# OCCUPANCY AND ABUNDANCE OF TIGERS AND THEIR PREY IN THE TERAI ARC LANDSCAPE, NEPAL

THESIS SUBMITTED TO THE

FOREST RESEARCH INSTITUTE UNIVERSITY

DEHRADUN, UTTARAKHAND

For

THE AWARD OF THE DEGREE OF

DOCTOR OF PHILISOPHY IN FORESTRY

(WILDLIFE SCIENCE)

By


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2011

# DECLARATION

I hereby declare that the thesis entitled "**Occupancy and Abundance of Tigers and their Prey in the Terai Arc Landscape, Nepal"** submitted for the award of the degree of doctor of Philosophy in Forestry, to Forest Research Institute University, Dehradun, is a record of original research work done by me under supervision of Dr. Y.V.Jhala, Professor and Head of the Faculty of Animal Ecology and conservation Biology, Wildlife Institute of India, Dehradun, and it has not been formed the basis for the award of any other degree or diploma. I also declare that the thesis embodies my own work, observation and analysis and in that respect the investigation appears to advance knowledge in this subject.

**Date:** September, 2011 **(Jhamak Bahadur Karki)**

**Place:** Dehradun Candidate

**Counter signed**

(**Dr. Y.V.Jhala**)

Supervisor

## CERTIFICATE

This is to certify that the thesis entitled "**Occupancy and Abundance of Tigers and their Prey in the Terai Arc Landscape, Nepal**" submitted for the award of the doctor of Philosophy in Forestry, to the Forest Research Institute University, Dehradun, embodies original research work carried out by Jhamak Bahadur karki under our guidance and supervision. No part of this thesis has been submitted for any other degree and it fulfills all the requirements laid down in the ordinance of Forest research Institute University, Dehradun for this purpose.


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## Acknowledgment

A large number of people and organizations helped me in many ways in this study and I wish to thank them all from the deepest core of my heart. The list is long, but I would like to name some important ones.

I would like to place on record my gratitude for the Ministry of Forests and Soil Conservation for granting me to work in this program. I would like to thank Dr. Uday R.Sharma, the then Secretary, Government of Nepal (Retd.) for inspiring me to continue the research.

I would like to place on record my gratitude for the Department of National Parks and Wildlife Conservation (DNPWC), for not only permitting me to be part of the ongoing research work and carry out this research but also sanctioning leave which enabled me to complete the thesis. I would like to name certain senior Officers of DNPWC in particular, the then Director General (DG)s Shyam Bajimaya (Retd.), Gopal P. Upadhyay; the then Deputy DG Megh B. Pandey, and Krishna P. Acharya (DG), who were particularly helpful in this regard. I would also like to thank S.R. Bhatta, L.P. Manandhar, F.R. Kharel, B.B. Thapa, B. Thapaliya, C.L. Shrestha and my other colleagues from DNPWC.

I am grateful to my supervisor Dr Y.V.Jhala, Prof and Head of the Animal Ecology and Conservation Biology Department, WII for accepting me to supervise in his busy schedule, guidance and supervision throughout with positive appreciation. He has been instrumental in shaping up my interest in research and implementing the findings. I would like to thank co-supervisor Dr. Bivash Pandav, Scientist D, WII for his great support in materializing the method by spending weeks in the remote forest, helping in analysis, generating interest and fund for the work while he was with WWF International. I thank co-supervisor Dr. Shant R.Jnawali, Director, National Trust for Nature Conservation, for insisting me continuously to do the research, guidance and generating support to cover the fee and logistics related to University.

I am thankful to WWF Nepal's country representative A.Manandhar for generating financial support for the field work. In particular, Dr. Ghana S. Gurung, who was not only able to play vital role in raising the funds for the program but also playing a catalytic role in materializing the program. In WWF Nepal, Dr. R. Shrestha (now WWF Canada) was key technical coordinator to help the matters for field, coordinate the data entry and support the analysis, K. Thapa (now PhD candidate, Univ. of Virginia Tech.) was involved in many ways, conducting the training, preparing logistics for the field, leading the field team and writing the report, G.J. Thapa, for preparing maps and training on GPS handling. P. Khanal, leading the field team and instrumental in making the field team members in always working mood in difficult terrain, P. Kunwar for assistance in the field site, Ms.S Malla for being in the field and refining the report and A. Baral for overall coordination from TAL DNPWC.

I thank the National Trust for Nature Conservation for implementing the project. In particular, Judda B. Gurung, member secretary. From field offices of NTNC, the then OIC K. Poudel, N. Subedi, OIC BCC, Chitwan for helping in multiple ways from field implementation to logistics management; B. Lamichane, for finalizing some maps and being in the field, R.K. Aryal and his team for logistic /financial arrangements; B. Lama, H.M. Lama, M.B. Lama, K. Pokhrel, N. Poudel and NTCN's volunteers for the all kinds of field support. M Pandey, then OIC,BCP, S. Yadav, B. Chaudhary, P. Chaudhary and their team; C. Pokhrel (PhD candidate, NTNC-BCC), H. Yadav, OIC, SCCP, H. KC and his team.

In BNP, I am thankful to T.R. Adhikari, Chief Conservation Officer, R.Thapa, Asst. Conservation Officer for coordinating the field work and providing support, and B.R.

Chaudhary, T. Tharu, L.B. Thapa, I.L. Jaisi, N.D. Tharu, R. Chaudhary and their team members for conducted the camera trap and line transect sampling.

In CNP, Dr. N.M.B. Pradhan, then chief Conservation Officer and his team Dr. K. Gairhe, L.B. Bhandari, L. Poudel, B.B. Khadka, P. Bhagat, L.J. Thapa, I. Mahato, elephant staffs, vehicle drivers for coordinating the work and providing elephant, transport, logistics and human resources for leading the team in the field work.

In SWR, N. Mishra (then Asst. Conservation Officer, current chief Conservation Officer, MBNP), Asst. Conservation Officers C.B. Chand and H.R. Das, A. Yadav for coordinating the study, providing elephant, human resources, transport and logistics; M. Joshi and his team members for leading the team in field work.

In PWR, T.R. Sharma, and B.R. Yadav, then chief Conservation Officer and Under secretary-tech. for coordination, elephant, transport and human resources, ranger and his team members for being in the field team.

NA Battalions and Company commanders and their force of BNP,CNP, SWR, and PWR, and support in protecting the park thereby protecting our camera traps and other logistic supports.

BZ communities for helping us in many ways by providing field assistants and providing logistic support to the camps and helping protect the park thus providing us the opportunity to work.

Department of Forests field officials of TAL districts for providing logistic support and staffs in conducting occupancy survey.

I thank following for their respective contributions N.Bhattarai, S.Subba, S.M.Shrestha, B.Shahi, Ms M.Shrestha for entering huge dataset and tireless efforts on managing them.

Volunteers from Universities, local from CNP, BNP, SWR, PWR buffer zones for helping us to implement camera trap and occupancy survey.

Dr.T.B. Thapa, Associate Prof., TU, had been in the field together for one season and greatly benefitted from his field based knowledge, we shared the room, tent, ideas, literatures and more over morning and evening walks after long hours of writing, reading and analysis in WII.

A. Harihar, P. Trivedi, U. Sinha, N. Awasthi, S. Saini, M. Fernandes, B. Yunman, A. Bista and the researcher community for helping in data analysis, literature, GIS work and lively working environment.

Computer, Library, GIS sections, Binay Sharma for facilitating the internal logistics at Supervisor office, and G. Chibber for processing support at Nodal Officer's office.

Ms. S.B. Meyer (then WWF US) for helping in design, implementation and analysis on occupancy. Sh. Quamar Quershi helping run analysis and clarifying statistical jargons, Dr K.Sankar for coordinating all including synopsis to RAC meetings, technical guidance and appreciation for the early achievement. At last, I thank the three anonymous reviewers for their reviewing and providing important feedback.

My wife Bidhya and Mother Krishnamaya took responsibility of running the family in my longer absence. Son Nabin and Prabin, and Daughter Rima were all helpful and observing patiently how a research is carried out and accomplished. I have no words for their cordial acceptance of my PhD research in this later stage of my service when I would have needed for their support to build their carrier in many ways.

**Summary**

Nearly 3,500 wild tigers (*Panthera tigris* Linnaeus 1758) occur in Nepal as well as 12 other range countries in Asia. In Nepal, they are restricted in isolated Chitwan - Parsa, Bardia - Khata and Suklaphanta populations in a land base of about 4,700 $km^2$ of National Park, buffer zone and corridor forests where the prey densities are still high in few Protected Areas (PAs).

Camera trap was used in the past to document the minimum tiger numbers but the estimation of more realistic number is crucial when number declined to two fifth of its population in the last decade (1996-2006).

The occupancy, distribution and tiger density are important information for management and conservation policy formulation. Realizing this need, this study was undertaken.

The major wild prey species of tiger are spotted deer (*Axis axis*), wild pig (*Sus scrofa*), sambar (*Rucervus unicolor*), swamp deer (*Rucervus duvaucelli duvaucelli*), barking deer (*Muntiacus muntjak*), hog deer (*Heylaphus porcinus*) and gaur (*Bos gaurus*) in Nepal.

To evaluate the occupancy of tiger in Nepal's Terai Arc landscape (TAL), sign survey was conducted in 96 grids (area 225 $Km^2$) in 14 districts, including PAs. To assess correlation of the tiger occupancy with the availability of wild prey, and the human disturbance with the habitat use by the tiger, the sign of human disturbances (fire, timber cut, fuel wood collection, sign of poaching) and prey presence were recorded during the winter season.

To estimate the density of tigers wild prey in PAs of Nepal's TAL, distance sampling was conducted along the predefined line transects during the summer season.

To estimate the abundance of tigers in PAs of Nepal's TAL, passive camera traps were employed during the dry season.

Use of the area by tiger was higher in prey rich areas with lower human disturbances. Prey depletion has been recognized as an important factor driving the current decline of wild tiger populations and hence a significant constraint on their recovery. Therefore, to increase tiger occupancy, otherwise suitable areas that have low prey bases should be managed with an important focus on increasing the primary prey base for tigers. Tiger occupancy was mainly influenced by large sized prey such as sambar, swamp deer, rhino, gaur and chital in PAs whereas by chital and wild pig outside, indicating that the conservation of large sized prey would help build tiger occupancy in tiger habitats outside PAs. Monitoring larger area with lower cost by using existing experienced technicians with nominal training provided a reasonable indication of the use of area by tiger. This result clearly indicated need for management intervention to improve the habitat conditions and also to reduce the human induced pressures in critical tiger habitat.

Availability of ungulate predicts the possibility of tiger availability. The higher tiger abundance in Chitwan National Park (CNP) with effective protection had shown stable tiger population in two consecutive years. Use of Churia habitat by tiger was documented and was possible due to the availability of wild ungulate in Churia. The tigers of CNP share the range with Parsa Wildlife Reserve (PWR). As the tiger status seems improving in CNP, the PWR would receive the tigers. The habitat management, waterhole development and stringent protection would help improve the status of prey base and thereby the tigers in PWR.

Though the wild prey base is reasonably high in Bardia National Park (BNP), about 50% of the tiger’s number declined over a decade. The reason could be poaching and reduction of prey base during the insurgency period. The overall improved protection, declaration of 180 $Km^2$ of buffer zone towards north and establishment of Banke National Park (BaNP) towards east has increased the legal protection of the area and provided the working opportunity with people. The upgraded status of Khata corridor by Government of Nepal (GoN) and functional use of the corridor by tiger with Katarniaghat Wildlife Sanctuary generate immense hope that the tiger number could come back to what was there a decade ago. This would require consistent intelligence, networking and youth involvement program in Khata corridor. Action should be initiated to enhance the prey status after assessing the prey base in BaNP and locating functional movement route of tigers from BNP to BaNP to facilitate the tiger movement and longer use leading to establishment in the newly declared BaNP.

The wild prey base is high in Suklaphanta Wildlife Reserve (SWR), where tiger's population declined to about 60% in 8 years. The potential reason could be poaching. The use of the area by tiger in the eastern and northern part of the Reserve was lower than the rest of the Reserve. The habitat encroachment coupled with human induced pressure could be the reason for this. Removal of the encroachment will help to restore the last remaining few tigers in SWR. The improved protection has stabilized the tiger in later years but there are very few breeding females to contribute population growth significantly. The area is connected with the Reserve Forest of Pilibhit Forest Division and Kishanpur Wildlife Sanctuary (KWS) in UP, India and conserving the forest between the KWS and Pilibhit forest may help regaining the population in SWR.

In Nepal, a total of 121 adult tigers (100-194) were estimated in 2009, of this CNP had 91 adult tigers. In CNP, the number of tiger has increased to 125 (95-183) in 2010 thereby adding 34 adults more when whole Park including churia was surveyed by camera traps. Better estimation tools are available, providing realistic estimation of the number and density of tigers by using capture recapture analysis framework. The density estimation using camera trap is based on the estimation of boundary strip width which is widely viewed as weak link (Karanth et al. 2006, Soisalo and Cavalcanti 2006) and overestimation by using half the mean maximum distance (MMDM) moved by the individual tigers (Dice 1938, Stickel 1954). The use of Spatially Explicit Capture recapture (SECR) models to overcome the geographical closure issue in combination with habitat mask has been useful. To overcome key problems of individual heterogeneity in capture probabilities, movement of traps, presence of potential holes in the array and ad hoc estimation of sample area by adopting Bayesian approach of analysis of the hierarchical model using data augmentation is providing better results (Royle et al. 2009 a, b). The free software SPACECAP (Singh et al. 2010) provides reasonable estimates developed using the Bayesian approach though the software needs to be more users' friendly and less time demanding in its operation.

The TAL's potential as a long-term stronghold for tigers, as indicated by the sign of presence in 10 of the 14 TAL districts, emphasizes the need to re-establish breeding habitat and dispersal corridors across this region (Wikramanayake et al. 2004, Barlow et al. 2009).

The camera trap in 20 day session may not be sufficient for Churia as indicated by this study and further testing is needed to come up with higher maximum capture of tigers with sufficient recaptures allowing estimating tiger with higher confidence. Monitoring tigers to differentiate between the breeding and non-breeding sections of the population will increase power to detect change and improve inferences regarding population status and long-term viability. This demands minimum of two years of camera trap in the same area and recording the evidence of cubs accompanying females. Alternatively, traditional monitoring with pug mark and tracing should be carried on larger area (Barlow et al. 2009).

University and local volunteers along with staff members from government and conservation partners in a team were used to generate quality data in one hand, and first hand field experience to the volunteers working in the core PAs in the other hand. This has helped to build the trust amongst managers and volunteers have realized the challenges of protecting PA holding the endangered species as tiger, rhino and wild elephant. This in turn would help to get more support from community, and help to improve the quality research by the university volunteers in future.

The joint resolution between Nepal and India (June 30, 2010) has opened up new collaborating avenues for conservation of tiger. Coinciding the monitoring of tiger with the trans-boundary PAs to gather the information on transient tigers would further strengthen the information for both the countries. Future collaboration on genetic studies, focussing the transboundary PAs, corridors and tiger habitat for tiger meta-population studies, piloting use of the Monitoring System for Tigers-Intensive Patrolling and Ecological Status (MSTrIPES) in Nepal's PAs and regular regional-local level trans-boundary meetings could be taken up for the benefit of the biodiversity conservation for both the countries.

The database prepared from this project was handed over to respective Parks and NTNC field offices. The hands on training to maintain and update is essential. Linking the MIS, ID based monitoring of rhino and MIST would provide information which would definitely help more access to researchers and managers in need.

At glance, the stronghold of tigers as a source population in Chitwan complex, potential to increase the tigers in Bardia and Suklaphanta complex and introduction/re-introduction of prey species in prey depleted area may certainly contribute to the global aim of doubling the tiger by 2022.

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# CHAPTER ONE : INTRODUCTION

## 1.1 INTRODUCTION

The tiger (*Panthera tigris* Linnaeus, 1758) is largest among the four big cats of the genus *Panthera*. Once ranged widely across Asia, from Turkey in the West to the Eastern coast of Russia (Nowell and Jackson, 1996), tigers have now disappeared from Southwest and Central Asia, from two Indonesian islands (Java and Bali) and from large areas of Southeast and Eastern Asia over the past 100 years, losing 93% of their former range (Sanderson et al. 2006, Dinerstein et al. 2006). A recent assessment of tiger distribution suggests that the tiger range has further shrunk by 41% from 1996 to 2006 (Dinerstein et al. 2007) primarily due to poaching (Chundawat et al. 2010), and loss of habitat as well as prey. Their number has been reduced by 96% (GTRP 2010). Only 5% of the world's wild tigers continue to survive since the last century (Linkie et al. 2010, Stokes 2010). A recent analysis has identified 42 tiger "source sites," representing a mere 6% of their existing range, that hold nearly 70% of the current estimated tiger population (Walston et al. 2010).

Tigers currently occur in thirteen Asian range states: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Russia, Thailand and Viet Nam. Their existence in North Korea appears to be doubtful.

Four of the nine indentified subspecies of tiger are already extinct. Bali tiger (*Panthera tigris balica*) found in the island of Bali, Indonesia was first to go extinct in the 1940s, followed by Caspian tiger (*Panthera tigris virgata* ) in 1970s, Javan tiger (*Panthera tigris sondaica*) in early 1980s and South China tiger (*Panthera tigris amoyensis*) in 1990s (Seidensticker 2010). Of the five extant species, Bengal tiger (*Panthera tigris tigris*) occurs in parts of India, Bangladesh, Nepal, Bhutan and Burma. The Indochinese tiger (*Panthera tigris corbetti*), is found in Cambodia, China, Laos, Burma, Thailand, and Vietnam. The Malayan tiger (*Panthera tigris jacksoni*) occurs in the Malay Peninsula and the Sumatran tiger (*Panthera tigris sumatrae*) is found only on the Indonesian island of Sumatra. The Siberian tiger (*Panthera tigris altaica*), also known as the *Amur*, *Manchurian*, *Altaic*, *Korean* or *North China* tiger, is confined to the Amur-Ussuri region of Primorsky Krai and Khabarovsk Krai in far eastern Russia.

The global tiger population is estimated at 3,566 (range 3,192-4,009), (Bangladesh 440, Bhutan 75 (67-81), Cambodia 10, China 45 (40-50), India 1,706(1,502-1,909), Indonesia 325 (250-400), Loa PDR 25, Malaysia 500, Myanmar 85, Nepal 155 (124-229 adults), Russia 360 (330-390), Thailand 170, and Vietnam 10 (DNPWC 2010, GTRP 2010, Jhala et al.2011). Globally all the extant subspecies of tigers have declined in number along with the loss of their habitat (Sanderson et al. 2006).

Historically, tigers occurred all along the lowland Himalayan forests in Nepal. However, surveys conducted between 1987 and 1997, documented only three isolated tiger populations in low lands of Nepal (Smith et al. 1998). The Chitwan population occupies the largest area (2,543 $km^2$) with 75% of the tiger population confined to Chitwan National Park (CNP). The Bardia population, 180 km west of Chitwan, occupies a land base of 1,840 $km^2$; Bardia National Park (BNP) encompasses 51 percent of this land base and Banke National Park (BaNP) encompasses 30 % of land base (550 $km^2$ of core area, declared in June 2010, DNPWC 2010). The third population is found in Suklaphanta in western Nepal, encompassing area of only 320 $km^2$.

Earlier population and density estimates were based on the premise of identifying individual tigers from their pugmarks which were seriously criticized by Karanth et al. (2003). Individual identification of a tiger can be confirmed by its stripe patterns (Schaller 1967, McDougal 1977, Karanth 1995). Capture-Mark-Recapture framework (Pollock et al. 1990) using camera traps (Karanth 1995) provides accurate and robust estimation of population and density of tigers.

The occupancy, distribution and tiger density are important parameters for management and conservation policy formulation. Two main projects, tiger ecology project in CNP and prey predator project in BNP have provided insights in to the understanding of the tiger ecology. Main research in CNP includes, identification of high priority areas for the conservation of free ranging tigers (Dinerstein et al. 1996); dispersal and communication (Smith 1984, 1993, Smith et al 1989), effective population size (Smith and McDougal. 1991), land tenure system in female tigers (Smith et al 1987 a), conservation strategy (Smith et al. 1987b), population characteristics (Tamang 1979), social organization (Sunquist 1981), movements and activities (Sunquist 1981), status of the tiger (Tamang 1982), and temporal variation in tiger populations (Barlow et al. 2009). The main research in BNP includes diet (Stoen 1994, Støen and Wegge 1996, Eliasen 2003), effects of trapping effort and trap shyness on estimates of tiger abundance (Wegge et al. 2004), predator prey relationships (Wegge et al. 2009), and status of the tigers (Froyland 1998, Pokhrel 2002). Limited study related to the status of tiger (Regmi 2000, DNPWC,WWF-N and NTNC 2003, 2005, 2006, 2008) has been carried out in Suklaphanta Wildlife Reserve (SWR).

The Ministry of Forests and Soil Conservation (MFSC), Government of Nepal (GoN) had decided to conduct the nationwide survey of tiger in every five year interval. Such a nationwide survey for tiger was conducted in 1995/96 and 1999/2000 (DNPWC 2001). The survey for

2005/06 was not possible due to social unrest in Nepal. The information provided by camera trapping in SWR between 2004/05 and 2007/08 showed a severe decline of tigers from 27 (2004/05) to 7 (2007/08). Some recovery of tiger body parts in Suklaphanta and seizure outside in the region on different occasions indicated that poaching was the likely reason for decline (Karki et al. 2008). This was also evident from the fact that there was drastic decline of tiger in India in the recent years (Jhala et al. 2008, 2011, Chundawat et al. 2010). This prompted the GoN to conduct the nationwide survey of tigers at the earliest. The current study was a part of this national initiative undertaken by the Department of National Parks and Wildlife Conservation (DNPWC), with technical and financial support from National Trust for Nature Conservation (NTNC), and WWF Nepal wherein all the Terai Arc Landscape (TAL) covering 14 districts and four tiger bearing PAs were surveyed in 2008-09. Additionally, CNP was again camera trapped by covering whole area including Churia range in 2009/10.

Chital (*Axis axis*), sambar (*Rucervus unicolor*), swamp deer (*Rucervus duvaucelli duvaucelli*), wild pig (*Sus scrofa*), hog deer (*Hyelaphus porcinus*), barking deer (*Muntiacus muntjak*), gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), rhesus macaque (*Macaca mulata*), common langur (*Semnopithecus entellus*), hispid hare (*Caprologus hispidus*), black naped hare (*Lepus nigricollis*), porcupine (*Hystrix indica*), four horned antelope (*Tetraceros quadricornis*), one-horned rhinoceros (*Rhinoceros unicornis*), Asian elephant (*Elephas maximus)* are among the main wild prey species of tiger in Nepal. Species like swamp deer is restricted to SWR and BNP. Similarly, gaur is restricted to CNP and Parsa Wildlife Reserve (PWR). Thus, sambar, chital, wild pig, hog deer, barking deer and swamp deer are the major wild prey species of tiger in Nepal (Tamang 1982, Wegge et al. 2009).

The estimation of abundance and density of tiger's wild prey in sal forest, mixed forest, riverine forest, tall grasslands and in moderate terrain in early dry season were the main challenge due to poor visibility. Thus the observation was done from the elephant back in all habitat types.

There was limited information available so far in these protected areas (PAs) in relation to density and abundance estimation. The Tiger Ecology Project in CNP launched during late 1970's, provides information for chital (Tamang 1982, Sidensticker 1976); hog deer (Sidensticker 1976, Dhungel and O'Gara, 1991), sambar (Tamang 1982), wild pig (Tamang 1982, Sidensticker 1976), and barking deer (Tamang 1982). Information from BNP for chital (Dinnerstein, 1976; Naess and Anderson 1993, Moe and Wegge 1994, Malla 2009), hog deer (Dinerstein 1980, Wegge et al. 2009, Malla 2009), swamp deer (Dinerstein 1980, Pokhrel 1996, Wegge et al. 2009), barking deer (Dinerstein 1980, Wegge et al. 2009, Malla 2009), wild pig (Dinerstein 1980, Wegge et al. 2009, Malla 2009), sambar (Dinerstein 1980, Malla 2009), blue bull (Khatri 1993, Subedi 2001), langur (Malla 200), rhesus macaque (Malla 2009), rhino (Jnawali 1994) and elephant (Pradhan et al. 2008 ) exists. Except Malla 2009, rest of the researches was mostly conducted in Karnali Flood Plain (KFP) area within the BNP (western part, about 100 $Km^2$). Some limited studies were carried out on swamp deer (Schaaf 1976, Yadav 2006, Pokhrel and Thapa 2008, Gyawali and Jnawali 2005), spotted deer (Yadav 2006), and hog deer (Yadav 2006) in SWR. Limited information exists for species level density is available for PWR for some species like gaur (Chetri 1999), chital (Bhattarai 2009), and elephant (Pradhan 2007).

The overall density and abundance of tiger's wild prey has not been assessed across the protected areas in TAL Nepal. The tiger ecology project in 1980's had estimated the abundance of wild tiger prey in CNP, mainly from the northern foot hills (FH) of Churia between Sauraha-Kasara areas. Thus the current study was aimed to find out the status of tiger and its prey across TAL Nepal.

## 1.2 OBJECTIVES

- To evaluate the occupancy, range, and population extents of tigers and their prey in the Nepal's Terai Arc landscape,
- To estimate the density of tigers and their prey in PAs of Nepal's Terai Arc landscape,
- To evaluate the relationship of tiger occupancy and density with covariates such as landscape characteristics, prey availability, human disturbances and legal protection.

