International Journal of Ecology and Environmental Sciences 48: 767-779, 2022
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2022.6767

Ecology of Indian Wolf *Canis lupus pallipes* in the Great Indian Bustard Sanctuary, Nannaj, Solapur, Maharashtra, India

SATISH KUMAR[1*] AND ASAD R. RAHMANI[2]
[1]*Department of Wildlife Sciences, Aligarh Muslim University, Aligarh-202 002, Uttar Pradesh, India*
[2]*Bombay Natural History Society, Hornbill House, Opp. Lion Gate, Shaheed Bhagat Singh Road, Mumbai-400 001, Maharashtra, India*
E-mail: skumar.wl@amu.ac.in; rahmai1.asad@gmail.com
***Corresponding author**

ABSTRACT
The Indian wolf, *Canis lupus pallipes* is an endangered carnivore of India listed in Schedule-1 of the Indian Wildlife (Protection) Act, 1972. There is not much information available on the species and with this perspective, the present study was initiated in the Great Indian Bustard Sanctuary in Maharashtra. Direct and indirect evidences were used to assess its population status and distribution, habitat use, feeding ecology, denning behaviour and wolf-human conflict emanating due to livestock depredation. Intensive ecological and behavioural studies were conducted at Nannaj on one pack between 1991 and 1994. The wolf survives all over the Sanctuary, which is densely populated by humans as elsewhere in its distribution range in India where wolf-human conflicts are common arising either due to livestock depredation or child-lifting. Usually, large packs were present in blackbuck *Antilope cervicapra* areas whereas smaller packs inhabited areas not supporting healthy populations of blackbuck. In blackbuck poor areas, the wolf survived mainly on livestock. The Sanctuary supports 40-58 wolves. The wolves had a seasonal pattern of habitat use related to movement of prey and livestock. Wolves selected those areas as rendezvous sites which had higher prey density, vegetation cover, minimum human disturbance and were located close to water source. On an average wolves consumed 3.68 (S.E.=0.17) kg/wolf/kill and kill periodicity was 3.65 days (S.E.=0.58). Wolves preyed largely on blackbuck during the non-breeding period and livestock during denning period. Predation was higher on male blackbuck than females despite female biased sex ratio. The average litter size of three packs was recorded to be 5 (range 4-6). The dominant male and female wolves guarded the dens more often than the helpers. They used multiple dens for raising pups that were excavated and/or renewed during denning period. Important conservation problems of wolf have also been discussed in the paper.

Key Words: Indian wolf, population status, habitat use, blackbuck, predation, denning, rendezvous sites, Great Indian Bustard Sanctuary Maharashtra

INTRODUCTION

Mammalian fauna of India is diverse with respect to carnivores. Although India forms only 2.2% of the land area of the world, it harbours 55 (about 24%) of the 231-241 total mammalian carnivore species (Johnsingh 1986). There are two subspecies of wolf in India: Indian wolf *Canis lupus pallipes* in the plains, and Tibetan wolf *C. l. chanco* (=*laniger*) in the Upper- and Trans Himalayas (Uttarakhand, Ladakh, Himachal Pradesh, and Sikkim) from 3,000 to 4,000 m (Kumar and Rahmani 1997). Both are classified as endangered and listed in Schedule-1 of the Indian Wildlife (Protection) Act, 1972. The Indian wolf has been placed in the Convention on International Trade on Endangered Species (CITES) Appendix II as Vulnerable. Globally, the distribution range of the *pallipes* extends from Israel through Syria, southern Iraq, Kuwait, southern Iran to southern Afghanistan and Pakistan into India (Mendelssohn 1983, Ranjitsinh 1997, Jhala 2013). In India, it is mainly found in isolated pockets in the plains of semi-arid, arid and the Deccan zones in Uttar Pradesh, Jharkhand, Madhya Pradesh, Rajasthan, Gujarat, Maharashtra, Orissa, West Bengal, Karnataka and Andhra Pradesh. However, occasionally the plains wolf has also been recorded from Bihar, Telangana and Chhattisgarh states in camera traps installed conducting tiger census (Kumar 1998, Kumar and Rahmani 1995, Maurya et al. 2021, Jhala et al. 2022). The large prey species of wolves are blackbuck *Antilope cervicapra*, Indian gazelle *Gazella benneti*, nilgai *Tragocamelus boselaphus* and wild boar *Sus scrofa* (Kumar 1998).

However, it is only the young of the Nilgai and the wild boar that are occasionally killed and predation on Indian gazelle is also rare of the adult animal.

The Indian wolf is one of the smallest wolves of the world and this subspecies represents the southern-most limit of the range of wolf distribution in the world (12°57' N and 76°50'E) (Kumar and Rahmani 2000). The Indian wolf lives in small packs, usually 4-7 individuals. During the first two decades of India's Independence, the blackbuck, which was abundant all over the Indian plains especially in the Deccan, was hunted out in most of its range. However, since the enactment of the Wildlife (Protection) Act of 1972, there has been resurgence of blackbuck populations in certain areas (Rahmani 1991). In response to revival of blackbuck in some areas, wolves have also increased or stabilised in some areas.

