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Density Estimation of Tiger (*Panthera tigris*) in the Buffer Zone of Corbett Tiger Reserve

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ABSTRACT
Information about how many animals is in an area is essential for designing management strategies for endangered species such as tiger. Due to the tigers' elusive behaviour, high mobility and occurrence at low densities, it is difficult to determine an unbiased estimate of tiger abundance. To overcome the problem, biologists proposed camera trapping as an effective method to determine the abundance of the tiger. We used camera trapping to determine the abundance and density of the tiger in the buffer zone of the Corbett Tiger Reserve. An effort of 240 trap nights results in the identification of 20 individual adult tigers. Tiger density was estimated at 13.69±3.3 tigers per 100 km^2. Our estimation of tiger density highlighted the role of the buffer zone in landscape-level conservation of tigers and indicated that buffer zones can support the high density of tigers if appropriately managed. Anthropogenic activities exert enormous pressure on the buffer zone and it is imperative to have holistic management strategies for the long-term conservation of tigers in the human-dominated landscape of Corbett Tiger Reserve.

Key words: Tiger, Camera Trapping, Trailmaster, Capture-recapture, Population, Management, Landscape

INTRODUCTION

How many tigers is perhaps the most common question that biologists or reserve managers are asked and it is the key to understanding how tiger populations are performing over time (Karanth 2001). Wild animals are rarely if ever, distributed randomly across the landscapes. Instead, they space themselves in complex ways dictated by habitat type or condition, resource abundance and availability, and through intricate social interactions between conspecifics (Morrison et al. 1992, Williams et al. 2002). Spatial distribution can be defined as the occurrence and spacing of individually recognizable individuals within a defined area over a specified period, and requires an understanding of home range size, which varies for each animal's gender and residency status (Sunquist and Sunquist 2002). Knowledge of distribution and abundance of species has implications for management and for tailoring management strategies and judging the success or failure of management inputs. Abundance estimation or density of animal population is essential for developing appropriate conservation policies and management protocols (Gelatt and Siniff 1999, Swann et al. 2002), particularly in the case of threatened or endangered species like tiger. Under the pressure of human activities, wild animals' habitats change drastically and the population of several species decreases to a critical level. The distributional range of tiger has shrunk by 93% of its historical range over the last 150 years (Dinerstein et al. 2007), and long-term conservation of tigers in the remaining range required implementation of conservation measures tailored on a sound understanding of population status of tiger in different landscapes.

To frame the management practices for the better management of tigers, it is a prerequisite to know the status, distribution and abundance of tigers in different landscapes. Having a sound and practical understanding of the status and distribution of the tiger population is critically important for scientific and management purposes. Field surveys combined with forest cover maps have generated more accurate distributional maps. Still, their utility for assessing the status and viability of the tiger population is limited by the absence of reliable data on population densities (Karanth and Nichols 1998).

The secretive and elusive nature of the tiger, coupled with the high mobility and dense habitat in which they live, make it difficult to study them (Karanth 1995). Historically, the pugmark census has been used to determine the population status of tigers all over its range (Choudhury 1970, Panwar 1979, Sawarkar 1987, Singh 1999). Still, there were many limitations of this method and it has been criticized by the scientific community (Karanth et al. 2003). Radio telemetry data can be used to derive estimates of tiger densities (Sunquist 1981, Smith et al. 1987a, b, Quigley 1993), however, presence of untagged animals in the population and excessive effort involved in the capture and radio tracking operations limits the usefulness of this technique for estimating tiger population size (Karanth 1995).

Tigers naturally occur at low population densities. Because of their secretive behaviour, it is impossible to count them visually under usual field conditions (Karanth and Nichols 1998). Therefore, biologists proposed camera trapping in a capture-recapture statistical framework to determine tiger densities (Pollock et al. 1990, Karanth 1995, Karanth and Nichols 1998, 2000, 2002, Karanth et al. 2003, 2004a, Per Wegge et al. 2004). The method is appropriate to determine tiger densities in small areas having high to medium densities and has high potential for monitoring source population and smaller sample areas within tiger occupied landscapes (Jhala and Qureshi 2004) and is superior to every other method for estimating tiger abundance and density (Karanth and Nichols 1998). Therefore, camera trapping under the statistical framework of capture-recapture is most appropriate and robust technique to determine densities of tiger and has effectively been used by several investigators (Pollock et al. 1990, Karanth 1995, Karanth and Nichols 1998, 2000, 2002, Kawanishi 2002, Karanth et al. 2004a, 2004b, 2006, Per Wegge et al. 2004, Rather et al. 2021).

