Tropical Ecology **53**(2): 137-148, 2012 ISSN 0564-3295

www.tropecol.com

Status of large carnivores and their prey in tropical rainforests of South-western Ghats, India

THARMALINGAM RAMESH[1*], NATARAJAN SRIDHARAN[1], KALYANASUNDARAM SANKAR[1], QAMAR QURESHI[1], KANAGARAJ MUTHAMIZH SELVAN[1], NEDUNCHERAN GOKULAKKANNAN[1], PICHAIYAN FRANCIS[1], KANNADASAN NARASIMMARAJAN[1], YADVENDRADEV V. JHALA[1] & RAJESH GOPAL[2]

[1]*Wildlife Institute of India, P.O. Box # 18, Chandrabani, Dehradun 248001, Uttarakhand, India*
[2]*National Tiger Conservation Authority, Government of India, Shahjahan Road, New Delhi 110011, India*

Abstract: Information on large carnivores and their prey is generally lacking in many tropical rainforest habitats of the world. During March to October 2006, 2007 and 2010, we conducted sign and automated camera trap surveys for tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) in Kalakad-Mundanthurai Tiger Reserve (KMTR), Western Ghats. Line transect sampling was carried out to estimate prey species density (total effort 353.2 km). Highest sign encounter rate per km walk was observed for leopard (1.26), followed by dhole (0.67) and tiger (0.18). Spatially explicit maximum likelihood and Bayesian model estimates (individuals 100 km^{-2}) were 2.2 ± 1.6 and 2.9 ± 1.4 for tigers and 2.8 ± 2.0 and 2.4 ± 1.3 for leopards, respectively. Photographic encounter rate of dhole was 1.9 in 2006 and 0.6 in 2010 / 100 trap-nights. Leopards exhibited peak activity at night while tigers were active during early mornings and late evenings. Dholes appeared to be mostly diurnal. Overall ungulate density was 11.9 ± 3.7 individuals km^{-2}. The ungulate biomass was 2614 kg km^{-2}. This study provides baseline information on prey - predator population in Kalakad-Mundanthurai Tiger Reserve.

Resumen: Hay una carencia generalizada de información sobre los carnívoros grandes y sus presas en muchos hábitats de bosque lluvioso tropical del mundo. Entre marzo y octubre de 2006, 2007 y 2010 llevamos a cabo prospecciones por medio de trampas-cámara automatizadas y búsqueda de rastros de tigres *(Panthera tigris)*, leopardos *(Panthera pardus)* y doles o cuones *(Cuon alpinus)* en la Reserva para Tigres Kalakad-Mundanthurai, Gates Occidentales. Se realizó un muestreo por medio de transectos lineales para estimar la densidad de especies de presas (esfuerzo total 353.2 km). La mayor tasa de encuentro de rastros por km caminado fue observada para el leopardo (1.26), seguida por el dole (0.67) y el tigre (0.18). Las estimaciones espacialmente explícitas de máxima verosimilitud y de modelos Bayesianos (individuos/100 km^2) fueron 2.2 ± 1.6 y 2.9 ± 1.4 para los tigres, y 2.8 ± 2.0 y 2.4 ± 1.3 para los leopardos, respectivamente. La tasa de encuentro fotográfico de los doles fue de 1.9 en 2006 y 0.6 en 2010/100 noches-trampa. Los leopardos tuvieron su pico de actividad en la noche mientras que los tigres estuvieron activos temprano por las mañanas y tarde por la noche. Los doles parecieron ser principalmente diurnos. En general, los ungulados tuvieron una densidad de 11.9 ± 3.7 individuos km^{-2} y una biomasa de 2614 kg km^{-2}. Este estudio proporciona información de línea base sobre las poblaciones de presas-depredadores en la Reserva para Tigres Kalakad-Mundanthurai.

* *Corresponding Author*; e-mail: ramesh81ngl@gmail.com

Resumo: De um modo geral a informação sobre os grandes carnívoros está ausente em muitos habitats florestais tropicais de chuvas no mundo. Durante os meses de Março a Outubro de 2006, 2007 e 2010, conduziram-se inquéritos de sinais e armadilhas com câmaras automáticas para o tigre *(Panthera tigres)*, leopardo *(Panthera pardus)* e o cão-asiático-selvagem *(Cuon alpinus)* na Reserva do Tigre em Kalakad-Mundanthurai (KMTR), Ghats ocidentais. Para avaliar a densidade especifica das presas utilizou-se uma amostragem usando-se linhas de transeptos (o esforço total igualou os 353,2 km). A maior taxa de encontros por km de caminho foi assinalada para o leopardo (1,26), seguida pelo cão-asiático-selvagem (0,67) e tigre (0,18). A máxima probabilidade espacialmente explicita, e as estimativas Bayesianas (indivíduos /100 km^2), foram de 2,2 ± 1,6 e 2,9 ± 1,4 para os tigres e 2,8 ± 2,0 e 2,4 ± 1,3 para os leopardos, respectivamente. A taxa de dos encontros fotográficos para o cão-asiático-selvagem foi de 1,9 em 2006 e 0,6 em 2010 / 100 noites de armadilha. Os leopardos exibiram um pico de atividade à noite, enquanto os tigres foram ativos de manhã cedo e no início da noite. Já os cães-asiáticos-selvagens parecem ser fundamentalmente diurnos. A densidade geral dos ungulados foi de 11,9 ± 3,7 indivíduos km^{-2}. A biomassa dos ungulados foi de 2614 kg km^{-2}. Este estudo proporcionou a informação base sobre a população presa - predador na reserva do Tigre em Kalakad-Mundanthurai.

Key words : Automated camera, large carnivores, line transect, prey, rainforest, sign survey, Western Ghats.

Introduction

Little is known about the status of large carnivores and their prey in tropical rainforests (Chauhan *et al.* 2006; Datta *et al.* 2008). Continued depletion of these forests and fragmentation of natural habitats have led to substantial ecological changes in these areas (Kawanishi 2002). Human induced changes can greatly influence habitat use and populations of carnivores and trophic structure of any ecosystem (Karanth *et al.* 2010). Some of important mammalian predators in Indian forest ecosystems which have suffered maximum due to habitat degradation and fragmentation include the tiger (*Panthera tigris*), common leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) (Johnsingh 1992; Karanth & Sunquist 1995; Ramesh *et al.* 2009; Ramesh 2010). In many forest ecosystems these species are sympatric (Richard 2007). Many large carnivores are cryptic, nocturnal or crepuscular and often solitary unlike dholes that live in packs and perform co-operative hunting. Carnivores naturally occur in low densities in rainforest environments (Eisenberg & Seidensticker 1976; Kawanishi & Sunquist 2004). Information on these nocturnal and elusive species helps in assessing the status of forest ecosystems (Karanth *et al.* 2004; Karanth & Nichols 2002; O'Brien *et al.* 2003). Estimating and monitoring the abundance of predators as well as prey species in the protected areas help in understanding their population ecology and evolving management strategies (Caughley & Sinclair 1994; Wilson & Delahay 2001).