The wolf is one of the most widely studied animals in the world, but studies on wolf in India are limited to those of Shahi (1982), Jhala and Giles (1991), Jhala (1991, 1993, 2013), Ranjitsinh (1997) Kumar and Rahmani (1995, 1997, 2000, 2008), Kumar (1998), Habib and Kumar (2006), Habib (2007), Agarwala et al. (2010), Maurya et al. (2021), Jhala et al. (2022). The present study was undertaken on Indian wolf to gain information on its ecology, behaviour and conservation problems in the Great Indian Bustard (GIB) Sanctuary, Maharashtra. The study was based on direct and indirect evidences such as, tracks scats and howling between June 1991 and September 1994 in an area of 30 km² within the GIB Sanctuary.

STUDY AREA

Before the rationalisation and reduction of the area, the Great Indian Bustard Sanctuary in Maharashtra used to cover an area of 8,496 km² with numerous villages, towns, crop fields, grazing lands and some pockets of forest land (Rahmani and Manakadan 1986). It falls in the Deccan biogeographic zone (Rodgers and Panwar 1988). Nannaj, where the present study was conducted is located 20 km north of Solapur between 17° 41'N and 75° 56'E at 486 m elevation located in the southeastern part of the Sanctuary.

The terrain is gently undulating with mild slopes and flat-topped hillocks with intermittent shallow valleys that form the major drainage channels. The study area can be broadly divided into: (1) plantations (2) grasslands (3) grazing land, and (4) crop fields. Grasslands are distributed in disjunct, fragmented patches forming a mosaic of grazing and agricultural lands and human settlements. Most of the grasslands are present on cultivable slopes and tops of the hillocks. These grasslands are either government owned or private and meant for grazing. There are three artificial waterholes and few percolation tanks in the study area.

In 1975, the World Bank initiated the Drought Prone Areas Programme (DPAP) in Solapur district. Subsequently few more programmes such as the District Rural Development Agency (DRDA), Employment Guarantee Scheme (EGS) and the Social Forestry schemes were also initiated in the district in 1980s for developing the area.

Due to the rain shadow created by the Western Ghats, the drought prone area of Solapur and its adjacent areas in the Deccan plateau receive an average rainfall of 750 mm which is distributed in 3 4 months (July to mid-October). The rainfall is erratic and droughts are a common phenomenon. Climate of Solapur is semi arid. The annual climate cycle includes three seasons: summer (February to mid-June), monsoon (mid-June to mid-October), and winter (mid-October to January). The monsoon season starts in late June or early July. However, there are dry spells during late July and early August. A dry spell occurs when the rainfall in consecutive weeks is less than 15 mm. There is adequate rainfall in late August and September, which ceases by mid October. The average temperature varies from 10°C in December to 45°C in May.

METHODS

A survey was carried out to assess wolf population in the entire GIB Sanctuary during November-December 1993 and information on wolf numbers, natural prey, breeding, livestock and public attitude was recorded by enquiring field staff of the Forest Department, villagers and shepherds followed by ground surveys. There was no problem in confirming wolf presence in an area since people very well know the wolf wherever it occurs because of its interaction with livestock. Based on information gathered from

villagers, shepherds, indirect evidences and movement pattern, presence of scats and kills of a pack that was studied intensively for behaviour, wolf numbers were deduced.

Intensive ecological and behavioural studies were carried out from June 1991 to September 1994 on a single pack named Nannaj Pack in southeastern part of the Sanctuary, Nannaj (Kumar 1998). It was not possible to radio-collar wolves during this study due to various financial constraints hence geographically elevated areas in the Sanctuary were selected to initially locate wolves. The pack was then followed with binoculars (10x50) and on few occasions on foot for behavioural observations until it moved out of the area. Pups in the text refer to individuals less than six months old, immature or juveniles as 6-7 months old, yearlings between 1-2 years and adults as two and more than two years of age. However, it was difficult to distinguish yearlings from adults in the field unless they were observed from close quarters. It was possible to identify the dominant male and female of the Nannaj Pack due to their relatively darker and lighter coats than the other members. We have referred the breeding years of wolves as 1991-92 and 1993-94 because pups were born during December and they remained in dens up to mid-February. The data on activities of wolves around dens was recorded 15-20 days after whelping till they were abandoned.

Chi-square test was used to know if there was any seasonal variation in habitat use by wolves followed by constructing Bonferroni confidence intervals (Neu et al. 1974, Byers et al. 1984, Griffith and Peek 1989) to establish which habitat types were preferred by wolves. Cover was estimated by Point-centered quarter (PCQ) method (Muller-Dombois and Ellenberg 1974) by establishing 1 km transects (or <1 km if the patch was smaller) in shrubland and plantations of the study area. Twenty-eight transects, 12 at rendezvous sites and the 16 in shrubland and plantations were sampled for computing vegetative cover to assign its value or importance to the wolves. The vertical and horizontal diameters of the crown of nearest plant encountered at each quarter were recorded. Variables such as human disturbance, blackbuck density, livestock density, distance from water source and stone quarries were measured in the Sanctuary including rendezvous sites of wolves as well as sites that were selected randomly. Principal Components Analysis (PCA) was performed (Norušis 1994) on the above-mentioned habitat variables to find out selection of rendezvous sites by the wolves.