# CHAPTER TWO : STUDY AREA

## 2.1 TERAI ARC LANDSCAPE

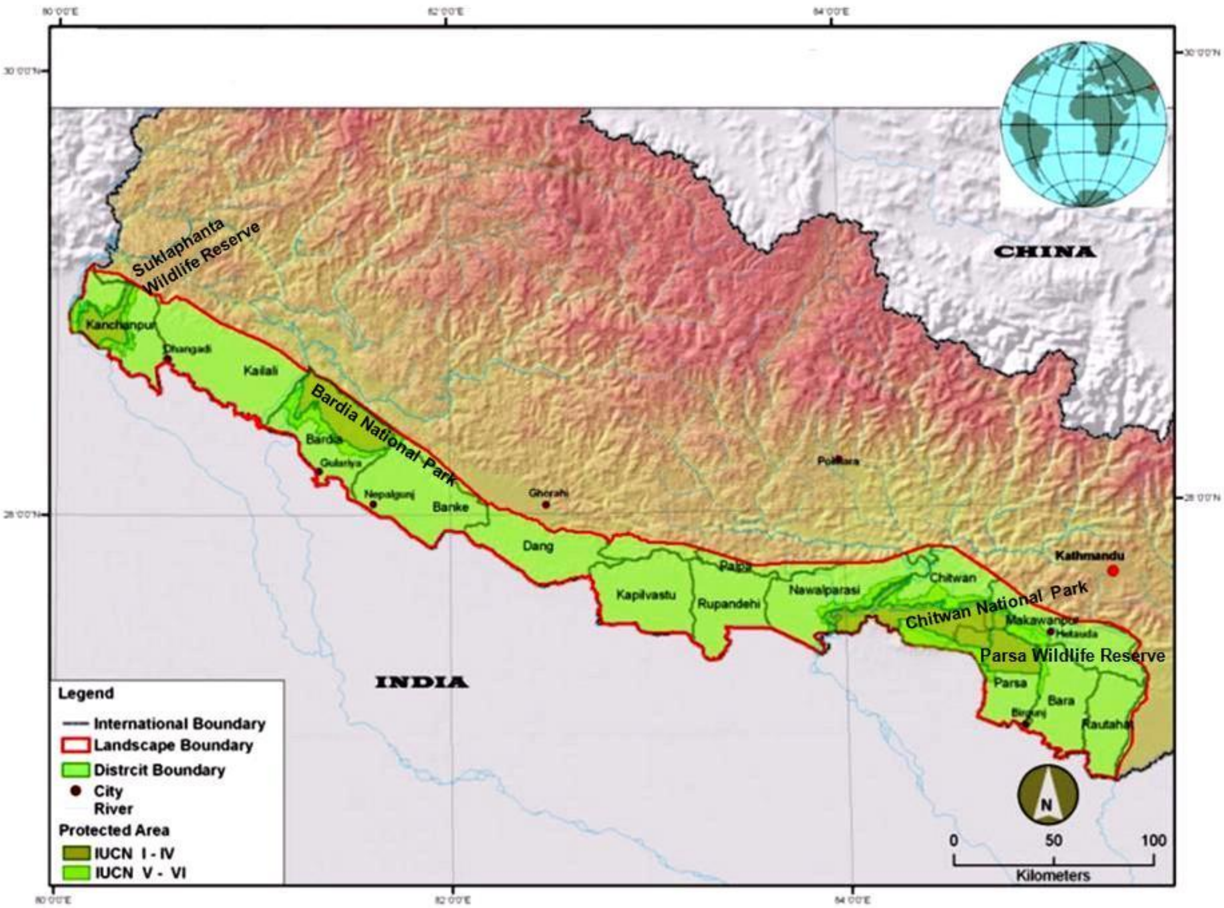
Terai Arc Landsccape spans over an area of 49,500 $km^2$, that extends from Bagmati river of Nepal in the east to Yamuna river of India in the west. TAL Nepal encompassses 6 PAs, PWR, CNP, BaNP, BNP, Krishnasar Conservation Area (KrCA), SWR and four forest corridors (Khata, Basanta, Laljhadi, Mahadevpuri) in Nepal (Table 2.1). TAL-Nepal has been identified as the first landscape level conservation initiative in Nepal and is the largest conservation undertaking of Government in the conservation history of Nepal. In Nepal, 20 districts are in Terai physiographic zone. TAL program is implemented in the 12 of these 20 Terai districts namely Rautahat, Bara, Parsa, Chitawan, Nawalparasi, Rupandehi, Kapilbastu, Dang, Banke, Bardia, Kailali, and Kanchanpur. In addition, two mid hill districts, Makawanpur and Palpa are also included in the TAL program. The total area covered by these 14 districts is 27,108 $km^2$ but TAL extends only over an area of 23,199 $km^2$ of above mentioned 14 districts (Figure 2.1). The objective of TAL Nepal program is to protect the representative Terai biodiversity with unique species assemblages while supporting the livelihood of the people dependent on it.

**Table 2.1. Corridor in Terai Area Landscape, Nepal.**

| SN | Corridor Name | CFCC | District | # of CF | VDC+ | Aarea ($Km^2$) |
|---|---|---|---|---|---|---|
| 1 | Khata | 1 CFCC,1 Cooperative | Bardia | 48 | 4 | 43.5 (forest) |
| 2 | Basanta | 4 CFCC, 4 cooperatives | Kailalai | 82 | 11 | 654 |
| 3 | Laljhadi | 2 CFCC, 2 Cooperative | Kanchanpur | 17 | 4 | |
| 4 | Mahadevpuri | 1 CFCC, 1 Cooperative | Banke | 37 | 2 | 209 |

+VDC= Village Development Committee, is the lowest political unit in Nepal, CFCC=Community Foret Coordination Committee.

**Figure 2.1. Districts of Terai under Terai Arc Landscape Program in Nepal.**




Three distinct seasons prevailing in the study area are rainy, winter and summer. The cool winter season occurs from October to February, spring starts from March and followed by summer that ends on June. Monsoon begins from late June and ends on September. The average annual mean temperature (2001-2006) of the TAL districts ranges from $21.7^0$C (Ghorahi, Dang) to $25.3^0$C (Gaur, Rautahat). Lowest annual mean temperature was $20.5^0$C in 2001 (Ghorahi Dang) and $26.1^0$C in 2006 (Rautahat).The annual rainfall (during 1971-2000) of the TAL districts ranges from 1,351mm (1,421 during 1999-2008) in Nepalgunj, Banke to 2,331 mm in Nijgadh, Bara. About 2-5 % of the total annual rainfall occurred during the winter season (CBS 2008, 2011).

The total human population was 6.713 million (range Palpa 0.268- Rupandehi 0.708) in 1.122 million households (hh) (average 6.0 person/hh, range Chitwan 5.1-6.6 Kapilbastu). The average population densities of these 14 districts are 247.7 person/$Km^2$ (range Makawanpur 162- Rupandehi 521) which increases up to 260 by excluding the two mid hill districts (Makawanpur and Palpa) (CBS 2008). This population density is lower than the average population of Terai physiographic zone of Nepal (392 person/$Km^2$, CBS 2011).

The average household income in the TAL Nepal is only NRs. 7,200 per annum and the majority of the population lives in poverty. The population composition pattern in *Terai* is a mix of local and migrants.

More than three fourth (77%) of the households in Terai use fuel wood and cow dung for cooking. The other sources of cooing energy are Kerosene (12.8%), LPG (7.7%), and Biogas (1.7%) (CBS 2008).

The major habitat types in the TAL are sal forest, mixed forest, riverine forest, grassland, degraded forest, water body and others (Figure 2.2, DoF 2001, Shrestha 2004). The sal (*Shorea robusta*) forest is the ecologically climax vegetation of the Terai (Shrestha, 2004). Natural and physical forces such as flood, fire, erosion, and soil aridity contribute to a continuously changing mosaic of grasslands, mixed deciduous, dry-thorny and riverine forests in various stages of succession in the Terai.

More than 75 % of the remaining forests of the Terai and foothills of Churia come under the purview of TAL Nepal (Figure 2.3). 12,806.71 $Km^2$ of forest (47.7%) and 1,168.16(4.4%) $Km^2$ of shrub land totaling 13,975 $Km^2$ (51%) are recorded in TAL as of 2001. The highest forest and shrub cover was in Kailali district 1,845 ($Km^2$) and lowest was in Rupandehi district 238 ($Km^2$)

by 2001. Other districts having forest and shrub cover over 1,000 $km^2$ were Makawanpur (1,598 $km^2$), Chitwan (1,390 $km^2$), Nawalparasi (1,048 $km^2$), Dang (1,783 $km^2$) and Bardia (1,046 $km^2$). Rest of the districts having forest and shrub cover less than 1,000 $Km^2$ were Kanchanpur (866 $km^2$), Rautahat (296 $km^2$), Bara (394 $km^2$), Parsa (741 $km^2$), Palpa (963 $km^2$), and Kapilbastu (627 $km^2$). There was reduction in forest cover in 8 districts (Kailali, Kanchanpur, Bara, Rupandehi, Kapilbastu, Banke and Bardia) and increase in four districts (Chitwawn, Rautahat, Nawalparas, and Dang) from 1991 to 2001 with overall reduction by 77 $Km^2$.The highest loss was 5% in Bardia and whereas the highest increase was 2.4% in Nawalparasi during the same period. The average annual forest cover change in the twenty districts of Terai was 1.3% for the same period (DoF 2001).

Agriculture and grassland (44.4 %) follows after forest (47.7%) and shrub cover (4.4%), barren land (2.7%) and water body (0.8%) and remaining others in land use cover in TAL. TAL-Nepal is considered as a 'biodiversity hotspot' and it comprises two of WWF's Global 2000 ecoregions viz. *Terai-Duar Savannas and Grasslands* ecoregion and the *Himalayan Subtropical Broadleaf Forests* ecoregion. It is a biologically diverse habitat with 86 species of mammals, 550 species of birds, 47 species of herpetofauna, 126 species of fish and over 2,100 species of flowering plants.

The Himalayas were formed by the collision of the Indian sub-continent with Eurasia, which began about 50 million years ago and continues today. Two of the four tectonic subdivisions of the Himalayas are: 1) The "middle hills" below the Main Central Thrust south to the Lesser Himalaya or Mahabharat lekh which is bounded by Main Boundary Thrust that abruptly elevates the Mahabharats 1,000 to 2,000 meters above hills to south. 2) The Chure Hills or Siwaliks or Subhimalaya are the southernmost foothills of the Himalayan Range and mainly composed of folded and overlapping sheets of sediment from the erosion of the Himalaya.

**Figure 2.2. Major habitat types of Terai Arc Landscape (2001), Nepal.**

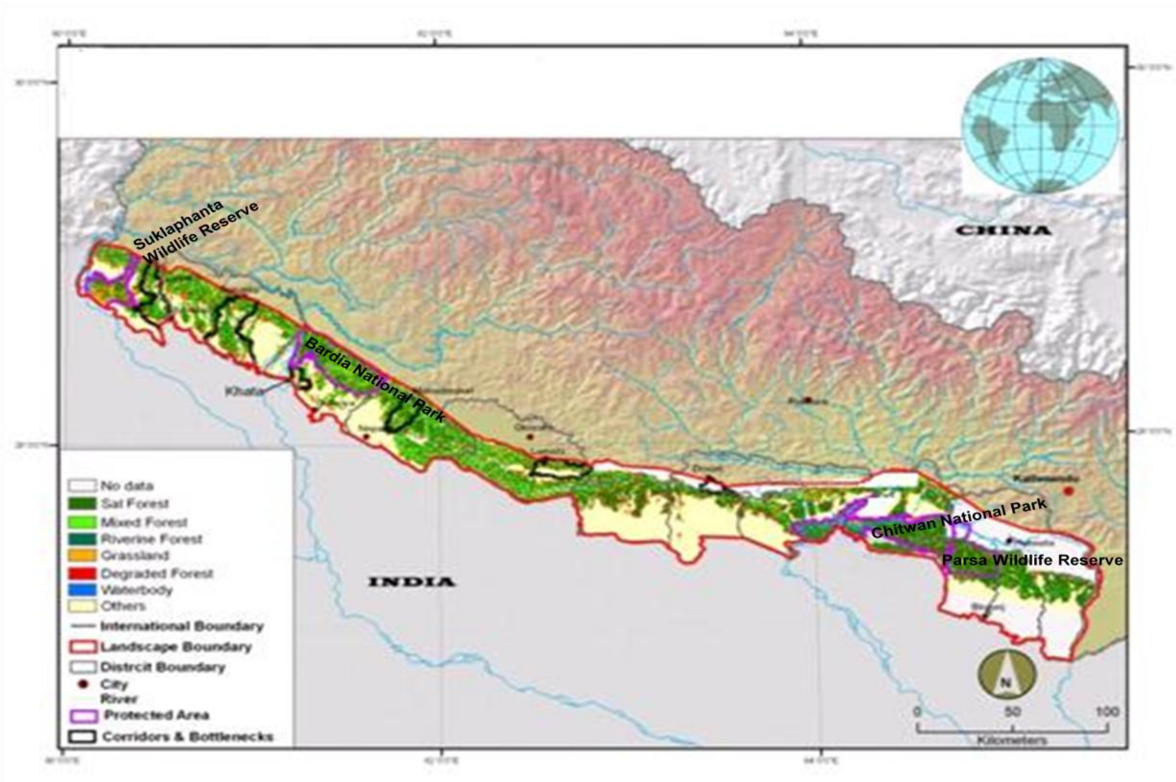
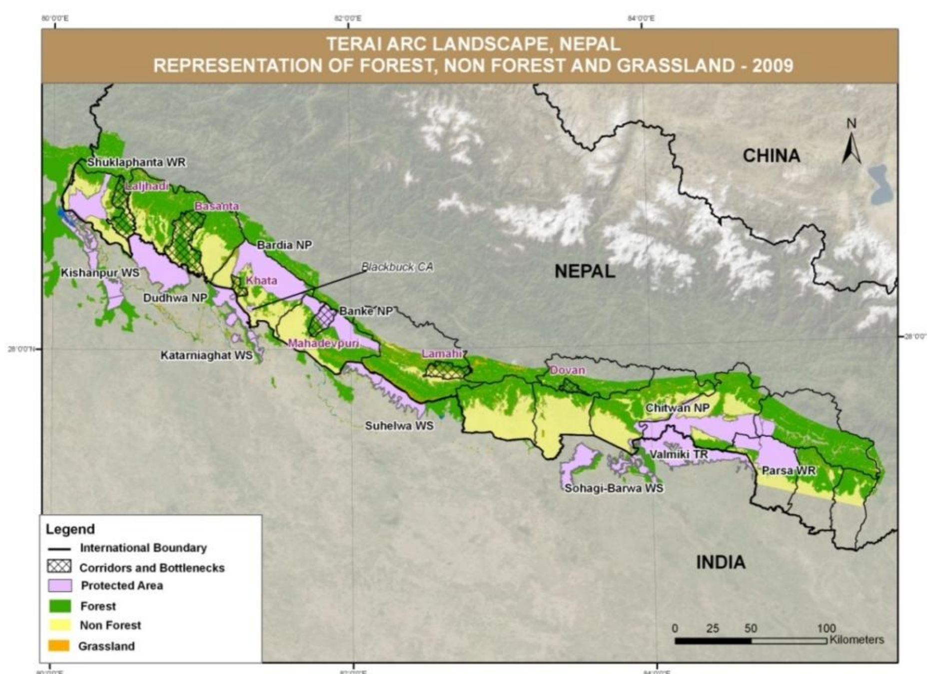



**Figure 2.3. Forested area in the Terai Arc Landscape, Nepal.**



They are bounded on the south by the Himalayan Frontal Thrust elevating them about 500 meters above the Gangetic plain. The Inner Terai valleys lie between the Churia/Siwalik (600-900 m high) and Mahabharat ranges (2,000-3,000 m high) or sometimes between different ranges in the Siwaliks. They hold flat plains with winding rivers that shift course from time to time, running northwest or southeast along the axis of the Siwalik ranges until they find a break and flow into the Outer Terai and Gangetic plain. Usually there is little difference in elevation between the Inner Terai valley floors and the plains of the Outer Terai.

Chitwan Valley is in central lowland Nepal in Narayani Zone stretching 150 km in length and roughly 30-48 km in width. The cities Bharatpur, Hetauda and Ratnanagar are in the valley. It is drained by the (East) Rapti river flowing from the southern flank of Mahabharat range near Hetauda, then west down the valley to join the Narayani west of Meghauli. The Narayani is also called Gandaki further upstream and *Gandak* downstream in India. CNP is the part of Chitwan valley (southwest of Kathmandu) and is one of our study areas.

The parallel Dang and Deukhuri valley in Rapti Zone of mid-western Nepal, in Dang District, is part of our occupancy study area (Similar valleys in India are called Dun or Doon**)**. Deukhuri Valley is the longer but narrower valley where the West Rapti river emerges from its gorge through the Mahabharat Range. Mahendra Highway crossing Nepal east to west follows Deukhuri Valley. The Babai river drains Dang valley, also flowing WNW along the Siwalik axis and finally exits the Siwaliks at BNP.

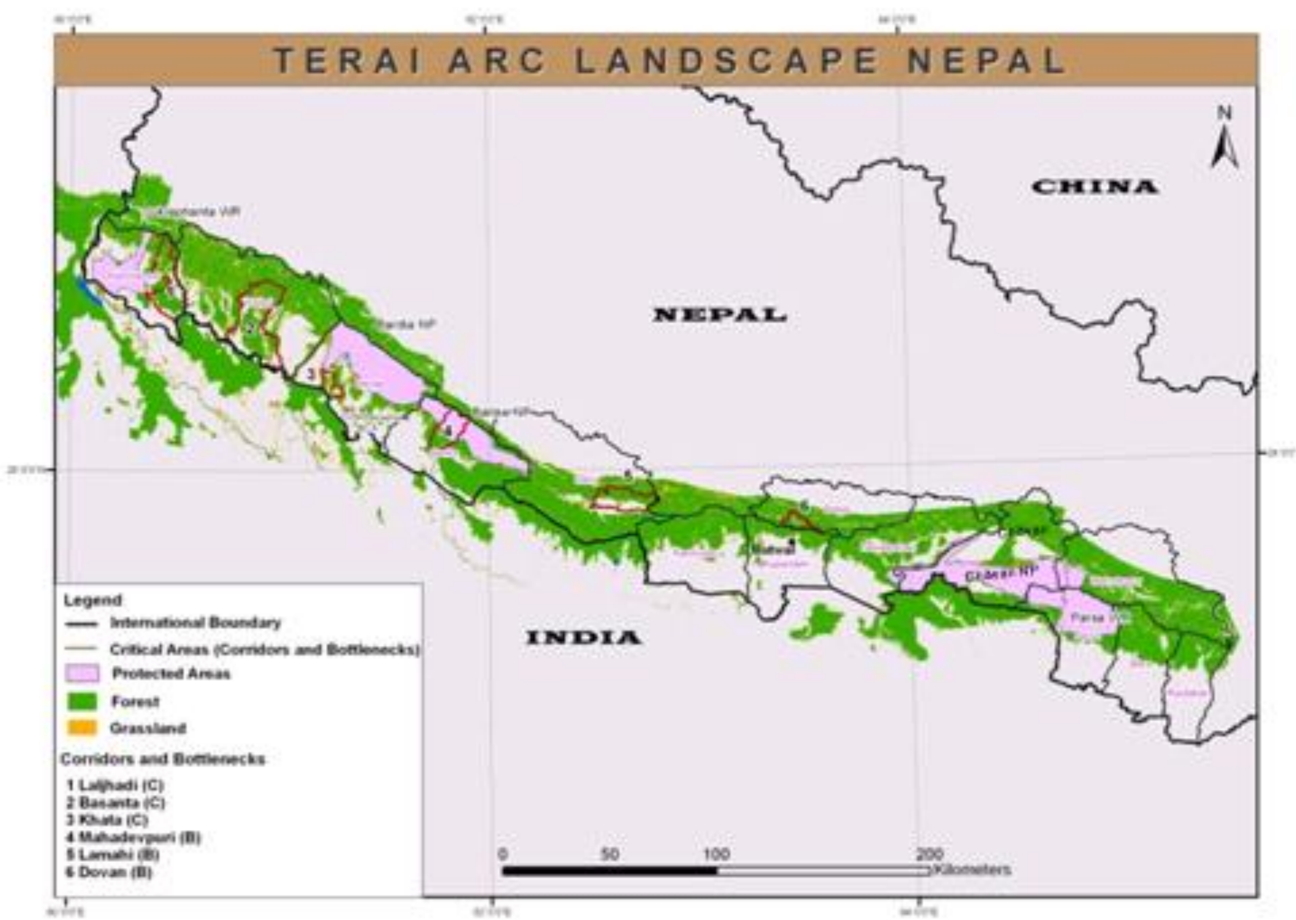
Babai valley (BV) is similar valley and lies within BNP. Outer Terai refers to the plains extending south of the Churia or Siwalik Hills bordering India.

## 2.2 PROTECTED AREAS IN TERAI ARC LANDSCAPE

TAL Nepal encompassses 6 PAs, Parsa Wildlife Reserve, Chitwan National Park, Banke National Park, Bardia National Park and Suklaphanta Wildlife Reserve and Krishnasar Conservation Area (Figure 2.4). Except KrCA, rest five PAs have declared Buffer Zones (BZs).

The three flagship species of TAL PA's are tiger, elephant, and rhinoceros. PAs account for approximately 25% of tiger habitat throughout the world (Smith et al. 1987b, Dinerstein et al. 1996); in contrast, 75% of tiger habitat is in forestlands where human activity is a dominant component in the ecological system.

**Figure 2.4. PAs of Terai Arc Landscape, Nepal including corridors and bottlenecks.**



### 2.2.1 Parsa Wildlife Reserve

PWR ($27^0$15'-$27^0$33'N and $84^0$41'-$84^0$58'E, 499 $km^2$, alt. range 150-950m) is located in the south-central lowland Terai. The resource profile (2003) estimated the area of the Reserve to be 558.1 $Km^2$ with cultivated land 2.42 $Km^2$, forest land 512.2 $Km^2$, shrub land 2.52 $Km^2$ and others (river/sand) 40.94 $Km^2$. It is connected with CNP in the west and extends to the Birgunj Hetauda highway in the east, towards north Rapti river and Churia ridge marks the boundary, and towards south is 3 Km long forest fire line. Two small villages, Ramouli and Pratapur, are located inside the Reserve, along the Rapti river in the inner Terai.

The mean monthly temperature ranges between $15^0$C in January-$30^0$C (June). The average monthly maximum temperature ranges from $22.2^0$C-$35.3^0$C and minimum temperature ranges form 8.8-$25.7^0$C. The climate is monsoonal type and precipitation occruing between June to September. The annual rainfall is 2,180 mm. Humidity ranges from 59-93%. Small amount of winter rain from westerly winds from the Arabian Sea is observed in this area.

Soil is primarily composed of gravel and conglomerates, making it susceptible to erosion. Brown shallow soil, brown black and red soils are found predominantly in the Reserve. Loamy texture brown black and red soils are found in the forest, and, in and around the Siwalik Hills. Black soils are found in the sal forest. Brown soil and well-sorted dry shallow soils are also found in and around the area. Sal and tropical deciduous hardwood forests are found on brown shallow soil. Pure pine and sal pine forest area found in the brown black and red soil. *Acacia* forest is found in sandy loam and sandy soils. Grasslands are seen on well drained or poorly drained brown soil.

The hills present a very rugged face with numerous gullies and dry streambeds. As the foothills are very porous, water flows underground and surfaces at a distance of about 15 km. from the hills base.

Perennial and seasonal streams flow from the watershed of Churia ridge through the Reserve. Hasta khola, Bhalu khola, Bagai khola flow northward and joins with the Rapti river. Bhera khola, Bhalu khola, Manbohi khola, Jamunia khola, Bhata khola, Oriya khola, Doharan khola flows to the south (Upadhyaya 2001).

Major vegetation types are Sal forest (approx 90%), *Acacia* forest, Pine forest, Mixed riverine forest, deciduous forest, and mixed hard wood deciduous forest. Chir pine (*Pinus roxburghii*) grows along the streams of Churia. khair (*Acacia catechu*), sissoo (*Dalbergia sissoo*) and silk cotton tree (*Bombax ceiba*) occur along the stream and river. Sabai grass (*Eulaliopsis binata*) grows well on the southern face of the Churia hills.

333 species of vascular plants - five pteridophytes, one gymnosperm, and 327 angiosperms (258 dicots and 69 monocots) belonging to 234 genera and 83 families are recorded in the Reserve. Life form characteristics are 52 herbs, 52 shrubs, 47 climbers and 83 tree species (Sah et al. 1999).

Parsa is home to 37 species of mammals, 500 species of birds, 13 species of reptiles/amphibians, and 8 species of fishes (DNPWC, 2002), and 31 species of butterflies (Sah et al. 1999). Wild elephants, tiger, leopard (*Panthera pardus*), sloth bear (*Melursus ursineus*), gaur, blue bull and wild dog (*Cuon alpinus*), sambar, chital, barking deer, four horned antelope, langur, rhesus, striped hyena (*Hyaena hyaena*), ratel (*Mellivora capenis*), palm civet (*Paradoxuris hemaphroditus*) and jungle cat (*Felis chaus*) are recorded in the Reserve. Rhino do arrives here occasionally from CNP and stay has been increasing after creation of new habitat in the relocated village sites in Rambhori-Bhata. The Giant hornbill, an endangered bird species, is found in the Southern flank. Peafowl, red jungle fowl, flycatchers and woodpeckers are a few of the other common birds in the Reserve. Snakes like king cobra, common cobra, krait, rat snake and python are also found in the Reserve.

PWR, true representation of Churia, is dry with confined water bodies. The recently relocated villages have water body with some better habitat for the prey including rhino and tiger.

The BZ was declared in 2005 with 298 $km^2$ area and accomodates 11 Village Development Committees (VDCs) of three districts (Makawanpur, Parsa and Bara). More than forty three thousand people from 7,228 households formed user groups (Table 2.2).

**Table 2.2. Buffer Zone of Nepal's Terai Arc Landscape tiger bearing Protected Areas.**

| SN | BZ | Year of Declaration | Area ( $km^2$) | No of District | No of VDCs | No of Households | Human Population |
|---|---|---|---|---|---|---|---|
| 1 | CNP | 1996 | 750 | 4 | 37 | 36,193 | 223,260 |
| 2 | Bardia NP | 1996 | 327 | 3 | 17 | 14,472 | 102,456 |
| | | 2010 | 180 | 1 | 4 | - | - |
| 3 | SWR | 2004 | 243.5 | 1 | 12 | 17,006 | 100,953 |
| 4 | Banke NP | 2010 | 343 | 3 | 14 | - | - |
| 5 | Parsa WR | 2005 | 298.17 | 3 | 11 | 7,228 | 43,238 |

### 2.2.2 Chitwan National Park

The CNP ($27^0$19-$27^0$33'N and $83^0$55'-$84^0$58'E, 932 $km^2$, alt. range 110-850m.) lying in the south central Nepal in the subtropical lowlands in the inner Terai was gazetted in 1973 as the first National Park in Nepal. It is a world heritage site and occurs between the Siwalik outer range and the Mahabharat Range or "Middle Hills". Initially the park area was 544 $km^2$, which was later extended in 1977 to its present size.

The forest area occupies 84.6%, grassland 4.7%, shrub land 0.5%, and others (river/sand) 10.2%. There was reduction of 0.2% of forest and 1.4% of grassland whereas increase of 0.5% of shrub land and 1.0% of others category between 1978-1992 (DNPWC 2000).