As part of an all India monitoring of tiger and its prey base during 2006 - 2010, we conducted systematic surveys of large carnivores and wild ungulates in Kalakad-Mundanthurai Tiger Reserve (KMTR) that is located in south-western Ghats. This reserve forms the southernmost limit of tiger distribution in Indian sub-continent and represents tropical rainforest ecosystem. Very few quantitative studies are available on large mammalian carnivores and their prey from this part (Ramakrishnan *et al.* 1999; Sathyakumar 1992; Sankaran 2001). This paper presents the results of a detailed ecological investigation on the large mammalian predators and prey in this park. Results are discussed along with management implications.

Materials and methods

Study area

Kalakadu-Mundanthurai Tiger Reserve (KMTR) is located in the southern part of Western Ghats of India. This region forms one of the important bio-

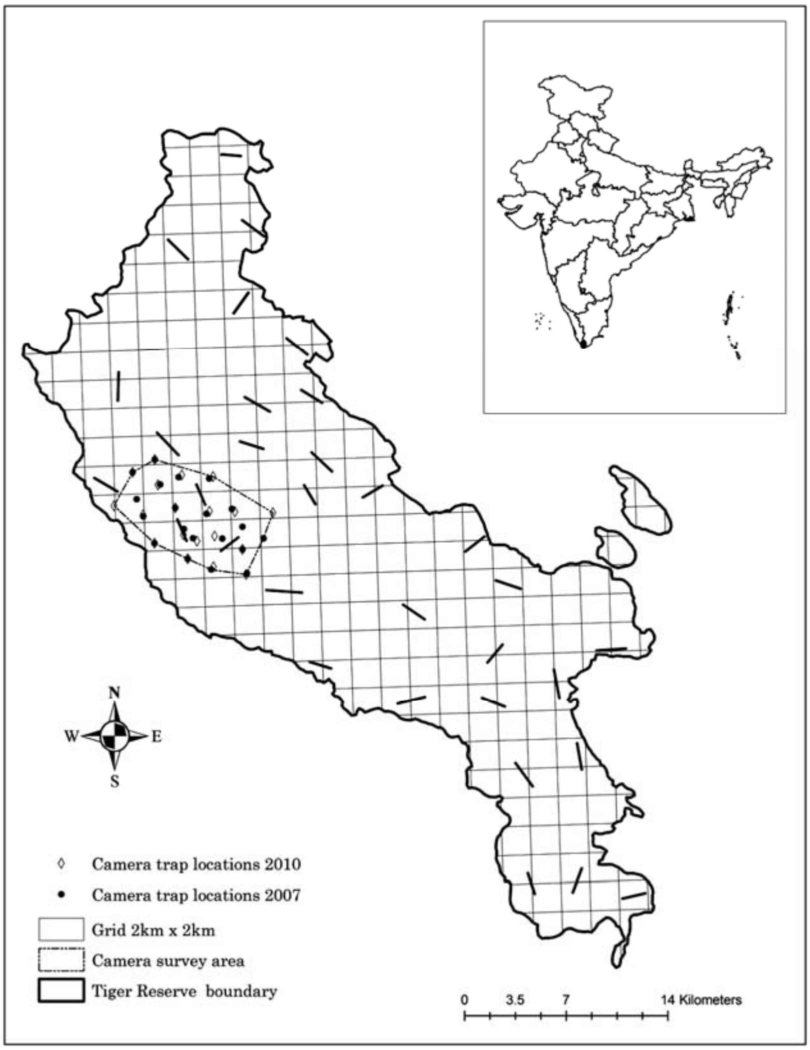


Fig. 1. Intensive camera survey area and locations of line transects in Kalakad-Mudanthurai Tiger Reserve, India.

diversity 'hotspots' (Ganesh *et al*. 1996; Johnsingh 2001; Myers *et al*. 2000; Ramesh *et al*. 1997) and recognized as Type-1 Tiger Conservation Unit (TCU) (Wikramanayake *et al*. 1998) due to its large and contiguous forested tracts. The reserve is spread over an area of 895 km^2 and located between longitudes 77° 10´E to 77° 35´E and latitudes 8° 25´N to 8° 53'N (Fig. 1). Altitude varies from 60 to 1866 m characterized by hilly terrain with low and high altitude plateaus. It receives both south-west and north-east monsoon with mean annual rainfall of over 3200 mm. Mean monthly temperature ranges from 15 to 30 °C. Besides three large carnivores, KMTR harbors several prey species such as sambar (*Rusa unicolor),* gaur (*Bos gaurus*), chital (*Axis axis),* wild pig (*Sus scrofa),* barking deer (*Muntiacus muntjak),* Indian chevrotain (*Tragulus meminna),* Asian elephant (*Elephas maximus*), black naped hare (*Lepus nigricollis nigricollis),* bonnet macaque (*Macaca radiata),* common langur (*Semnopithecus entellus),* lion-tailed macaque (*Macaca silenus*), Nilgiri tahr (*Hemitragus hylocrius),* Indian porcupine (*Hysterix indica),* Indian giant squirrel (*Ratufa indica),* grey jungle fowl *(Gallus sonneratii),* red spur fowl *(Galloperdix spadicea)* and Indian peafowl (*Pavo cristatus).* In addition, a considerable number of domestic livestock (cattle and buffaloes) graze in several parts of the reserve, especially close to villages. Major forest types include Southern Hill Top Evergreen, Southern Tropical Wet Evergreen, Tirunelveli Semi-evergreen, Southern Moist Mixed Deciduous, Tropical Riparian Fringe, Dry Teak, Southern Dry Mixed Deciduous, Carnatic Umbrella Thorn, Ochlandra Reeds, Southern Montane Wet Temperate Forests and Grasslands of low and high altitudes (Champion & Seth 1968).