In the Sanctuary, both wolf and stray dogs were predators of blackbuck, so to study the food habits of wolves, it was necessary to carefully examine and identify their kills. Indirect evidences of wolves such as tracks, mode of feeding, presence of scats around kills, and kill remains were sought after they had moved away. When it was not possible to ascertain a kill, it was excluded from analysis. The crows *Corvus* spp. and raptors such as the pariah kite *Milvus migrans* helped to locate wolves on kills as they started hovering over them. Sometimes movement of stray dogs in the Sanctuary made us suspect of the presence of kill in the area. Once the pack was located on a kill, continuous attention was paid to it until pack members moved away from the kill. For each kill, data were collected on sex and age, habitat around kill site, biomass left unconsumed, distance of kill from the den and nearest vegetative cover. The weight of each kill left unconsumed, the number of wolves known to have fed on the kill were recorded carefully to compute the mean consumption rate of wolves. Data on 11 consecutive kills of wolves was used for calculating average consumption by wolves and also food consumption per wolf presuming that there was no other kill made by wolves besides the above 11. Logarithmic regression analysis (SPSS 10) was used to establish the least-squares fit between pack size and biomass consumption.

Data on livestock kills were collected by ground surveys and also from information given by shepherds and farmers around the Sanctuary. During investigation, attempts were made to get first hand investigation so as to minimize false claims by people on livestock kills by wolves.

RESULTS

Population

The results of the surveys revealed that the wolf exists disjointedly all over the Sanctuary, often in densely populated areas. We estimate 40-58 wolves (Table 1) in eight sub-divisions of Solapur and Ahmadnagar

Table 1. Estimated wolf numbers in the Great Indian Bustard Sanctuary of Maharashtra

District Solapur Sub-division	numbers	District Ahmednagar Sub-division	numbers
Karmala	5-9	Newasa	6-8
Mohol	6-8	Shrigondha	4-5
Madha	2-4	Karjat	10-12
North Solapur	7-12		
Population size	20-33		20-25

districts of Maharashtra falling within the Sanctuary. Elsewhere in Maharashtra, the wolf is distributed in small pockets of semi-arid areas comprising Ahmadnagar, Akola, Aurangabad, Beed, Buldana, Dhule, Jalgaon, Jalna, Nanded, Parbhani, Latur, Osmanabad, Pune, Nasik, Sangli, Satara, and Yavatmal districts (Kumar and Rahmani 1997).

At the start of this study in 1991, there were seven individuals in Nannaj Pack that increased to 12 in 1992 after recruitment in 1991. From September 1992 to February 1993, the pack of 12 wolves split into smaller social units and then reunited several times till a pack of only two individuals was finally left in the territory by March 1993. The Nannaj Pack did not breed in 1992 due to drought. It whelped in 1993-94 and reared six pups. Subsequently, four wolves dispersed and only four were left in the pack.

Of 497 observations on wolves at the study site, maximum (47%) were of more than two wolves, 33% were of two wolves, 19% of a solitary wolf, and minimum (1%) comprised ≥12 wolves. No mortality was recorded in pups after they left their natal dens to rendezvous sites untill they were 6-7 months old. However, carcasses of two adult wolves were recovered in the territory of Nannaj Pack in 1992.

Apart from the Nannaj Pack, there were two more packs- Gangewadi Pack and Mohol Pack. The Gangewadi Pack comprising of five wolves was present 20 km (linear distance) northwest from the territory of Nannaj Pack. This pack was left with only three individuals at the end of this study. The Mohol Pack was present 25 km west of the territory of Nannaj Pack. This pack comprised seven wolves which increased to 14 in 1992 and finally dropped to four individuals during 1993-94.

During the survey we interviewed 438 people for their attitude towards wolves and all but 5% ($n = 23$) responded negatively towards wolf preservation. Only in few areas people favoured wolf preservation where blackbuck is locally abundant. This is mainly because they think wolves as a suppressing factor for the blackbuck population. In many agricultural areas in the Deccan, blackbuck are considered as pests as they consume crops.

Habitat Use and Preference

Using chi-square test it was found that for all three seasons there was significant variation ($\chi^2=42.71$; $P<0.05$, $d.f.=6$, *Chi-square test*) in habitat use of wolves against utilisation of the available habitats in proportion to occurrence. Bonferroni confidence intervals were calculated (Tables 2-4) to test whether wolves used available habitat types in proportion to their occurrence or which habitat types were preferred or avoided.

During monsoon and winter seasons, the wolves utilised the grassland habitat more than expected by chance whereas plantation and shrubland habitat types were utilised in proportion to the availability. Grazing land was used by wolves less often than the proportion with which it occurred (Tables 2 and 3).

During summer, the wolves utilised plantations and grasslands more than expected whereas utilisation of grazing land was less than expected. The shrubland habitat was used in proportion with which it occurred (Table 4). In daytime, the pack was found to range within 30-35 km^2 area of the Sanctuary but their nocturnal movement may be covering more than 100 sq km area based on the location of the kills.