Most of the studies on the abundance of the tiger were conducted in the core zone of protected areas, free from human disturbance (Karanth 1995, Karanth and Nichols 1998, Kawanishi 2002, Per Wegge et al. 2004). The present study is aimed to determine the status and abundance of tiger in buffer zone of the Corbett Tiger Reserve, subjected to human disturbances.

MATERIALS AND METHODS

Study area

The study was conducted in the Corbett Tiger Reserve (CTR), located in the civil districts of Nainital, Pauri Garhwal and Almora of Uttarakhand state of India (Fig. 1). The Corbett Tiger Reserve, within its boundary, incorporates areas of Corbett National Park and Sonanadi Wildlife Sanctuary and is spread over an area of 1,288 km^2. The terrain of the study area is hilly and consisting of many ridges and valleys. The geological formation of the study area is divided into recent and Siwalik series. The altitude ranges from 350 m to 1210 m. Climate is tropical with three distinct seasons, i.e., summer, monsoon and winter. The average temperature varies from 13 ^{0}C in January to 31 ^{0}C in May. The vegetation of the area is quite heterogeneous. A major part of the area is covered by sal *Shorea robusta* along with its several associates. According to the forest classification of Champion and Seth (1968), eight forest types are found in the CTR. The study was conducted from September 2006 to March 2007.

Methodology

Camera trap survey

Since tigers occur at low densities of 10-20 animals/ 100 km^2, even at the best sites, getting 'photographic capture' of a tiger is a rare and uncertain event (Karanth and Nichols 1998). Therefore, to maximize the probabilities of tiger capture, it is necessary to select the best sites to place camera traps, instead of placing camera traps randomly. An extensive reconnaissance survey of the study area was conducted to select the most optimal locations for placement of camera traps to maximize the capture probabilities of tiger. During the reconnaissance survey, *nullahs*, trails and forest roads were searched for indirect evidences of tigers. Data on indirect evidences of the tigers were used to determine optimal trap location in each grid.

Camera trapping was conducted in the north-eastern and southern part of the buffer zone of the Corbett Tiger Reserve (Fig. 2). The area was divided into 24 grids (4x4 km), and one camera unit was deployed in each grid. Trailmaster (USA) camera units were used for the photo trapping of tigers. Each unit consisted of TM35-1 camera kit (Canon A1/ Prima AS-1; 35mm weather-proof, auto focus and auto find), TM 1550 infrared (IR) transmitter and TM 1550 active Infrared trail monitor (receiver) that activates the camera and records the date, time and event. During the study period, the 36+ exposure 35 mm negative colour Kodak 400 speed and Fuji 400

