Estimating tiger and its prey abundance in Bardia National Park, Nepal

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We estimated tiger and wild prey abundance in the Bardia National Park of Nepal. Tiger abundance was estimated from camera trap mark recapture in 85 days between December, 2008 to March, 2009 by placing 50 camera trap pairs in 197 trap locations with a sampling effort of 2,944 trap nights. We photo captured 16 individuals (≥1.5 year old) tigers identified on the basis of their unique stripe patterns. The number and density (per 100 km^2) of tiger was 19 (SE 3.3) and 1.31 (SE 0.32), respectively. Distance sampling was used to assess the prey abundance on 170 systematically laid line transects between May–June, 2009. The density of all the wild prey (individuals/km^2) was 56.3 (SE 6.5). The density (individuals /km^2) of Chital was 29.3 (SE 4.3). The density of barking deer, wild pig and sambar were in higher to medium, medium and medium to low range as compared to other protected areas in South Asia respectively. The study indicated decline of tiger in Bardia National Park even though the existing level of the prey population appears to be adequate to support higher tiger numbers. There is hope of meeting the ambitious goal of doubling the tiger population by 2022 set by the Tiger Range Countries which was evident in 2014 with 50 tigers in Bardia National Park and Khata Corridor. The tiger habitats outside the protected areas should be managed with the local community-based initiatives to ensure the acceptance of low density tiger movement.

Key words: Bardia, camera trap, density, line transect, tiger, wild prey

Terai Arc Landscape (TAL) Nepal encompasses an area of 23,199 km^2, covering 14 Terai districts from Rautahat in the east to Kanchanpur in the west, and consists of over 75% of the remaining forests of the Terai and the foot hills of Churia. The protected areas (PAs) are part of the global tiger conservation landscape and are source to maintain the wildlife. The corridor and connectivity within and between the countries are vital for the long-term maintenance of wildlife. Thus, the regular monitoring of the forest resources and wildlife is important for the management of the wildlife. The Bardia National Park (BNP) has been listed as category II tiger conservation landscape in global tiger conservation scenario (Dinerstein *et al.*, 2007).

Over the past 200 years, wild tiger populations have declined by more than 98% in the Indian Subcontinent (Mondol *et al.*, 2009) and probably by the same percentage through the rest of the tiger's range (Seidensticker, 2010).

The current global tiger population is comprised of <5% of what was estimated just a century ago (Dinnerstein *et al.*, 2007) with the current adult number estimated to be mean 3643, distributed in Bangladesh 440, Bhutan 75 (67–81), Cambodia 10–30, China 45 (40–50), India 1,411 (1,165–1,657), Indonesia 325 (250–400), Lao PDR 17 (9–23), Malaysia 500, Myanmar 85, Nepal 155 (124–229), Russia 360 (330–390),Thailand 200 and Vietnam 10s (estimated) (GTIS, 2011).

Historically, tigers were distributed continuously across the lowland Himalayan forests in Nepal but the surveys, between 1987 and 1997, documented only three isolated tiger populations (Smith *et al.*, 1998); BNP being one.

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In Nepal, the oldest population estimates of tiger come from Chitwan National Park (CNP). The estimates until the mid 1990's were mainly based on either radio-telemetry (Sunquist, 1981; Smith, 1993; Smith *et al.*, 1999) or pugmark surveys (McDougal, 1999). Although they provide a minimum estimate, these methods face the issues of incomplete spatial sampling of the area of interest and incomplete detection of animals even within the area that is sampled. Thus, population sampling approaches that explicitly deal with these two problems by employing appropriate statistical models are essential for robust estimation of animal abundance (Seber, 1982; Williams *et al.*, 2002; Thompson, 2004). This study uses the spatially explicit capture-recapture likelihood approach.

Chital (*Axis axis*), sambar (*Cervus unicolor*), swamp deer (*Cervus duvauceli duvauceli*), wild pig (*Sus scrofa*), hog deer (*Axis porcinus*) and barking deer (*Muntiacus muntjak*) are major prey species of tiger in the BNP. The quantification of these prey species is of utmost importance in these PAs that are supporting different carnivores species including tiger, leopard (*Panthera pardus*) and wild dog (*Cuon alpinus*).

In this paper, we have described the use of camera-trap mark-recapture method to obtain the abundance estimate of tigers, and line transects to obtain the density of the tiger wild prey.

Materials and methods

Study area

The study was conducted in the BNP situated in the Terai plains and the Siwaliks of the Mid-Western Nepal. Established in 1969 and extending over an area of 968 km², the Park is located between 28°15' N and 28°35.5' N latitude and between 80°10' E and 81°45' E longitude. The terrain of the Park ranges from 152 m to 1,440 m from the mean sea level. Most of the Park area is occupied by the lowland flood plains and the inner valley; about 80% of the Park area is covered by forests.