Sign surveys

Fieldwork was conducted from March to October in 2006, 2007 and 2010. Large carnivore sign surveys (Jhala *et al.* 2008) were conducted throughout the tiger reserve during March to October in 2006 and same period in 2010 following Jhala *et al.* (2008). Signs such as scats (old, fresh and very fresh), scrapes, rakes and pugmarks were recorded along foot trails, road sides, stream and river beds and roadsides. The total search effort amounted to 709 kms. On an average, 3.5 hrs were spent to walk 5 km. A team of two persons were involved in walking each of the 5 km walk. Tiger and leopard scats were distinguished from one another by size, diameter and presence of ancillary signs like pugmarks, tracks (Johnsingh 1983; Karanth & Sunquist 1995; Ramesh 2010) with other supplementary evidences such as scrapes and rake marks. Tiger scats were distinguished from that of leopard in having larger size, less coiled, having a larger distance and diameter between two successive constrictions within a single piece of scat (Johnsingh 1983; Ramesh 2010). Dhole scats could be easily distinguished based on their characteristic smell, smaller size, and deposition pattern i.e., in clusters at the intersection of trails/ roads/wheel tracks on bare or exposed soil (Acharya 2007; Johnsingh 1983; Karanth & Sunquist 1995; Ramesh 2010). Sloth bear (*Melursus ursinus*) scats were distinguished by their size, shape, composition of seeds, plant and animal remains along with associated indirect evidences (track, signs) (Ramesh *et al.* 2010). Carnivore sign encounter rate was calculated as number of signs/km walk.

Camera trapping

The study area was selected for camera surveys based on evidences of tiger sign encounter rate in an area covering 43 km^2 in 2007. Study area was divided into 2 × 2 km^2 grids (Fig. 1). Within each grid at least one pair of analog cameras was placed at 20 sites and operated for 45 days continuously. These cameras were later replaced by digital ones and the study area was later extended to 51 km^2 with 19 camera sites, replacing a few sites, operated for 80 days in 2010. In addition, ten cameras were randomly placed in other parts of Reserve (OPR) at > 800 m altitude outside the study area in 2007. At each site two cameras were placed opposite to each other at a distance of 3 - 6 m apart from the centre of the trail/ road so as to photograph the target species (i.e., tiger and leopard). Cameras were mounted in iron boxes at a height of 35 cms from the ground. We maintained the inter-camera trap distance at 1.5 - 2.5 km to maximize tiger and leopard photographic rate. Since KMTR has poor road network, all 20 sites were checked once in three days. Each camera was given a unique identification number and each film roll was given a unique code enabling us to match the date, time and picture. Based on the stripe and rosette patterns on flanks, limbs and fore-quarters, individual tigers and leopards were identified (Karanth 1995; Karanth & Nichols 1998). Unique number of tigers and leopards were identified on the basis of right or left flank photographs of individuals separately. Here we used the flank that had maximum number of unique individuals for abundance estimation of tiger and leopard to avoid the possibility of double counting an individual**.** Further, capture history was created for each individual by assigning either "1" or "0" if the individual was captured on each occasion, where each trap day represented a separate capture occasion. Individual capture histories of tiger and leopard were developed in an "X matrix format" (Otis *et al.* 1978). Capture histories were analyzed using the software CAPTURE (Rexstad & Burnham 1991) using models developed for closed populations. The appropriate model was selected based on the discriminant function score. The density was estimated using Full Mean Maximum Distance Moved (MMDM), Half MMDM and likelihood-based spatially explicit capture-recapture(SECR) methods in program DENSITY 4.4 (Efford 2009) and Bayesian-based SECR methods using SPACECAP 1 (Singh *et al.* 2010). In SPACECAP analysis, Poisson distribution was assumed, buffer of 5 km was used, and proximity trap option was chosen which allowed for multiple captures on the same occasion. Half normal function was fitted to the distance between the home range centres and trap location. To achieve spatial Bayesian estimate (Royle *et al.* 2009), Bernoulli distribution and trap response absent were used for both tiger and leopard. We generated systematic home range centres in an area contained within 5 km buffer which was larger than mean maximum distance moved, around camera traps. The large buffer around the sampled area was used to ensure inclusion of all individual home ranges within a reach of cameras (Kalle *et*

Table 1. Population estimates of tiger and leopard using conventional MMDM methods in the intensive camera survey area of Kalakad-Mudanthurai Tiger Reserve, Western Ghats.

Year	Species	Best Model	Methods	P hat	N ± SE	MMDM ± SE	ETA	D ± SE
2007	Leopard	Mo Null	1/2 MMDM	0.081	3.0 ± 0.3	4.96 ± 1.10	125.0	2.4 ± 0.49
	Mt + 1 = 3		MMDM				246.8	1.2 ± 0.30
2010	Leopard	Mo Null	1/2 MMDM	0.040	3.0 ± 0.6	4.05 ± 1.34	121.2	2.5 ± 0.77
	Mt + 1 = 3		MMDM				217.2	1.4 ± 0.54
2007	Tiger		1/2 MMDM				116.0	0.86 ± 0.00*
	Mt + 1 = 1		MMDM				222.0	0.45 ± 0.00*
2010	Tiger	Mo Null	1/2 MMDM	0.049	4.0 ± 0.6	4.54 ± 2.24	131.4	3.0 ± 1.1
	Mt + 1 = 4		MMDM				244.1	1.6 ± 0.88

Mt+1 = Number of individuals captured, Mo = Model Null, 1/2 MMDM = Half Mean Maximum Distance Moved, Full MMDM = Full Mean Maximum Distance Moved, P hat = Capture probability, N = Population size, SE = Standard Error, MMDM = Mean Maximum Distance Moved, ETA = Effective Trapping Area, D = Number of individuals/100 km^2,* = Density estimated using 1/2MMDM and MMDM of tiger from 2010 data added to the minimum convex polygon area of 2007.

al. 2011; Royle & Dorazio 2008). In Likelihood-based and Bayesian-based spatially explicit capture-recapture method the estimates stabilized at 5 km buffer width. The detailed description of all four methods can be referred in published articles (Efford *et al.* 2004; Efford 2009; Kalle *et al.* 2011; Karanth 1995; Karanth & Nichols 1998; Royal *et al.* 2009). To use closed population models, the population should be demographically and geographically closed (Otis *et al.* 1978). To test our closure assumption, program Close Test 3 was used (Stanley & Burnham 1999). Mean encounter rate (no. of photo captures / 100 trap nights) was calculated for tiger, leopard, dhole and their prey species. Large carnivore temporal activity pattern was assessed from the date and time imprinted on photographs.