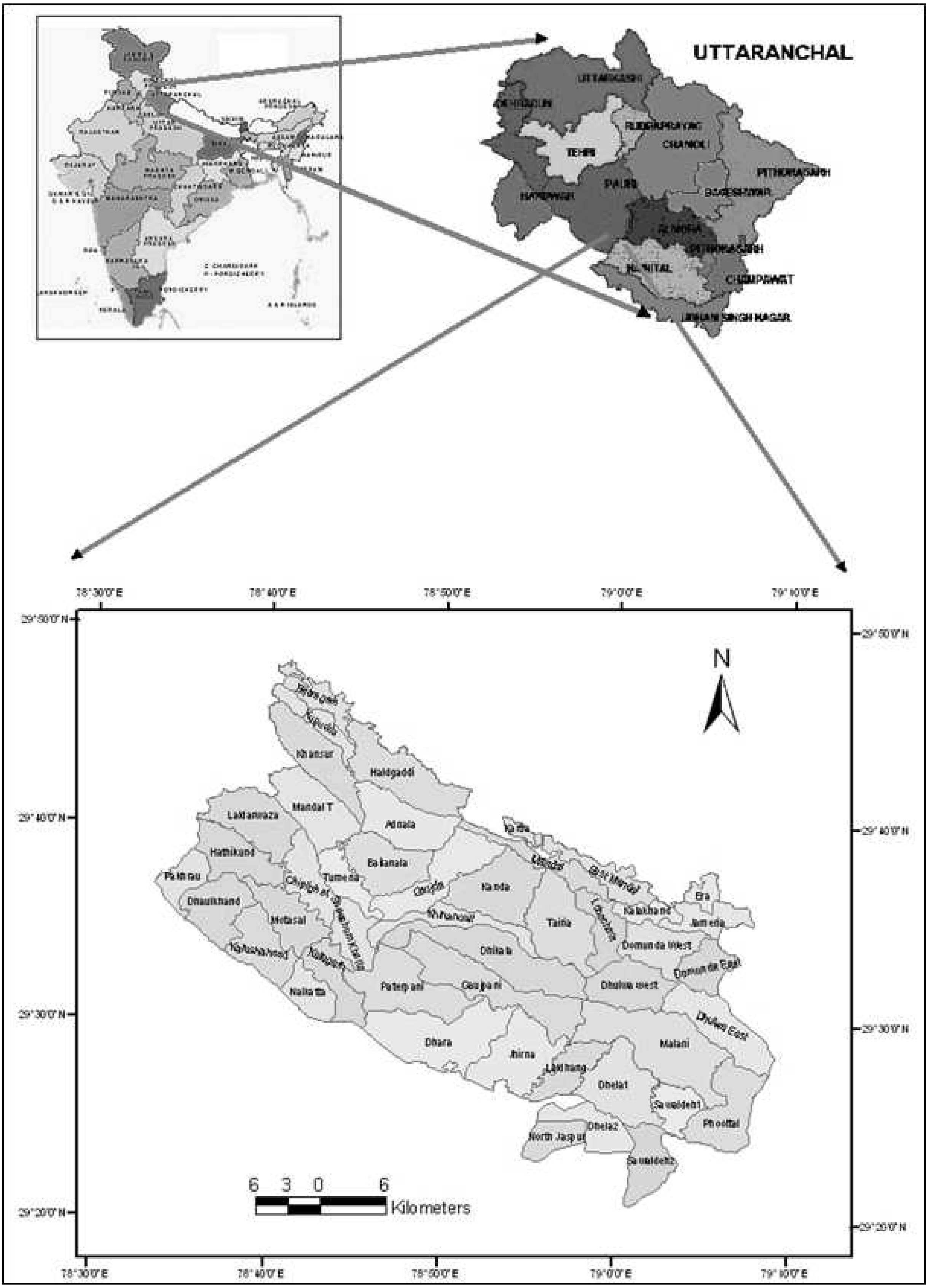

Figure 1. Location map of Corbett Tiger Reserve

speed camera rolls were used. Specially designed wooden cages were used to mount cameras to prevent the theft of cameras and protect them from damage by wild animals. Camera units were framed in such a way so that the tiger's both flanks would get photographed clearly. Camera traps were set up 7 m or sometimes >7 m away, on either side of the tiger trail or path. To avoid flaring of photos from mutual flash interference, two cameras were not positioned directly facing each other. The infrared beam was set at the height of 45 cm above the ground so that camera units could capture both adults and cubs. Cables connecting the whole unit were hidden in soil and leaf litter. After the setup of the camera trap, units were concealed with vegetation. At each location, camera traps were placed for 10 consecutive days.

As camera trapping was carried out in the buffer zone, which during daytime have a human presence. So, to avoid theft and damage by local people, camera units were set up in the evening and were taken out in the morning.

Statistical framework

Each photograph of the tiger captured during the survey was carefully examined for the unique shape and pattern of natural markings to identify individual tigers. In addition to stripe patterns, the pattern on tail, genital organs and other unique patterns on the body of the tiger were also taken into consideration. Individually identified tigers were given a unique identification code, and subsequent identification of new individuals was conducted by comparing and matching each photograph with uniquely identified tigers.