Field methods

Camera trap survey (Karanth and Nichols, 1998 and 2002; DNPWC, 2005 and 2008; Dhakal *et al.*, 2014) was conducted in 20 blocks of 50–100 km^2; altogether, 197 traps were located (Fig. 1) at different points covering a total area of 1,456 km^2 (½ Mean Maximum Distance Moved: MMDM area) in 2,944 trap nights. Each block was camera trapped for 15 days between December, 2008 and March, 2009 by employing Stealth Cam and Moultrie passive camera traps placed around 16:00 hours and removed after 09:00 hours to avoid theft.

Camera traps were rotated between blocks to cover the entire area. At each site, paired cameras were deployed using 15-day sampling period in

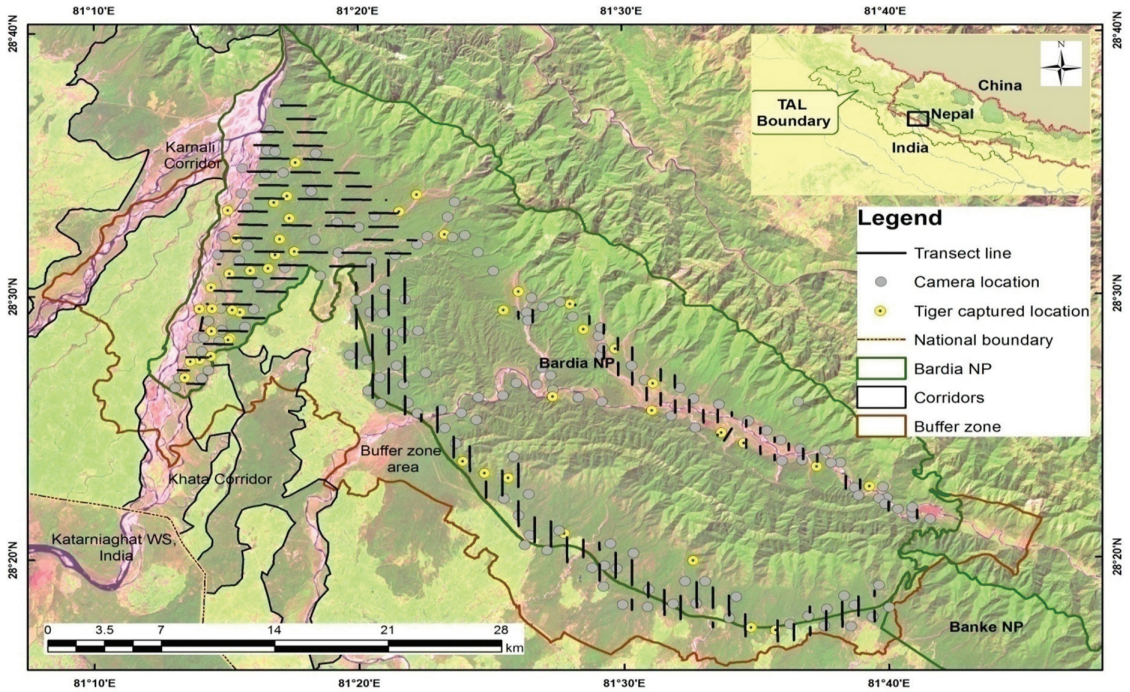

Fig. 1: Map showing the line transects and the location of camera traps within the study area (BNP)

each of the camera locations. The trap distance between the two trapping stations was 1.5 km. Care was taken not to leave any potential gaps in the sampling area of interest.

Transects were laid out systematically using DISTANCE Software (Thomas *et al.*, 2009) with the random start option for tiger's wild prey. We determined minimum two temporal replicates and 170 spatial replicates (127 in the Karnali flood plains and the Churia foot hills and 43 in the Babai Valley) (Fig. 1). Computer-generated transect points were laid on the map and uploaded on the GPS.

During May–June after the burning heat, two observers, on elephant-back, moved between 06:00–09:00 hours and 16:00–19:00 hours when the prey-animals were most active along the line transect recording all the prey species, the number of individual animals, the radial sighting distance to the animal (or the centre of the animal cluster) and the sighting angle between the transect line and the animal or the centre of the cluster of the animals observed (Buckland *et al.*, 2001).

Data analysis

Photographic capture-recapture analysis (Karanth and Nichols, 1998; Pollock *et al.*, 1990) was undertaken to estimate tiger population parameters. Capture histories (X matrices) were developed on individual tigers identified on the basis of the stripe pattern on the body flanks, legs and face (Karanth, 1995; McDougal, 1977; Schaller, 1967; DNPWC, 2005). Data were analyzed using the CAPTURE 2 Interface Program (Otis *et al.*, 1978; Rexstad and Burnham, 1991; White *et al.*, 1982) for estimation of the number.

We used spatial density analysis (Maximum Likelihood Spatially Explicit Capture Recapture, DENSITY Software (Efford, 2009) to overcome the issue of geographical closure using tiger habitat.