Prey abundance

Line transects (n = 32) were laid randomly in the study area covering major vegetation types except for inaccessible areas. Each line transect was walked four to six times during 2006 and 2010. The length of line transects varied from 1.5 to 2 km (Fig. 2). The total length and sampling effort amounted to 61.9 and 353.2 km respectively. All transects were walked between 06.30 h and 09.00 h. For each potential prey species, detection, time, species group size, group composition, animal bearing (using a hand held compass) and angular sighting distance (using a laser range finder) were recorded. Abundance of prey species was estimated using program Distance 6.0 (Thomas *et al.* 2009) following line transect method (Buckland *et al.* 2001; Burnham *et al.* 1980; Lancia *et al.* 1994). All density estimates were done after 1 % truncation of the farthest sighting data from the line transect. Analysis was done by fitting different detection functions to the observed data for estimation of densities. The best model was selected on the basis of the lowest Akaike Information Criteria (AIC) values (Buckland *et al.* 1996; Burnham *et al.* 1980). Halfnormal Cosine-Binomial model was fitted for the species which was sighted < 10 times.

Results

Carnivore sign encounter rates

We recorded the highest sign encounter rate for leopard (1.26 km^{-1}) followed by sloth bear (0.77 km^{-1}), dhole (0.67 km^{-1}) and tiger (0.18 km^{-1}) within the Tiger Reserve. Sign survey results showed the presence of all three large carnivores (tiger, leopard and dhole) across all vegetation types. Tiger sign encounter rate was higher at high altitude forests (> 1400 m) which were interspersed with open grasslands as compared to mid-altitude and low-altitude (< 600 m) especially in rainforests. Encounter rates of leopard, dhole, and sloth bear were higher in deciduous forests and scrub vegetation which are below 800 m.

Carnivore densities based on camera trapping

During 45 days of camera surveys in 2007, a total sampling effort of 900 camera-nights yielded two left flanks and one right flank photograph of

Table 2. Population estimates of tiger and leopard using spatially explicit capture-recapture methods in intensive camera survey area of Kalakad-Mudanthurai Tiger Reserve, Western Ghats.

Year	Species	Methods	D ± SE	σ ± SE	g0/λ ± SE	Psi ± SE	N(X) ± SE	ETA
2007	Leopard	Max likelihood	1.3 ± 1.0	2.8 ± 1.2	0.022 ± 0.014			
	Mt + 1 = 3	Bayesian	2.2 ± 1.0	0.40 ± 0.34	0.032 ± 0.019	0.34 ± 0.17	5.9 ± 2.8	320 km^2
2010	Leopard	Max likelihood	2.8 ± 2.0	1.5 ± 0.47	0.014 ± 0.008			
	Mt + 1 = 3	Bayesian	2.4 ± 1.3	0.29 ± 0.24	0.012 ± 0.010	0.44 ± 0.24	7.9 ± 4.4	320 km^2
2007	Tiger	NA						
	Mt + 1 = 1							
2010	Tiger	Max likelihood	2.2 ± 1.6	2.7 ± 1.1	0.009 ± 0.005			
	Mt + 1 = 4	Bayesian	2.9 ± 1.4	0.68 ± 0.57	0.007 ± 0.003	0.32 ± 0.17	9.1 ± 4.7	320 km^2

D = Density of individuals 100 km^{-2}, σ = Spatial scale parameter, g0 = Detection probability (frequentist), λ = lambda expected encounter frequency (Bayesian)-at trap location considered as home range centre, Psi = Data augmentation parameter, N (X) = Population size of individuals having their activity centres within the effective trapping area, ETA = Trapping area with 5 km buffer.

Table 3. Photographic encounter rates of different species in the intensive camera survey area of Kalakad-Mudanthurai Tiger Reserve, Western Ghats.

Species	Scientific Name	2007	2010
Tiger	*Panthera tigris*	0.2 ± 0.2	1.4 ± 0.6
Leopard	*Panthera pardus*	1.7 ± 0.7	1.3 ± 0.6
Dhole	*Cuon alpinus*	1.9 ± 0.8	0.6 ± 0.3
Sloth bear	*Melursus ursinus*	0.3 ± 0.3	0.3 ± 0.2
Small Indian civet	*Viverricula indica*	0.1 ± 0.1	0.6 ± 0.6
Brown palm civet	*Paradoxurus jerdoni*	0.6 ± 0.4	-
Grey mongoose	*Herpestes edwardsii*	0.3 ± 0.2	0.2 ± 0.2
Smooth - coated otter	*Lutrogale perspicillata*	0.4 ± 0.3	-
Indian pangolin	*Manis crassicaudata*	0.1 ± 0.1	-
Indian porcupine	*Hystrix indica*	1.2 ± 0.7	0.2 ± 0.1
Elephant	*Elephas maximus*	4.3 ± 2.3	2.7 ± 0.8
Gaur	*Bos gaurus*	8.0 ± 5.1	3.3 ± 1.2
Sambar	*Rusa unicolor*	4.2 ± 2.0	0.8 ± 0.4
Wild pig	*Sus scrofa*	3.5 ± 1.7	0.5 ± 0.2
Mouse deer	*Moschiola meminna*	3.2 ± 1.1	1.1 ± 0.5
Indian muntjac	*Muntiacus muntjak*	0.6 ± 0.4	0.1 ± 0.1
Peafowl	*Pavo cristatus*	2.4 ± 2.0	0.1 ± 0.1
Red spur fowl	*Galloperdix spadicea*	0.3 ± 0.2	0.3 ± 0.2
Grey jungle fowl	*Gallus sonneratii*	3.0 ± 1.1	0.3 ± 0.3
Crested serpent eagle	*Spilornis cheela*	0.4 ± 0.3	-
Domestic buffalo	*Bubalus buvalis*	2.0 ± 1.1	-
Emerald dove	*Chalcophaps indica*	0.1 ± 0.1	-
Three- striped palm squirrel	*Funambulus palmarum*	0.3 ± 0.2	0.1 ± 0.1
Bonnet macaque	*Macaca radiata*	-	0.1 ± 0.1
The Asian Fairy-bluebird	*Irena puella*	-	0.1 ± 0.1

one male tiger, 15 photographs (five right flanks and 10 left flanks) of leopard and 17 independent photographs of dhole. Two individual leopards were identified from right flank photos and three individuals from left flank photos. Eighty days of camera trapping in 2010, led to a total sampling effort of 1520 camera-nights that yielded 23 photographs of tiger (eight left flanks, 13 right flanks and two unidentified). Two male tigers, a tigress and an unidentified sex were identified from right

Table 4. Estimated prey species density in Kalakad-Mudanthurai Tiger Reserve, Western Ghats.