Capture history for each individually identified adult tiger was developed. The capture history for individual tigers is in the form of a matrix, having individually identified tigers making up the rows and different sampling occasions making up the matrix columns. The capture histories are in a series of 1's or 0's, denoting capture with "1" and non-capture with a "0". These matrices were then utilized for the estimation of the abundance of the tiger. The capture history data were analyzed using program CAPTURE (Otis et al. 1978, White et al. 1982, Rexstad and Burnham 1991). The program computes abundance under seven models that differ in their assumed source of variation in the capture probability (Nichols 1992).

Within program CAPTURE, there are 3 sources of variation affecting capture probability: time variation (M_t), behaviour variation (trap-response) (M_b), and heterogeneity variation (M_h). There are also combinations of all three sources of variation (e.g., M_{tb}, M_{th}, M_{bh}, and M_{tbh}). Individual heterogeneity (M_h) means variation in capture probability among different individuals. Each and every tiger is thought to have its own capture probability, which differs from the capture probability of all other individual tigers. Behavioural responses ($M_{b)}$ refer to changes in capture probability that occur due to a change in the response of a tiger to the presence of a camera trap after an individual is caught for the first time. It means, at any sampling occasion j, unmarked individuals have one capture probability and previously marked animals have a different capture probability. Time variation (M_t) deals with variation in capture probability from one sampling occasion to another.

Program CAPTURE computes the number of individuals in the sampled area and associated standard error of abundance. From this estimate of tiger abundance, the density of tigers in the sampled area was calculated. The density of the tiger is described as D = N/A where N is the number of individuals, and A is the area in which the individuals roamed. Since during the camera trapping sampling, only a small portion of tiger habitat available was sampled and it is necessary to calculate effective area from which animals were sampled. The effective sampled area encompasses the camera traps polygon with a buffer around the peripheral camera traps that considers those tigers whose home range may include areas that are only partially contained within the sampling area. There are numerous approaches to calculate the buffer. Karanth and Nichols (2002) used a buffer whose width was based upon half the mean maximum distance moved (HMMDM) among multiple captures of individuals during the study period. According to Dice (1938), buffer width is half of the average diameter of the species' home range. Spacing of camera traps in survey area affects the home-range size estimated based on capture data (Stickel 1954), but the effect is reduced for animals caught 6 or more times (Tanaka 1980). Since no tiger was captured more than twice during the survey period, buffer width estimation based on recapture data would have been biased. Therefore, the value of half of the mean maximum distance moved (MMDM) in Kanha (2.17 km) used by Karanth and Nichols (1998) was used to calculate the effective sampled area. Geographical Information System (GIS) was used to create the buffer around the peripheral camera units to estimate the effective sampled area (Fig. 2).

RESULTS

The total sampling efforts, spread for five months, amounted to 240 trap nights and resulted in the identification of 20 individual tigers in the sampled area. The average trapping effort was 10 trap nights per capture. During the survey period, 24 photographic captures of tigers were recorded (Fig. 3).

Computation of capture frequencies indicated that four individual tigers were captured twice and the rest (16) of the individual tigers was caught only once (Table 1). The assumption of closed population or null hypothesis could not be rejected (z=0.075, p=0.53). Closed-capture models should ideally not be used to calculate the abundance of a small (<20) population (White et al. 1982), but the survey area had a larger population than recommended.

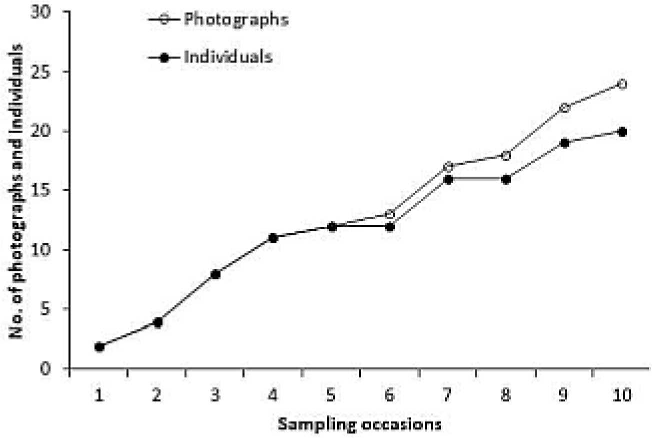

Figure 3. Cumulative number of tiger photographs indicating the number of individual tigers captured with increasing sampling occasions