Tiger wild-prey was first analyzed as one group for the whole Park along a total of 559.2 km distance within the three distinct strata *viz.* i) the Karnali flood plains (KFP, along 211.9 km distance), ii) the Foot hills (FH, along 273.1 km distance) and iii) the Babai Valley (BV, along 74.2 km distance) and followed by species having more than 40 observations afterwards. For selecting the best model (or models) to use for generating density estimates, model robustness, relative Akaike Information Criterion (AIC) values, various goodness of fit tests, relative estimate precision and the detection function shape (wide shoulder near the y axis) were considered. The more robust group approach (Buckland *et al.*, 2001) prior to analyses was performed in case of spiked data.

Results and discussion

Tiger abundance

In the 197 trap locations throughout the BNP, 16 individual tigers (5 male, 8 female and 3 gender unknown) were identified. About 70% of the total individual tigers were recaptured more than once with a mean maximum distance between the two capture events of 8.9 km (SD 10). No new tigers were trapped after the 10th night (pooled across blocks), while the total number of captures increased steadily until the 14th night (pooled across blocks). Nearly 65% of the total individual tiger captures were made during the first 5 days of camera trapping.

The estimated tiger number was 19 (SE 3.3 with range 17.2–36) from the model Mh-Jackknife from CAPTURE. The density was 1.31 (SE 0.32) and 0.87 (SE 0.28) tigers/100 km^2 from ½ MMDM and MMDM of Program DENSITY (Table 1). The density from Spatial Explicit Capture-recapture of Maximum likelihood provided 0.61(SE 0.15)

Table 1: Number and density in tigers in Bardia National Park, Nepal

Best Model CAPTURE Score	Camera Trap nights	Pop. Estimate N (SE)	D (SE) from ½ MMDM ETA (Km^2)	D (SE) (MMDM) ETA (Km^2)	D(SE)ML SECR	
					All area	Mask
Mh-Jacknife 0.98	2,944	19 (3.3)	1.31 (0.32) 1,456	0.87 (0.28) 2,182	0.61 (0.15)	0.94 (0.23)

Note:
Pop. Estimate N (SE) = Population Estimate Number (Standard Error); D (SE) MMDM ETA = Density (Standard Error) Mean Maximum Distance Moved Effective Trapping Area; ML SECR = Maximum Likelihood Spatially Explicit Capture Recapture.

ranging from 0.37–0.99. Habitat mask was used and density was estimated at 0.94 (SE 0.23) 95% CI 0.58–1.52 with the area of 1,896 km^2 from the DENSITY Program.

For density analysis, the likelihood approach (Efford *et al.*, 2004) seems to be appropriate being comparatively less sensitive to buffer width as it is directly based on parameters estimating density unlike Bayesian and is faster, and both spatial methods (Royle *et al.*, 2009) have not shown any significant difference in terms of density estimation (Kalle *et al.*, 2011). Thus, the likelihood approach was interpreted for discussion.

During 1990, there were 28 tigers estimated based on 1994–96 (Basnet *et al.*, 1998). The drastic decline in the tiger population in the BNP was consistent till this study period from 42 (Bhatta *et al.*, 2002) to 18 in 2010/011 (Table 2).

This study strongly shows that the decline is not due to prey loss as compared to the dense tiger bearing PAs (Table 3) but may be due to poaching of tiger and its prey (Check, 2006; Gopal *et al.*, 2010; Karki *et al.*, 2008; Chundawat *et al.*, 2011). The current Government's effort to reinforce the protection of the Park and trans-boundary initiative is very positive and the Government's commitment to make the 2010 tiger population double by year 2022 could be achieved provided these areas are supplemented with additional prey species particularly in the Babai Valley of the Park. The doubling of the tiger population by 2022 (T x 2) is possible from the population of 37 adult breeding tigers (15 male and 22 female) in the BNP (BNP, 2012) and 50 (45–55) in BNP and Khata Corridor (forest) (Dhakal *et al.*, 2014). Dhakal *et al.* (2014) found the density of tiger to be 3.38 /100 km^2, which was quite higher than the one found in 2009 (0.9/100 km^2) in the BNP.

The improvement of tiger prey density as well as the tiger population in the BNP indicates the success of control of poaching and illegal wildlife trade including the control of poaching and illegal wildlife trade (Dhakal *et al.*, 2014).

The candidate species for introduction in the Babai Valley are wild water buffalo and swamp deer to supplement the prey-animals and rhino to build

Table 2: Population of tiger in BNP Nepal during the period of 1998–2013

Year	Density/100 km^2			Number					
	1987[2]	1998/99[3]	2000/01[3]	1998[1]/(area km^2)	1999/2000	2005	2009	2010	2011	2013
BNP	2.7	2.08	2.18	25/50	32–40	32–40	18	18	37	50

[1]Smith *et al.*, 1998; [2]Smith *et al.*, 1987; [3]Wegge *et al.*, 2009

Table 3: Number and densities of tiger and their wild prey in the PAs of Nepal and India