Rendezvous Sites

After leaving the natal den, the pups moved to rendezvous site, a secluded and sheltered area meant basically for pup rearing and was also the meeting place of pack members. A rendezvous site was also the area of principal activity of wolves during summer after the pups vacated their natal dens. Another major activity of pups at the rendezvous sites was to play among themselves and sometimes with the parents. At Nannaj, the pups were restricted to these secluded sites till May when they were about five months. At this age they started moving with the free-ranging parental pack. However, by March when pups were nearly three months old, they began

Table 2. Habitat use by wolves during monsoon (1991-1994) using simultaneous Bonferroni confidence intervals

Habitat	Expected proportion usage (P_{io})	Observed Usage (O_i)	Actual proportion of usage (p_i)	Bonferroni confidence intervals for pi
Grassland	0.085	77	0.456	$0.360 \leq p_i \leq 0.552$**
Grazing land	0.711	62	0.367	$0.274 \leq p_i \leq 0.460$
Shrubland	0.133	15	0.089	$0.034 \leq p_i \leq 0.144$*
Plantation	0.070	15	0.089	$0.034 \leq p_i \leq 0.144$*

**selected and used more than expected (0.05 significance level)
*utilised in equal proportion of occurrence (0.05 significance level)

Table 3. Habitat use by wolves during winter (1991-1994) using simultaneous Bonferroni confidence intervals

Habitat	Expected proportion usage (P_{io})	Observed Usage (O_i)	Actual proportion of usage (p_i)	Bonferroni confidence intervals for pi
Grassland	0.085	46	0.319	$0.222 \leq p_i \leq 0.416$**
Grazing land	0.711	52	0.361	$0.261 \leq p_i \leq 0.461$
Shrubland	0.133	26	0.181	$0.101 \leq p_i \leq 0.261$*
Plantation	0.070	20	0.139	$0.067 \leq p_i \leq 0.211$*

**selected and used more than expected (0.05 significance level)
*utilised in equal proportion of occurrence (0.05 significance level)

Table 4. Habitat use by wolves during summer (1991-1994) using simultaneous Bonferroni confidence intervals

Habitat	Expected proportion usage (P_{io})	Observed Usage (O_i)	Actual proportion of usage (p_i)	Bonferroni confidence intervals for pi
Grassland	0.085	42	0.258	$0.172 \leq p_i \leq 0.344$**
Grazing land	0.711	42	0.258	$0.172 \leq p_i \leq 0.344$
Shrubland	0.133	30	0.184	$0.108 \leq p_i \leq 0.260$*
Plantation	0.070	49	0.301	$0.211 \leq p_i \leq 0.391$**

**selected and used more than expected (0.05 significance level)
*utilised in equal proportion of occurrence (0.05 significance level)

moving occasionally with the pack up to the waterholes. The growing pups were fed both regurgitated food and also the food carried to these sites by the parents and/or assisting members ('helpers'). When the pups were five months old, the parents instead of regurgitating or bringing food to the rendezvous sites started taking pups to the kill sites.

Characteristics of Rendezvous Sites and their Selection

The study pack used six rendezvous sites in both the breeding years- two in 1992 and four in 1994. The first two were located in grazing land less than a km from the water source. One rendezvous site was used by wolves in both the breeding years.

Principal Components Analysis (PCA) revealed that wolves preferred rendezvous sites in patches

having higher density of blackbuck, maximum vegetative cover and minimum human disturbance (Table 5). Rendezvous sites were located away from stone quarries and closer to water sources. All rendezvous sites except one were located in shrubland. One was located in a deep groove covered with grass from all sides and was thus fully shaded. The rendezvous sites had tracks all around and a characteristic odour, which was due to the presence of scats of pups and kill remains. A tree was always located at the rendezvous site selected by wolves, which provided excellent shade to the pups in summer. The first two rendezvous sites were closer to the active den than the rendezvous sites that were used subsequently. This is probably because the young ones could enter dens immediately on perceiving any disturbance. The distance between the rendezvous sites varied from 140-500 m ($\bar{x}$ = 220±143.1). The pack continued to use a particular site for 2-3 weeks if there was not any disturbance in that area.

Table 5. Principal Components Analysis of rendezvous sites variables for wolves

Variables	Component loadings		
	1	2	3
Human disturbance	-0.596	0.061	0.764
Vegetative cover	0.773	0.466	-0.154
Blackbuck density	0.754	-0.154	0.284
Livestock density	0.584	-0.529	0.276
Distance to water source	-0.245	0.786	-0.075
Distance to stone quarry	0.440	0.668	0.410
% total variance explained	35.25	26.49	15.61
Cumulative variance	35.25	61.74	77.34

Resting Sites

The resting sites were different from rendezvous sites and were used by wolves to rest during daytime when there was an increase in the ambient temperature. The resting sites were located in shrubland, sparsely wooded grassland, grazing land and plantations. Unlike rendezvous sites, the pups were never fed at resting sites nor were they meeting place of pups and pack members. The use of resting sites was found to change seasonally. Low lying areas were used for resting in winter mornings probably to avoid the cool breeze blowing in the early morning hours whereas during daytime they generally moved into the plantations. The wolf at a resting site dug out a surface 14-16 cm deep to expose moist area of the soil underneath and lay down there during the hot hours of the day. As the air temperature rose during the day, the resting wolves woke up and dug out the soil further to expose more moisture presumably to cool their bodies.