Two PAs, PWR to the east and Valmiki Tiger Reserve to the south in India, are adjacent and together support one of the largest tiger populations in South Asia (Wikramanayake et al. 1998).

From the watershed of the Churia ridge numerous permanent and seasonal streams flow into the Rapti and Reu rivers. In the southwest of the park where the Nepal-India border follows the crest of the Someswor hill range, a number of similar streams flow throughout the year northwards into the Reu river. The Rapti and Reu rivers flow through the park and ultimately join the Narayani river. In between, there are several depressions forming lakes and marshes with perennial water sources.

The Narayani river marks the western boundary and Rapti river marks the northern boundary of the park.

About 85-90% of the total area of the park falls within the Rapti watershed and its major tributary is Reu river. Average maximum discharge of Reu river was 200-400 cum./sec. and minimum was 1.2 cum./sec. near the outlet of park area (Banskota et al. 1996).

There are about 40 lakes, ponds and marshes covering about 114 ha area in the park. The ox-bow lakes, and flood plains of Rapti, Reu and Narayani rivers provide diverse habitat. Devi Tal (11 ha), Tamor Tal (10ha), Nandan Tal (9 ha), and Lami Tal (7ha) are important wetlands of the park (DNPWC 2000). Beeshhazari Tal (100 ha), Devi Tal (2.6 ha), Pandethan Tal (2.1 ha), Khageri canal, Baghmara lake, Kumrose ox-bow lake, Kathar lake, Gaida Tal, Gaida pokhari, Budhi Rapti Tal, Narkat ghol, and Dabdabe ghol are important wetlands in the BZ. Beeshhazari Tal (Ramsar site) is the main corridor linking the park to Mahabharat range towards north. Other rivers that cut across the BZ are Manahari, Lothar, Amuwa khola, Khageri Khola, Chamka khola, Audhori Khola, Bhalu khola, Harda Khola, Hasta khola, Dhode Khola, etc. All the rivers are the tributaries of the Narayani river system and form rich and fertile flood plains.

The Chitwan valley lies within the Siwalik belt (upper and lower) and consists of thick alluvial deposits. Upper Siwalik consists of gravel and conglomerate beds with sand and silt layers. The rocks are well exposed in many places. Middle Siwalik rocks are represented by thick bedded sandstone and siltstone. The upper part of middle Siwalik is accompanied by conglomerates. The Siwalik dip northward. Gravel beds, sand and silt and silt-stones of upper siwaliks are weak in nature. The northerly aspect is relatively more unstable (JICA 1973).

The valley lying within the Siwalik belt is filled with thick alluvial deposits of boulders, cobbles, gravel, sand and silt. The fans are composed of fluvial deposits. Fans are located on the end of the slopes where the stream also enters the flat terrain. The fans are composed of predominantly sand, gravel, cobble and boulders with at little of silt and clay. River terraces were developed by the rivers in long run.

Terrace and valley are dissected by parallel series of broad, north-south valleys. The stream valleys have one to three terrace levels with slope gradient 2-5%. The side of the valley slopes have 10-30% slope with occasional vertical bluffs. The soil are deep reddish sand loams and silt loams. The streams make braided channels although it is full of water only during the monsoon. Stream bank cutting is prevalent. Central valley occupies major part in an outwash plain with several levels, slope 1-5%. Soils are deep, silt loams and sandy loams. Gravels are present in scattered low ridges. Flood plains are formed along the south side of the valley including lowlands of Rapti and Narayani rivers. The soil is deep, loamy and fine sands. Most of the area inside the park is of this type.

The climate is tropical monsoon with relatively high humidity. The river flooding is important which occurs between June-September. Average monthly maximum temperature ranges from $24^0$ C (January) to $38^0$ (May) and Minimum temperature varies from $11^0$ C in January to $26^0$ C in June, and come down up to $6^0$ C. The average annual rainfall ranges between years 2004-2007 was 2,437 mm but for the period between years 1971-1986 was only about 2,100 mm. The minimum relative humidity was 89% (April-January) and highest was 98% (November-mid February) and becomes average between spring and summer.

Six major vegetation types identified by Laurie (1978) are: 1. Sal and hill forest 2. Riverine forest (Khair-Sissoo, b. *Bombax-Trewia*, c. *Eugenia* woodland, d. Tropical evergreen forest) 3. Tall grassland (a. *Themeda villosa*, b. *Sachharam - Narenga* , c. *Arundo-Phragmites* associations, d. *Imperata cylindrica*) 4. Short grasslands and river banks 5. Permanent lakes and 6. Scrub. Banskota et al. (1996) have described two more riverine forest types: *Litsea-Bombax* forest and *Machilus* forest.

Lehmkull (1994) and Peet (1997) have further classified grasslands into 8 types-two Themeda associations, four mixed tall grassland associations of *Narenga porphyrocoma*, *Saccharum bengalensis* and *S.spontaneum* with weak woody components and two grass-shrub associations with strong woody components with *Saccharum spontaneum* and *Narenga porphyrocoma* .

Sal forest covers more than 70%, followed by 20% of grasslands, riverine forest (7%) and sal with chir pine (3%) in CNP. The floral diversity consists of about 570 species of plants (3 gymnosperms, 13 pteridophytes, 415 dicots, 137 monocots, 9 orchids). It is one of the highly visited parks in Nepal.

More than 50 mammal species, over 526 bird species (Baral and Upadhyay 1998), 156 species of butterflies, 49 species of reptiles and amphibians (Mitchell and Zug, 1986) and 120 species of fishes (Edds 1986) are recorded from the park. Rhino, tiger, common leopard, wild dog, wild elephant, sloth bear, gangetic dolphin, gaur, four-horned antelope, striped linsang (*Prionodon pardicollor*), leopard cat, Pangolin are among the important mammals. Great hornbill, black stork, white stork, sarus crane, bengal florican, lesser florican are important birds. Gharial, python, common monitor lizard, Maskey frog (*Tomoptera maskey*, endemic) are important herpeto fauna of the park.

750 $km^2$ of buffer zone was declared in 1996 that consists 46% agricultural land and 43% community forests and rest includes shrub land, grassland, and rivers/water bodies (DNPWC and PPP 2000). There are more than 36 thousand households from the 37 village development committees of four districts (Chitwan, Makawanpur, Nawalparasi and Parsa).

Tharu inhabitants are the aboriginal from the area. Other casts such as Brahmin and Chetri later migrated from the hills. The BZ forests in the Madi valley watershed encompass 45% of the entire BZ forest surrounding CNP (DNPWC and PPP 2000). About 264.21 $Km^2$ of forest is estimated in the bufffer zone VDCs, of which sal constitutes 130.53 $Km^2$, riverine forest 16.59 $Km^2$ and mixed hardwood 117.09 $Km^2$. Other than Barandabhar BZ, Dumkibas forest (links with the forest of Siwalik hills) and Madi valley forest (link with VTR, India) serve as important wildlife corridors (DNPWC 2000).

### 2.2. 3 Banke National Park

Banke National Park (27° 58' 13''-28° 21' 26''N 81°39' 29''-82°12'19''E, 550 $km^2$, altitudinal range 153-1,247m) in Banke district is contiguous with the eastern boundary of BNP and was declared on 12 July 2010 (DNPWC 2010).

The BaNP is divided in to Churia, the rugged foot hills, Bhabar zone and the Terai flat alluvial land. The Churia ridge is made up of tertiary materials consisting of fine grained sandstone with deposition of clay and shale. The Bhabar zone consists of boulders and gravels. The southern part is flat lands consisting of fine alluvial soil with deposits of the quaternary materials. The BaNP can be divided into parts in terms of drainage system. The southern aspect of the Churia range falls in Rapti basin, whereas the northern aspect falls in the Babai basin. All the rivers of BaNP originate from the Churia hills. Main rivers in the southern aspect are Jhanjhari, Baghsala, Munguwa, Khairi, Sukhar and Bairiya and in the northern aspect is Malai khola. Flash flood occurs in several streams originating from the Churia whereas seasonal flooding occurs in Babai and Rapti rivers.

This park covers parts of Banke, Bardia, Dang and Salyan districts and includes heterogeneous communities with a wide range of ethnic groups such as Brahmins, Chhetri, Newars, Matwali, Khas, Magar, Bote, Tharu and others occupational castes including Kami, Tamang, Gurung, and Magar. Tharus constitute about 10% of the total population and are present mainly in the southern area. The population of Banke district in 1981 was 205,323 and reached 285,604 by 1991 (CBS 1992). More than 95% of the population of Banke has doubled within a period of two decades. A total of 3,160 ha. land is under cultivation in the BZ. An average cultivated landholding is about 0.65 ha per household and about 0.08 ha per capita which is less than the national average. Livestock is the next source of income after agriculture crop. Short and long-term migration to India and other countries is common for off-season employment opportunity. Mean annual minimum and maximum temperature, mean annual precipitation and mean annual relative humididy recorded during 1979-1998 at Sikta (195 masl-0.5 Km south of area) were 17.1 ° C., 30.9 ° C, 1,557.3 mm and 82% respectively.

Park encompasses eight ecosystems with 124 plant species in flood plains, river valleys and Churia. The faunal components include 32 species of mammals (7 protected and 11 rare and endangered), over 300 species of birds (protected, great pied hornbill, lesser florican), 24 species of reptiles (protected, python, monitor lizard), 7 species of amphibians, and over 55 species of fish. Tiger, Asian elephant, and four-horned antelope are main endangered species and other species found are common Leopard, sloth bear, jackal, rhesus macaque, and common langur.

90% natural forest coverage is composed of mainly Sal, Adina, Khair, and Sissoo (Basnet 2001). Stainton has described 6 types of vegetation in Bardia and Banke districts forests, which comes under the Bhabar and Terai forest. Basnet (1989) classified vegetation types in to Sal forest (dominated by *Shorea robusta* and associated species such as *Terminalia tomentosa*, *T.belerica*), Khair-sissoo forest (*Bombax ceiba*, *Streblus asper*), deciduous revirine forest (*Ficus glomerata*, *Eugenia jambolona* in upper layer, *Mallotus philippinensis* and *Eguenia* sp. lower layer, *Calamus tenuis* climbing palm in the under storey), savannahs and grasslands (*Imperata cylindrica*, *Erianthus ravennae*, *Vetiveria zyzanoides*, *Arundo donax*, *Phragmites karka*, *Panicum* spp, *Chrysopogan* spp, *Erianthus* spp and *Saccharum spontaneum*), Mixed hardwood forest (*Colebrookia oppositifolia*, *Pogestomons plectranthoides*, *Murrya koeniggii*), flood plain community (*Saccharum spontaneum*, *Tamarix dioica*, *Erianthus ravennae*, *Arundo donax*, *Phragmites karka*) and Bhabar/foot hill of Churia forest separately (common along the southern flanks of the Churia). Canopy layer species includes *Shorea robusta*, *Lagerstroemia parviflora*, *Terminalia tomentosa*, *Bauhinia variegata*, and *Dillenia pentagyna*.

BZ covers 344 $km^2$ in 14 VDCs, seven from Banke district (Khaskusum, Kanchanpur, Mahadevpuri, Kohalpur, Chisapani, Navbasta, Rajhena), three from Dang district (Goltauri, Panchkule, Purandhara), three from Salyan district (Kalimati Rampur, Kalimati Kalche, Kavrechaur) and one Surkhet district (Belawa).

4,861 households with 35,712 populations (Basnet 2001) reside in BZ. 90% of the local economy is based on agriculture. People have low living standard because of insufficient land (0.65 ha/HH). Rice, wheat, maize are the main crops. Animal husbandry is other source of income. People depend on forest for timber, fodder, fuel and livestock grazing (Kuinkel, 2003).

During our field work, this park had a status of national and community forests under the jurisdiction of Department of Forests.

### 2.2.4 Bardia National Park

Bardia National Park (28°15’ to 28°35.5’ N and 80°10’ to 81°45’ E, 968 $km^2$, altitudinal range 152-1440m., Estb.1969) is situated in the Bardia and Banke districts, Mid-Western lowlands. It is located in the south western fringe of the country bordering India on the south and Banke, Kailali and Surkhet districts to the east, west and north, respectively. It is the largest PAs in the Terai. First established as the Royal *Shikar* (Hunting) Reserve (348 $km^2$) which prominently included the Karnali Flood Plain. During the establishment, human settlements (villages) were relocated to the southern border of the Reserve. It was renamed as the Karnali Wildlife Reserve and area was extended to the present size (1984) of 968 $Km^2$ including Babai Valley to the east. During extension, 1,500 families from 20 villages in 1981 were relocated (Upreti 1994) to Taratal, near district headquarter Gularia. In was upgraded to National Park status in 1989 (Bhatta, 1994).

The park is drained by two large rivers, the Geruwa (a tributary of Karnali) in the west and the Babai in the east (Figure 2.8). The average discharge of Karnali river at Chisapani was 1,346 cumec. (1,400 in 1971-214 in 1967) (Upreti 1994). Kareli and Orahi are other small rivers present in the park. Some manmade water holes scattered in the park are used by the wildlife. There are no oxbow lakes inside the park (GoN, 2007). The Bheri river is one of the main tributaries of the Karnali river that originates in the glacier of the Himalayas and flows westwards and joins the Karnali river about 15 Km upstream from Chisapani (Yadav 2002), just above the NW corner of the park border. The Babai river, a tributary of the Karnali river, joins the Karnali river about 50 Km downstream from Nepal-India border. Babai originates from a low mountain in Siwalik and flow southwestward parallel to Bheri river then passes through Babai valley (Yadav 2002).

Most of the rains (1,560 mm to 2,230 mm) fall between June and September, somewhat later than in the eastern part of the country (Bolton, 1976 in Pradhan, 2007). Annual rainfall varies from about 2,000 mm at Chisapani to about 1,400 mm at Gularia depending upon the proximity of hills (GoN, 2006). Average annual minimum temperature is estimated at 18.5°C. The absolute minimum temperature may fall to 3°C. Frequent occurrences of cold waves keep the area covered with clouds for about four weeks (GoN, 2007). Average temperature in the cool season drops to 10°C in January while in the hot-dry season temperature may rise up to 41°C in May (Dinerstein, 1979).

The mosaic of the matrix has formed a unique landscape. Dinerstein (1979) described the following six types of vegetation from Karnali section which lies in the south western section of the park:

1. *Shorea robusta-Buchanania latifolia* forest = Sal forest, 2. *Dalbergia sissoo-Acacia catechu* forest = early riverine forest, 3. *Ficus glomerata-Mallotus philippinensis-Eugenia jambolana* forest = mixed riverine forest, 4. *Bombax* savannah/grassland = savannah/grassland, 5. Ecotonal secondary open mixed hardwood forest and 6. *Saccharum spontaneum-Tamarix* flood plain = tall grass flood plain

Janawali and Wegge (1993) revised it and brought into seven types by splitting type 5 and 6 into three -Floodplain grassland, Wooded grassland and Phanta.

The south western part of the park created by the KFP (124 km²) is defined as a bio-diversity hot spot (Wegge, at al., 2004).

The habitats were assembled into three associations based on similarity: Floodplain, riverine and Sal forest, consisting of a total of 17 different habitat types. Four types in Sal forest association-Dense Sal forest, Open Sal forest, Sal wooded grassland, Phanta; five types in riverine association (riverine forest, Wet mixed hardwood forest, Dry mixed hardwood forest, *Mallotus* dominated mixed hardwood forest, *Terminalia* forest) and six types in Floodplain association (Tall floodplain grassland, riparian forest, Khair-Sissoo forest, Old Khair forest, Mixed wooded grassland, Bushy pasture) were identified under the major habitat types with vegetation cover.

Other two major habitat types are aquatic habitat (rivers) and river bed. Sal forest (58.2 $km^2$) was more common association encountered, followed by Flood plain (28.8 $km^2$) and riverine associations (17 $km^2$) respectively (Sharma 1999).

Park harbors 57 species of mammal, 407 species of birds, 42 species of reptiles and amphibians, and 124 species of fish (BPP 1995 and DNPWC 2001). 33 species of fish (Hall et al. 2001) was recorded alone in Babai river, BNP.

BZ (507 $Km^2$) spreads over in 21 VDCs of Bardia, Banke and Surkhet districts. Over 102,456 people from 14,472 households (94 wards) have organized into 230 User Groups of 15 User Committees and 1 BZ Management Committee. 88 eco clubs are formed in schools. The users are combination of native Tharu and hill migrants- Brahmin, Chhetri, Magars, and Kami, Damai and Sarkis. About 59% of the BZ covered with forest. Subsistence agriculture is prevalent in the area with rice, wheat and maize comprising the major crops. Lentils, mustard, linseed and potatoes are also cultivated. Ginger, turmeric and garlic are grown as accessory cash crops.

### 2.2.5 Krishnasar Conservation Area

Krishnasar Conservation Area (15.95 $Km^2$) lies in Gularia Municipality (Bardia district) and was declared in March 6, 2009 (2065/11/23 BS). It is the first PA after the name of an endangered, protected wildlife, Blackbuck (*Antelope cervicapra cervicapra*) (NPWC Act 1973, CITES - II) in Nepal. Krishnasar denotes blackbuck in vernacular Nepali.

When the last remaining herd of blackbuck was observed at Khairapur area in 1975, a team of five staff were assigned with the task of protecting the area by constructing a guard post. Efforts were on to compensate the crop damaged by blackbuck to individual households.

In 1995, 488 hectares of land (173 ha. registered land, 105 ha. unregistered government land and 210 ha forest) was legally set aside for blackbuck occurring habitat in Nepal. The Government allocated NRs.18 million and procured 167 hectares of registered land out of the above mentioned 173 hectares from the local community in the name of BNP.

The predation by stray dog, disease outbreak from nearby villages (eight blackbucks have lost their lives due to Foot and Mouth Disease in Sep., 2009), habitat encroachment, inadequate infrastructure and human resources are some of the problems that threatening the long term survival of blackbuck in the area. The population of blackbuck had gone down to 9 in 1975 but reached up to 177 in 1990 and reached highest of 217 (9 July, 2010).

With the primary objective of the long-term survival of the last remaining population of blackbuck in Nepal through community participation, Blackbuck Conservation Action Plan was prepared by DNPWC in 2007. The final approval of Blackbuck conservation action plan is awaited.

The main habitat/forest types are Sissoo-mixed forest, degraded shrubland, and grassland. The boundary area with seasonal water during the rain from the older channel of Babi river forms a habitat and a natural boundary. The artificial supply of water from the pipe and recent of construction of fish pond along the river channel fulfils the seasonal requirememt of water to blackbuck. There are 32 species of plants (9 species of grass, 12 species of forbs, 4 species of shrub and 7 species of trees) of which blackbucks feed on 9 species of grass and forbs and 3 tree species. The supplements consists 6 species of agriculture crop and raiding crop in the neighboring crop fields (DNPWC 2007).

Encroachment in the adjoining areas has reached 514 households including above 300 households of liberated bonded laborers and the rest of landless people. The KrCA includes about 1663 households. The mjority are Tharu followed by Brahmin-Chetri, Matwali and lower caste. Agriculture and livestock rearing are the main occupation of the local people. They depend on the adjoining community forest and blackbuck habitat for firewood, fodder and grazing their livestock. The households living farther away from the blackbuck habitat and community forests use agricultural residue and steams of invasive species (*Ipomoeia fistula*) as energy (DNPWC 2007).

### 2.2.6 Suklaphanta Wildlife Reserve

SWR ($28^o$ 45'- $28^o$ 57' N to $80^o$ 07' to $80^o$ 21' E, 305 $km^2$, gazetted 1973, 305 $Km^2$, altitudinal range 80-600m) lies in the far Western Nepal in Kanchanpur district and is bordered by the Chaudhar river on the east and by forests and cultivated fields on the north. Towards south, it is bounded by the international boundary with Uttar Pradesh, and towards west by Mahakali river, adjoining Uttarakhand, India. The land use is abandoned agriculture land 7.87%, forest 65.02%, grassland 16.1%, shrub land 3.76% and water bodies 7.25% (DNPWC 2006). It consists mostly of Terai and some areas lie in the Bhabar zone. Mahakali, Bauni, Chaudhar and Syauli rivers drain the reserve. Major wetlands are located on the floodplains of these rivers and eight oxbow lakes are found in the reserve (Sah 2002) of which Rani Tal (20 ha) and Kalikich Tal (10 ha) are large and rich in biodiversity. The 155 $Km^2$ reserve was extended in 1984.

Habitat types are forests, grasslands and wetlands (Sah 2002). Sal forest is the dominant forest type (70%) in the Reserve, and is found in well drained upland areas. It contains more than 665 plant species belonging to 438 genera and 118 families. Riverine forest on the banks of rivers and streams are dominated by *Acacia catechu* and *Dalbergia sissoo*. In Mixed Deciduous Forest, there is an assemblage of species such as *Adina cordifolia*, *Celtis tetrandra*, *Mallotus philippinensis*, *Syzygium cumini*, and *Trewia nudiflora*. The species composition of the forest is *Shorea robusta*, *Lagestroemia parviflora*, *Terminalia belerica* and *Terminalia chebula*. Forest can be grouped into sal forest and deciduous revirine forest. Under deciduous revirine forest, a) *Trewia* forest, b) *Syzizium* forest, c) *Mallotus* forest, d) Bet forest, e) *Acacia* forest, and f) *Sissoo* forest are found. Six type of Grassland: a) *Themeda* type, b) *Imperata* type, c) *Chrysopogon* type, d) *Paspalum* type, e) *Saccharum spontaneum* type, f) *Saccharum bengalensis* type are recorded. Under aquatic habitat, Mahakali river and its tributaries flow in the west of the reserve, and Rani tal, Sikari tal, and Kalikitch tal host aquatic vegetations.

SWR is famous for the most extensive tracts of grasslands (20%) within the PA network of Nepal. Suklaphanta is the largest grassland which covers an area of 54 $Km^2$. *Imperata cylindrica*, *Saccharum bengalensis*, *Saccharum spontaneum*, *Narenga porphyrocoma*, and *Desmostachya bipinata* are the dominant species in Suklaphanta.

43 species of mammals including rhino, tiger, common leopard, Asian elephant, swamp deer, hispid hare (Oliver 1985, Yadav 2006); 349 species of birds including Bengal florican (*Huboropsis bengalensis*), great hornbill (*Buceros bicornis*), sarus crane (*Grus antigone*), lesser florican (*Sypheotides indicus*), swamp francolin (*Francolinus gularis*); 5 species of amphibians – khasre bhyaguto (*Bufo melanostictus*), madeshe bhyaguto (*Limnonectes Teraiensis*), rani bhyaguto (*Sphaerotheca swani*), sirke paha (*Hoplobatrachus tigerinus*), tik-tike paha (*Euphlytis cyanophlyctis*) and 20 species of reptiles-Bangali kalo kachuwa (*Melanochelys trijuga indopeninsularis*), sun gohoro (*Varanus flavencens*), pani sarpa (*Xenochrophis piscator*), sarpa (*Lycodon jara*), common krait (*Bungraus caerulues*), goman (*Naja naja*), dhaman (*Ptyas mucosa*

*mucosa*), machha gidhi (*Enhydris enhydris*), naram khabate kachuwa (*Aspideretes gangeticus*), sirise rukh sarpa (*Dendrelaphis tristis*), ajingar (*Python molurus bivittatus*), tin dharke kachuwa (*Melanochelys tricarinata*), Kareli ghar bhitti (*Hemidactylus frenatus*), bhaise gohoro (*Varanus bengalensis*), bhalemungro (*Asymblepharus sikimmensis*), mugger gohi (*Crocodylus palustris*), bhanemungro (*Mabuya macularia macularia*), girgit (*Sitana schleichi*), baghaichae chheparo (*Calotes versicolor versicolor*), bhanemungro (*Lygosoma albopunctatum*) (Shrestha and Shrestha 2008), 35 species of butterfly and 24 species of fishes have been recorded from the reserve (DNPWC 2003, 2005).

The climate is tropical monsoon type. The highest and the lowest annual rainfall of 2,375 mm and 1,257 mm occurred in the year 1998 and 1992, respectively. The average monthly maximum and minimum temperatures of 38.8 $^{0}$C and 6.0 $^{0}$C were recorded in May 1995 and January 1997, respectively in SWR. The maximum temp reaches up to 42 $^{0}$C in pre-monsoon. The relative humidity was recorded max 95% (January) and min 37% (April) (Pokhrel 2005).

The soil is considered of light colored inseptisols. Soil types are loamy sand, sandy loam, silty loam and clay loam.

The BZ of SWR was declared in 2004 with an area of more than 240 $km^2$ in which more than 17 thousand households of 280 settlements (100,953 people) of 11 VDCs and one municipality resides (Table 2.2). The yearly fuel wood need is 130 thousand ton and only 14 thousand ton can be fulfilled by BZ forests. Fodder demand is 50 thousand ton and only 9 thousand ton gets fulfilled. The timber yield is 7,745 ton and deficit is 3,157 ton (DNPWC 2003).