The hypothesis that the above capture-recapture statistics came from an underlying model M_0 could

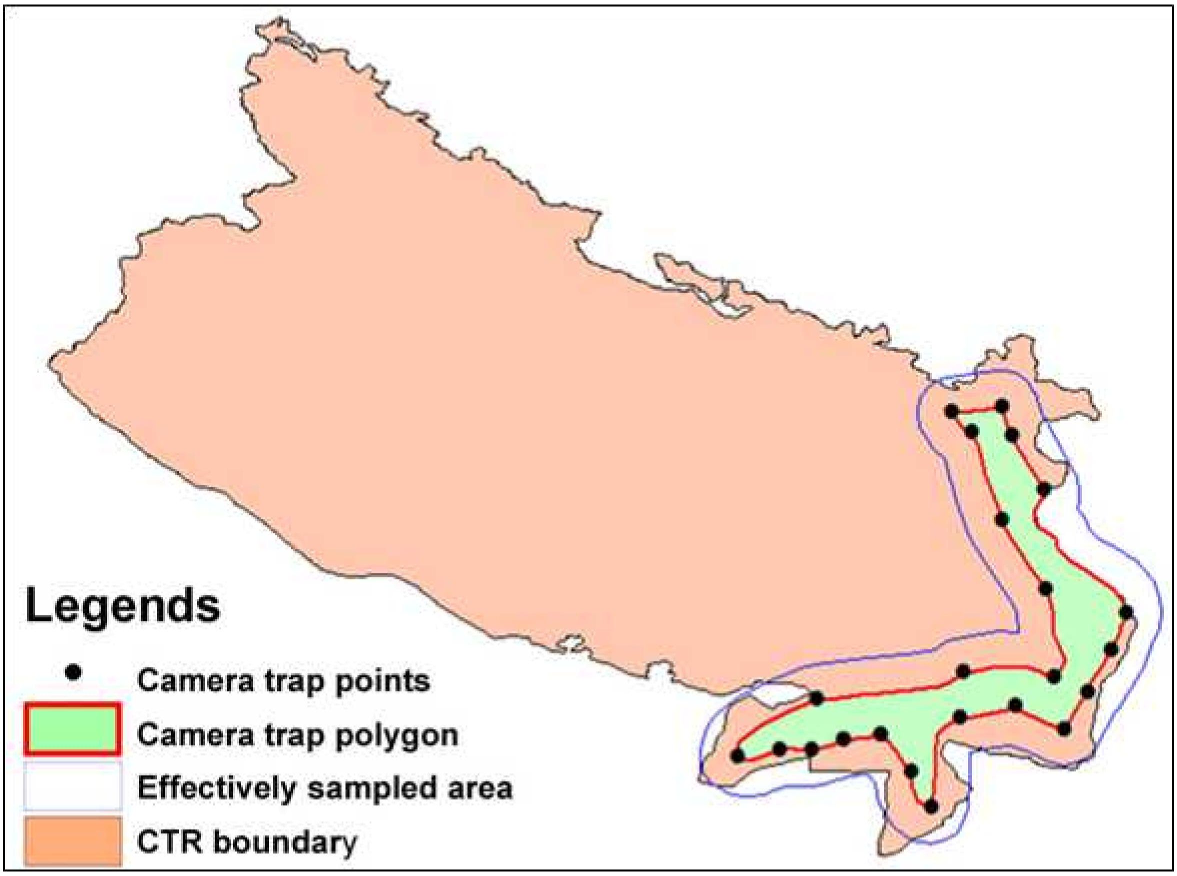

Figure 2. Map of CTR showing layout of camera trap with effective sampled area

Table 1. Summary of capture-recapture statistics for tigers obtained from camera trap sampling in the buffer zone of the Corbett Tiger Reserve