Use of Waterholes

The Nannaj Pack was found to visit one of the waterholes more frequently than the other two (see discussion). There was a significant seasonal variation ($H = 8.32$, $P = 0.016$, Kruskal-Wallis test) in waterhole usage by the pack members. The frequency of sighting of the pack at waterholes was found to be higher during summer (n = 151) and winter (n = 28) than monsoon (n = 12). During summer, the wolves also used to wade through the waterholes. Whenever the pack was found approaching a waterhole, the pups were the first to arrive and the adult members came cautiously to a waterhole and reached last. This probably was due to the fact that people working at stone quarries in the surroundings used to come here regularly to fetch water and during drought years even livestock of the area frequented these waterholes.

Predation on Blackbuck

Based on our data of 11 consecutive wolf kills of blackbuck, average consumption rate of the Nannaj Pack was found to be 3.68 kg/wolf/kill (n = 11, S.E. 0.17). On an average, wolves made kill every 3.65 days (n = 19, S.E. 0.58) and thus the everyday consumption rate was found to be 1 kg/wolf. However, in summer kill-interval was 2.1 days (n = 10, S.E. 0.7) because of recruitment of pups when wolves require more food for them. The pups require 2-3 times as much food as do adults for their energy and growth requirements. The wolves are known to feed six times more than their normal food intake because of possessing distensible stomachs (Mech 1970). Whenever adult blackbuck was killed by a small pack, they fed heavily and food consumption was much higher than their average consumption rate. We used data of 45 wolf kills of blackbuck (Table 6) for developing the relationship between

Table 6. Pack-size of wolves and food consumed by them

Pack Size	Number of Kills	Biomass consumed (kg/wolf/day)
6	4	0.5 - 4.88
2-5	18	0.71 - 4.5
7-11	15	0.14 - 2.73
7-12	8	0.22 - 3.89

food consumption and pack size. The regression analysis of biomass consumption per wolf per day and pack size (Fig. 1) showed an inverse curvilinear relationship ($y = -0.727 \ln(x) + 1.366$; $r^2 = 0.13$) indicating no increase in food acquisition per wolf with an increase in pack size. Other studies have showed similar trend (Thurber and Peterson 1993, Schmidt and Mech 1997, Ballard et al. 1997, Hayes et al. 2000). The wolves kept visiting the kill sites and utilised more and more until almost they consumed the entire kill. In July 1992, we found four individuals of the Nannaj Pack of 12 kept coming to a kill for four consecutive days.

The proportion of blackbuck killed by wolves during non-denning period was higher than the proportion of livestock killed (Table 7). The wolves switched to livestock during denning and pup rearing period (Table 7). They had a strong selection for male blackbuck ($U = 42$, $P = 0.01$, Mann-Whitney U test) despite higher number of females in the population (sex ratio 1:6.5- adults; 1:4.6- adults and sub-adults) (Kumar 1998, Kumar and Rahmani 2008). Seasonally, there was no significant difference in frequency of occurrence of kills ($H = 0.090$, $P = 0.956$, Kruskal-Wallis one-way ANOVA) (Kumar and Rahmani 2008). The sex and age composition of blackbuck killed by wolves in the GIB Sanctuary is given in Table 8.

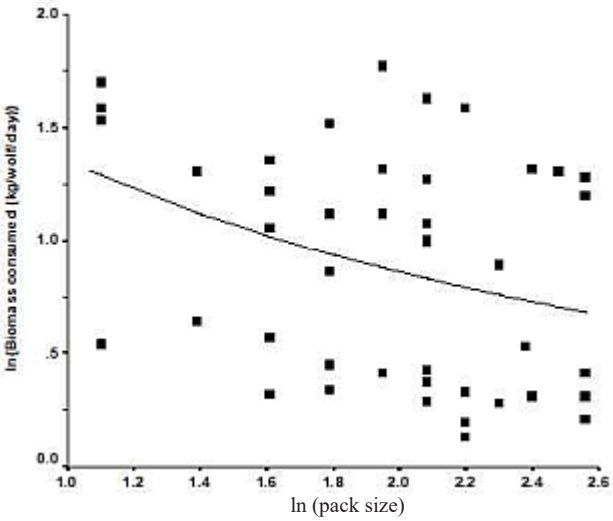

Figure 1. Relationship between biomass consumed per wolf and wolf packs of different sizes preying on blackbuck in the Great Indian Bustard Sanctuary, Maharashtra, $\ln(y) = 1.366 - 0.727 \ln(x)$, $r^2 = 0.13$, $d.f. = 43$, $P = 0.001$

Table 8. Age and sex composition of Blackbuck killed by wolves in the Great Indian Bustard Sanctuary, Nannaj during the study period

Year	Adult		Sub-adult			Fawn	Wolves
	M	F	M	F	U		
1991*	10	-	1	2	2	6	7
1992	17	7	5	3	2	3	12
1993	8	4	-	-	1	4	2
1994**	7	2	2	1	1	1	8

* includes kills from July to December
** includes kills from January to August
M = Male, F = Female, U = Unsexed

Table 7. Blackbuck and livestock numbers available and their proportions taken by wolves in the GIB Sanctuary

Prey	Denning and Pup Rearing Period		Non-Denning Period	
	Average number	Proportion killed	Average number	Proportion killed
Blackbuck	630 (±61.7)	0.06 (6%)	518 (±70.7)	0.10 (10%)
Livestock	392 (±53.7)	0.18 (17.6%)	526(±101.8)	0.061 (6.1%)

After wolves killed a blackbuck, they generally fed first on the visceral parts and the rump. Limbs and neck regions were consumed next and the head region in the last. Nevertheless, for some of the blackbuck kills ($n = 5$), it was not possible to ascertain if killed by wolves or dogs. The dogs stayed at least 100 m away from the wolf kill and wolves sometimes were observed threatening stray dogs and chasing them off from their kills, which even lead to aggressive encounters. The Nannaj Pack was rarely seen feeding on a kill after 07:30 h. The adult members of the pack moved away from their kills earlier than the young ones probably to make food accessible to the latter more than themselves. The digestive tract was dragged few meters away from the kill site and was usually not consumed.