## 2.3. INTENSIVE STUDY AREA

### 2.3.1 Occupancy survey

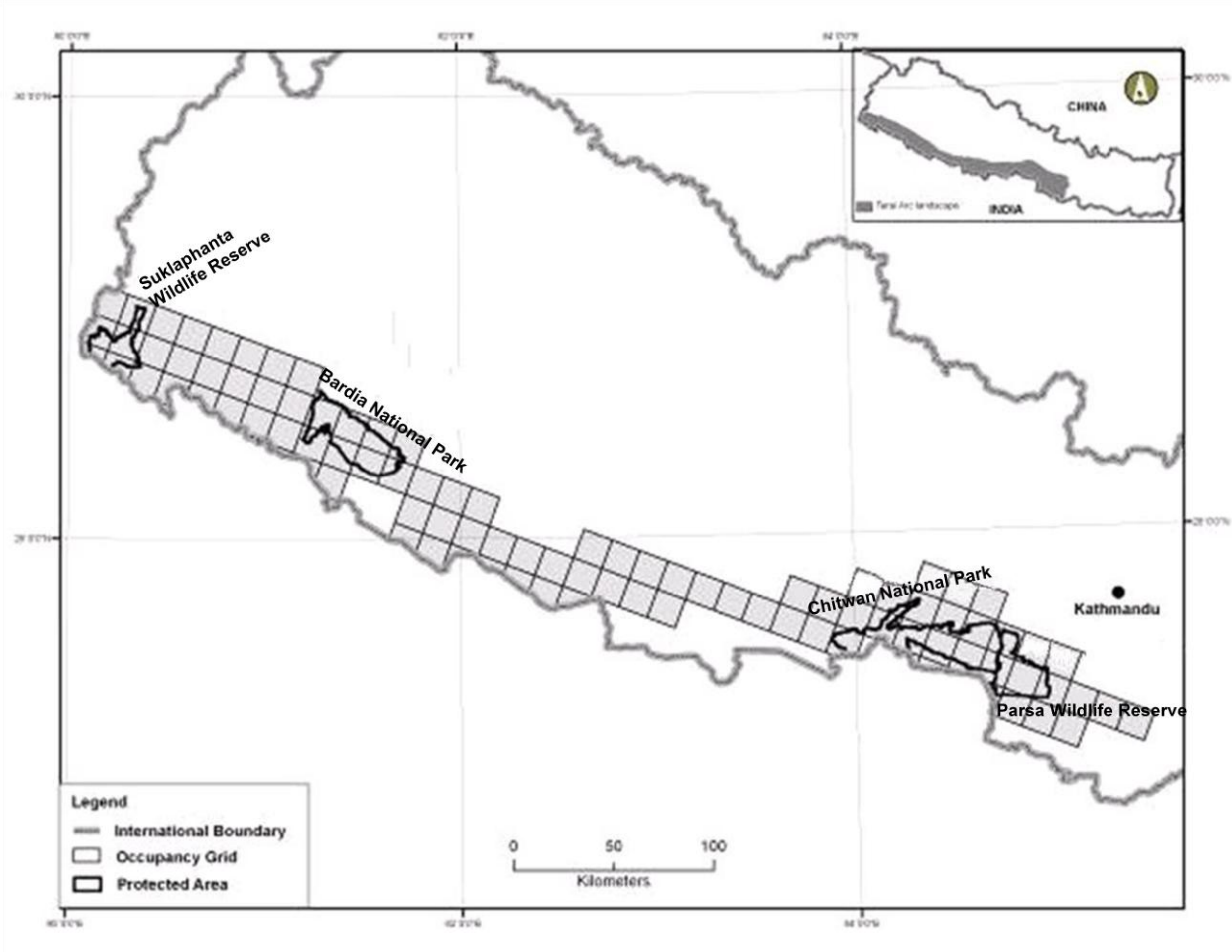
Occupancy survey was conducted in 14 districts and four PAs of TAL, Nepal (Figure 2.5) covering 2,127 Km length in 96 grids (15 Km x1 5 Km). The lowest number of grid surveyed was one grid in Palpa district with 10 Km of survey length and maximum was 14 grids with 327 Km of survey length in Kailali district (Table 2.3).

**Table 2.3. Number of grids and length covered in occupancy survey in TAL districts and PAs, Nepal.**

| **District/ PA** | **No. of Grid** | **Length (Km)** | **District / PA** | **No. of Grid** | **Length (Km)** |
|---|---|---|---|---|---|
| 1.Banke | 9 | 245 | 2.Bara | 4 | 82 |
| 3.Bardia | 1 | 11 | 4.Chitwan | 3 | 69 |
| 5.Dang | 11 | 260 | 6.Kailali | 14 | 327 |
| 7.Kanchanpur | 6 | 148 | 8.Kapilbastu | 6 | 137 |
| 9.Makawanpur | 3 | 15 | 10.Nawalparasi | 6 | 129 |
| 11.Palpa | 1 | 10 | 12.Parsa+ | 5 | 156 |
| 13.Rupandehi | 3 | 52 | 14.Rautahat | 5 | 120 |
| 15. Bardia NP | 8 | 110 | 16. CNP | 10 | 199 |
| 17.SWR | 4 | 57 | **Grand total** | **96** | **2,127** |

+ This also includes the grids from the Parsa Wildlife Reserve

**Figure 2.5. Map of TAL Nepal showing occupancy grids in TAL districts and PAs.**



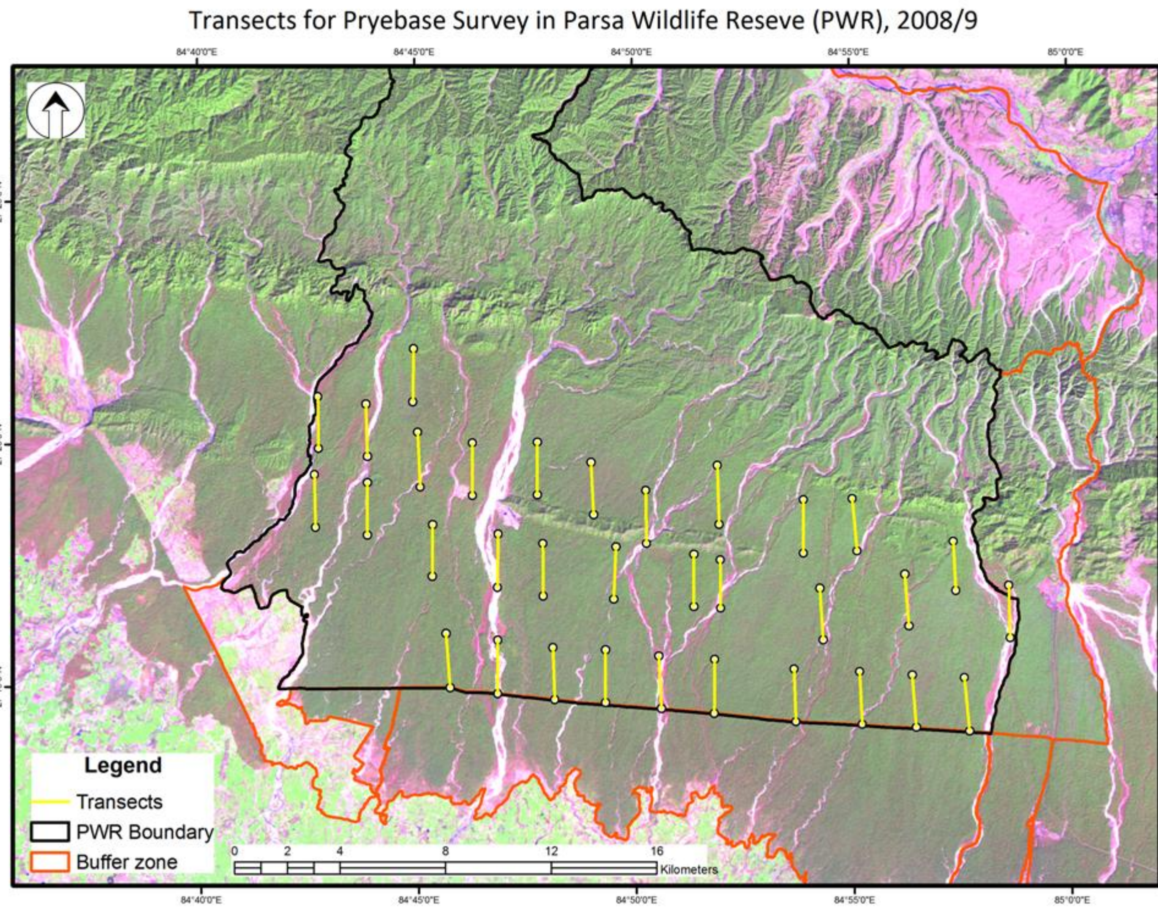

## 2.3.2 Camera trap and line transects

The tiger bearing PAs are located in the lowlands and inner valley from central to west Nepal. PWR in the east is in the outer foot hills and is connected with CNP towards west. Similarly, BaNP is connected with BNP towards the west.

### 2.3.2.1 Parsa Wildlife Reserve

Except the Churia slope and small part of south west portion, remaining 242 $Km^2$ was used for camera trap and line transects (Figure 2.6).

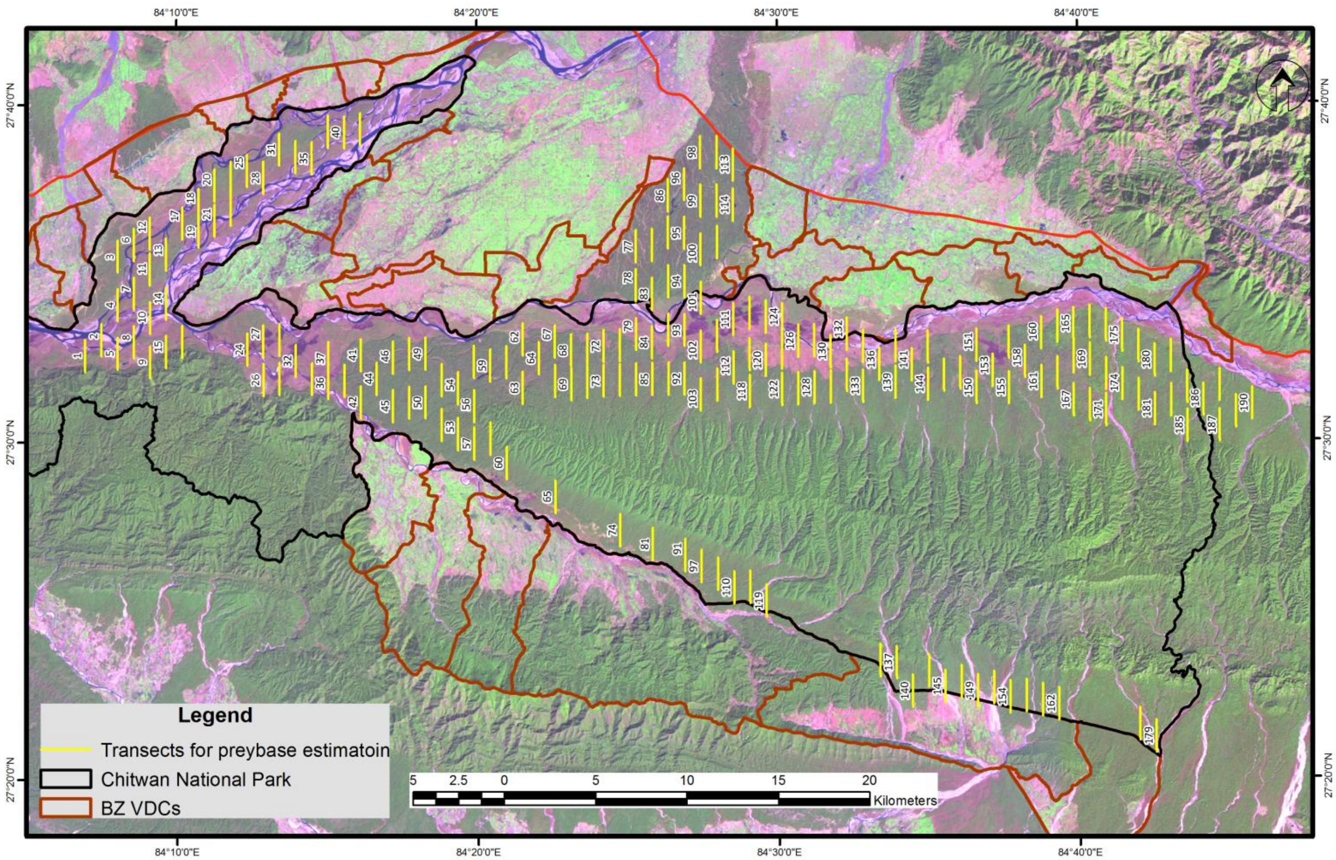
**Figure 2.6. Location of transect lines in Parsa wildlife Reserve, Nepal.**




## 2.3.2.2 Chitwan National Park

The 612 $Km^2$ area of CNP was covered for line transects and camera trap in 2008/09. Camera trap was extended to whole park, including Churia ranges in 2009/10. For the ease of understanding for the location of line transects, the area can be described in northern slope of Churia from Sunachuri to Kasara, southern slope of Churia towards Madi valley from Nirmalbasti to Bankatta, Barandabhar (BZ forest), Rapti-Reu flood plain between Kasara-Bankatta in the east to Rapti-Reu confluence, northern foothill from tiger tops lodge area to temple tiger lodge area, and Narayani island forest (Figure 2.7).

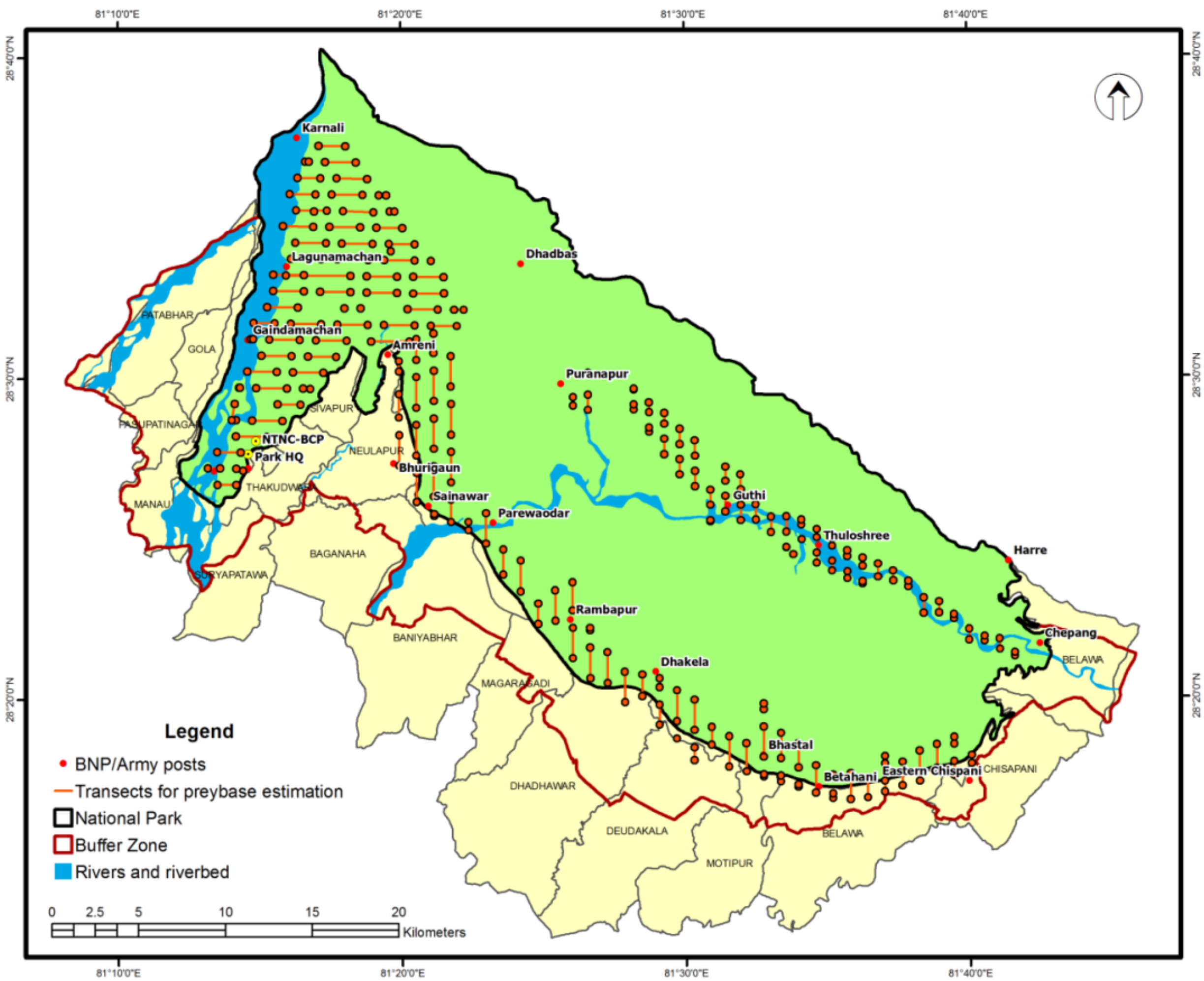
**Figure 2.7. Location of transect lines in Chitwan National Park, Nepal.**




### 2.3.2.3 Bardia National Park

Three strata, KFP, foot hill and Babai valley, were chosen for line transects and camera trap. The occupancy survey was conducted in the same general area within the prescribed grid and randomly selected sub-grid. The Babai valley, about 40 Km in length, and oriented east-west extends north east from Parewawodad to Chepang has about 131 Km$^2$ area and valley slope of about 373 Km$^2$ areas (Malla 2009). The study in Babai valley was concentrated in the Babai river flood plain area, both for camera trap and line transects (Figure 2. 8).

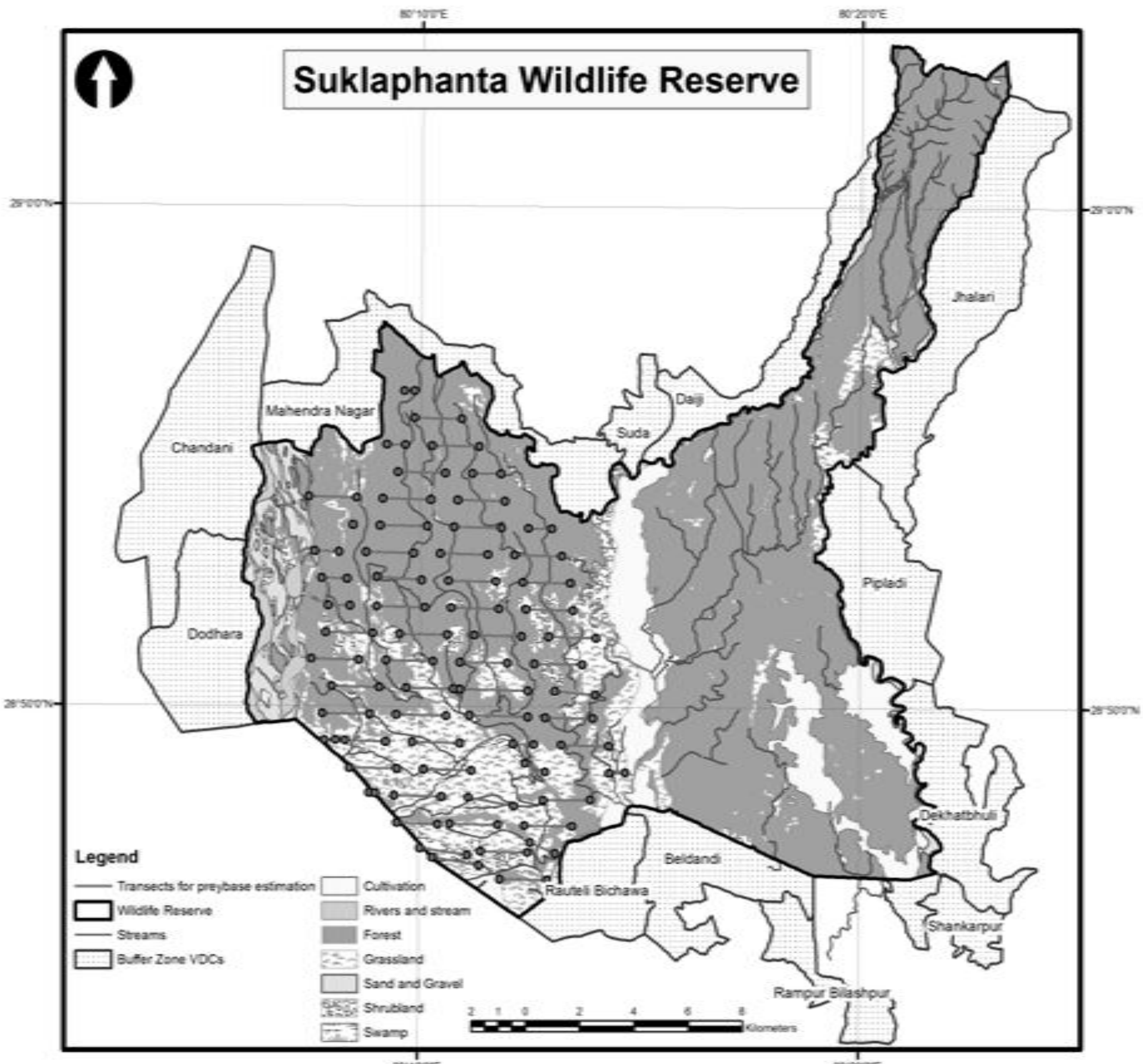
**Figure 2.8. Location of transect lines in Bardia National Park, Nepal.**




## 2.3.2.4 Suklaphanta Wildlife Reserve

The 197 Km$^2$ of the SWR, between the Mahakali river in the west and up to 5-6 kilometers east of Chaudhar river in the east, has been used for the camera trap and line transects (figure 2. 9). Towards south, it is bounded with the Laggabagga-Pilibhit forests in India. Suklaphanta is one of the biggest grassland (53 Km$^2$) in PAs of Nepal.

**Figure 2.9. Location of transect lines in Suklaphanta Wildlife Reserve, Nepal.**



# CHAPTER THREE : TIGER OCCUPANCY IN TERAI ARC LANDSCAPE, NEPAL

## 3.1 INTRODUCTION

Potential tiger habitat outside PAs are under intense human pressure due to agricultural expansion, infrastructural development and excessive livestock grazing as the human population density in these areas is 248 people/km$^2$ - one of the highest in the country (CBS, 2001). Different breeds of cow (*Bos primigenius*), water buffalo (*Bubalus bubalis*), sheep (*Ovis aries*), goat (*Capra aegagrus hircus*), and pig (*Sus domestica*) constitute the major domesticated livestock and an average household owns 4 livestock animals (CBS 2001).

Outside PAs, tigers were recorded in 28 sites in the Bara forest (east of PWR), Madi forest (South of CNP), Barandabhar (current BZ of CNP), Shumshergunj (current BaNP), Babai forest (current BNP), Katarniaghat forest, Chattiwan forest and Basanta forest (Smith et al. 1987c). Tigers were reported in Trijuga forest (NW of current Koshi Tappu Wildlife Reserve) but there is no confirm record after 1994 (Gurung 2002).

Previous tiger population monitoring throughout the TAL was limited with studies using different methods at inconsistent spatial and temporal scales to address varying objectives within PAs (Sunquist 1981, Smith 1993, Smith *et al.* 1998, McDougal 1999). It therefore is difficult to reliably compare results across these studies. To establish reliable landscape-scale benchmark data on tiger distribution patterns both inside and outside PAs, an occupancy survey approach throughout the TAL was employed.

Large-scale occupancy surveys and monitoring programs are now used throughout the world to inform conservation decisions. Occupancy can be defined as the "the proportion of patch occupied", or in some cases "used" rather than "occupied" (MacKenzie et al. 2006).

Occupancy requires only detection and non-detection data gathered during repeat surveys, which can be collected more rapidly than species abundance data. The rapidity of the technique means it can be applied across a large number of sites, in low cost, making it an ideal candidate for landscape scale surveys.

Most occupancy modeling requires some sort of replication in order to obtain the information needed to estimate detection probability and, thereby, probabilistically separate true absence from presence and non-detection (MacKenzie et al. 2006, Royle and Dorazio 2008). The usual sampling situation involves multiple visits to each sample unit during some period of time over which the units are assumed to be closed to changes in true occupancy. In some cases it is possible to substitute spatial replication for temporal replication in order to obtain this information about detection probability. Specifically, multiple survey sites or locations are selected from each sample unit randomly and with replacement and are then surveyed a single time, usually on the same day (MacKenzie et al. 2006). Such a design permits estimation of occupancy at the level of the sample unit (not at the level of the specific sites or locations within each unit). When the species (or sign of the species) occupies a sampling unit, but is not present at all sites within the sampling unit, detection probability consists of two components: (1) Pr (present at survey site) and (2) Pr (detection j present at survey site). Resulting estimates of detection probability in such designs correspond to each specific survey site and are reasonable estimates of the product of these components.

We conducted TAL-wide occupancy study following the above mentioned approach by replacing temporal replication with spatial replication.

## 3.2 OBJECTIVE

To evaluate the occupancy of tigers in the Nepal's TAL with prey availability and human disturbances covariates.

## *3.3 STUDY AREA*

This study was conducted within the 23,129 km$^2$ TAL (Fig. 2.1, E 80$^o$ 04' to E 85$^o$ 30' and N 26$^o$ 45' to N 29$^o$ 07') that spreads along the outer foothills of the Himalayas and extends from the Bagmati river in the east to the Mahakali river in the west. Details have been provided under Chapter Two.

## 3.4 *METHODS*

### 3.4.1 Survey

A TAL-wide tiger occupancy survey was conducted including the four PAs- Parsa and Suklaphanta Wildlife Reserves, and Bardia and Chitwan National Parks, (The Banke NP was declared on 12 July 2010 after the field work was completed. Thus, for analysis it is considered as Banke district), their BZs and adjoining potential tiger habitats to model the distribution of tigers by quantifying habitat occupancy. The survey was conducted in three months between December 2008 to February 2009 to maintain temporal closure (in terms of habitat use by tigers) and similar winter seasonal conditions at sites across the TAL. The basic conceptual framework for occupancy survey design is taken from Mackenzie *et al.* (2006) and we used a modified cluster sampling design for logistical reasons (Hines *et al.* 2010). We selected a sampling unit (grid cell) of 225 km$^2$ (15 km x 15 km) because the largest expected home range of a tiger is expected to be ~200 km$^2$ in South Asia (Karanth and Sunquist 2000).  We included in our sampling frame only grid cells that contained more than 10% tiger habitat (as determined by vegetative cover from GIS data) because we did not generally expect tigers to be resident in smaller patches (Hines *et al.* 2010), although they may pass through them.

Each grid cell was divided into 16 sub-cells (3.75 km x 3. 75 km). Prior to the survey, we randomly selected one sub-cell (of those coded as tiger habitat) per grid cell through which field teams were required to include in their survey of that particular grid cell. We focused our surveys on high probability locations for tiger sign detection (e.g., trails, ridgelines, forest roads, and river and stream beds) within each grid cell. A maximum of 40 km was surveyed per grid cell with each contiguous 1-km segment considered a "spatial replicate". To maintain similarly-scaled survey effort across grid cells, the number of spatial replicates per grid cell (i.e., km walked) was proportionate to % tiger habitat in each grid cell so that, for example, grid cells containing 100% and 10 % tiger habitat would be surveyed with 40 and 4 contiguous 1-km spatial replicates, respectively. We based our measurement of 1-km walks on a combination of GPS measurements and individuals' average stride lengths.

Observers recorded each direct sighting of all study species (i.e., tiger and main prey). For tigers, we also recorded each new instance of tiger tracks (e.g., as determined by direction of travel, size of tracks, number of tigers in the group, etc.) and each instance of tiger scratch marks, scat and spray within every 100 m of each 1-km replicate. For prey, calls, tracks, pellet/dung piles, etc, were recorded only the first encounter of each type of sign/evidence within each 100 m of each 1-km replicate. We recorded signs of human presence (e.g., livestock presence, poaching evidence, human-caused fire, cut stumps, and lopping trees) in the same manner as prey.