Name of PA	Tiger number (SE)	Tiger density (D)/100 km^2 (SE) ML SECR	D_Prey/Km^2
Corbett TR*	109 (5.4)	16.23 (1.63)	72.4
Ramnagar FD*	27 (1.5)	13.8 (2.74)	72.4
Kaziranga NP*	69 (0.5)	12.63 (1.5)	56.1
Kishanpur (Dudwa, TR)*	19 (7.31)	4.64 (1.11)	25
Katerniaghat (Dudwa, TR)*	20 (2.61)	4.82 (1.19	25
Dudhwa NP (Dudwa, TR)*	21 (5.47)	4.79 (1.28)	25
Pilibhit FD*	12 (0.17)	3.78 (1.17)	25
Chitwan NP (Karki *et al.*, 2013)	126 (21)	2.30 (0.31)	51.7
Valmiki TR*	8 (2.1)	1.12 (0.52)	
BNP, 2009 PS	19	0.9 (0.23)	56.3
Suklaphanta WR, 2009 PS (Karki *et al.*, 2015)	7	2.1 (0.8)	144.8
Parsa WR-PS (Karki, 2011)	4	0.61 (0.32)	6.6

*Jhala *et al.*, 2011 Note: TR = Tiger Reserve; FD = Forest Division; NP = National Park; WR = Wildlife Reserve and PS = Present Study

viable population in the BNP. A regular habitat management for ungulates by cutting grass in the early winter (Karki, 1997; Peet, 1997), and control burning to regulate succession in the relocated villages are essential. The current prey abundance in the BNP can support about 100 tigers assuming the removal of the current abundance of 10% per year (the annual removal of 50 ungulates/yr/tiger ranging from rhesus to wild elephant in size). The past highest tiger abundance did not cover the Babai Valley for estimation. It links with Katerniaghat (India) *via.* Khata Corridor, and with the Suhelwa Wildlife Sanctuary (India) *via.* Banke National Park which further supports tiger in this landscape. The number of tiger was found to have increased in BNP (DNPWC, 2013; Dhakal *et al.*, 2014); the new tigers probably entering from the south eastern part. One tigress was found to have regularly used the Khata Corridor while another tiger was found to have routinely visited the Corridor from the flood plains of the BNP (BNP, 2012).

Ungulate estimates

The density estimates for the wild-prey of tiger (individuals/km^2) in the year 2009 were 56.3 (SE 6.5); 50.5 (SE 8.4); 21.8 (SE8.4) and 19.2 (SE 5.2) for the entire BNP, the Karnali flood plains, the Churia foot hills and the Babai Valley of the BNP, respectively (Table 4). The Half Normal Model was found to best fit for the data of the BNP, the Karnali flood plains and the Babai Valley while the Uniform Cosine was best for the data of Churia foot hills. The average density estimates (chital/km^2) based on the Model were 29.3 (SE 4.3), 50.5 (SE 8.4), 21.8 (SE 8.4) and 19.2 (SE 5.2) for the whole BNP, the Karnali flood plains, the Churia foot hills and the Babai Valley, respectively. Besides, the Half Normal Model was also found to be best fit for the data for chital.

The density estimates (number/km^2) for sambar, wild pig, barking deer, langur, rhesus macaque and barking deer and hog deer combined were 3.07 (SE 0.7), 2.4 (SE 0.6),1.4 (SE 0.3), 9.2 (SE 2.3), 10.6 (SE 2.8) and 2.3 (SE 0.58) barking deer and hog deer, respectively based on the global detection function and cluster size (Table 4). We could not have sufficient data for the swamp deer points for the BNP due to their narrow distribution range in the Karnali flood plains.

Table 4: Density of tiger's prey species (individuals/km^2) in the Karnali Flood plains, Churia foot hills and Babai Valley of the BNP, Nepal

Species	Species model	ESW (SE)	Cluster size (±SE)	DS (±SE)/ km^2	D (±SE)/ km^2	Encounter rate (±SE/ km)	Total effort	Cut point L, R (m)
BNP_T.	Half N.	43.6 (1.4)	5.6 (0.3)	12.9 (1.3)	56.3 (6.5)	1.1 (0.1)	559.16	88, 0.2
KFP	Half N.	47.0 (1.9)	6.0 (0.3)	21.0 (2.2)	103.7 (12.8)	2.0 (0.2)	211.93	85, 0.2
Foot Hills	Unif. Cos.	37.6 (2.7)	7.4 (1.1)	3.7 (0.8)	22.2 (6.5)	0.3 (0.06)	273.08	65.3
B. Valley	Half N.	47.7 (3.5)	2.4 (0.2)	16.8 (2.7)	37.3 (6.6)	1.6 (0.2)	74.16	100
Chital	Half N.	49.4 (2.4)	7.0 (0.4)	5.4 (0.7)	29.3 (4.3)	0.22 (0.03)	559.16	91
Ch-KFP	Half N.	50.0 (3.0)	6.5 (0.5)	9.7 (1.4)	50.5 (8.4)	1.0 (0.1)	211.93	87
Ch-FH	Unif. Cos.	39.5 (6.1)	10.5 (1.6)	2.2 (0.7)	21.8 (8.4)	0.2 (0.05)	273.08	80
Ch-BV	Half N.	42.0 (5.4)	3.2 (0.5)	6.6 (1.5)	19.2 (5.2)	0.6 (0.1)	74.16	82
Sambar	Half N.	41.7 (4.9)	2.3 (0.2)	1.3 (0.3)	3.0 (0.7)	0.1 (0.02)	559.16	67
Wild pig	Half N. Cos.	40.6 (6.8)	2.2 (0.3)	1.0 (0.2)	2.4 (0.6)	0.08 (0.02)	559.16	98.1
Bk. Deer	Unif. Cos.	31.8 (3.4)	1.2 (0.07)	1.1(0.2)	1.4 (0.3)	0.07 (0.01)	559.16	54
Langur	Unif. S.P.	53.6 (3.2)	7.6 (0.8)	1.4 (0.3)	9.2 (2.3)	0.1 (0.02)	559.16	77.7
R. macaque	Unif., Cos.	44.8 (3.6)	8.5 (1.0)	1.2 (0.2)	10.6 (2.8)	0.1 (0.02)	569.12	77.7
B + H. deer	Half N.	32.8 (3.5)	1.5 (0.1)	1.6 (0.3)	2.3 (0.5)	0.1 (0.02)	569.16	65.4

