds were occasionally observed during pre-winter in wetland area as reported in Pench[45], when stags, females, fawns and yearlings associate in small temporary feeding units. Stags come together with female groups during rutting forming large herds of a few hundred individuals. Sambar is known to live in small groups of up to six animals as reported from protected areas like Bandipur[46] and Mudumalai[47], in contrast to the low abundance of them in KNP, occurring mostly in smaller groups, usually a female with fawn and/or yearling along with solitary males.

The sex-ratio of all ungulates is skewed towards females. Although mortality data of different age-sex categories is not available, it is speculated that there is greater male mortality due to male–male competition[48] causing this skewness. However, the number of males per females doubled between 1989 and 2015 for chital and feral cattle, and the lack of predation pressure[49] is speculated to be the reason for their dominance in the entire park. Whereas it is lower in the case of nilgai and sambar (Table 7) and cumulative impact of several changes that have happened over the years such as periodic droughts, habitat alterations[15,28] is speculated for this change.

The current population density of chital and wild boar in KNP is comparable with other protected areas in the country (Table 8). The density of nilgai was found to be higher in KNP as compared to other parks like Ranthambore[50,51], Gir[52] and Sariska[53]. Further, the densities of all the three have been reported to be higher in 2015 than 1989 (ref. 49). The density of chital in particular was five folds higher in the park (Table 9). The large number of ungulates is speculated due to lack of predation pressure and inter-specific competition[49]. The high nilgai and feral cattle density probably led to higher inter-specific competition for sambar resulting in sharp decline of their number. The population of blackbuck has disappeared from the park possibly due to a loss of suitable habitat.

This study reveals that the mammalian diversity in the region has changed to a great extent with several carnivores becoming locally extinct along with a few herbivores. Recent worldwide decline in mammal abundance has highlighted the importance of effective assessment of trends in the distribution and abundance of species[50]. There is a shortage of reliable data on the nature and extent of changes in population parameters. Thus continuous monitoring is essential for obtaining reliable information on the effect of changes in the habitat on mammals. It is prudent to monitor the changes in animal population and their age-sex structure in KNP on regular basis so that the long-term trends of variations in population become evident. The park management can adopt continuous, quick and convenient assessment techniques for population monitoring facilitating practical and efficient design of management plans.

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