### 3.4.2 Analysis

#### 3.4.2.1 Terai Arc Landscape

Naïve estimates of habitat occupied (i.e., probability of detection is assumed to be near 1) were calculated as the proportion of grid cells where tiger sign was recorded. Because occupancy methods explicitly estimate and account for the probability of detection (which is always $\leq 1$), occupancy-generated estimates are always greater than or equal to the naïve estimate. Occupancy analyses focus on two key parameters: $\psi$ *(psi)*, the probability a site is occupied or used by a species; and *p*, the probability of detecting the species, given the species is present (MacKenzie et al. 2006). We generated detection histories as a vector composed of the sequence of detections (1) and non detections (0) for tiger sign in each spatial replicate (1 km traversed) within each grid cell such that a detection history for a grid cell surveyed for 40 km would contain 40 digits. We used Program PRESENCE v. 2 (Hines 2006) to model tiger occupancy and generate estimates based on these detection histories and associated covariates. We used Akaike's Information Criteria (AIC) to compare and select models (Burnham and Anderson 2002). In the case of competing models (i.e., top models were < 2 ΔAIC, Burnham and Anderson 2002), we used model averaging.

We started with a custom model that considered spatial correlation between contiguous segments surveyed within each grid cell (Hines *et al.* 2010). There are two probabilities associated with this correlation depending on tiger presence in the previous segment surveyed; 1) $\theta_0$, the probability that tiger sign is present on a segment given that the grid cell is occupied and tiger sign *was not* present on the previous segment and 2) $\theta_1$, the probability that tiger sign is present on the segment given that the grid cell is occupied and tiger sign *was* present on the previous segment. Because we surveyed tiger presence in continuous segments of a survey walk, with data collection commencing 1-2 km from settlements and campsites, we hypothesized that our occupancy data would follow a single season custom spatial correlation model with the initial $\theta_0$ not equal to other $\theta_0$'s on each survey.

To confirm this we tested three base models in Presence:

1. 1 group, $p(.)$; no spatial correlation, constant $p$
2. $\psi$, $\theta_0$, $\theta_1$,$p(.)$ [all $\theta_0$'s =]; spatial correlation with all $\theta_0$'s being equal, constant $p$
3. $\psi$, $\theta_0$, $\theta_1$,$p(.)$; spatial correlation with initial $\theta_0$ not equal to other $\theta_0$'s, constant $p$

Because we hypothesized *a priori* that grid-cell specific variables would influence $\psi$ (i.e., prey index and human impacts index) and sampling-specific variables would influence $p$ (i.e., observer expertise index) we included these factors as covariates in modeling tiger occupancy. We quantified the covariates as follows. For the prey index we included prey animals such as barking deer, spotted deer, hog deer, sambar, swamp deer, blue bull, gaur, wild pig, rhino, Rhesus macaque (*Macaca mulatta*), and Hanuman langur (*Semnopitheaus entellus)*. We did not consider other suboptimal tiger prey items such as hare and porcupine.

We added the unique detection of signs and divided by number of kilometer surveyed in that grid cell to get the average prey detection for each grid.

In addition impacts that humans have on tiger occupancy through prey depletion (primarily captured in the prey index covariate), human caused fire, fuel wood collection, wood cutting, grass cutting/collection, trails, grazing, livestock dung/hoof marks, lopping, evidence of poaching, and human presence were included in the analysis. Similar to the prey detection, unique detection were added and divided by number of kilometers surveyed in that grid cell to get the average detection of disturbances.

We assessed observer expertise at the grid cell level as good or fair on the basis of the team's previous level of experience and training. Although intensive training was conducted prior to the survey, we were interested whether variation in previous experience might influence a team's ability to detect tiger sign at the scale of grid cells, thereby, influencing the detection probability (*p*).

To assess the influence of aforementioned covariates, we tested 28 additional models (for a total of 31) using the base spatial correlation model structure with initial $\theta_0$ not equal to other $\theta_0$'s, i.e., model 3 above:

4. 1.psi (PI-10 spp; HI-10 variables),thta0,thta1,p(.), probability of occupancy influenced by spatial correlation, prey species (10 species) and human impacts (10 impacts) with detection probability influenced by observer expertise.

4. 2.psi (PI-10 spp; HI-10 variables),thta0,thta1,p(0), probability of occupancy influenced by spatial correlation, prey species (10 species) and human impacts (10 impacts) with constant detection probability.

5. psi (Sb,Sd;HI-all 10),thta0,thta1,p(.);probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impacts (10 impacts) with constant detection probability.

6.psi(Sb,Sd),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) with constant detection probability.

7. psi(Sd),thta0,thta1,p(.);probability of occupancy influenced by spatial correlation, prey species (Sambar) with constant detection probability.

8. psi(Sb,Sd,Rm;HI-all 10),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, Rhesus macaque and common langur) and human impacts (10 impacts) with constant detection probability.

9.1. psi(Sb,Sd,Rh,Bd;HI-all 10),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino and barking deer) and human impacts (10 impacts) with constant detection probability.

9.2. psi(Sb,Sd,Rh;Gz,Hp,Po,Tl),thta0,thta1,p(.);probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, and rhino) and human impacts (Grazing, Human presence, evidence of poaching and trails) with constant detection probability.

10. psi(SB,Sd,Rh,Wp;HI-all 10),thta0,thta1,p(.);probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino and wild pig) and human impacts (10 impacts) with constant detection probability.

11. psi(Sb,Sd,Wp;HI-all 10),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, wild pig) and human impacts (10 impacts) with constant detection probability.

12. psi(Sb,Sd,Rh,Bb;HI-all 10),thta0,thta1,p(.);probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino and blue bull) and human impacts (10 impacts) with constant detection probability.

13.1 psi(Sb,Sd,Rh,Gr;HI-all 10),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino and gaur) and human impacts (10 impacts) with constant detection probability.

13.2 psi(Sb,Sd,Rh;Lp,Hp),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino) and human impacts (lopping and human presence) with constant detection probability.

14. psi(Sb,Sd,Rh;Lp),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer and rhino) and human impacts (lopping) with constant detection probability.

15. psi(Sb,Sd;Gz,Hp,Po,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, and spotted deer) and human impacts (grazing, human presence, poaching and trails) with constant detection probability.

16.psi(Sb,Sd,Rh,Bb;Gz,Hp,Po,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino and blue bull,) and human impacts (grazing, human presence, poaching and trails) with constant detection probability.

17. psi(Sb,Sd,Rh,Wp;Gz,Hp,Po,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino and wild pig,) and human impacts (grazing, human presence, poaching and trails) with constant detection probability.

18. psi(Sb,Sd,Rh,Bd;Gz,Hp,Po,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer, rhino and barking deer) and human impacts (grazing, human presence, poaching and trails) with constant detection probability.

19. psi(Sb,Sd,Rh;Lp,Po),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer and rhino) and human impacts ( lopping and poaching ) with constant detection probability.

20. psi(Sb,Sd;Lp,Po), thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impacts (lopping and poaching ) with constant detection probability.

20.1 psi(Sb,Sd, Bb;Lp,Po),thta0,thta1,p(.), probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer and blue bull) and human impacts (lopping and poaching ) with constant detection probability.

20.2. psi(Sb,Sd,Gr;Lp,Po),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer and gaur) and human impacts (lopping and poaching) with constant detection probability.

20.3. psi(Sb,Sd,Wp;Lp,Po),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer and wild pig) and human impacts (lopping trees and poaching ) with constant detection probability.

20.4. psi(Sb,Sd, Bd;Lp,Po),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer and barking deer) and human impacts (lopping and poaching ) with constant detection probability.

21.1 psi(Sb,Sd,Rh;Lp,Hp,Po,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar, spotted deer and rhino) and human impacts (lopping, human presence, poaching and trails) with constant detection probability.

21.2 psi(Sb,Sd;Lp),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impact (lopping) with constant detection probability.

22. psi(Sb,Sd;Lp,Hp,Po,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impacts (lopping, human presence, poaching and trails) with constant detection probability.

23. psi(Sb,Sd;Hp,Po,Lp),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impacts (human presence, poaching and lopping) with constant detection probability.

24.psi(Sb,Sd;Po),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impact (poaching) with constant detection probability.

25. psi(Sb,Sd;Tl,Po,Lp),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impacts (trails, poaching and lopping) with constant detection probability.

### 3.4.2.2 Outside PAs

Similar analysis was conducted separately for 69 grids laid outside PAs.

To test the hypothesis that our occupancy data would follow a single season custom spatial correlation model with the initial $\theta_0$ not equal to other $\theta_0$'s on each survey, the same models as used for the 96 grids were tested in Presence:

1. 1 group, $p$(.); no spatial correlation, constant $p$
2. $\psi$, $\theta_0$, $\theta_1$,$p$(.) [all $\theta_0$'s =]; spatial correlation with all $\theta_0$'s being equal, constant $p$
3. $\psi$, $\theta_0$, $\theta_1$,$p$(.); spatial correlation with initial $\theta_0$ not equal to other $\theta_0$'s, constant $p$

Further to test that grid-cell specific variables would influence $\psi$ (i.e., prey index and human impacts index) and sampling-specific variables would influence $p$, prey species covariate (barking deer, wild pig, blue bull, spotted deer, and sambar) and human impact covariates (fire wood collection, human presence, trails and wood cutting) were used.

To assess the influence of aforementioned covariates, we tested 18 additional models (for a total of 21) using the spatial correlation model structure with initial $\theta_0$ not equal to other $\theta_0$'s, i.e., model 3 above:

Model 4. (Global Model): psi(preys-barking deer-Bd, wild pig-Wp, blue bull-Bb, spotted deer-Sd, sambar-Sb; human impacts-firewood collection-Fw, human presence-Hp, trail-Tl, wood cutting-Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (barking deer, wild pig, blue bull, spotted deer and sambar) and human impacts (firewood, human presence, trails and wood cutting) with constant detection probability.

5. psi(Wp,Bb,Sd;Fw,Tl,Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig, blue bull and spotted deer ) and human impacts (firewood, trails and wood cutting) with constant detection probability.

6. psi(Bb,Sd;Tl,Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (blue bull and spotted deer ) and human impacts (trails and wood cutting) with constant detection probability.

7. psi(Wp,Bb,Sd;Tl,Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig, blue bull and spotted deer) and human impacts (trails and wood cutting) with constant detection probability.

8. psi(Wp,Bb,Sd;Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig, blue bull and spotted deer) and human impact (wood cutting) with constant detection probability.

9. psi(Wp,Bb,Sd;Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig, blue bull and spotted deer) and human impact (trails) with constant detection probability.

10. psi(Wp,Bb,Sd;Fw),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig, blue bull and spotted deer) and human impact (fire wood) with constant detection probability.

11. psi(Wp,Bb,Sd;Fw,Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig, blue bull and spotted deer) and human impacts (fire wood and wood collection) with constant detection probability.

12. psi(Wp,Sd;Fw,Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig and spotted deer) and human impacts (fire wood and wood collection) with constant detection probability.

13. psi(Wp,Sd;Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig and spotted deer) and human impact (wood collection) with constant detection probability.

14. psi(Wp,Sd;Fw),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig and spotted deer) and human impact (fire wood collection) with constant detection probability.

15. psi(Wp,Bb,Sd;Fw,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (wild pig, blue bull and spotted deer) and human impacts (fire wood collection and trails) with constant detection probability.

16. psi(Sd;Fw,Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (spotted deer) and human impacts (fire wood collection and wood cutting) with constant detection probability.

17. psi(Sd;Wc),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (spotted deer) and human impact (wood cutting) with constant detection probability.

18. psi(Sd;Fw),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (spotted deer) and human impact (fire wood collection) with constant detection probability.

### 3.4.2.3 Protected Areas

Similar analysis was conducted separately for 27 grids in PAs.

To test the hypothesis that our occupancy data would follow a single season custom spatial correlation model with the initial $\theta_0$ not equal to other $\theta_0$'s on each survey, the same models as used for the 27 grids were tested in Presence:

1. 1 group, *p*(.); no spatial correlation, constant *p*
2. $\psi$, $\theta_0$, $\theta_1$,*p*(.) [all $\theta_0$'s =]; spatial correlation with all $\theta_0$'s being equal, constant *p*
3. $\psi$, $\theta_0$, $\theta_1$,*p*(.); spatial correlation with initial $\theta_0$ not equal to other $\theta_0$'s, constant *p*

Further to test that grid-cell specific variables would influence $\psi$ (i.e., prey index and human impacts index) and sampling-specific variables would influence *p*, prey species covariates (barking deer-Bd, wild pig-Wp, blue bull-Bb, chital-Ch, gaur-Gr, rhino-Rh, hog deer-hd, swamp deer-Sd and sambar-Sb) and human impact covariates (fire wood collection-Fw, human induced fire-Fr, human presence-Hp, trails-Tl, grass cutting-Gc, grazing-Gz, poaching-Po, lopping-Lp, livestock dung-Ld and wood cutting-Wc) were used.

To assess the influence of aforementioned covariates, we tested 19 additional models (for a total of 22) using the spatial correlation model structure with initial $\theta_0$ not equal to other $\theta_0$'s, i.e., model 3 above:

4(global model). psi(Sd,Wp;Fw,Hp,Wc,Tl),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (chital-Ch, rhino-Rh, gaur-Gr, barking deer-Bd, sambar-Sb, hog deer-Hd, swamp deer-Sd, blue bull-Bb, and wild pig-Wp) and human impacts (fire wood collection-Fw, human induced fire-Fr, woodcutting-Wc, livestock dung-Ld, grass cutting-Gc, grazing-Gz, human presence-Hp, wood cutting-Wc, evidence of poaching-Po and trails-Tl) with constant detection probability.

5. psi(Fr,Ld,Po;Bb,Gr,Hd,Sd),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Gr, Hd, Sd and Bb) and human impacts (Fr, Ld and Po) with constant detection probability.

6. psi(Fr,Ld,Po;Bb,Gr,Hd,Sd,Ch),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Bb,Gr, Hd, Sd and Ch) and human impacts (Fr, Ld and Po) with constant detection probability.

7. psi(Fr,Ld,Po;Bb,Gr,Sd,Ch),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Bb,Gr, Sd and Ch) and human impacts (Fr, Ld and Po) with constant detection probability.

8. psi(Fr,Ld,Po;Bb,Gr,Hd,Sd,Rh),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Bb,Gr, Hd, Sd and Rh) and human impacts (Fr, Ld and Po) with constant detection probability.

9. psi(Fr,Ld,Po;Bb,Hd,Sd,Rh),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Bb, Hd, Sd and Rh) and human impacts (Fr, Ld and Po) with constant detection probability.

10. psi(Fr,Ld,Po;Bb,Sd,Rh),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Bb, Sd and Rh) and human impacts (Fr, Ld and Po) with constant detection probability.

11. psi(Fr,Ld,Po;Sd,Rh),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd and Rh) and human impacts (Fr, Ld and Po) with constant detection probability.

12. psi(Ld;Sd,Rh),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd and Rh) and human impact (Ld) with constant detection probability.

13. psi(Ld;Sd,Rh,Ch),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd,Rh and Ch) and human impact (Ld) with constant detection probability.

14. psi(Ld;Sd,Rh,Ch,Sb),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd, Rh, Ch and Sb) and human impact (Ld) with constant detection probability.

15. psi(Ld,Po;Sd,Rh,Ch,Sb),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd, Rh, Ch and Sb) and human impacts (Ld and Po) with constant detection probability.

16. psi(Ld;Rh,Ch,Sb),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Rh, Ch and Sb) and human impacts (Ld ) with constant detection probability.

16.1 psi(Ld,Fr;Sd,Rh,Ch,Sb),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd, Rh, Ch and Sb) and human impacts (Ld and Fr) with constant detection probability.

16.2 psi(Ld;Sd,Rh,Sb,Gr),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd, Rh, Sb and Gr) and human impact (Ld) with constant detection probability.

17. psi(Ld,Fr,Po;Sd,Rh,Ch,Sb),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd, Rh, Ch and Sb) and human impacts (Ld, Fr and Po) with constant detection probability.

18. psi(Ld,Fr;Sd,Rh,Ch,Sb,Gr),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd, Rh, Ch, Sb and Gr) and human impacts (Ld and Fr) with constant detection probability.

19. psi(Ld,Fr;Sd,Rh,Sb,Gr),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Sd, Rh, Sb and Gr) and human impacts (Ld and Fr) with constant detection probability.

20. psi(Ld;Rh,Ch,Sb,Gr),thta0,thta1,p(.); probability of occupancy influenced by spatial correlation, prey species (Rh, Ch, Sb and Gr) and human impact (Ld) with constant detection probability.

## 3.5 RESULTS

### 3.5.1 Terai Arc Landscape

A total of 96 grid cells covering 2041 km were surveyed in 124 days. We commenced contiguous survey walks 1-2 km from settlements in 76 (79%) grid cells and the remaining 20 (21%) grid cells from our campsite.

Based on the global model (4.2 above as listed in analysis section, Table 3.1), the model 20 (psi(Sb,Sd;Lp,Po),thta0,thta1,p(.):20. probability of occupancy influenced by spatial correlation, prey species (Sambar and spotted deer) and human impacts (lopping and poaching) with constant detection probability (as listed above in analysis section) was selected based on Akaike's Information Criteria (AIC) comparisons (i.e., $< 2\ \Delta AIC$, Burnham and Anderson 2002).

Other competing models having $< 2\ \Delta QAIC$ were 23, 19, 20.1-20.4 and 25 . Model 20 has AIC 749.02 and AIC weight 0.1724, model 23 has AIC 749.89 and AIC weight 0.1116, model 19 has AIC 750.02 and AIC weight 0.1046, model 20.1 has AIC 750.24 and AIC weight 0.0937, model 20.3 has AIC 750.40 and AIC weight 0.0865, model20.4 has AIC 750.55 and AIC weight 0.0802, model 20.2 has AIC 750.76 and AIC weight 0.0722 and model 25 has AIC 750.78 and AIC weight 0.0715 (Table 3.1).

**Table 3.1 Model selection results using Akaike Information Criteria (AIC)a**

| Model | AIC | deltaAIC | AIC wgt | Model Likelihood | no. Par. | 2*LogLike |
|---|---|---|---|---|---|---|
| psi(Sb,Sd;Lp,Po),thta0,thta1,p(.)--------------20 | 749.02 | 0.00 | 0.1724 | 1.0000 | 8 | 733.02 |
| psi(Sb,Sd;Hp,Po,Lp),thta0,thta1,p(.)---------23 | 749.89 | 0.87 | 0.1116 | 0.6473 | 9 | 731.89 |
| psi(Sb,Sd,Rh;Lp,Po),thta0,thta1,p(.)---------19 | 750.02 | 1.00 | 0.1046 | 0.6065 | 9 | 732.02 |
| psi(Sb,Sd,Bb;Lp,Po),thta0,thta1,p(.)------20.1 | 750.24 | 1.22 | 0.0937 | 0.5434 | 9 | 732.24 |
| psi(Sb,Sd,Wp;Lp,Po),thta0,thta1,p(.)-------20.3 | 750.40 | 1.38 | 0.0865 | 0.5016 | 9 | 732.40 |
| psi(Sb,Sd, Bd;Lp,Po),thta0,thta1,p(.)------20.4 | 750.55 | 1.53 | 0.0802 | 0.4653 | 9 | 732.55 |
| psi(Sb,Sd,Gr;Lp,Po),thta0,thta1,p(.)------20.2 | 750.76 | 1.74 | 0.0722 | 0.4190 | 9 | 732.76 |
| psi(Sb,Sd;Tl,Po,Lp),thta0,thta1,p(.)----------25 | 750.78 | 1.76 | 0.0715 | 0.4148 | 9 | 732.78 |
| psi(Sb,Sd;Lp,Hp,Po,Tl),thta0,thta1,p(.)-----22 | 751.46 | 2.44 | 0.0509 | 0.2952 | 10 | 731.46 |
| psi(Sb,Sd,Rh;Gz,Hp,Po,Tl),thta0,thta1,p(.)---9.2 | 752.07 | 3.05 | 0.0375 | 0.2176 | 12 | 728.07 |
| psi(Sb,Sd,Rh;Lp,Hp,Po,Tl),thta0,thta1,p(.)—21.1 | 752.13 | 3.11 | 0.0364 | 0.2112 | 11 | 730.13 |
| psi(Sb,Sd;Gz,Hp,Po,Tl),thta0,thta1,p(.)------15 | 752.39 | 3.37 | 0.0320 | 0.1854 | 11 | 730.39 |
| psi(Sb,Sd,Rh,Wp;Gz,Hp,Po,Tl),thta0,thta1,p(.)-17 | 753.99 | 4.97 | 0.0144 | 0.0833 | 13 | 727.99 |
| psi(SB,Sd,Rh,Bd;Gz,Hp,Po,Tl),thta0,thta1,p(.)----18 | 754.01 | 4.99 | 0.0142 | 0.0825 | 13 | 728.01 |
| psi(Sb,Sd,Rh,Bb;Gz,Hp,Po,Tl),thta0,thta1,p(.)----16 | 754.34 | 5.32 | 0.0121 | 0.0699 | 13 | 728.34 |
| psi(Sb,Sd;HI-all 10),thta0,thta1,p(.)------------5 | 758.16 | 9.14 | 0.0018 | 0.0104 | 16 | 726.16 |
| psi(Sb,Sd,Rm;HI-all 10),thta0,thta1,p(.)-------8 | 758.92 | 9.90 | 0.0012 | 0.0071 | 17 | 724.92 |
| psi(Sb,Sd,Rh,Gr;HI-all 10),thta0,thta1,p(.)--13 | 759.45 | 10.43 | 0.0009 | 0.0054 | 18 | 723.45 |
| psi(Sb,Sd,Rh,Bb;HI-all 10),thta0,thta1,p(.)--12 | 759.65 | 10.63 | 0.0008 | 0.0049 | 18 | 723.65 |
| psi(SB,Sd,Rh,Wp;HI-all 10),thta0,thta1,p(.)-10 | 759.67 | 10.65 | 0.0008 | 0.0049 | 18 | 723.67 |
| psi(Sb,Sd,Rh,Bd;HI-all 10),thta0,thta1,p(.)---9 | 759.71 | 10.69 | 0.0008 | 0.0048 | 18 | 723.71 |
| psi(Sb,Sd,Wp;HI-all 10),thta0,thta1,p(.)-----11 | 759.71 | 10.69 | 0.0008 | 0.0048 | 17 | 725.71 |
| psi(Sb,Sd;Po),thta0,thta1,p(.)-----------------24 | 761.75 | 12.73 | 0.0003 | 0.0017 | 7 | 747.75 |
| psi,thta0,thta1,p(.)-----------------Global-------4.2 | 768.24 | 19.22 | 0.0000 | 0.0001 | 22 | 724.24 |
| psi(Sb,Sd,Rh;Lp),thta0,thta1,p(.)--------------14 | 772.43 | 23.41 | 0.0000 | 0.0000 | 8 | 756.43 |
| psi(Sb,Sd,Rh;Lp,Hp)10,thta0,thta1,p(.)-----13.2 | 774.41 | 25.39 | 0.0000 | 0.0000 | 9 | 756.41 |
| psi,thta0,thta1,p(0)-------------Global-------------4.1 | 776.90 | 27.88 | 0.0000 | 0.0000 | 22 | 732.90 |

| Model | AIC | deltaAIC | AIC wgt | Model Likelihood | no. Par. | 2*LogLike |
|---|---|---|---|---|---|---|
| psi(Sb,Sd;Lp),thta0,thta1,p(.)------------------21.2 | 783.25 | 34.23 | 0.0000 | 0.0000 | 7 | 769.25 |
| psi(Sd),thta0,thta1,p(.)------------------------------7 | 793.61 | 44.59 | 0.0000 | 0.0000 | 5 | 783.61 |
| psi(Sb,Sd),thta0,thta1,p(.)--------------------------6 | 794.62 | 45.60 | 0.0000 | 0.0000 | 6 | 782.62 |
| psi,thta0,thta1,p(.)----------------------------------3 | 855.42 | 106.40 | 0.0000 | 0.0000 | 4 | 847.42 |
| psi,thta0,thta1,p(.)----------------------------------2 | 865.72 | 116.70 | 0.0000 | 0.0000 | 4 | 857.72 |
| 1 group, Constant P----------------------------------1 | 1052.89 | 303.87 | 0.0000 | 0.0000 | 2 | 1048.89 |

[a]Given are the Model No. (model numbers) as referenced in methods, relative difference in IAC values compared to top ranked model (Δ AIC), AIC model weights (W), number of parameters in the model (k), and twice the negative log likelihood (-2l).

All eight models incorporated prey species (sambar and spotted deer) and human impact (lopping and poaching). In addition model 23 included human presence, model 19 included rhino, model 20.1 included blue bull, model 20.3 included wild pig, model 20.4 included barking deer, model 20.2 included gaur and model 25 included trails.

The naïve occupancy estimate was 0.35 (34/96). For comparison as determined from model 3, independent of covariates the probability of occupancy estimate (ψ) was 0.37 (SE 0.06, 95% CI 0.27 - 0.50) and probability of detection estimate (p) was 0.77 (SE 0.06 , 95% CI 0.64 - 0.86). Because p was less than 1, the Presence-generated ψ estimate from model 3 was approximately a 6% increase from the naïve estimate.

Considering the top model, most of the grid cells with the higher probability of occupancy (>0.70) were located inside PAs except for 5 grids, two in Banke district in and around the Mahadevpuri corridor (east of current Banke NP), two in Bara district (east of Parsa WR) and one in Kailali in Basanta corridor.

The model averaged probability of occupancy of the top 8 models (< 2 ΔQAIC) is 0.63 (SE 0.15, 95% CI 0.36-0.87) and probability of detection was 0.72 (SE 0.05) 95% CI 0.60-0.81 (Table 3.2).