	Sampling occasion (j)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Animal caught (n_j)	2	2	4	3	1	1	4	1	4	2
Total caught (m_j)	0	2	4	8	11	12	12	16	16	19
Newly caught (μ_j)	2	2	4	3	1	0	4	0	3	1

n_j, no. of animals captured on the *j*th sampling occasion
m_j, no of previously caught animals before the *j*th sampling occasion
μ_j, no. of new animals captured in the *j*th sample

not be rejected in contrast to the alternative hypothesis of the underlying models, respectively, M_b (χ^2 = 0.409, d. f. =1, p= 0.52) or M_t (χ^2 = 6.447, d. f. = 9, p = 0.69). A test comparing, model M_0 versus M_h and model M_t versus not model M_t, could not be conducted because expected values were too small. Goodness-of-fit test comparing null hypothesis of model M_h versus not model M_h, and M_b versus not model M_b failed to reject the null hypothesis (χ^2 = 6.231, d. f. = 9, p= 0.72), (χ^2 = 12.282, d. f. =15, p = 0.65), respectively. Similarly, test for behavioural responses in the presence of heterogeneity also failed to reject the null hypothesis of model M_h versus the alternative hypothesis of model M_{bh} (χ^2 = 9.938, d. f. = 7, p = 0.19).

The model selection criteria value computed for different models were; M_0 = 1.00, M_h = 0.80, M_b = 0.35, M_{bh} = 0.63, M_t = 0.00, M_{th} = 0.32, M_{tb} = 0.31, M_{tbh} = 0.70. Although the null model (M_0), based on criterion selection value, appears to be most appropriate for the data, White et al. (1982) cautions against its use when sample size is too small or individual heterogeneity and trap response may be present. Since the tiger is a territorial animal (Sunquist 1981, Smith et al. 1987a), capture probabilities were likely to be heterogeneous for tigers in the surveyed area. Therefore, model M_h was selected as the second-highest selection criterion value and the most appropriate model. Program CAPTURE provided two different estimations for M_h model; the Jackknife estimator (Otis et al. 1978) and the Chao estimator (Chao 1987).

The estimated population, together with the standard error and 95% confidence intervals and average capture probabilities (p) derived using model M_0, M_h (Jackknife), and M_h (Chao) are provided in Table 2. It is evident that M_h (Jackknife) model provided the most appropriate estimation of tiger population (N) with lower standard error and therefore, this model is likely to include true value of 'N'.

Thus, the estimated population size *N* (SE [*N*]) was 44 (10.69). The 95% confidence intervals estimated by estimator M_h (Jackknife) as 31-75, is narrower than the interval, 29-135, generated by M_h (Chao) estimator. The area of trap polygon (*A*) formed by using the location of peripheral camera traps was measured to be 109.07 km^2. With a boundary strip width (*W*) of 2.17 km, effective sampled area *A* (*W*) was calculated at 321.54 km^2. Therefore, the estimated tiger density D (SE [*D*]) for the sampled area of the buffer zone of the CTR is 13.68 (3.32) per 100 km^2.

DISCUSSION AND CONCLUSIONS

A camera trap survey can yield robust estimates of the tiger at sites where tiger densities are 3

Table 2. Estimates of population size (*N*) together with average capture probability (*p*), standard error (*SE*) of N and 95% confidence intervals (N_{ci}) for the tiger population in the buffer zone of the Corbett Tiger Reserve during the survey period

Model used	*P*	*N*	SE	N_{ci}
M_0 **(Null)**	0.043	55	23.05	32-133
M_h **(Jackknife)**	0.054	44	10.69	31-075
M_h **(Chao)**	0.046	55	23.32	29-135

individuals/100 km^2 or higher (Karanth and Nichols 2000). Estimates of tiger abundance support earlier findings (Karanth and Nichols 1998, Karanth et al. 2004a) that photographic capture-recapture sampling is a reliable technique for estimating the abundance of tiger and other secretive animals that can be identified individually based on their natural markings.

To identify individual tigers, different recognizable sections on individual tigers were used. Since tigers were not always captured at the same angle to the camera, a specific pattern of stripe could have been obscured in a particular photograph, making identification difficult if only one region of the body was used for identification.

The assumption of population closure (no birth and no death during study period) used in the estimation of tiger densities may be a limitation of the camera trapping technique. Closed population models are the most robust to estimate the population size of animals, which assume that there are no emigration or immigration of animals and no birth or death (White et al. 1982). It is difficult, if not possible, to ascertain the closure of the biological population in the wild (Soisalo and Cavalcanti 2006) since birth or death of individuals or taken over of territory by transient individuals may cause violation of assumption.