Note:
BNP_T. = Total of the BNP; KFP = Karnali Flood Plains; B. Valley = Babai Valley; Ch-KFP = Chital Karnali Flood Plains; Ch-FH = Chital Foot Hills; Ch-BV = Chital Babai Valley; Bk. deer = Barking deer; R. macaque = Rhesus macaque; B + H. deer = Barking and Hog deer combined; N. = Normal; Unif. = Uniform; Cos.=Cosine; S.P. = Simple polynomials ; ESW = Effective Strip Width, SE = Standard Error; DS = Group Density, D = Density; L = Left; R = Right

The overall density of the Park had increased from 56.3 animals/km^2 in 2008 to 92.6 animals/km^2 in 2013 (Dhakal *et al.*, 2014), which is in the higher range as compared to those (5.3–107 animals/km^2) in some PAs of the South Asia region. The improvement was found to have been contributed mainly by Chital.

Nominal decrease in the densities of barking deer, sambar and wild pig was because of the larger area covered in current study compared to the earlier studies conducted in the Karnali flood plains (Wegge and Storaas, 2009 Wegge *et al.*, 2009; Dinerstein,1980). The combined density (19.9/km^2) of langur (9.2) and rhesus macaque (10.7) was found to be slightly higher than the one (16.7±6.6) found out by Malla (2009).

In both the Karnali flood plains and the Babai Valley of the BNP, the wild prey density was comparable with that of Malla (2009), but that of chital was slightly lower in the Karnali flood plains. However, this study had covered large area in the Karnali flood plains as compared to the studies conducted by Wegge *et al.* (2009) and Malla (2009). The density (individuals/km^2) of Chital (29.3) was similar to the one found by Malla (2009) in the Babai Valley. However, the density of Chital in the entire BNP was found to in the moderate range as compared to the one

Table 5: Density of prey-animals (individuals/km^2) in the PAs of South Asia

PA/Prey habitat	D_Prey Tot	D±SE	Density of Chital	Sambar	Wild pig	Barking deer
Bardia NP, 2009 PS	56.3	56.3 (6.5)	29.3 (4.3)	3 (0.7)	2.4 (0.6)	1.4 (0.3)
Bardia NP, 2014 (Dhakal *et al.*, 2014)	92.6	92.6 (8.8)	53.99 (10.3)	4.45 (0.8)	4.8 (0.5)	1.97 (0.5)
Babai, BNP, 2009 (Malla, 2009)					1.2	2.5
Karnali, BNP, 2009 (Malla, 2009)			50.5		3.1	3.1
Karnali, BNP, 1976 (Dinerstein, 1980)			33.9	3.5	4.2	1.7
Karnali, BNP, 1993 (Wegge *et al.*, 2009)					1	2.6
Chilla Range, Rajaji NP, 2005 and 2006 (Harihar *et al.*, 2006)	76.2	6.5 ± 4.1	43.5	19.6		
Chitwan NP, 1982 (Tamang, 1982)			16.8	2.7		6.6
Chitwan NP, 2008, 2009, 2010 (Thapa, 2011)	113.8	113.8	86.3	8	10.5	4.1
Chitwan NP, 2009 (Karki, 2011)	51.7	52.88 ±4.9	32.3	3.5	3.4	2.1
Dudwa,Valmiki, Pilibhit, Katerniaghat 2010 (Jhala *et al.*, 2011)	24.92	24.92 (3.75)	13 (2.17)	0.14 (0.02)	1.99 (0.55)	0.72 (0.23)
Gir LS, 1997 (Khan and Vohra,1997)			50.8	2	2.1	
Kanha NP, 1987 (Newton, 1987)	55.5	57.3 ± 4.07	3.2	0.9	0.5	0.4
Kaziranga (Jhala *et al.* 2011)	56.1	58.1 ± 6.51				
Melghat (Jhala *et al.* 2011)	5.3	5.3 ± 0.76				
Nagarhole, 2092 (Karanth and Sunquist, 1992)	52.9	56.1 ± 3.95	50.6	5.5	4.2	4.2
Parsa WR, 2009 (Karki, 2011)	6.6	6.6 ±1.1				
Pench TR, 2000 (Karanth and Nichols, 2000)			51.3	9.6		
Rajaji-Corbett, 2010 (Jhala *et al.*, 2011)	72.4	72.4 ±13.0	46.71 (13.25)	7.49 (1.78)		
Ranthmbore, Sariska, 2010 (Jhala *et al.*, 2011)	107.7	107.7 ±10.0	31.62 (10.4)	8.24 (1.8)	4.86 (7.7)	
Suklaphanta WR, 2009 (Karki, 2011)	144.8	144.8 ±22.8	79			
Melghat, Pench, Tadoba, 2010 (Jhala *et al.*, 2011)	107.74	107.74 (9.95)	37 (6.06)	5.34 (0.57)	5.83 (1.11)	0.61 (0.15)