**Table 3.2 Probability of occupancy (ψ) and probability of detection (p) of top 8 models.**

| Models | Psi | SE | 95%CI | | P | SE | 95% CI | |
|---|---|---|---|---|---|---|---|---|
| Model20 | 0.6224 | 0.1403 | 0.3468 | 0.8492 | 0.7148 | 0.0521 | 0.6031 | 0.8053 |
| Model23 | 0.6344 | 0.1453 | 0.3464 | 0.8753 | 0.7153 | 0.0522 | 0.6032 | 0.8059 |
| Model19 | 0.6306 | 0.1452 | 0.3416 | 0.8723 | 0.7167 | 0.0514 | 0.6064 | 0.8059 |
| Model20.1 | 0.6295 | 0.1414 | 0.3442 | 0.8714 | 0.7159 | 0.0522 | 0.6073 | 0.8064 |
| Model20.3 | 0.6218 | 0.1412 | 0.3442 | 0.8625 | 0.7177 | 0.0523 | 0.6052 | 0.8064 |
| Model20.4 | 0.6299 | 0.1793 | 0.3454 | 0.8711 | 0.7167 | 0.0521 | 0.6047 | 0.8083 |
| Model20.2 | 0.6199 | 0.1794 | 0.3427 | 0.8599 | 0.7136 | 0.0522 | 0.6017 | 0.8043 |
| Model25 | 0.6159 | 0.1415 | 0.5038 | 0.8656 | 0.7135 | 0.0522 | 0.6016 | 0.8043 |
| Average | 0.6255 | 0.1517 | 0.3644 | 0.8659 | 0.7155 | 0.0521 | 0.6042 | 0.8059 |

### 3.5.2 Outside Protected Areas

Of the total 96 grid cells, 69 grid cells outside PAs were analyzed separately to assess the probability of occupancy of tiger.

Based on the global model (4 above in analysis, table 3.3), the model 16 psi(Sd;Fw,Wc),thta0,thta1,p(.): probability of occupancy influenced by spatial correlation, prey species (Spotted deer) and human impacts (fire wood collection and wood cutting) with constant detection probability (as listed above in analysis section) was selected based on Akaike's Information Criteria (AIC) comparisons (i.e., < 2 ΔAIC, Burnham and Anderson 2002).

Other competing models having < 2 ΔQAIC were 17 and 18 . Model 16 has AIC 201.10 and AIC weight 0.2693, model 17 has AIC 202.34 and AIC weight 0.1449 and model 18 has AIC 202.65 and AIC weight 0.1241 (Table 3.3).

All three models incorporated prey species covariate (spotted deer). In addition model 16 included fire wood collection and wood collection as human impact covariate whereas model 17 included and 18 included woodcutting and fire wood collection as human impact covariate which was already incorporated by model 16 (the top model).

The naïve occupancy estimate was 0.1594 (11/69). For comparison as determined from model 3, independent of covariates the probability of occupancy estimate (ψ) was 0.2672 (SE 0.0933, 95% CI 0.1253 - 0.4813) and probability of detection estimate (p) was 0.8264 (SE 0.4129, 95% CI 0.0166 - 0.9993). Because p was less than 1, the Presence-generated ψ estimate from model 3 was approximately a 11% increase from the naïve estimate.

Considering the top model, most of the grid cells with the higher probability of occupancy (>0.70) were located either in the corridors or in the forest that has link with PA.

The model averaged probability of occupancy of the three 3 models (< 2 ΔQAIC) was 0.5756 (SE 0.1150, 95% CI 0.0718 - 0.7982) and probability of detection was 0.4129 (SE 0.1375, 95% CI 0.1650-0.6607).

**Table 3.3. Model selection results using Akaike Information Criteria (AIC)a**

| Model | AIC | Delta AIC | AIC wgt | Model Likelihood | no.Par. | -2* LogLike |
|---|---|---|---|---|---|---|
| psi(Sd;Fw,Wc),thta0,thta1,p(.)---------------16 | 201.10 | 0.00 | 0.2693 | 1.0000 | 7 | 187.10 |
| psi(Sd;Wc),thta0,thta1,p(.)-------------------17 | 202.34 | 1.24 | 0.1449 | 0.5379 | 6 | 190.34 |
| psi(Sd;Fw),thta0,thta1,p(.)-------------------18 | 202.65 | 1.55 | 0.1241 | 0.4607 | 6 | 190.65 |
| psi(Wp,Sd;Fw,Wc),thta0,thta1,p(.)----------12 | 203.25 | 2.15 | 0.0919 | 0.3413 | 8 | 187.25 |
| psi(Wp,Sd;Wc),thta0,thta1,p(.)--------------13 | 203.45 | 2.35 | 0.0832 | 0.3088 | 7 | 189.45 |
| psi(Bb,Sd;Tl,Wc),thta0,thta1,p(.)-------------6 | 203.68 | 2.58 | 0.0741 | 0.2753 | 8 | 187.68 |
| psi(Wp,Bb,Sd;Fw,Wc),thta0,thta1,p(.)------11 | 203.97 | 2.87 | 0.0641 | 0.2381 | 9 | 185.97 |
| psi(Wp,Bb,Sd;Wc),thta0,thta1,p(.)------------8 | 204.32 | 3.22 | 0.0538 | 0.1999 | 8 | 188.32 |
| psi(Wp,Bb,Sd;Fw,Tl,Wc),thta0,thta1,p(.)----5 | 205.06 | 3.96 | 0.0372 | 0.1381 | 10 | 185.06 |
| psi(Wp,Bb,Sd;Tl,Wc),thta0,thta1,p(.)--------7 | 206.16 | 5.06 | 0.0215 | 0.0797 | 9 | 188.16 |
| psi(Wp,Sd;Fw),thta0,thta1,p(.)--------------14 | 207.07 | 5.97 | 0.0136 | 0.0505 | 7 | 193.07 |
| psi(Wp,Bb,Sd;Fw),thta0,thta1,p(.)----------10 | 208.63 | 7.53 | 0.0062 | 0.0232 | 8 | 192.63 |
| psi,thta0,thta1,p(.)-----------------------------3 | 209.28 | 8.18 | 0.0045 | 0.0167 | 4 | 201.28 |
| psi,thta0,thta1,p(.)-----------------------------2 | 209.37 | 8.27 | 0.0043 | 0.0160 | 4 | 201.37 |
| psi(Bd,Wp,Bb,Sd,Sb;Fw,Hp,Tl,Wc),tht0,tht1,p(.)4 | 209.67 | 8.57 | 0.0037 | 0.0138 | 13 | 183.67 |
| psi(Wp,Bb,Sd;Fw,Tl),thta0,thta1,p(.)-------15 | 209.87 | 8.77 | 0.0034 | 0.0125 | 9 | 191.87 |
| 1 group, Constant P----------------------------1 | 216.36 | 15.26 | 0.0001 | 0.0005 | 2 | 212.36 |
| psi(Wp,Bb,Sd;Tl),thta0,thta1,p(.)-------------9 | 222.89 | 21.79 | .0000 | 0.0000 | 8 | 206.89 |

[a]Given are the Model No. (model numbers) as referenced in methods, relative difference in IAC values compared to top ranked model (Δ AIC), AIC model weights (W), number of parameters in the model (k), and twice the negative log likelihood (-2l).

### 3.5.3 Protected Areas

Of the total 96 grid cells, 27 grid cells of PAs were analyzed separately to assess the probability of occupancy of tiger.

Based on the global model (4 above as listed in analysis section, table 3.4), the model 16 psi(Ld;Rh,Ch,Sb),thta0,thta1,p(.): probability of occupancy influenced by spatial correlation, prey species (rhino, chital and sambar) and human impact (livestock dung) with constant detection probability (as listed above in analysis section) was selected based on Akaike's Information Criteria (AIC) comparisons (i.e., < 2 ΔAIC, Burnham and Anderson 2002).

Other competing models having < 2 ΔQAIC were 20 and 16.1 . Model 16 has AIC 563.73 and AIC weight 0.2126, model 20 has AIC 565.41 and AIC weight 0.0914 and model 16.1 has AIC 565.48 and AIC weight 0.0882 (Table 3.4).

All three models incorporated prey species covariate (chital, sambar and rhino) and human impact covariate (livestock dung). In addition model 20 included gaur as prey species covariate, and model 16. 1 included swamp deer as prey species covariate and fire as human impact covariate.

The naïve occupancy estimate was 0.8519 (23/27). For comparison as determined from model 3, independent of covariates the probability of occupancy estimate (ψ) was 0.9536 (SE 0.1126, 95% CI 0.1230 - 0.9997) and probability of detection estimate (p) was 0.7099 (SE 0.0666, 95% CI 0.5650 - 0.8218). Because p was less than 1, the Presence-generated ψ estimate from model 3 was approximately a 10% increase from the naïve estimate.

The model averaged probability of occupancy of the three 3 models (< 2 ΔQAIC) was 1.0 (SE 0.00, 95% CI 0.0718 - 0.7982) and probability of detection was 0.7066 (SE 0.0604, 95% CI 0.5763-0.8099).

**Table 3.4. Model selection results using Akaike Information Criteria (AIC)a**

| Model | AIC | Delta AIC | AIC wgt | Model Likelihood | no.Par. | -2*LogLike |
|---|---|---|---|---|---|---|
| psi(Ld;Rh,Ch,Sb),thta0,thta1,p(.)----------------16 | 563.73 | 0.00 | 0.2116 | 1.0000 | 8 | 547.73 |
| psi(Ld;Rh,Ch,Sb,Gr),thta0,thta1,p(.)-------------20 | 565.41 | 1.68 | 0.0914 | 0.4317 | 9 | 547.41 |
| psi(Ld,Fr;Sd,Rh,Ch,Sb),thta0,thta1,p(.)-------16.1 | 565.48 | 1.75 | 0.0882 | 0.4169 | 10 | 545.48 |
| psi(Ld;Sd,Rh,Ch,Sb),thta0,thta1,p(.)------------14 | 565.73 | 2.00 | 0.0779 | 0.3679 | 9 | 547.73 |
| psi(Ld,Po;Sd,Rh,Ch,Sb),thta0,thta1,p(.)--------15 | 566.18 | 2.45 | 0.0622 | 0.2938 | 10 | 546.18 |
| psi(Ld;Sd,Rh,Ch),thta0,thta1,p(.)----------------13 | 566.18 | 2.45 | 0.0622 | 0.2938 | 8 | 550.18 |
| psi(Ld;Sd,Rh),thta0,thta1,p(.)------------------ -12 | 566.53 | 2.80 | 0.0522 | 0.2466 | 7 | 552.53 |
| psi(Ld,Fr,Po;Sd,Rh,Ch,Sb),thta0,thta1,p(.)-----17 | 566.96 | 3.23 | 0.0421 | 0.1989 | 11 | 544.96 |
| psi(Ld,Fr;Sd,Rh,Ch,Sb,Gr),thta0,thta1,p(.)-----18 | 567.16 | 3.43 | 0.0381 | 0.1800 | 11 | 545.16 |
| psi(Fr,Ld,Po;Sd,Rh),thta0,thta1,p(.)-------------11 | 567.23 | 3.50 | 0.0368 | 0.1738 | 9 | 549.23 |
| psi(Fr,Ld,Po;Bb,Sd,Rh),thta0,thta1,p(.)---------10 | 569.23 | 5.50 | 0.0135 | 0.0639 | 10 | 549.23 |
| psi(Fr,Ld,Po;Bb,Hd,Sd,Rh),thta0,thta1,p(.)-------9 | 572.53 | 8.80 | 0.0026 | 0.0123 | 11 | 550.53 |
| psi(Fr,Ld,Po;Bb,Gr,Hd,Sd,Rh),thta0,thta1,p(.)---8 | 573.94 | 10.21 | 0.0013 | 0.0061 | 12 | 549.94 |
| psi(Ld;Sd,Rh,Sb,Gr),thta0,thta1,p(.)-----------16.2 | 574.18 | 10.45 | 0.0011 | 0.0054 | 9 | 556.18 |
| psi(Ld,Fr;Sd,Rh,Sb,Gr),thta0,thta1,p(.)----------19 | 574.55 | 10.82 | 0.0009 | 0.0045 | 10 | 554.55 |
| psi(Fr,Ld,Po;Bb,Gr,Hd,Sd),thta0,thta1,p(.)-------5 | 575.90 | 12.17 | 0.0005 | 0.0023 | 11 | 553.90 |
| psi(Fr,Ld,Po;Bb,Gr,Hd,Sd,Ch),thta0,thta1,p(.)---6 | 576.74 | 13.01 | 0.0003 | 0.0015 | 12 | 552.74 |
| psi(Fr,Ld,Po;Bb,Gr,Sd,Ch),thta0,thta1,p(.)-------7 | 577.24 | 13.51 | 0.0002 | 0.0012 | 11 | 555.24 |
| psi,thta0,thta1,p(.)-------global--------------------4 | 581.35 | 17.62 | 0.0000 | 0.0001 | 23 | 535.35 |
| psi,thta0,thta1,p(.)-----------------------------------3 | 583.12 | 19.39 | 0.0000 | 0.0001 | 4 | 575.12 |
| psi,thta0,thta1,p(.)-----------------------------------2 | 593.58 | 29.85 | 0.0000 | 0.0000 | 4 | 585.58 |
| 1 group, Constant P----------------------------------1 | 675.32 | 111.59 | 0.0000 | 0.0000 | 2 | 671.32 |

[a]Given are the Model No. (model numbers) as referenced in methods, relative difference in IAC values compared to top ranked model (Δ AIC), AIC model weights (W), number of parameters in the model (k), and twice the negative log likelihood (-2l).

### 3.6 *DISCUSSION*

Our naïve estimate of tiger occupancy (0.35) closely agrees to that found in a similar study in southwestern India (0.33) conducted during 2006 and 2007 at the scale of 200 $km^2$ grid cells (Hines *et al.* 2010) and India (0.415) conducted during 2010 at the scale of 100 $Km^2$ grid cells (Jhala et al. 2011). In our study, PRESENCE-generated tiger occupancy estimates ranged from 0.00 in some grid cells outside PAs to 1.00 in grids of PAs. Prey depletion has been recognized as an important factor driving the current decline of wild tiger populations and hence a significant constraint on their recovery (Karanth and Stith 1999). Our results are consistent with this.

The top eight models ranked higher based on AIC comparisons had spotted deer, sambar followed by rhino, blue bull, wild pig, barking deer, and gaur as prey species predicting tiger occupancy. The lopping, human presence, trails and evidence of poaching were the main human disturbances affecting the tiger occupancy. Therefore to increase tiger occupancy, otherwise suitable areas that have depleted prey bases should be managed with an important focus on increasing the primary prey base for tigers.

Because the human impacts covariate incorporated lopping, presence of humans and trails for various activities such as wood cutting, fuel wood and grass collection, grazing and evidence of poaching, mitigating these factors should be considered to increase tiger occupancy even in areas where the prey base is already deemed sufficient. There is selective poaching of tigers prey due to their high commercial value in local markets, it is possible to deplete tigers from forests that have good prey base (Chundawat et al. 2010, Karki et al. 2008). This is particularly true in the case of SWR and BNP, where existing levels of primary tiger prey appear to be adequate to support the viable tiger populations (Karanth *et al.*, 2004). Thus, it is essential that management focus on maintaining and/or increasing the prey base while curbing human impacts such as ongoing tiger poaching and trade in their parts for the effective recovery of tiger populations in Nepal.

The 23 grid cells with the higher probability of occupancy (>0.70) were located inside PAs. Three of the five grids that had higher probability of occupancy (>0.70) were in the corridors (Mahadevpuri in Banke district and Basanta in Kailali district) and remaining two in Bara district. Tiger used to occur in the Mahadevpuri and Basanta corridor in the past (Smith et al. 1998) but were declining thereafter. The small population of tiger in Suhelwa (around 5 individuals) shared with Mahadevpuri-Lamahi forests of Nepal with an occupancy of 441 $Km^2$ (Jhala et al. 2011). After the restoration of habitat, tiger signs have increased in these corridors (Wikramanayake et al. 2010). The signs of tiger occurrence was reported in the past (Smith et al. 1987c) and continue to occur in the Bara forest, extended east from PWR.

Separate analysis of the probability of tiger occupancy outside PAs showed that the spotted deer and wild pig has higher influence in the tiger occupancy. This indicates that the bigger size prey such as sambar and blue bull could additionally contribute to the tiger occupancy outside PA if their conservation is strengthened. In addition to the areas under corridors, the forests of Dang, Chitwan, Rautahat and Rupandehi districts has higher probability of tiger occupancy. Chitwan and Rupandehi forests are connected with CNP, and Rautahat forest is connected with Bara forest which further west links with Parsa Wildlife Reserve. Thus if the corridors are further protected and tiger use increases, then these areas can provide some prey base to support tiger. Thus, improvement in the protection and reduction of the human impacts, would further enhance the habitat for use by tiger.

In conjunction with the simultaneous research that occurred inside PAs, this TAL-wide occupancy survey conducted has established permanent monitoring systems for tigers and their prey (Karki et al. 2009). Furthermore, a pool of highly trained wildlife technicians has been created among conservation partners, stakeholder and decision-making groups through capacity-building activities. The information generated through monitoring activities required systematic storage. Database management and effective retrieval system was initiated. These successes and the established benchmark data on tiger occupancy across the TAL highlight such work as a milestone for tiger conservation in Nepal.

To build upon the foundation of established benchmark data that was generated, we recommend a TAL-wide occupancy survey be conducted every four years supplemented by additional data collection during intervening years such as, for examples; camera-trapping within PAs every two years, yearly reporting on human-tiger and livestock-tiger conflict through the TAL, and monthly briefs on poaching and retaliatory killings along with details of spatial and temporal patrolling efforts (DNPWC 2009).

Our findings provide valuable insights for managers and conservationists in evaluating conservation successes, developing strategies to deal with new situations and thus facilitating science-based management to maintain viable tiger populations (Karanth and Nichols 2002) in the TAL.

Future TAL-wide tiger occupancy surveys will not only provide information on tiger presence but may also indicate changes in overall tiger reproduction (as indexed by cub tracks detected) and potentially abundance, and changes in the prey base, poaching intensity and other human impacts. Furthermore, because tiger occupancy is very high within PAs and much lower outside, we suggest that corridors between PAs be monitored seasonally to determine tiger use patterns and additional human encroachment which can happen very quickly. Only through repeated strategic monitoring that examines conservation intervention impact will managers have the information they need to make important decisions during these critical times for Nepal's tigers.

# CHAPTER FOUR : UNGULATE ABUNDANCE IN TIGER BEARING PAS OF NEPAL

## 4.1 INTRODUCTION

The conservation future of the tiger depends largely on the availability of suitable prey species. TAL has been recognized as one of the global priority landscapes for tigers (Wikramanayake et al., 1998). TAL's alluvial grasslands are among the most critically threatened tiger and their prey base habitats in the world. Thus, conservation initiatives requires more comprehensive and reliable ecological knowledge to undertake the scientific management of tiger prey base populations (GoN, 2007).

Chital, sambar, swamp deer, wild pig, hog deer, barking deer, gaur, blue bull, rhesus macaque, common langur, hispid hare, black naped hare, porcupine, four horned antelope, one-horned rhinoceros and Asian elephant are among the main wild prey species of tiger in Nepal. Swamp deer is restricted to SWR and BNP and forms the major share of prey base for tiger in SWR. Similarly, gaur is restricted to CNP and PWR and is important food of the tiger.

This study was conducted in May-June 2009 to establish reliable information on the population status and distribution of the tiger's prey species across PAs which shall form a basis for future monitoring program.

## 4.2 OBJECTIVE

The specific objective was to estimate the population of tiger's wild prey species in Parsa and SWRs, and Chitwan and BNPs.

## 4.3 STUDY AREA

The tiger bearing PAs are located in the lowlands and inner valley from central to far west Nepal. The PWR in the east, with 499 $km^2$ area, is in the outer foot hills. PWR is connected with CNP towards west to make continuous habitat. Combined these two PAs forms the major part of category one tiger conservation unit (TCU). CNP is connected with the Valmiki Tiger Reserve (VTR) in India towards its southern side. The CNP with an area of 932 $km^2$, the first PA in Nepal, world heritage site, lies in the inner Dun valley drained by Narayani, Rapti and Reu rivers.

BNP, the largest PA in lowland, 968 $km^2$, in the western development region of Nepal comprises of the Karnali Flood Plain (KFP) and Babai Valley (formed by Babai river originated from mid hill) which adjoins with the recently declared BaNP towards east. It forms the part of the second important category one TCU in Nepal. Towards its south, it is connected with Khata corridor (Nepal) and Khata corridor further connects Katerniaghat Wildlife Sanctuary (KWS) (India) in its south.

SWR with an area of 305 $km^2$ established to provide the refuge for the largest herd of swamp deer, lies in the lowland in the far-western development region of Nepal adjoining with the Lagga-Bagga forest area  and forests of Pilibhit forest division (India) further south. Details of the intensive study area and maps are provided in chapter 2.3.2. and figures 2.6 to 2.9.

## 4.4 METHODS

Use of line transect surveys within the distance sampling framework (Buckland et al. 2001) to obtain estimates of tiger prey populations has been suggested as the most appropriate method and is now becoming the standard monitoring protocol in the most of the tiger range countries in the South Asia  (Karanth and Nichols, 1999; Wegge and Storaas, 2009).

### 4.4.1 Survey design and field methods

Following the reconnaissance survey, transects were laid out systematically using the built-in survey design protocol in DISTANCE software with the random start option. We determined at least 30 spatial replicates in each sampled area to achieve sufficient sample size based on anecdotal estimated encounter rate information from previous surveys. Computer generated transect points were laid on a map and uploaded on the GPS (Table 4.1). Because of the random allocation of transects, we avoided oversampling of line transects concentrated near roads and those running parallel to rivers or other features of the landscape, which may bias sightings of ungulates.

**Table 4.1: Sampling details for the line transect surveys in tiger bearing PAs, Nepal.**

<table>
<tr><th>Area</th><th>Number of repeats (temporal replicates)</th><th>Number of transects (spatial replicates)</th></tr>
<tr><td>Parsa WR</td><td>2</td><td>40</td></tr>
<tr><td>Chitwan NP</td><td>2</td><td>198</td></tr>
<tr><td>Bardia NP</td><td></td><td>170</td></tr>
<tr><td>- KFP</td><td>2</td><td rowspan="2">127</td></tr>
<tr><td>- Churia foot hill</td><td>2</td></tr>
<tr><td>- Babai valley</td><td>4</td><td>43</td></tr>
<tr><td>SWR</td><td>2</td><td>62</td></tr>
</table>

After burning grasslands during May-June, two trained and experienced observers on elephant back traveled along the line transect counting all prey animals observed, between 06:00-09:00 and 16:00-19:00 hours when prey animals were most active. For each observation, the species, number of individual animals, the radial sighting distance to the animal (or center of the animal cluster) and the sighting angle between the transect line and the animal or center of cluster of animals observed, was recorded. The sighting distance was measured with laser range finders (Busnell 400 with 366 meter range) and the horizontal angles (bearings) were recorded using SILVA compas. Data were collected from elephant backs as recommended by Wegge and Storaas (2009) to maximize observer height for sighting and to minimize prey disturbance and flight.

### 4.4.2 Analytical method

Not all the individuals that the observers pass would be detected, but a fundamental assumption of the method is that all individuals that are actually on the transect line are detected. In general, there will be fewer detections with increasing distance from the transect line. Thus, the key to distance sampling analysis is to fit a detection function to the observed distances, and use this fitted function to estimate the proportion of individuals missed during the survey. These models compute the sighting probabilities to estimate the animal abundance (N) in the sampled area from the counts (C) obtained in the survey. Because metadata on the area sampled are incorporated into the estimation process, density can be estimated directly, as opposed to the separate estimation of abundance and area sampled as in the capture-recapture approach. Free software DISTANCE Version 6 (Thomas et al. 2009) was used to design and analysis of distance sampling surveys.

Distance sampling works on the premise that detection of animals along a line transect decreases with increasing distance from the line. The data obtained on animal sightings are then used to model this detection function. Distance offers a variety of models to fit the observation data.

These models includes a) exponential decay b) uniform decay c) hazard rate and d) half normal models along with cosine and key function adjustments. The best fit model is selected on the basis Akaike Information Criteria that incorporated log likelihood of model fit penalized by number of parameters in the model. The best model has the smallest AIC value (Buckland et al. 2001).

We analyzed all tiger wild prey >6 Kg body mass as one group in each PA and then, whenever possible, we analyzed by species. We excluded sub-optimal prey such as hares (i.e., body weight < 6 kg) (Karanth and Nichols 2002) for analysis though tigers eat these animals but are not as important in determining tiger densities. Individual species density analysis was done to help compare within and across PAs over time wherever possible. Since 60-80 observation events are recommended for analyses by DISTANCE (Buckland et al. 2001), densities of some species like blue-bull, gaur and four-horned antelope could not be analyzed due to low observations.

In selecting the best model (or models) for estimating effective strip widths, model robustness, relative Akaike Information Criterion (AIC) values, goodness of fit tests, relative estimate precision and the detection function shape (wide shoulder near the y axis) were considered (Buckland et al. 2001).

A larger number of observations near the 0 distance than would likely be expected ("heaping") in BNP and CNP datasets were observed (i.e., "spikes" of observations nearest the y axis when number of observations was plotted vs. perpendicular distance to the transect line). These were probably the result of slight rounding of the compas bearings (e.g., 0.05 degrees rounded to 0 degrees) for animals sighted near the transect line. This resulted in the need to group the data into "cut points" (or interval bins) prior to analyses. Alternatively, one can attempt to left truncate the data. However, left truncation is not favorable because data closest to the y axis has the greatest influence on the density estimate and these data are lost when left truncating. Also, density estimates are very sensitive to exactly where the left truncation is done and there is no acceptable clear method for determining exactly where the left truncation should occur. Therefore, the more robust approach is to group the data prior to analyses (Buckland et al. 2001). In BNP, there were additional challenges because of 3 strata (i.e., KFP, Churia foothill, and Babai valley) having very different encounter rates of prey. Because the 3 strata vary significantly, it was not ideal to group the data for entire park across all 3 strata (unless transect placement is originally designed in DISTANCE without respect to strata). However, because the transects were designed with respect to strata – the data were analyzed according to strata whenever possible. This was possible for the "all tiger prey" category and chital analyses but not with other individual species because of the limited observations in each stratum. Therefore, instead of individual species density analysis by strata, estimates for all park was obtained.