The maximum (36%) blackbuck kills were located within 1-4 m from the nearest vegetative cover. The minimum (7%) of them were at a distance of about 1 m from the nearest vegetation (Table 9). All these blackbuck were probably ambushed by the wolves. Of the remaining kills, 13% were within 5-8 m, 10% within 9-12 m, 18% within 13-16 m, and 16% were within 17-20 m distance from the nearest vegetative cover. We could not make out the exact location of about 19% ($n = 14$) wolf-killed blackbuck that were dragged away from the actual kill locations. The fawns were hunted by wolves in open grasslands. The distance of wolf kills of blackbuck made outside the Sanctuary during denning period did not differ from the distance of kills during non-breeding period ($D = 0.2463$, $P = 0.462$, Two-sample Kolmogorov-Smirnov test). Also, the distance of kills from the dens did not differ significantly ($U = 366.5$, $P = 0.30$, Mann-Whitney U test) during the denning and non-denning periods.

Livestock Depredation

Table 9. Distance of blackbuck and livestock kills of wolves from the nearest vegetation cover

Prey	Distance from nearest vegetation cover type					
	<1 m	1-4 m	5-8 m	9-12 m	13-16 m	17-20 m
Blackbuck	4	22	8	6	11	10
Livestock	4	50	16	9	1	–

The wolves killed more goats and sheep during breeding years 1991-92 ($U = 2631$, $P<0.001$, Mann-Whitney U test) and 1993-94 ($U = 1280$, $P<0.01$, Mann-Whitney U test) than during the non-breeding year (i.e., 1992-93). Depredations were higher during the denning period 1991-92 ($H = 48$, $P<0.001$, Kruskall-Wallis test) as well as 1993-94 ($H = 14.3$, $P<0.01$, Kruskall-Wallis test) when pups were dependent on parents and/or helpers for food followed by the period when juveniles also started hunting, and low during non-breeding period. There was differential predation on goats and sheep. Goats were more susceptible ($\chi^2 = 14.25$, 1 *d.f.*, $P<0.001$, Chi-square test) to wolf depredation than sheep during the study period despite higher availability of the latter. The ratio of goats to sheep counts was 1:2.8 (Kumar and Rahmani 2000). The preference of goats despite their low abundance as wolf prey could be due to one or a combination of the following factors: goats were ambushed by wolves when browsing shrubs and short bushes or because goats were more dispersed as compared to the compact herds of sheep.

Breeding Behaviour

During 1991-92, some of the Nannaj Pack members restricted their movement around a particular area for 2-3 weeks before the pups were born. Similarly, one of the members of the Nannaj Pack was often seen around a den nearly for one month during 1993-94 and one of the dominant females whelped in the same den. The dens were burrows in the ground or ridges along the percolation tanks, which are common all over the drought prone areas of Maharashtra. The pack either excavated the dens or merely enlarged and renovated the burrows of other animals such as the common Indian fox *Vulpes bengalensis* or the common Indian monitor *Varanus bengalensis*. Wolf tracks leading to den entrances were seen around the denning sites from all sides. Homesites (dens and rendezvous sites) as referred by Joslin (1967), Harrington and Mech (1978) and several other workers were the focal areas of activity of the pack during late winter and summer.

In both the breeding years of the Nannaj Pack, pups were born during December-January. During the breeding year 1991-92, it used only one den whereas during 1993-94, the pack used four dens

and kept shifting pups between them till dens were finally abandoned them. The average distance between the dens was 0.78 km (range=1.2-1.8 km). The alpha pair excavated two dens simultaneously in December 1993. One den that was used in both the breeding years by the pack is of special interest because it was an artificial den made of Reinforced Concrete Cement (RCC) pipe situated in a percolation tank (PT), which was meant for draining surplus water from the PT during rainy season. Percolation tanks are slight depressions in the study area, which are purposely created by the Soil Conservation Department to minimize surface runoff so as to percolate water to recharge the ground water storage. Of the remaining dens, two had ≥2 main openings and others having a single. One of the dens, an enlarged fox den, had 3-4 aeration burrows. The dens were located close to some water source, usually less than 1 km from the den.

Average litter size of the Indian wolf for three packs was recorded five pups (range = 4-6). The figures represent the pups seen after they had left their dens since mortality within the dens was unknown. The pups vacated their natal dens in February however, they had been emerging and making short forays of 5-8 m outside dens at 3-4 weeks of age in January. After abandoning dens, the pups moved to the first rendezvous site, located 104 m from the den. All these relationships between dens, rendezvous sites and water sources have been summarised in Table 10. Emerging of pups from dens was usually observed after the sunset or half an hour after sunrise, and rarely outside these timings. The main activities of pups during these forays were suckling and playing among themselves. The pups were extremely alert during these trips and used to scurry down into the den with the slightest disturbance or noise produced by galloping blackbuck, whistling of shepherds, calls of the common Indian fox, great horned owl *Bubo bubo* or Indian peafowl *Pavo cristatus*.