Model M_h, which assumes that capture probabilities vary with heterogeneity effect among individuals, but the probability of each individual being recaptured remains same throughout the sampling period, was selected, although model selection criterion value was lower than null model M_0. Due to the social structure and unequal access to camera traps, there was a heterogeneity effect on capture probabilities of different tigers; therefore, model M_h provided reliable population size estimates. Moreover, the robustness of the Jackknife M_h estimator to deviation from model assumptions (Otis et al. 1978) made it more appropriate. In several camera trapping studies (Karanth 1995, Karanth and Nichols 1998, Karanth et al. 2001, Kawanishi 2002, Kawanishi and Sunquist 2004), model M_h was selected to estimate the population size of tiger in different parts of its range. Model M_h assumes that each animal has a unique capture probability that is not affected by animals' response to trap or time. There is no violation of assumption since camera trapping is a non-invasive technique. Moreover, the study was conducted in a buffer zone (under anthropogenic pressures) and tigers were already habituated to the occurrence of negligible disturbance due to camera traps.

The high density of tigers in the study area indicated that the buffer zone could support a high density of tigers and play an important role in long-term conservation of tigers in the Corbett Tiger Reserve. Inspite of biotic pressure from local people in terms of grazing, cutting and lopping buffer zone has the potential to support a high density of tiger and need proper habitat management to sustain its

Table 3. Comparison of tiger density in different protected areas

Location	Forest type	Tiger Density (Per 100 km^2)	Source
Pench (MP)	Moist-deciduous Forest	04.9	Karanth and Nichols (2000)
Kanha	Moist-deciduous Forest	11.7	Karanth and Nichols (2000)
Kaziranga	Alluvial grassland Forest	16.8	Karanth and Nichols (2000)
Nagarahole	Moist Forest	11.9	Karanth and Nichols (2000)
Bhadra	Moist Forest	03.4	Karanth and Nichols (2000)
Bandipur	Moist-deciduous Forest	11.9	Karanth and Nichols (2000)
Ranthambore	Dry Forest	08.2	Karanth and Nichols (2000)
Sundarbans	Mangrove Forest	0.84	Karanth and Nichols (2000)
Panna	Dry Forest	6.94	Karanth et al. (2004a)
Chilla Range of Rajaji	Moist-deciduous Forest	3.01	Harihar et al. (2006)
Corbett (Core)	Moist-deciduous Forest	20.79	Contractor (2007)
Corbett (BZ)	Moist-deciduous Forest	13.7	Present Study

population.

Comparison of the estimate of tiger density with various studies in other protected areas (Table 3) indicated that the buffer zone of the CTR supports quite high density of tiger. The mean density of tiger at survey area (13.68 tigers/100 km^2) is higher than at other moist-deciduous forest sites at Pench (4.9 tigers/100 km^2), Kanha (11.7 tigers/100 km^2) and Bandipur (11.9 tigers/100 km^2). The probability behind the high density of tigers in the buffer is that the buffer zone acts as additional habitat to the source populations from the core zone of CTR. The core zone of the Corbett Tiger Reserve has one of the highest tiger densities in the world (Contractor 2007, Bisht et al. 2019). The high density of tigers in the core zone of CTR enhances the probability that the spillover tigers from the core zone are establishing their territories in the buffer zone. The buffer zone also acts as the corridor for tigers establishing territories in various forest divisions located adjoining to Corbett Tiger Reserve and highlights its importance in the long-term conservation of tiger in the Corbett landscape.

The density of wild prey species in the buffer zone of the CTR is quite high (58 animals/km^2) (Kumar 2010). Tiger requires annually an average of 3000 kg of live prey/tiger (Sunquist 1981) and tigers kill about 10% of the standing prey numbers each year (Karanth et al. 2004a). Our estimated tiger density of 14 individuals/100 km^2 based on camera trapping is higher than the calculated density (11 tigers/100 km^2) based on prey abundance equation given by Karanth et al. (2004b). This could be because of the contribution of livestock to tigers' diet.

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