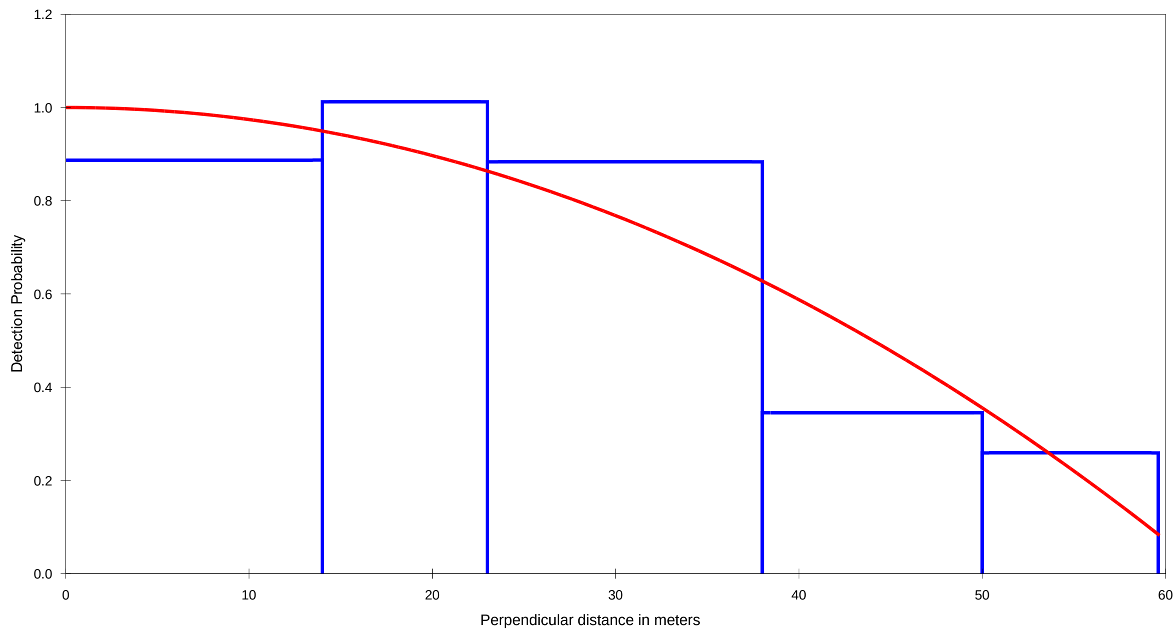
## 4.5. RESULTS

The major tiger wild prey species such as chital, sambar, hog deer, barking deer, swamp deer and wild pig were analyzed for estimating number and density. The rhesus macaque and common langur were analyzed separately wherever the observations were more than 40 and combined otherwise.

### 4.5.1. Parsa Wildlife Reserve

The density estimate for main wild prey > 6 Kg was 6.6 per km$^2$ (SE=1.1, 95% CI=.4.8-9.1, P=0.7, $\chi2$=1.4, df=3, Table 4.3), indicating approximately 1,591 wild prey animals in PWR's 242 km$^2$ (95% CI=1,154-2,192, Table 4.5). Uniform model with series simple polynomial best fitted the data for all species in PWR.

**Detection probability curve (uniform simple polynomial) for all species in PWR.**

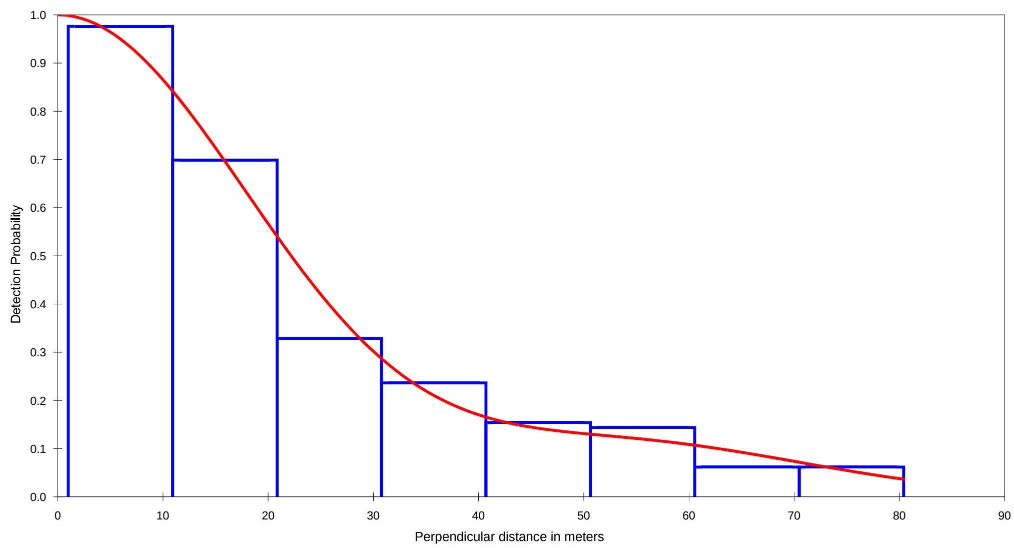



### 4.5.2. Suklaphanta Wildlife Reserve

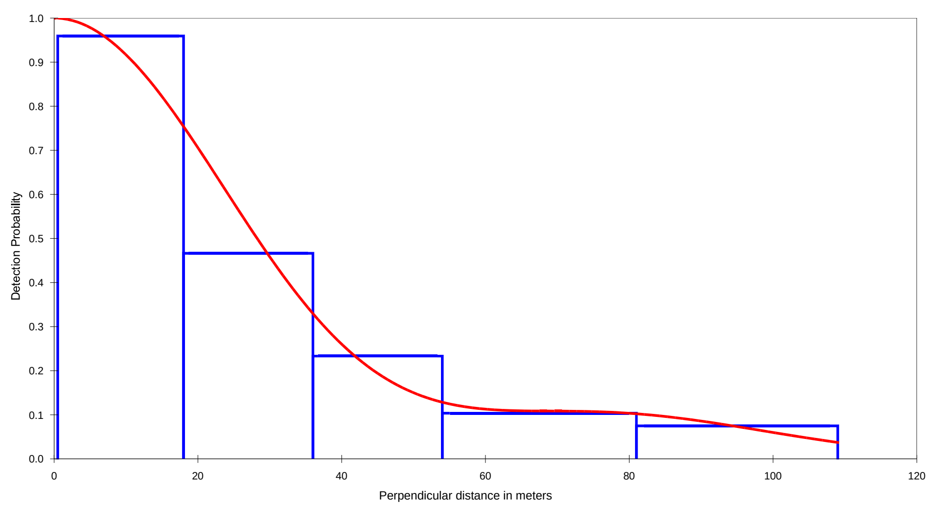
The density estimate for main wild prey >6 Kg after right truncation at 80.4 m and left truncation at 1 m provided 144.8 per km$^2$ (SE=22.8, 95%CI=106.3-197.2, P=0.7, $\chi$2=3.2, df=5, Table 4.3) which provides approximately 25,548 wild prey animals in SWR's 197.14 km$^2$ (95% CI=20,963-38,879, Table 4.5). Model half normal with series cosine best fitted the data for the estimation of density of all species in SWR.

Next, the same general procedures were followed separately analyzing the densities of chital, swamp deer, and hog deer. The model-averaged density after right truncation at 109 m and left truncation at 0.5 m provided 79.0 chital per km$^2$ (SE=19.0, 95%CI=49.5-126.0, P=0.259,$\chi$2=4.02,df=3, Table 4.3) which provides approximately 15,563 chital in SWR's 197.14 km$^2$ (95%CI= 9,749.0-24,844.0, Table 4.5). Model half normal with series cosine best fitted the data to estimate the density of chital in SWR.

**Detection probability curve (half normal cosine) for all species in SWR.**

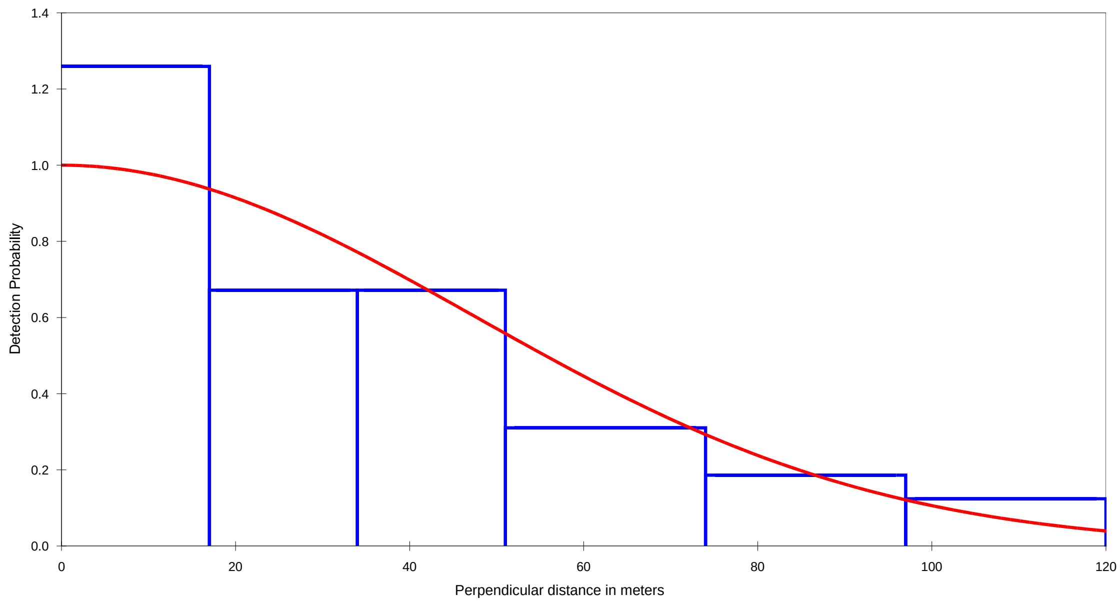



**Detection probability curve (half normal cosine) for chital in Suklaphanta Wildlife Reserve**



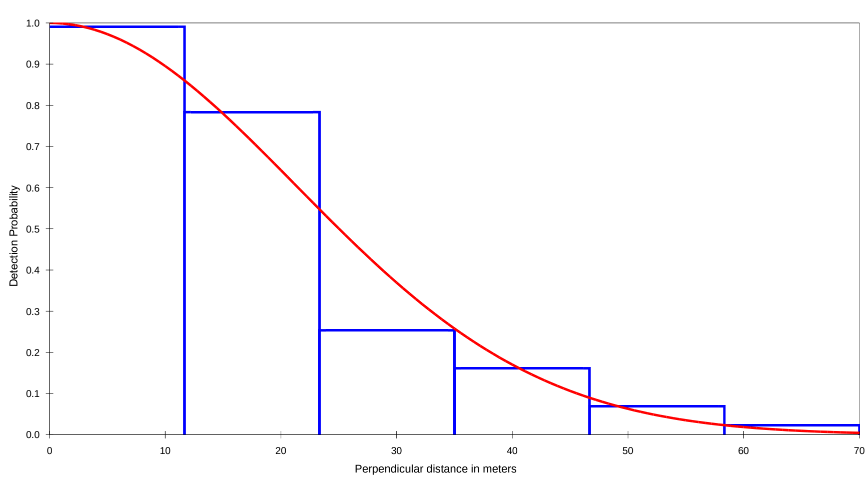

For swamp deer, right truncation of 120 m was done. The model-averaged density estimate was 30.0 swamp deer per $km^2$ (SE=16.1, 95%CI=11.0-81.7, P=0.6, $\chi 2$=2.0, df=3, Table 4.3,) which shows approximately 5,909 swamp deer in SWR's 197.14 $km^2$ (95%CI=2,167-16,112, Table 4.5). Uniform model best fitted the data to estimate the density of swamp deer in SWR.

**Detection probability curve (uniform) for swamp deer in Suklaphanta Wildlife Reserve**



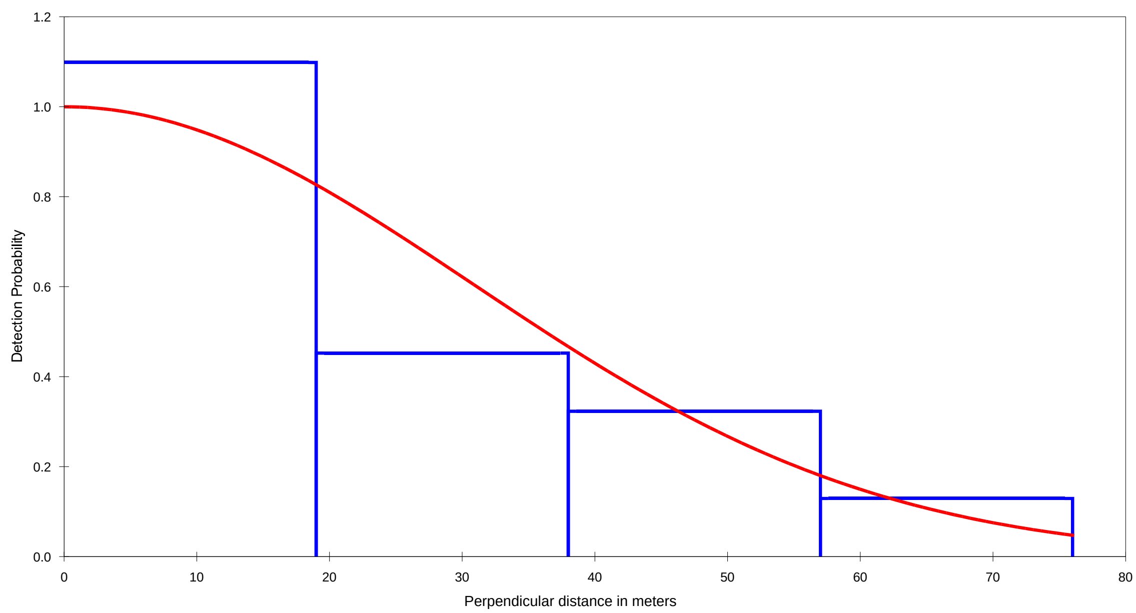

For hog deer, a right-truncation distance of 70 m was used. The model-averaged density estimate was 21.6 hog deer per $km^2$ (SE=4.4, 95%CI=14.5-32.1, P=0.4, $\chi 2$=3.2, df=3, Table 4.3) which is approximately 4,252 hog deer in SWR's 197.14 $km^2$ (95%CI=2,856-6,329, Table 4.5). Half normal model best fitted the data to estimate the density of hog deer in SWR.

**Detection probability curve (half normal) for hog deer in Suklaphanta Wildlife Reserve.**



Rhesus macaque and common langur were analyzed together due to low number of observations for individual density estimation. Right truncation of 76 m was done. The combined density was 14.8 primates per $km^2$ (SE=4.6, 95% CI=8.1-27.2, P=0.5, $\chi2$=1.5, df=2, Table 4.3) which is approximately 2,924 primates in SWR's 197.14 $km^2$ (95% CI=1,596-5,357, Table 4.3). Half normal model best fitted the date to estimate the density of rhesus macaque and common langur in SWR.

**Detection probability curve (half normal) for primate in Suklaphanta Wildlife Reserve.**

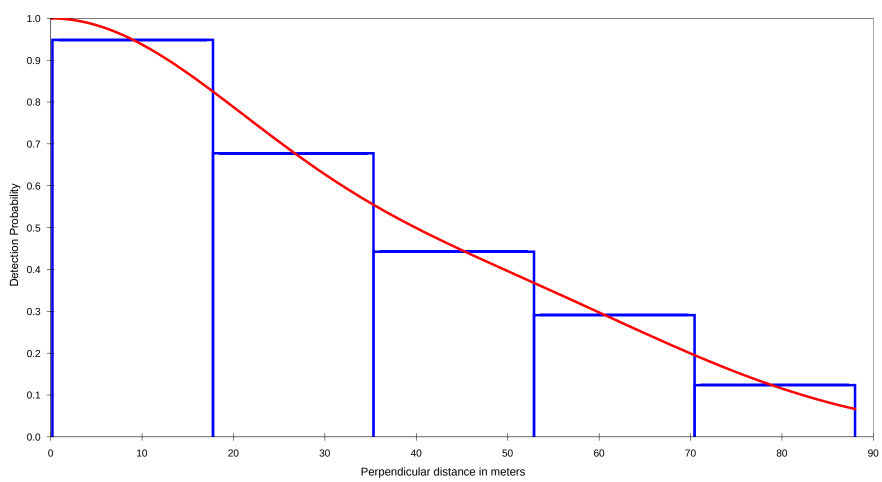



Summing the point estimates from each species that was analyzed separately resulted in an estimated 28,648 individuals of wild prey animals in SWR (does not include blue bull – 2 observations, wild pig – 3 observations and barking deer – 1 observation). This is near the point estimate and well within the confidence interval of the overall estimate of 25,548 wild prey animals in SWR's 197.14 $km^2$ (95% CI=20,963-38,879).

#### 4.5.3. Bardia National Park

Data were grouped according to “cut points” following general recommendations by Buckland et al. (2001) to achieve appropriate model fit. Cluster size data were not grouped according to these intervals but exact distances were used for size-biased regression analyses. Right truncation of 88 m and left truncation of 0.2 m was done to appropriate model fit. The density estimate for main wild prey >6 Kg was 56.3 per km$^2$ (SE=6.5, 95% CI=40.5-70.5, P=0.9, $\chi2$=0.3, df=2, Table 4.3) which is approximately 18,356 individuals of wild prey animals (95% CI=14,661-22,983, Table 4.5) in BNP’s 326.12 km$^2$. Half normal model best fitted the data used in the estimation of parameters for all species in BNP.

**Detection probability curve (half normal) for all species in Bardia National Park.**




Right truncation of 85 m and left truncation of 0.2 m was done to appropriate model fit. Results from the KFP indicated 103.7 individual wild prey per km$^2$ (SE=12.8, 95% CI=81.4-132.2, P=0.6, $\chi2$=2.6, df=4, Table 4.3) which is an estimated 15,901 wild prey animals (95% CI=12,480-20,260, Table 4.5) in the 153.318 km$^2$ included in this stratum. Half normal model best fitted the data to estimate the detection function for all species in flood plain area.

Right truncation of 65.3 m was done to appropriate model fit. Results from the Churia Foothills indicated 22.2 individual tiger wild prey per $km^2$ (SE=6.5, 95%CI=12.6-39.0 P=0.8, $\chi 2$=1.8, df=4, Table 4.3) which translates to an estimated 2,553 tiger wild prey animals (95% CI=1,452-4,487, Table 4.5) in the 115.113 $km^2$ included in this stratum. Model uniform with series cosine best fitted the data to estimate the detection function for all species in FH.

Right truncation of 100 m was done to appropriate model fit. Results from the Babai Valley indicated 37.3 individual wild prey per $km^2$ (SE=6.6, 95% CI=26.3-50.0, P=0.9, $\chi 2$=0.5, df=3, Table 4.3) which translates to an estimated 2,153 wild prey animals (95%CI=1,515-3,059, Table 4.3) in the 57.69 $km^2$ included in this stratum. Half normal model best fitted the data to estimate the detection function for all species in BV.

The encounter rate (observations/length of transect line) was highest in the KFP (2.0, SE= 0.2) and lower in both Babai Valley (1.6, SE=0.2) and the Churia Foothill (0.3, SE=0.06).

The estimation of number and density for chital was done for whole study area (effort 559 km) as well as separately for three strata (effort -212 Km for KFP, 273 Km for FH and 74 Km for BV). The right truncation was done at 91 m for estimation of number and density for chital in BNP. The model-averaged density estimate was 29.3 chital per $km^2$ (SE=4.3, 95% CI=22.0-39.1, P=0.7, $\chi 2$=2.4, df=4, Table 4.3). This translates to approximately 9,596 chital (95%CI=7,180-12,743, Table 4.5) in BNP's 326.12 $km^2$. Half normal model best fitted the data to estimate the detection function for chital in BNP.

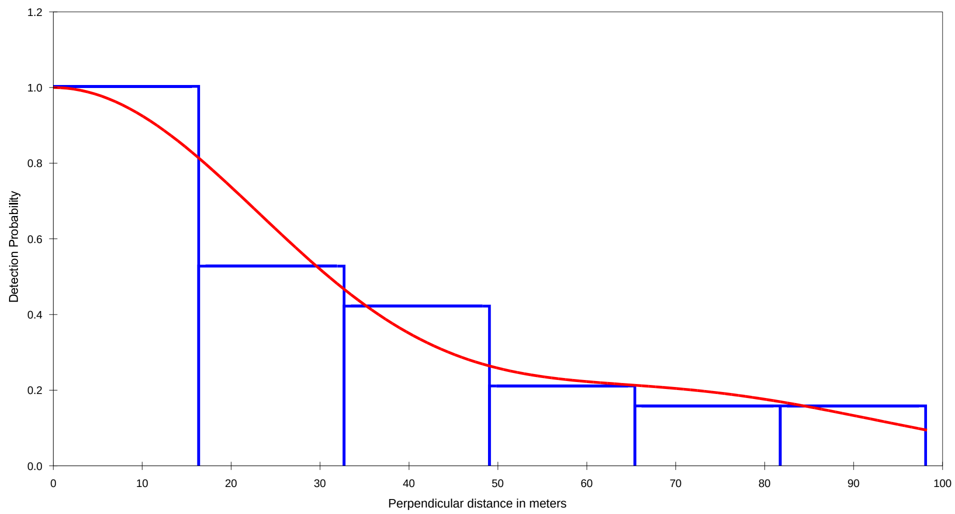
The right truncation was done at 87 m for estimation of number and density for chital KFP. The model-averaged density estimate was 50.5 chital per $km^2$ (SE=8.4, 95% CI=36.4-70.1, P=0.2, $\chi 2$=6.1, df=4, Table 4.3). This translates to approximately 7,743 chital (95% CI=5,581-10,743, Table 4.5) in KFP area. The right truncation was done at 80m for estimation of number and density for chital in foot hill. The model-averaged density estimate was 21.8 chital per $km^2$ (SE=8.4, 95% CI=10.5-45.1, P=0.6, $\chi 2$=2.2, df=3, Table 4.3). This translates to approximately 2,512 chital (95% CI=1,207-5,228, Table 4.5) in foot hill area. The right truncation was done at 82 m for estimation of number and density for chital Babai valley. The model-averaged density estimate was 19.2 chital per $km^2$ (SE=5.2, 95% CI=11.4-32.4, P=0.9, $\chi 2$=0.1, df=2, Table 4.3). This translates to approximately 1,108 chital (95% CI=656-1,872, Table 4.5) in Babai valley area. The half normal model best fitted the data for chital in KFP and Babai valley whereas uniform model with cosine series best fitted the data for chital in foot hill.

We could not obtain sufficient observations in each stratum to estimate stratum estimates for detection function, density, encounter rate and cluster size for wild pig, barking deer, sambar, hog deer, common langur and rhesus macaque. Therefore, detection function and cluster size were determined for entire park.

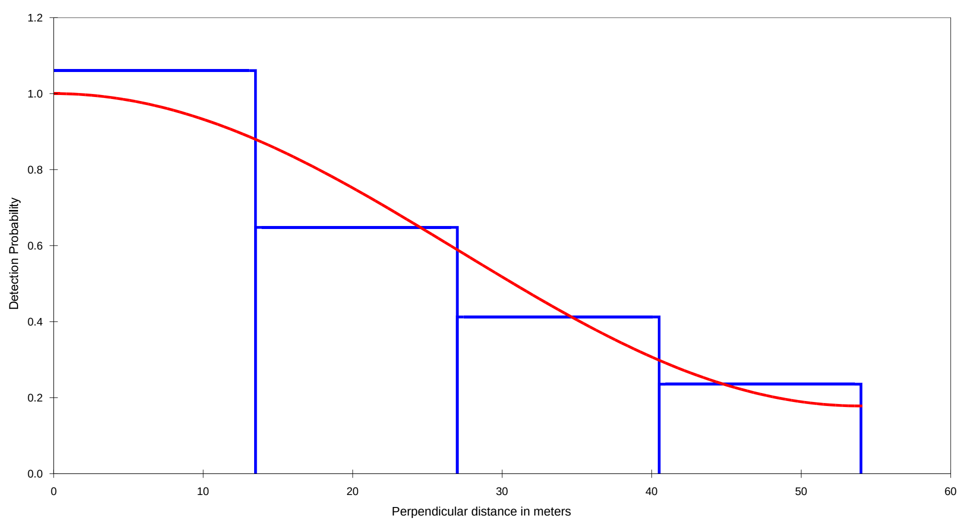
Because of limited observations (i.e., 50 prior to sufficient right-truncation of an elongated tail, 47 following), right truncation was done at 98.1 m to achieve reasonable model fit. The density estimate was 2.4 wild pig per $km^2$ (SE=0.6, 95% CI=1.4-4.0, P=0.8, $\chi 2$=1.0, df=3, Table 4.3). This translates to approximately 784 wild pigs (95%CI=469-1,309, Table 4.3) in BNP's 326.12 $km^2$. Half normal model with series cosine best fitted the data for wild pig in BNP.

For barking deer, we could not obtain sufficient observations in each stratum to generate stratum estimates for detection function, density, encounter rate and cluster size. Therefore, detection function and cluster size were determined globally. Because there were only a total of 43 observations, these results should be considered with caution as 60-80 observations are recommended. Data were right truncated at 54 m to achieve reasonable model fit. The model-averaged density estimate was 1.4 barking deer per $km^2$ (SE=0.3, 95% CI=0.9-2.1, P=0.8, $\chi2$=0.4, df=2, Table 4.3). This translates to approximately 454 barking deer (95% CI=297-696, Table 4.5) in BNP's 326.12 $km^2$. Uniform model with series cosine best fitted the data for barking deer in BNP.