(5.3–107) in the Indian PAs (Table 5), indicating the availability of adequate prey-animals of tiger in the Park. On the other hand, the density of sambar (3) in the Park was in the lower range as compared to the one (0.14–19.6) in the Indian PAs. Similarly, the density of wild pig (2.4) in the Park was in the medium range as compared to that (0.5–5.8) in the Indian PAs. Likewise, the density of barking deer (1.4) in the Park was in the medium range as compared to that (0.4–4.2) in the Indian PAs.

The density of swamp deer could not be determined due to the limited data points, but significantly preferred (Hayward *et al.*, 2012; Wegge *et al.*, 2009) by tiger owing to large-bodied wild prey-animals (sambar and nilgai) in the Karnali flood plains of the BNP.

Conclusion

The population of tiger in the BNP was found to have increased from 18 in 2009 to 50 in 2013. The reason behind is the habitat management of wild prey-animals of tiger in the Park and control in poaching and illegal trade of wild animals from the Park. Therefore, habitat management of wild prey-animals of tiger together with the control in poaching of wild animals and illegal wildlife trade will result in further increase in the population of tiger.

In order to support the tiger doubling aim of Nepal by the end of 2020, it is recommended to improve the prey-base. One of the ways to improve the prey-base in the BNP is to increase the number of swamp deer in the Babai Valley, study the feasibility of introducing gaur and wild water buffalo in BNP.

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References

Basnet, K., Shrestha, K. M., Sigdel, R. and Ghimire, P. 1998. **Bardia Extension Area: Biodiversity Survey.** WWF Nepal Program, Kathmandu, Nepal.

Bhatta, S. R., Bajimaya, S. and Jnawali, S. R. 2002. **Status, Distribution and Monitoring of Tigers in Protected areas of Terai Arc Landscape-Nepal.** A photographic Documentation of camera-trapped tigers. WWF Nepal, NTNC and DNPWC, Kathmandu, Nepal.

BNP. 2012. **Tiger and Prey Base Monitoring in Bardia National Park and Khata Corridor, Nepal.** Final Progress Report submitted to DNPWC, Bardia National Park (BNP), Nepal.

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

Check, E. 2006. The tiger's retreat. *Nature* **441:** 927–930.

Chundawat, R. S., Habib, B., Karanth, U., Kawanishi, K., Ahmad Khan, J., Lynam, T., Miquelle, D., Nyhus, P., Sunarto, S., Tilson, R. and Wang, S. 2011. *Panthera tigris*. In *IUCN Red List of Threatened Species, Version 2011.2.* www.iucnredlist.org accessed on 2 March, 2012.

Dinerstein, E. 1980. An ecological survey of the Royal Karnali-Bardia Wildlife Reserve, Nepal: Part III: ungulate populations. *Biological Conservation* **18 (1):** 5–37.

Dinerstein, E., Loucks, C., Wikramanayake, E., Ginsberg, J., Sanderson, E., Seidensticker, J., Forrest, J., Bryja, G., Heydlauff, A., Klenzendorf, S., Leimgruber, P., Mills, J., O'Brien, T. M., Shrestha, M., Simons, R. and Songer, M. 2007. The fate of wild tigers. *Biosciences* **57 (6):** 508–514.

Dhakal, M., Karki, M., Jnawali, S. R., Subedi, N., Pradhan, N. M. B., Malla, S., Lamichane, B. R., Pokhrel, C. P., Thapa, G. J., Oglethorpe, J., Subba, S. A., Bajracharya, P. R., and Yadav, H. 2014. **Status of Tiger and Prey in Nepal.** Department of National Parks and Wildlife Conservation, Kathmandu, Nepal.

DNPWC 2005. **National Report Status of Tiger in Nepal.** Department of National Parks and Wildlife Conservation, Ministry of Forests and Soil Conservation, Government of Nepal, Kathmandu, Nepal.