During denning time, some of the pack members, usually 1-2 individuals were always seen sitting around active dens and guarding them. These dens were also aggressively defended whenever there was any risk (Kumar 1998). During the breeding year 1991-92, the dominant male and female of the Nannaj Pack were found to guard the den more often than

Table 10. Relationships between dens, rendezvous sites, water source and core area

DENS				RENDEZVOUS SITES							
				I Rendezvous site				II Rendezvous site			
Period Occupied	Periods during which dens were vacated	Distance from	Distance from water source core area	Period occupied	Dist. from Den	Dist. from Core area	Dist. from water source	Period occupied	Dist. from Den	Dist. from Core area	Dist. from water source
Dec 26± 1991 to Feb. 6, 1992	Feb. 2 to Feb. 6	2.47 km	2.88 km	Feb. 7± to Mar 10	1.8 km	0.60 km	0.88 km	Mar. 15± to Mar. 18	2.18 km	0.45 km	0.70 km
Jan 4± 1994 to Feb. 20, 1994	Feb. 18 to Feb. 23	2.22 km	0.18 km	Feb.19± to Feb.28	0.13 km	2.12 km	0.15 km	Mar. 1± to Mar. 9	1.73 km	0.55 km	0.80 km

the helpers or auxiliary members of the pack (c^2 = 35.4, 1 *d.f.*, P<0.01, Chi-square test). The dominant male was observed guarding dens more often than the dominant female (c^2 = 26.9, 1 *d.f.*, P<0.01, Chi-square test) during 1993-94 when other pack members had already dispersed.

DISCUSSION

It is difficult to make accurate estimates of wolf populations because the wolf is an elusive predator, occurring in relatively low density, and wolves travel over large areas. Therefore, the few estimates of wolf numbers, which have been made anywhere have varied greatly in precision and area covered (Mech 1973). The wolf density varies in relation to the density of prey base. Nevertheless, the various methods of estimating wolf density and abundance available in literature are non statistical because no sampling was done. However, camera trap data has recently been used for modeling wolf distribution in India (Jhala et al. 2022)

The Bustard Sanctuary of Maharashtra is one of the few protected areas in India where wolves still survive. The maximum wolf density in Solapur was four individuals per 100 km² (Kumar and Rahmani 1997). The population estimate for wolf has been made as 396 individuals (range = 322-481) in Maharashtra (Jhala et al. 2022). The wolves have been regularly breeding in the Sanctuary. However, every year September onwards, the pack start breaking into smaller social units which could either be in response to suppression by higher-ranking pack members in relation to breeding or due to an increase in competition for food after recruitment. The separation among pack members continues for 3-4 months until a stable pack is formed. If male and female wolves find a suitable vacant area and mate, they may start their own pack. For some behavioral reason, some young wolves leave their natal pack and become loners and search out mates to begin new packs in new areas (Peters and Mech 1975, Rothman and Mech 1979, Ream et al. 1991) and some dispersing individuals are even reported travelling more than 800 km straight line (Fritts 1983). During their wanderings if they cannot avoid resident packs, they may be chased and attacked (Mech 1970).

Small packs of 2-3 individuals survive in the Sanctuary where blackbuck population is low and they mainly subsisted on goats and sheep and other small mammals and birds whereas the pack size was usually large and more than four individuals in areas supporting healthy population of blackbuck. For instance, North Solapur, Mohol, and Karjat areas had large packs while remaining areas of the Sanctuary were inhabited by small packs. Ranjitsinh (1997) has also reported low pack size in areas where wolves became almost totally dependent upon smaller prey consisting of hares and birds, which do not require communal hunting and are too small for sustenance of a large pack size. Another reason for low pack sizes in these areas is probably dense human population and disturbance due to intensive agricultural activities.

In 1975 the Drought Prone Areas Programme (DPAP) financed by the World Bank was initiated in Solapur district. The DPAP is essentially an area development programme, aimed at integrating efforts in agriculture and allied sectors to mitigate the adverse effects of drought. The District Rural Development Agency (DRDA), a programme started in early 1980s also established and protected few plantation plots in the Sanctuary. Several pasture and plantation plots have been developed under these schemes from time to time in the Bustard Sanctuary and have been protected by the Forest Department. After protecting these pastures and plantations, the wolf population has witnessed some resurgence. The blackbuck population has also increased after protecting these areas.

It was seen that the grasslands were used by wolves more than expected in monsoon and winter whereas plantations and shrubland were used in proportion to availability because blackbuck congregate in large herds in grasslands due to lush grass growth during these seasons. Plantations were frequented less than grasslands by wolves due to thick foliage and less number of blackbuck in these seasons. Grazing land was avoided due to various disturbance factors (Tables 2, 3). In summer, plantations were utilised more than expected because of shade and better prey base. Blackbuck used plantations in summer probably because of relatively more grass and browse availability in them. It is therefore, essential to maintain these shrubland and plantation patches and the Sanctuary Managers

should not allow cutting or thinning of shrubs and bushes in the Sanctuary. Like plantations, wolves also used grassland habitat more in summer largely because of occurrence of waterholes within them. Wolves avoided grazing land habitat during daytime because of disturbance resulting from stone quarries and movements of people (Table 4). However, they were frequently sighted in the grazing land in early morning or late evening hours when human beings were absent.