Species	Total effort (km)	Model	No. of group	ESW ± SE	G ± SE	Dg ± SE	D ± SE
Gaur	353.2	Halfnormal Polynomial	18	33.2 ± 6.1	4.7 ± 0.93	0.76 ± 0.28	3.6 ± 1.5
Sambar	353.2	Uniform Cosine	85	25.0 ± 1.1	1.4 ± 0.11	4.8 ± 1.0	7.0 ± 1.5
Wild pig	353.2	Halfnormal Cosine-Binomial	8	17.9 ± 4.9	2.0 ± 0.62	0.63 ± 0.29	1.3 ± 0.71
Nilgiri langur	353.2	Halfnormal Hermite	61	27.2 ± 2.6	3.1 ± 0.23	3.2 ± 0.82	9.9 ± 2.6
Grey Jungle Fowl	353.2	Halfnormal Hermite	75	11.1 ± 1.0	1.5 ± 0.12	9.5 ± 1.7	14.7 ± 2.9
Peafowl	353.2	Halfnormal Cosine-Binomial	5	20.7 ± 7.5	1.0 ± 0.20	0.34 ± 0.21	0.41 ± 0.26
Indian Giant Squirrel	353.2	Uniform Polynomial	15	12.8 ± 1.7	1.0 ± 0.00	1.7 ± 0.86	1.7 ± 0.86

ESW = Effective Stripe Width, SE = Standard Error, G = Group size, Dg = group density, D = Individual density km^{-2}.

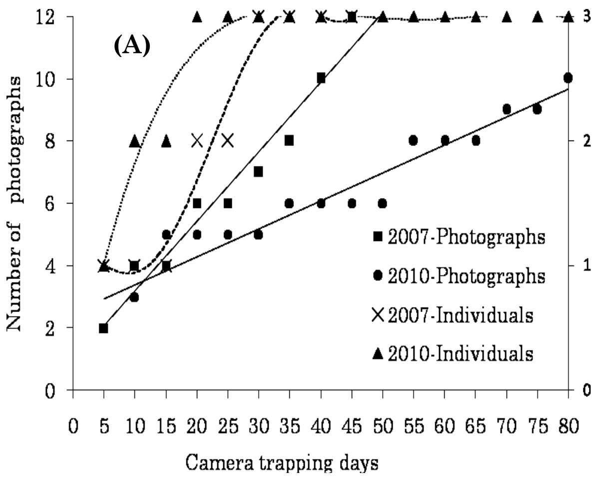
flank photos and two male tigers from left flank photos. In case of leopard, 17 photographs of nine left flanks and eight right flanks resulted in identification of three individuals (two males and one female). Ten independent photographs of dhole were obtained.

The tiger density ranged from 1.6 to 3.0 individuals 100 km^{-2} while leopard density ranged from 1.2 to 3.5 100 km^{-2} using different statistical methods (Tables 1 & 2). Statistical tests for population closure supported the population closure assumption both for tiger (χ^2 = 5.1, P = 0.74) and leopard (χ^2 = 7.0, P = 0.43 in 2007, χ^2 = 1.3, P = 0.87 in 2010). Among large carnivores the mean photographic encounter rate of dhole was highest, followed by leopard, sloth bear and tiger in 2007. However, during 2010 the mean photographic encounter rate of tiger was highest, followed by leopard, dhole and sloth bear (Table 3). Photographs of two tigers (one male and female), eight leopards (four males, two females and two unidentified gender individuals) and eight photographs of dhole were obtained outside the intensive camera survey area in 2007.

Sample adequacy for leopard population estimate indicated a minimum of 40 sampling days using 20 pairs of cameras in 2007 and 20 sampling days with 19 pairs of cameras in 2010 which was sufficient to capture the likely individuals present in the camera-trap survey area while 60 days for tiger was sufficient to capture the individuals present in the study area (Fig. 2). Leopards exhibited peak activity at night while tigers were most active in the early morning and late evening. Dhole activity was higher during the dawn and dusk and active only during the day time (Fig. 3).

Prey densities

In total 14 potential prey species viz., gaur, Nilgiri langur, sambar, grey jungle fowl, red spur fowl, Indian giant squirrel, black-naped hare, bonnet macaque, chital, elephant, lion-tailed macaque, mouse deer, peafowl and wild pig were detected on line transects and of which, sambar, gaur, Nilgiri langur, grey jungle fowl and Indian giant squirrel were sighted $\geq$ 5 times. Density of grey jungle fowl was the highest followed by Nilgiri langur, sambar, gaur, wild pig, Indian giant squirrel and peafowl (Table 4). The estimated overall prey density was 38.6 (SE 10.3) individuals km^{-2} which included wild ungulates: 11.9 (SE 3.7) km^{-2}, arboreal mammals: 11.6 (SE 3.5) km^{-2} and fowl: 15.1 (SE 3.2) km^{-2} (Table 1). The estimated ungulate biomass was 2614 kg km^{-2}. Uniform detection function with cosine adjustment was the best fit model for sambar (χ^2 = 0.30, P = 0.66) while half normal detection function with hermite adjustment was the best fit model for Nilgiri langur (χ^2 = 0.30, P = 0.57) and grey jungle fowl (χ^2 = 0.06, P = 80). For wild pig (χ^2 = 0.77, P = 0.67) and peafowl (χ^2 = 0.56, P = 0.45) the model selection was half normal cosine - binomial and for gaur (χ^2 = 0.28, P = 0.59) and Indian giant squirrel (χ^2 = 0.032, P = 0.98) the model selected was half normal polynomial and uniform polynomial respectively. Common langur was



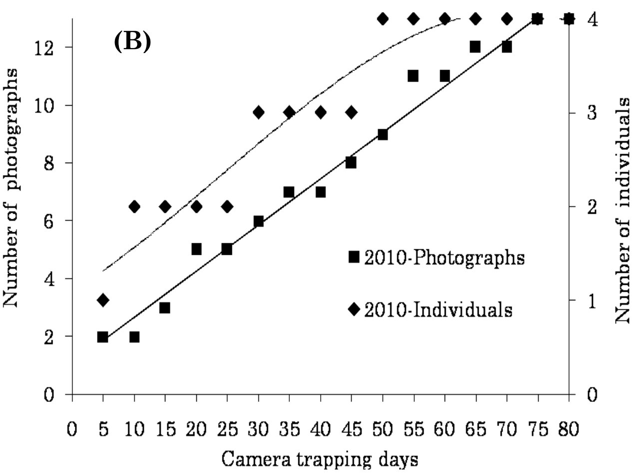


Fig. 2. Sample adequacy for estimation of (A) leopard and (B) tiger populations in the intensive camera survey area of Kalakad-Mudanthurai Tiger Reserve, India.

not encountered along transects for both years but does occur in KMTR.