DNPWC. 2008. **Tiger Monitoring protocol, Nepal.** Department of National Parks and Wildlife Conservation (DNPWC), Kathmandu, Nepal.

DNPWC. 2013. **Annual Progress Report (FY 2069–70).** Department of National Parks and Wildlife Conservation (DNPWC), Kathmandu, Nepal.

Efford, M. G., Dwson, D. K. and Robbins, C. S. 2004. DENSITY: software for analyzing capture data from passive detector arrays. *Animal Biodiversity and Conservation* **27 (1):** 217–225.

Efford, M. 2009. **DENSITY 4.4 Spatially explicit capture-recapture 4.4.1.2 4/19/2009.** Zoology Department, University of Otago, New Zealand.

Gopal, R., Qureshi, Q., Bharadwaj, M., Singh, RKJ., and Jhala, Y. V. 2010. Evaluating the status of the endangered tiger *Panthera tigris* and its prey in Panna Tiger Reserve, Madhya Pradesh, India. *Oryx* **44:** 383–389.

GTIS. 2011. **Global Tiger Recovery Program 2010–2011.** Global Tiger Secretariat. Washington DC, USA.

Harihar, A., Pandav, B. and Goyal, S. P. 2006. **Monitoring Tiger and its Prey in Chilla Range, Rajaji National Park.** Uttaranchal, India.

Hayward, M. W., Jedr zejewski, N. and Jedrzekewska, B. 2012. Prey Preferences of the tiger (*Panthera tigris*). *Journal of Zoology* **286:** 221–231.

Jhala, Y. V., Qureshi, Q., Gopal, R. and Sinha, P. R. 2011. **Status of the Tigers, Co-predators and Prey in India, 2010.** National Tiger Conservation Authority, Govt. of India, New Delhi and Wildlife Institute of India, Dehradun, India.

Kalle, R., Ramesh, T. Qureshi, Q. and Sankar, K. 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* **56 (4):** 335–342.

Karanth, K. U. and Sunquist, M. E. 1992. Population Structure, density and biomass of large herbivore in the tropical forests of Nagarhole, India. *Journal of Tropical Ecology* **8:** 21–35.

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

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

Karanth, K. U. and Nichols, J. D. 2000. **Ecological Status and Conservation of Tigers in India.** WCS, US Fish and Wildlife Service, Center for Wildlife Studies, Banglore, India.

Karanth, K. U., and Nichols, J. D. 2002. **Monitoring Tigers and Their Prey: A Manual for Researchers, Managers and Conservationists in Tropical Asia.** Centre for Wildlife Studies, Banglore, India.

Karki, J. B. 1997. **Effects of Grazing, Utilization and Management on Grasslands of Royal Bardia National Park, Nepal.** M.Sc. Dissertation, Wildlife Institute of India, Saurastra University, Rajkot, India.

Karki, J. B., Poudel, B. S. and Shrestha, P. B. 2008. Threat from poaching and illegal trade in tiger, its parts and derivatives and actions taken/required to combat the same in Nepal. In *Biodiversity Coservation Efforts in Nepal: a special issue published on the occasion of 12th Wildlife Week* (eds) Manandhar, L. P. Department of National Parks and Wildlife Conservation, Kathmandu, Nepal.

Karki, J. B., Pandav, B., Jnawali, S. R., Shrestha, R., Pradhan, N. M. B., Lamichane, B. R., Khanal, P., Subedi, N. and Jhala, Y. V. 2013. The largest tiger population in Nepal: estimating tiger from flood plains and Churiya, Chitwan National Park. *Oryx* **49**

(1): 15–156.

Karki, J. B., Barber-Meyer, S. M., Jhala, Y. V., Pandav, B., Jnawali, S. R., Shrestha, R., Thapa, K., Thapa, G., Pradhan, N. M. B., Lamichane, B. R. and Dhakal, M. 2015. Estimating the abundance of tigers and their prey in Suklaphanta Wildlife Reserve of Terai Arc Landscape, Nepal. In *Biodiversity Conservation Efforts in Nepal: a special issue published on the occasion of 20th Wildlife Week* (eds) Dhakal, M. and Shrestha, R. Department of National Parks and Wildlife Conservation, Kathmandu, Nepal, 41–56.

Karki, J. B. 2011. Occupancy and abundance of tigers and their prey in the Terai Arc Landscape, Nepal. PhD. Dissertation, FRIU, Dehradun, Uttarakhand, India.

Khan, J. A. and Vohra, U. 1997. Estimation of ungulate densities by line transect method in Gir forest, India. *Tropical Ecology* **38 (1):** 65–72.

McDougal, C. 1977. **The Face of the Tiger.** Rivington Books, London, UK.

McDougal, C. 1999. You can tell some tigers by their tracks with confidence. In *Riding the Tiger: Tiger Conservation in Human-dominated Landscapes* (eds) Seidensticker, J., Christie, S. and Jackson, P. Cambridge University Press, Cambridge, UK.

Malla, S. 2009. Estimating the Status and Impact of Hunting on Tiger Prey in Bardia National Park, Nepal. M.Sc. Thesis, Saurastra University, Gujrat, India.