The wolves preferred those sites as resting and rendezvous sites where the vegetative cover predominantly comprised an association of a short shrub *Cassia auriculata* and *Acacia leucophloea* and/or *Acacia nilotica* trees, which provided shade to them unlike pure *C. auriculata* patches. The pack used one waterhole regularly than the other two in summer because of less disturbance. One of the waterholes in the Sanctuary was located very close to the road and was usually occupied by people or grazers by bringing in their livestock for water. It is therefore, essential that no livestock herding be allowed at the waterholes in summer which are the only source of water to wolves in summer.

The wolf exists in marginal areas of the Sanctuary and there is a tremendous livestock pressure on these areas. During our wolf survey in the Sanctuary, it was found that there are several plantations established in the Sanctuary under the DPAP, DRDA and Social Forestry schemes. These plantations are very useful for wolves to den and rest since they are protected and no grazing is allowed but attention must be paid for mixed plantations of *Acacia* spp. and *C. auriculata* because the former provide shade to wolves especially in summers whereas cover is provided by the latter. Secondly, the wolves can disperse from these plantations and colonise surrounding suitable unoccupied area as they have great dispersing ability and once given protection, they can expand their range rapidly (Fuller et al. 1992, Mech 1995). The plantations therefore in a way could help wolf recovery in these areas. Blackbuck is essentially a grassland animal that has also benefited through plantations since the latter are spread all over the grassland ecosystem of the Sanctuary.

All over the Sanctuary, people are against wolves because of depredation of their livestock by them. In order to preserve wolves in these drought prone areas, it is essential to compensate farmers and shepherds promptly by the Government for their livestock losses to wolves. The wolves are probably playing a key role in suppressing blackbuck numbers in the Sanctuary. During denning period and the following summer the wolves switch over largely to livestock to conserve energy, which probably is an ecological adaptation of the species.

Denning occurs in April-May in North American wolves and the pups after abandoning their natal dens have been reported to stay at the rendezvous sites for about 3 months till they begin travelling with adults (Mech 1970, Carbyn et al. 1993). The pups at Nannaj started travelling to waterholes with adults after having spent one month at the rendezvous sites because of higher atmospheric temperature but otherwise they kept themselves to the rendezvous sites till April.

Carbyn (1975) has also reported wolves shifting dens in Jasper National Park, Canada due to human disturbance. Indian wild dog *Cuon alpinus* is also reported to change dens at the slightest disturbance (Johnsingh 1982) and so does the African wild dog *Lycaon pictus* (Kühme 1965, van Lawick 1971, Schaller 1972). It seems the large canids generally do not tolerate disturbance around their active dens, which was also observed in the common Indian fox (*pers. obs.*) in the Bustard Sanctuary.

The wolves in the Bustard Sanctuary live in close proximity to (human) settlements and interact with dogs all over their distribution range. This actually is a concern not only for losing population of the Indian wolf demographically but also genetically due to its probable hybridisation with dogs. It is thus essential to undertake more studies on their genetics for exploring possibility of any hybridisation between these closely related canids. The Forest Department has recently initiated a scheme to compensate farmers and shepherds for livestock depredation in the Sanctuary in which 75% value of a livestock loss to wolves is compensated. Similar compensation packages may be implemented in other areas of wolf distribution in the state. More studies in the Sanctuary as well as unprotected habitats inhabited by wolves should be taken up on priority to investigate their habitat requirements, ranging and dispersal patterns, inter relationships with humans (wolf-human conflict) and livestock, and predation patterns.

In this study we have found that in drought years the shepherds migrate from low to high rainfall areas and they lose their livestock to wolves during migration. To investigate if wolves follow their livestock during migration, some wolves need to be radio-collared at the beginning of migration of shepherds and followed to investigate their movements for a minimum of six months when they return to their native areas. All this information will be useful in developing an effective conservation plan for the species.

ACKNOWLEDGEMENTS

We are thankful to the U.S. Fish & Wildlife Service and the Ministry of Environment, Forest and Climate Change, India for funding and sponsoring the Grassland Ecology Project under which this study was conducted. We are thankful to Mr. David A. Ferguson for all his encouragement during this study. The authors are also grateful to the Forest Dept. (Wildlife Division) of Maharashtra State for their cooperation and giving permission to conduct this study. We wish to thank the Chairperson, Department of Wildlife Sciences and the Director, Bombay Natural History Society for all help extended during the study. We also appreciate the help of our field assistants Mr. Rajesh Jadhav and Mr. Navnath Vaghe for all their help during the study. The Bombay Natural History Society and the Department of Wildlife Sciences assisted in providing logistics. The authors are also thankful to one anonymous reviewer.

Authors' contributions: Both the authors contributed equally

Conflict of interest: The authors confirm that there was no conflict of interest in this research and anything else that could be inferred as a potential conflict of interest.

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Received:13th October 2021
Accepted:30th August 2022