Discussion

Sign surveys indicated the presence of tiger and other predators in different habitats of the park. Tiger evidence was more common at high altitude where they would prey on large bodied prey such as sambar and gaur. Leopard and dhole signs were distributed throughout the park but more common at lower altitudes (< 800 m).

The high variability in camera trapping results suggests more intensive trapping and larger geo-

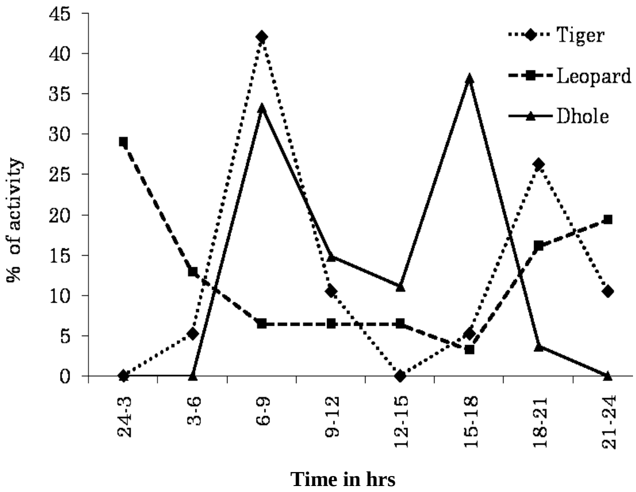


Fig. 3. Activity pattern of tiger, leopard and dhole in the intensive camera survey areas of Kalakad-Mudanthurai Tiger Reserve, India.

graphical coverage. The estimated tiger density was higher in KMTR as compared to other evergreen forest areas (Chauhan *et al.* 2006; Kawanishi & Sunquist 2004). The estimated density of tiger in rainforests of Pakke Tiger Reserve in Arunachal Pradesh, India and Sumatra was 1.15 100 km^{-2} and 1.65 100 km^{-2} (Chauhan *et al.* 2006; Griffiths 1994) respectively, while in Taman Negara National Park, Malaysia it was 1.6 tigers 100 km^{-2} (Kawanishi & Sunquist 2004). However, the estimated tiger density in KMTR was low as compared to deciduous habitats in India. This may be due to restricted availability of chital in the park which is otherwise one of the major prey species of tiger elsewhere in the sub continent. Kawanishi (2002) suggested that estimation of tiger following a capture-recapture framework in a rainforest requires huge sampling effort (more than 900 trap nights) covering larger areas. The closure test suggested that the capture period was sufficient to meet the assumption of a closed population for both tiger and leopard during the survey period. Tiger sign was recorded high at high altitude interspersed with open grasslands. This is probably because tigers are generally more abundant in areas of intermixing forests and grasslands when these areas have higher abundance of ungulate prey (Saundars 2009).

The estimated leopard density in the evergreen forest of KMTR was very low compared to non-rainforest areas. This is probably attributed to low densities of medium-sized prey and the intensive camera trapping area was selected especially based on high encounter rate of tiger signs. Bailey

(1993) and Jenny (2009) argued that terrestrial mammalian prey biomass was lower in rain forests than savannah habitat and leopard density correspondingly lower. The photographic encounter rate showed high abundance of dhole in 2007 compared to tiger and leopard while it was lower than tiger in 2010. The reason is not known. Temporal time separation has been proposed as a strategy adopted by sympatric tiger, leopard and dhole to allow coexistence (Johnsingh 1983; Karanth & Sunquist 2000; Seidensticker 1976). The higher level of activity of predators is probably associated with the activity patterns of their prey (Karanth & Sunquist 2000; Sunquist 1981). Though the peak activity of tiger, leopard and dhole were at different times, there was considerable overlap between species observed during the present study. Ramesh (2010) and Ramesh *et al.* (2010) found that tiger was crepuscular, leopards were active throughout the day and dholes were found to be diurnal in Mudumalai Tiger Reserve. Activity pattern within a species varies depending on the geographical location, climate, the distribution of prey and their interaction with other species (Leuthold 1977).

Both camera and line transect surveys indicated high abundance of gaur. As reported by Prater (1980) it was found in hilly terrain especially in the interspersed patches of open short grassland and evergreen forests. The reported abundance of sambar in KMTR is comparable with other protected areas in Western Ghats (Karanth & Sunquist 1995; Ramesh *et al.* 2009; Ramesh 2010). This may be attributed to sambar's preference for hilly terrain (Sankar & Acharya 2004) and the forest protection in the study area. However, the reported density of sambar in Mundanthurai plateau of KMTR was low (Sankaran 2001). Nilgiri langur density was high in KMTR and most of their sightings were observed in evergreen patches and some in deciduous parts. Even though, this primate is highly adapted to exploit various habitat types, it has preference for wet-evergreen forests (Ramachandran & Joseph 2001). KMTR has a large areas of continuous evergreen forest (> 400 km^2) that can support a good population of Nilgiri langur. However, its contribution to tiger prey could be limited as is the case of other smaller prey species. Similarly, spotted deer was not encountered anywhere except in the Munadanthurai plateau. The major limitation in our study was the smaller camera survey area and hence we recommend larger camera sampling area to be assessed in KMTR to improve carnivore density estimates. Since the estimated tiger and leopard density is specific to evergreen forests of KMTR, we suggest that intensive camera survey should be carried out even in other forest types of the Tiger Reserve. The population densities of large carnivores are directly related to biomass of wild prey (Carbone & Gittleman 2002; Karanth *et al.* 2004; Ramesh *et al.* 2009; Stander *et al.* 2009). Large carnivores indicate the health of forest ecosystems and monitoring their populations through non-invasive technique such as camera trapping is proving to be much more cost effective. This study provides baseline information on large mammalian predators and prey base in KMTR, one of the few PAs representing India's remnant rainforests.