Mondol, S., Karanth, K. U. and Ramakrishnan, U. 2009. Why the Indian subcontinent holds the key to global tiger recovery? *PLoS Genet* **5 (8):** doi:10.1371/journal.pgen.1000585 accessed on 18 March, 2016.

Newton, P. 1987. The social organization of forest hanuman langur (*Presbytes entellus*). *International Journal of Primatology* **8:** 199–232.

Otis, D. L., Burnham, K. P., White, G. C., and Anderson, D. R. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monograph* **62:** 1–135.

Pollock, K. H., Nichols, J. D., Brownie, C and Hines, J. E. 1990. Statistical inference for capture-recapture experiments. *Wildlife Monograph* **62:** 135.

Peet, N. B. 1997. Biodiversity and management of tall grasslands in Nepal. Ph.D. Thesis, University of East Anglia, Norwich, UK.

Rexstad, E., and Burnham, K. P. 1991. **User's Guide for Interactive Program Capture.** Abundance Estimation of Closed Animal Populations. Colorado State University, Colorado, USA.

Royle, J. A., Karanth, K. U., Gopalaswamy, A. M. and Kumar, N. S. 2009. Baysian inference in camera trapping studies for a class of spatial capture-recapture models. *Ecology* **90 (11):** 3233–3244.

Seidensticker, J. 2010. Saving wild tigers: A case study in biodiversity loss and challenges to be met for recovery beyond 2010. *Integrative Zoology* **5:** 285–299. doi: 10.1111/j.1749-4877.2010.00214.x accessed on 18 March, 2016.

Schaller, G. 1967. **The Deer and the Tiger.** University of Chicago Press, Chicago, USA.

Seber, G. A. F. 1982. **The Estimation of Animal Abundance and Related Parameters.** 2nd edition. Macmillan, New York, USA.

Smith, J. L. D., McDougal, C. and Sunquist, M. E. 1987. Land tenure system in female tigers. In *Tigers of the World: the Biology, Biopolitics, Management and Conservation of an Endangered Species* (eds) Tilson, R.L. and Seal, U.S. Noyes Publication, Park Ridge, New Jersey, USA, 464–474.

Smith, J. L. D. 1993. The role of dispersal in structuring the Chitwan tiger population. *Behavior* **124:** 165–195.

Smith, J. L. D., Ahearn, S. C., and McDougal, C. 1998. Landscape analysis of tiger distribution and habitat quality in Nepal. *Conservation Biology* **12 (6):** 1338–1346.

Smith, J. L. D., McDougal, C., Ahearn, S. C., Joshi, A. and Conforti, K. 1999. Metapopulation structure of tigers in Nepal. In *Riding the Tiger: Tiger Conservation in Human-*

dominated Landscapes (eds) Seidensticker, J., Christie, S. and Jackson, P. Cambridge University Press, Cambridge, UK.

Surquist, M. E. 1981. The social organization of tigers (*Panthera tigris*) in Royal Chitwan National Park, Nepal. *Smithsonian contribution to Zoology* **336:** 1–98.

Tamang, K. M. 1982. The Status of Tiger (*Panthera tigris*) and its Impact on Principal Prey Populations in Royal Chitwan National Park, Nepal. PhD Dissertation. Michigan State University, Michigan, USA.

Thapa, T. 2011. Habitat Suitability Evaluation for Leopard (*Panthera pardus*) using Remote Sensing and GIS in and around Chitwan National Park, Nepal. PhD Thesis. Saurashtra University, Rajkot, India.

Thomas, L., Laake, J. L., Rexstad, E., Strindberg, S., Marques, F. F. C., Buckland, S. T., Borchers, D. L., Anderson, D. R., Burnham, K. P., Burt, M. L., Hedley, S. L., Pollard, J. H., Bishop, J. R. B. and Marques, T. A. 2009. "Distance 6.0. Release "x". Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/ accessed on 18 March, 2018.

Thompson, W. L. 2004. **Sampling Rare or Elusive Species: Concepts and Techniques for Estimating Population Parameters.** Island Press, Washington D.C., USA.

Wegge, P. and Storaas, T. 2009. Sampling tiger ungulate prey by the distance method: lessons learned in Bardia National Park, Nepal. *Animal Conservation* **12:** 78–84.

Wegge, P., Odden, M., Pokhrel, C. P. and Storaas, T. 2009. Predator prey relationships and responses of ungulates and their predators to the establishments of protected areas: a case study of tigers, leopards and their prey in Bardia National Park, Nepal. *Biological Conservation* **142 (1):** 189–202.

White, G. C., Andrson, D. R., Burnham, K. P., and Otis, D. L. 1982. **Capture-recapture and Removal Methods for Sampling Closed Populations.** National Laboratory, Los Alamos, New Mexico, USA.

Williams, B. K., Nichols, J. D. and Conroy, M. J. 2002. **Analysis and Management of Animal Populations.** Academic Press, San Diego, California, USA.