Acknowledgements

We thank the Director and Dean, Wildlife Institute of India and the Chief Wildlife Warden, Tamil Nadu for granting permission to work in KMTR. We would like to thank the Field Director Mr. Ramkumar, Deputy Director Mr. Venkatesh and Range officers of KMTR for the logistic support extended in the field. Special thanks to Riddhika for her editorial comments on the manuscript. We thank our field assistants P. Durai, M. Anilkumar, M. Ranjith and staff of Forest Department for their assistance during field work.

References

Acharya, B. B. 2007. *The Ecology of the Dhole or Asiatic Wild Dog (Cuonalpinus) in Pench Tiger Reserve, Madhya Pradesh*. Ph.D. Thesis. Saurashtra University, Rajkot.

Bailey, T. N. 1993. *The African Leopard: Ecology and Behavior of a Solitary Felid*. Columbia University Press, New York.

Buckland, S. T., D. A. Elston & S. J. Beaney. 1996. Predicting distributional change, with application to bird distributions in northeast Scotland. *Global Ecology and Biogeography Letters* **5**: 66-84.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers & L. Thomas. 2001. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations.* Oxford University Press, Oxford, UK.

Burnham, K. P., D. R. Anderson & J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. *Wildlife Monographs* **72**: 1-202.

Carbone, C. & J. L. Gittleman. 2002. A common rule for the scaling of carnivore density. *Science* **295**: 2273-2276.

Caughley, G. & A. R. E. Sinclair. 1994. Counting animals. pp. 334. *In*: G. Caughley & A. R. E. Sinclair (eds.) *Wildlife Ecology and Management*. Blackwell Science, Cambridge.

Champion, H. G. & S. K. Seth. 1968. *A Revised Survey of the Forest Types of India*. Oxford & IBH Publishers, New Delhi.

Chauhan, D. S., R. Singh, S. Mishra, T. Dadda & S. P. Goyal. 2006. *Estimation of Tiger Population in an Intensive Study Area of Pakke Tiger Reserve, Arunachal Pradesh, India*. Wildlife Institute of India, Dehradun, India.

Datta, A., M. O. Anand & R. Naniwadekar. 2008. Empty forests: large carnivore and prey abundance in Namdapha National Park, north-east India. *Biological Conservation* **141:** 1429-1435.

Efford, M. G. 2009. DENSITY 4.4: software for spatially explicit capture-recapture. Department of Zoology, University of Otago, Dunedin, New Zealand. http://www.otago.ac.nz/density. Accessed 10 Oct 2010.

Efford, M. G., D. K. Dawson & C. S. Robbins. 2004. DENSITY: software for analysing capture-recapture data from passive detector arrays. *Animal Biodiversity and Conservation* **27**: 217-228.

Eisenberg, J. F. & J. Seidensticker. 1976. Ungulates in southern Asia: a consideration of biomass estimates for selected habitats. *Biodiversity and Conservation* **10**: 293-308.

Ganesh, T., R. Ganesan, M. Soubadra Devy, P. Davidar & K. S. Bawa. 1996. Assessment of plant biodiversity at a mid-elevational evergreen forest of Kalakad-Mundanthurai Tiger Reserve, Western Ghats, India. *Current Science* **71**: 379-392.

Griffiths, M. 1994. Population density of Sumatran tigers in Gunung Leuser National Park. pp. 93-102. *In:* R. L. Tilson, Komar Soemarna, Widodo Ramono, Sukianto Lusli, K. Traylor-Holzer & U. S. Seal (eds.) *Sumatran Tiger Report: Population and Habitat Viability Analysis*. Apple Valley, Minnesota, Indonesian Directorate of Forest Protection and Nature Conservation and IUCN/SSC Conservation Breeding Specialist Group. Available at http://www.5tigers.org/Indonesia/PHVA/intrphva.htm.

Jenny, D. 2009. Spatial organization of leopards *Pantherapardus* in Tai National Park, Ivory Coast: is rainforest habitat a 'tropical haven'? *Journal of Zoology* **240:** 427-440.

Jhala, Y. V., Q. Qureshi & R. Gopal. 2008. *Status of Tigers, Co-predators and Prey in India*. National Tiger Conservation Authority, Govt. of India, New Delhi, and Wildlife Institute of India, Dehradun.

Johnsingh, A. J. T. 1983. Large mammalian prey-predators in Bandipur. *Journal of the Bombay Natural History Society* **80**: 1-57.

Johnsingh, A. J. T. 1992. Prey selection in three large sympatric carnivores in Bandipur. *Mammalia* **56**: 517-526.

Johnsingh, A. J. T. 2001. The Kalakad-Mundanthurai Tiger Reserve: A global heritage of biological diversity. *Current Science* **80**: 378-388.

Kalle, R., T. Ramesh, Q. Qureshi & K. Sankar. 2011. Density of tiger and leopard in a tropical deciduous forest of Mudumalai Tiger Reserve, southern India, as estimated using photographic capture-recapture sampling. *Acta Theriologica* (In press).

Karanth, K. U. 1995. Estimating tiger (*Panthera tigris*) populations from camera-trapping data using capture-recapture models. *Biological Conservation* **71:** 333-338.

Karanth, K. U. & M. E. Sunquist. 1995. Prey selection by tiger, leopard and dhole in tropical forests. *Journal of Animal Ecology* **64**: 439-450.

Karanth, K. U. & J. D. Nichols. 1998. Estimation of tiger densities in India using photographic captures and recaptures. *Ecology* **79:** 2852-2862.

Karanth, K. U. & M. E. Sunquist. 2000. Behavioural correlates of predation by tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon al pinus*) in Nagarahole, India. *Journal of Zoology* **250:** 255-265.

Karanth, K. U. & J. D. Nichols. 2002. *Monitoring Tigers and their Prey*. Centre for Wildlife Studies, Bangalore, India.

Karanth, K. U., J. D. Nichols & N. S. Kumar. 2004. Photographic sampling of elusive mammals in tropical forests. pp. 229-247. *In*: W. L. Thompson (ed.) *Sampling Rare or Elusive Species: Concepts, Designs, and Techniques for Estimating Population Parameters*. Island Press, Washington.

Karanth, K. K., J. D. Nichols, K. U. Karanth, J. E. Hines & N. L. Christensen. 2010. The shrinking ark: pattern of large mammal extinction in India. *Proceedings of the Royal Society, Biological Sciences* **277:** 1971-1979.

Kawanishi, K. 2002. *Population Status of Tigers (Panthera pardus) in a Primary Rainforest of Peninsular Malaysia*. Ph.D. Thesis. University of Florida.

Kawanishi, K. & M. E. Sunquist. 2004. Conservation status of tigers in a primary rainforest of Peninsular Malaysia. *Biological Conservation* **120:** 329-344.

Lancia, R. A., J. D. Nichols & K. N. Pollock. 1994. Estimation of number of animals in wildlife populations. pp. 215-253. *In*: T. A. Bookhout (ed.) *Research and Management Techniques for Wildlife and Habitats*. Bethesda, The Wildlife Society, Maryland.

Leuthold, W. 1977. *African Ungulates*. Springer Verlag, Berlin.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. Da Fonseca & J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

O'brien, T. G., M. F. Kinnaird & H. T. Wibisono. 2003. Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. *Animal Conservation* **6**: 131-139.

Otis, D. L., K. P. Burnham, G. C. White & D. R. Anderson. 1978. Statistical inference from capture data of closed populations. *Wildlife Monographs* **2**: 1-13.

Prater, S. H. 1980. *The Book of Indian Animals*. Bombay Natural History Society, Bombay, India.

Ramachandran, K. & G. K. Joseph. 2001. Feeding ecology of nilgiri langur (*Trachypithecusjohini*) in Silent Valley National Park, Kerala, India. *The Indian Forester* **127**: 1155.

Ramakrishnan, U., R. G. Coss & N. W. Pelkey. 1999. Tiger decline caused by the reduction of large ungulate prey: evidence from a study of leopard diets in southern India. *Biological Conservation* **89:** 113-120.

Ramesh, B. R., S. Menon & K. S. Bawa. 1997. A vegetation based approach to biodiversity gap analysis in the Agastyamalai Region, Western Ghats, India. *Ambio* **26**: 529-536.

Ramesh, T., V. Snehalatha, K. Sankar & Q. Qureshi. 2009. Food habits and prey selection of tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu, India. *Journal of Scientific Transactions in Environment and Technovation* **2**: 170-181.

Ramesh, T., K. Riddhika, K. Sankar & Q. Qureshi. 2010. Large predators and prey population in Mudumalai Tiger Reserve, Western Ghats. pp. 54. *In*: R. V. Varma, P. Nayar, C. K. Peethambaran, G. M. Nair, T. Radhakrishnan, A. S. K. Nair & S. Rajasekaran (eds.) *First Indian Biodiversity Congress*. Centre for Innovation in Science and Social Action, India.

Ramesh, T. 2010. *Prey Selection and Food Habits of Large Carnivores: Tiger Panthera tigris, Leopard Panthera pardus and dhole Cuon alpinus in Mudumalai Tiger Reserve, Tamil Nadu*. Ph.D. Thesis, Saurashtra University, Rajkot, Gujarat.

Ramesh, T., K. Sankar & Q. Qureshi. 2010. Additional notes on the diet of sloth bear *Melursus ursinus* in Mudumalai Tiger Reserve as shown by scat analysis. *Journal of Bombay Natural History Society* **106**: 204-206.

Richard, T. Corlett. 2007. What's so special about Asian tropical forests? *Current Science* **93**: 1551-1557.

Rexstad, E. A. & K. P. Burnham. 1991. User's guide for interactive program CAPTURE: abundance estimation of closed animal populations. Colorado Cooperative Fish and Wildlife Research Unit. Colorado State University, Fort Collins, Colorado.

Royle, J. A. & R. M. Dorazio. 2008. *Hierarchical Modeling and Inference in Ecology: The Analysis of Data from Populations, Metapopulations and Communities.* Academic Press, Bullington, MA, USA.

Royle, J. A., K. U. Karanth, A. M. Gopalaswamy & N. S. Kumar. 2009. Bayesian inference in camera trapping studies for a class of spatial capture-recapture models. *Ecology* **90**: 3233-3244.

Sankar, K. & B. Acharya. 2004. Ungulates of India. *Envis Bulletin* **7:** 163-180.

Sankaran, M. 2001. *Disturbance, Diversity and Community Dynamics in a Southern Indian Savanna-grassland Ecosystem*. Ph.D. Thesis. Syracuse University, Syracuse.

Sathyakumar, S. 1992. Food habits of leopard *Panthera pardus* on Mundanthurai Plateau, Tamil Nadu India. *Tiger Paper* **19**: 8-9.

Saundars, C. M. 2009. *Factors Influencing Conservation Success or Failure in Tiger Range States*. Degree of Bachelor of Arts Thesis submitted to Waterville, ME.

Seidensticker, J. 1976. On the ecological separation between tigers and leopards. *Biotropica* **8**: 225-234.

Singh, P., A. M. Gopalaswamy, A. J. Royle, N. S. Kumar & K. U. Karanth. 2010. *SPACECAP: A Program to Estimate Animal Abundance and Density using Bayesian Spatially-Explicit Capture-Recapture Models.* Wildlife Conservation Society, India Program, Centre for Wildlife Studies, Bangalore, India. Version 1.0

Stander, P. E., P. J. Haden, H. Kaqece & H. Ghan. 2009. The ecology of asociality in Namibian leopards. *Journal of Zoology* **242**: 343-364.

Stanley, T. R. & K. P. Burnham. 1999. A closure test for time-specific capture-recapture data. *Environmental and Ecological Statistics* **6**: 197-209.

Sunquist, M. E. 1981. The social organization of tigers (*Panthera tigris*) in Royal Chitwan National Park. *Smithsonian Contribution to Zoology* **336**: 1-98.

Thomas, L., J. L. Laake, E. Rexstad, S. Strindberg, F. F. C. Marques, S. T. Buckland, D. L. Borchers, D. R. Anderson, K. P. Burnham, M. L. Burt, S. L. Hedley, J. H. Pollard, J. R. B. Bishop & T. A. Marques. 2009. Distance 6.0. *Research Unit for Wildlife Population Assessment.* University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance.

Wikramanayake, E. D., E. Dinerstein, J. G. Robinson,

U. Karanth, A. Rabinowitz, D. Olson, T. Mathew, P. Hedao, M. Conner, G. Hemley & D. Bolze. 1998. An ecology-based method for defining priorities for large mammal conservation: The tiger as case study. *Conservation Biology* **12:** 865-887.

Wilson, G. J. & R. J. Delahay. 2001. A review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. *Wildlife Research* **28**: 151-164.

(Received on 09.09.2010 and accepted after revisions, on 23.06.2011)