**Detection probability curve (half normal cosine) of wild pig in Bardia National Park.**

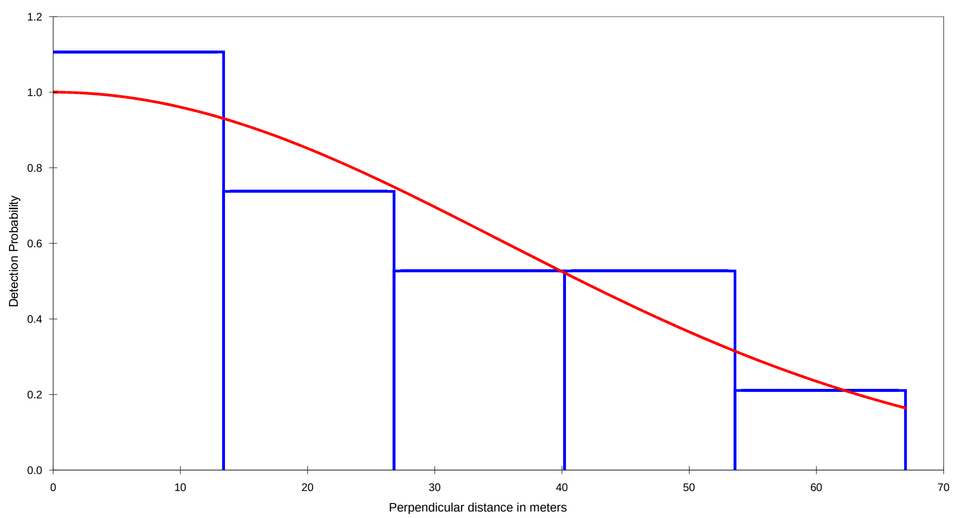



**Detection probability curve (uniform cosine) for barking deer in Bardia Nation Park.**



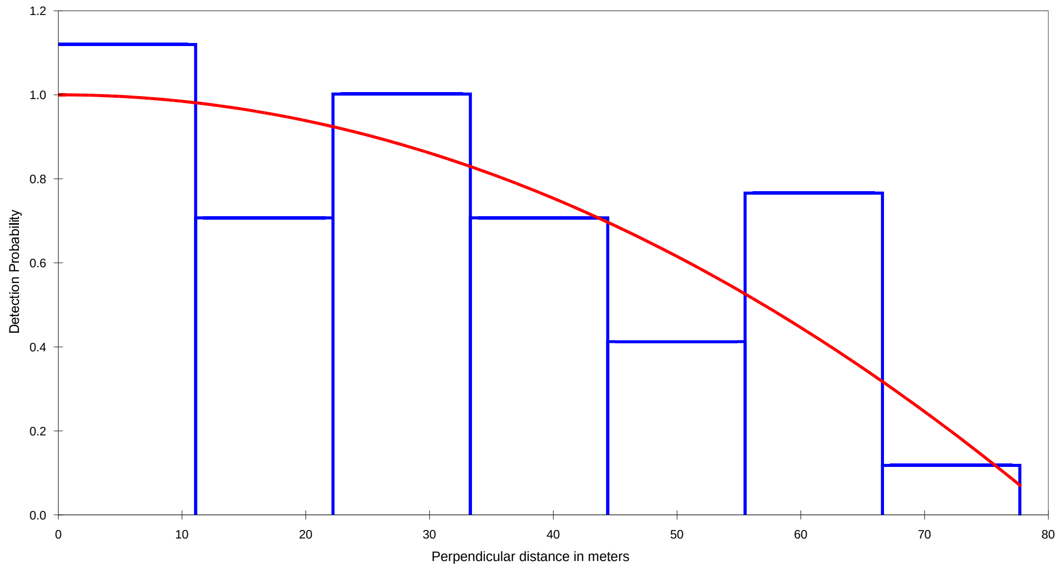
For sambar, we could not obtain sufficient observations in each stratum to generate stratum estimates for detection function, density, encounter rate and cluster size. Therefore, detection function and cluster size were determined globally. Data were truncated at 67 m. The model-averaged density estimate was 3.0 sambar per $km^2$ (SE=0.7, 95% CI=1.8-4.8, P=0.7, $\chi2$=1.5, df=3, Table 4.3). This translates to approximately 964 sambar (95% CI=596-1558, Table 4.5) in BNP's 326.12 $km^2$. Half normal model best fitted the data for sambar in BNP.

**Detection probability curve (half normal) for sambar in Bardia National Park.**




Right truncation of 77.7m was done to fit the model for common langur as we could not obtain sufficient observations in each stratum to generate stratum estimates for detection function, density, encounter rate and cluster size. The model-averaged density estimate was 9.2 langur per $km^2$ (SE=2.3, 95% CI=5.7-14.9, P=0.2, $\chi2$=8.1, df=5, Table 4.3).This translates to approximately 3,012 langurs (95% CI=1,868-4,855, Table 4.5) in BNP's 326.12 $km^2$. Uniform model with series simple polynomial best fitted the data for common langur in BNP.

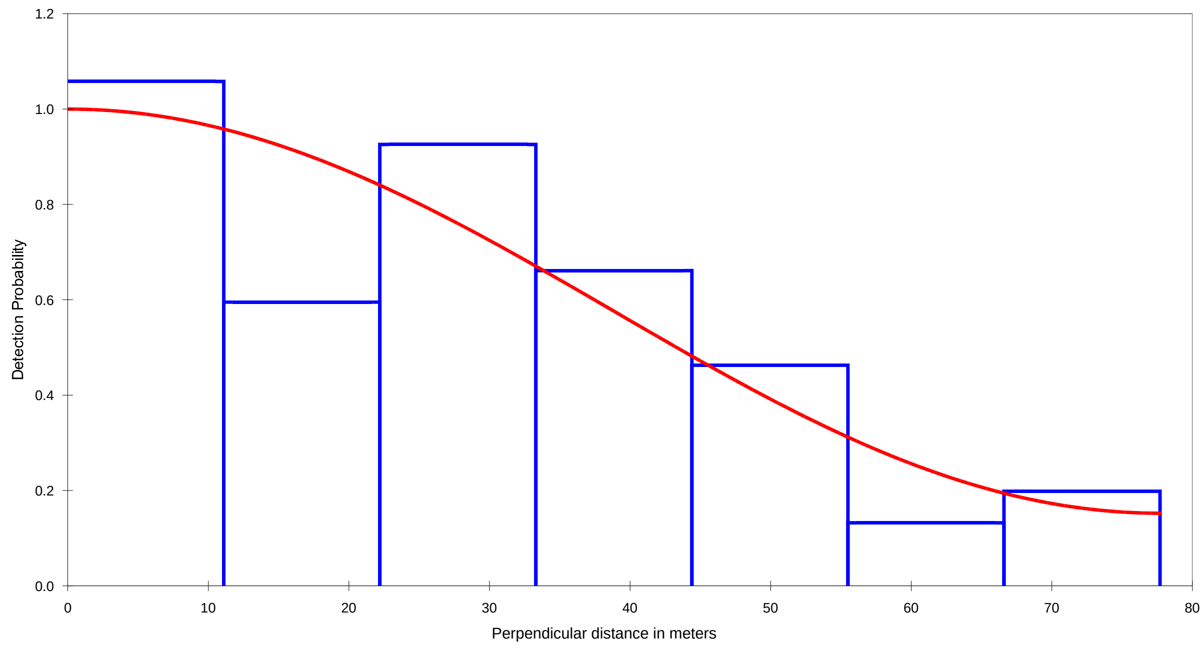
**Detection probability curve (uniform simple polynomial) for langur in Bardia National Park.**




Right truncation of 77.7 m was done to fit the model for rhesus macaque as we could not obtain sufficient observations in each stratum to generate stratum estimates for detection function, density, encounter rate and cluster size. The model-averaged density estimate was 10.6 macaques per km$^2$ (SE=2.8, 95%CI=6.3-17.8, P=0.6, $\chi$2=3.5, df=5, Table 4.3).This translates to approximately 3,448 macaques (95%CI=2,051-5,798, Table 4.3) in BNP's 326.12 km$^2$. Uniform model with series cosine best fitted the data for rhesus macaque in BNP.

Right truncation of 65.4 m was done to fit the model for barking deer and hog deer as we had only 23 observations for hog deer alone to carry out analysis separately. For this combined analysis, global estimates for detection function, density, encounter rate and cluster size was used. The model-averaged density estimate was 2.3 individuals per km$^2$ (SE=0.5, 95%CI=1.5-3.4, P=0.1, $\chi$2=4.5, df=2, Table 4.3). This translates to approximately 746 hog deer and barking deer (95%CI=501-1,109, Table 4.5) in BNP's 326.12 km$^2$. Half normal model best fitted the data for combined hog deer and barking deer in BNP.

**Detection probability curve (uniform cosine) for rhesus macaque in BNP**



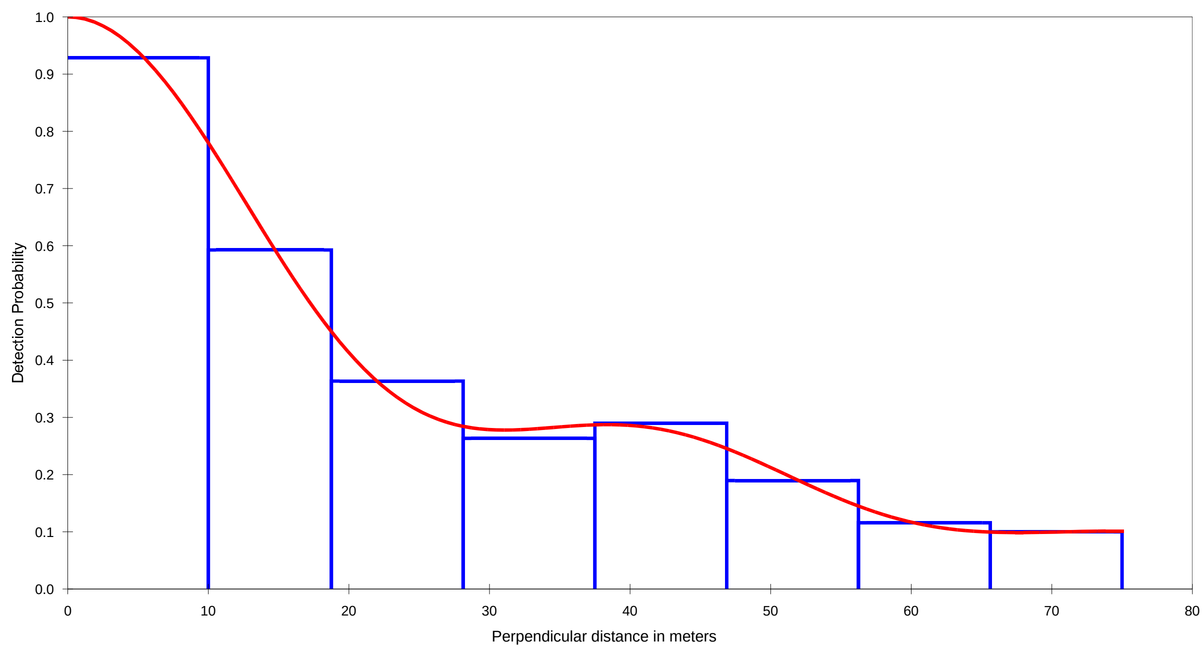

Summing the point estimates from each species that was analyzed separately (excludes four horned antelope – 9 observations, swamp deer – 10 observations and blue bull – 1 observation, rhino - 1 observation, wild elephant 3 - observations), results in an estimated 18,550 main wild prey animals in BNP.  This is within the point estimate and the confidence interval of the overall estimate of 18,356 individuals of wild prey animals (95%CI=14,661-22,983) in Bardia's 326.12 km$^2$.

### 4.5.4. Chitwan National Park

Data were grouped automatically at 75 m cut point and exact distances were used for size-biased regression analyses.

The model-averaged density estimate for main wild prey >6 Kg was 51.7 per km$^2$ (SE=4.9, 95%CI=42.9-62.1, P=0.9, $\chi$2=0.7, df=3, Table 4.3). This is approximately 31,624 wild prey animals (95% CI=26,293-38,036, Table 4.5) in CNP's 612 km$^2$. Uniform model with series cosine best fitted the data for all species in CNP.

**Detection probability curve (uniform cosine) for all species in Chitwan National Park.**

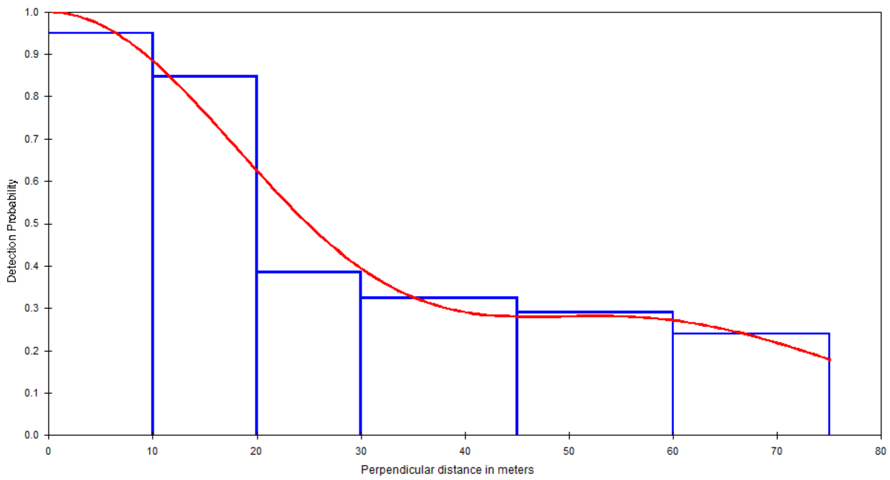



Next, the same general procedures were followed separately analyzing the densities of chital, sambar, wild pig, barking deer, hog deer, primate (Rhesus macaque and common langur combined) and rhino. For chital, data were automatically grouped in to intervals at cut-points of 75 m. Based on model averaging, there were an estimated 32.3 chital per km$^2$ (SE= 6.3, 95%CI=22.1-47.3, P=0.7, $\chi$2=1.5, df=3, Table 4.3) which is an estimated 19,775 chital (95% CI=13,507-28,953, Table 4.5) in CNP's 612 km$^2$. Half normal model best fitted the data for chital in CNP.

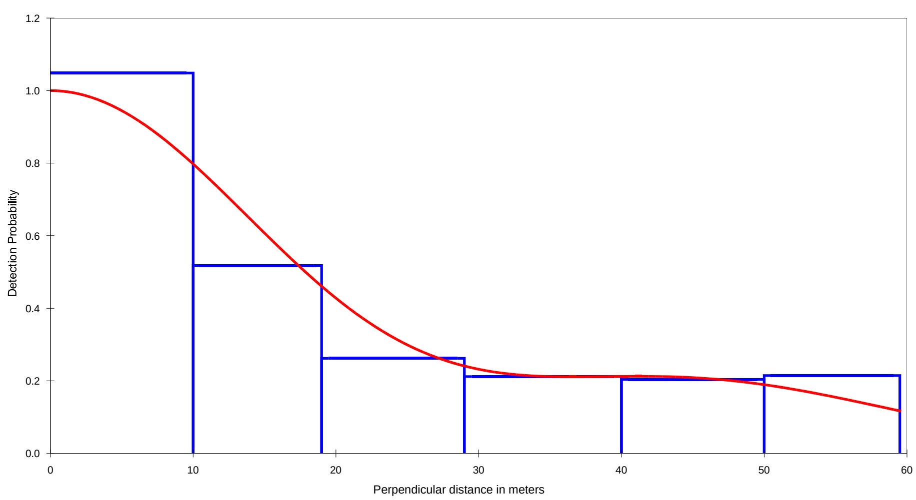
For sambar, data were grouped into automatic class intervals for 59.5 m. The model-averaged density indicated there were an estimated 3.5 sambar per km$^2$ (SE= 0.7, 95%

CI=2.4-5.0, P=0.5, $\chi2$=2.5, df=3, Table 4.3), which is an estimated 2,113 sambars (95% CI=1,554-3,073, Table 4.5) in CNP's 612 $km^2$. Half normal model with series cosine best fitted the data for sambar in CNP.

**Detection probability curve (half normal) for chital in Chitwan National Park.**

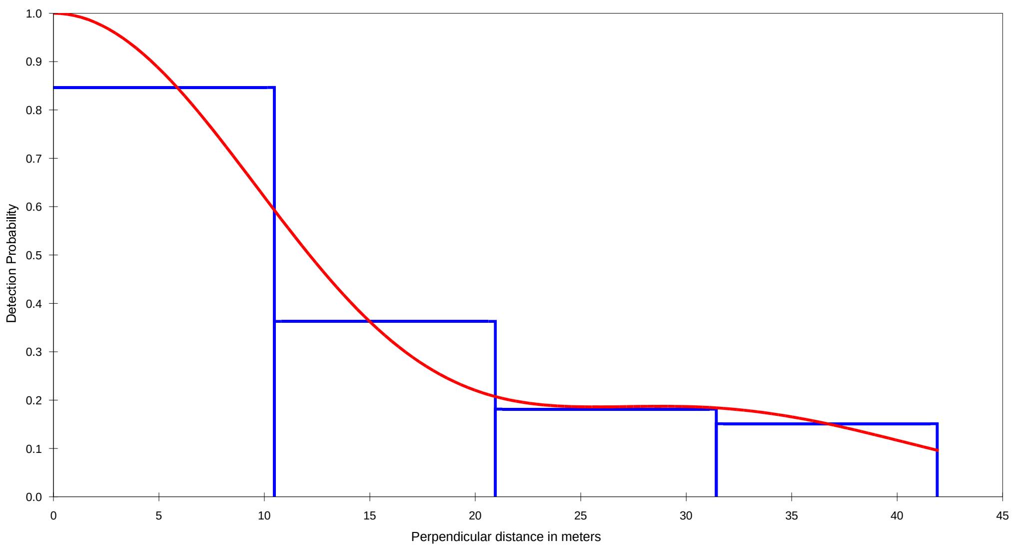



**Detection probability (half normal cosine) for sambar in Chitwan National Park.**



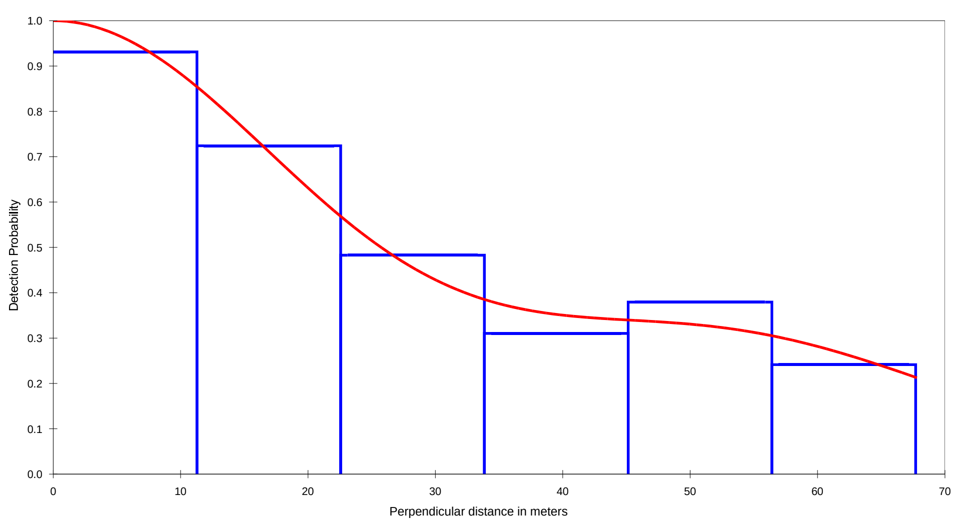

For wild pig, data were classified to 41.9 m. Based on model averaging, there were an estimated 3.4 wild pigs per $km^2$ (SE= 0.8, 95%CI=2.2-5.4, P=0.9, $\chi2$=0.01, df=1, Table 4.3) which is an estimated 2,107 wild pigs (95% CI=1,338-3,318, Table 4.5) in CNP's 612 km$^2$. Half normal model with series cosine best fitted the data for wild pig in CNP.

**Detection probability curve (half normal cosine) for wild pig in Chitwan National Park.**



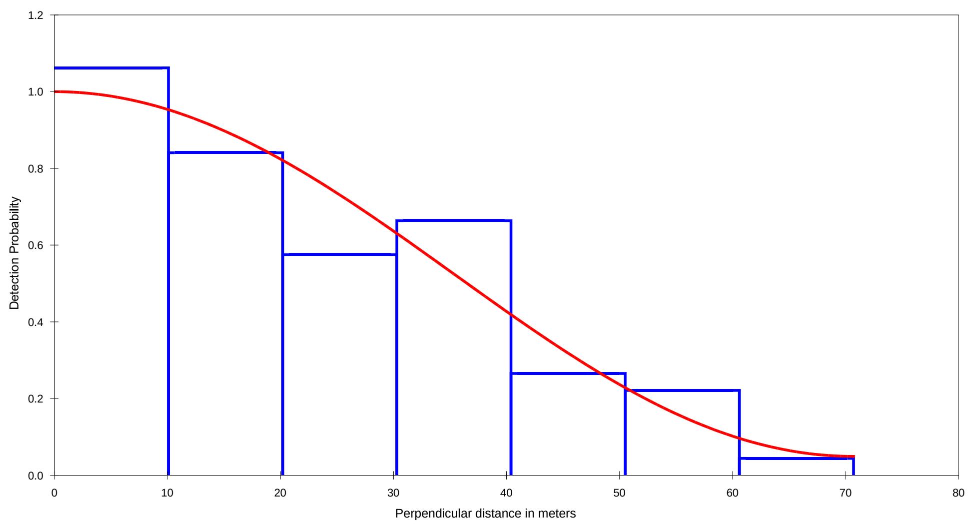

For barking deer, data were grouped for 67.7 m. Based on model averaging, there were an estimated 2.1 barking deer per km$^2$ (SE= 0.4, 95%CI=1.4-3.0, P=0.9, $\chi 2$=0.5, df=3, Table 4.3) which is an estimated 1,275 barking deer's (95%CI=872-1,862, Table 4.5) in CNP's 612 km$^2$. Half normal model with series cosine best fitted the data for barking deer in CNP.

**Detection probability curve (half normal cosine) for barking deer in CNP.**



For hog deer, data were grouped automatically into 6 class intervals up to 70.7 m. The model-averaged density indicated there were an estimated 2.7 hog deer per $km^2$ (SE= 0.5, 95%CI=1.9-3.7, P=0.7, $\chi2$=2.7, DF=5, Table 4.3), which is an estimated 1,636 hog deer's (95%CI=1,171-2,284, Table 4.5) in CNP's 612 $km^2$. Uniform model with series cosine best fitted the data for hog deer in CNP.

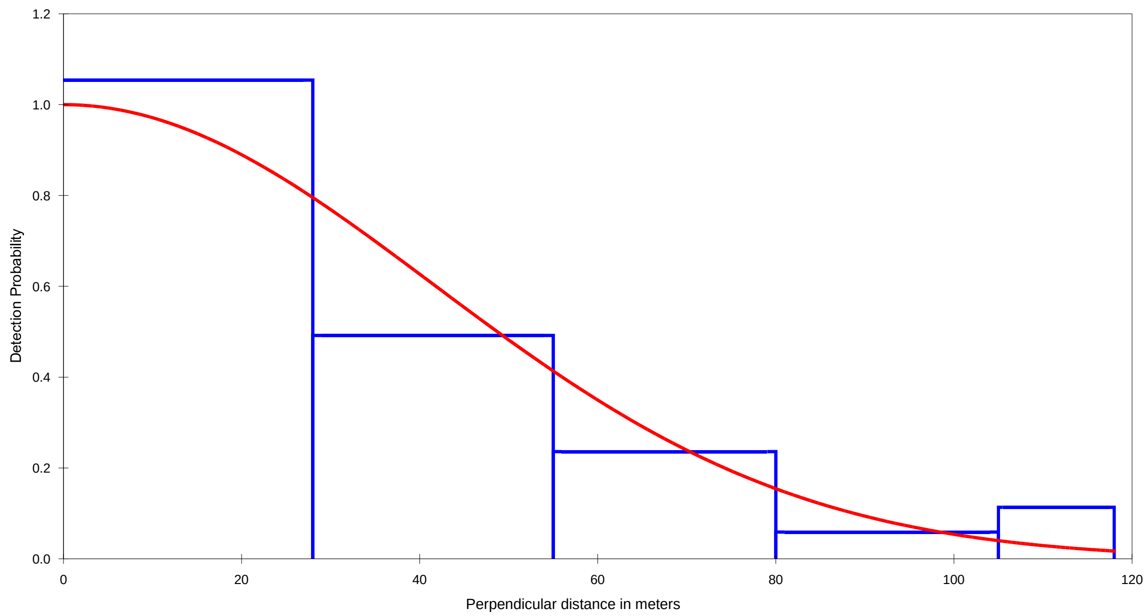
**Detection probability curve (uniform cosine) for hog deer in Chitwan National Park.**



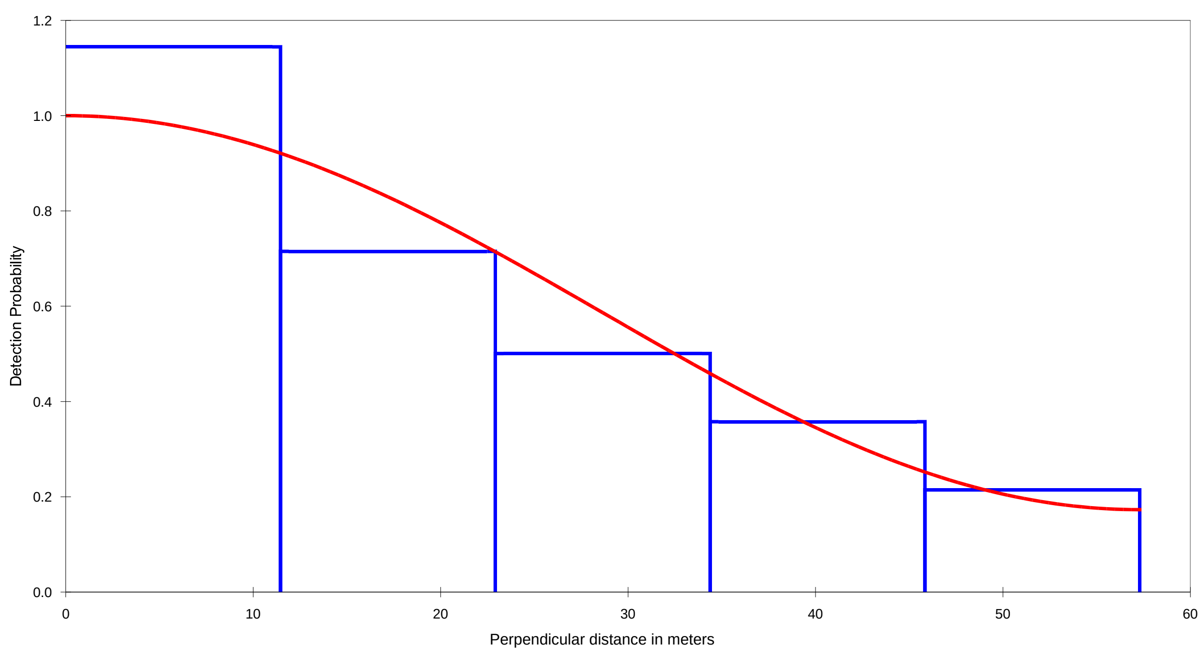

For rhino, data were right truncated to 118 m. The data should be used with precaution as only 38 observations were recorded. Based on model averaging, there were an estimated 0.9 rhino per $km^2$ (SE= 0.2, 95%CI=0.5-1.4, P=0.4, $\chi2$=0.7, df=1, Table 4.3) which is an estimated 528 rhino's (95%CI=323-863, Table 4.5) in CNP's 612 $km^2$. Half normal model with cosine series best fitted the data for rhino in CNP.

For primates (rhesus macaque and common langur was combined), data were right truncated to 57.3 m. The data should be used with precaution as only 41 observations of total 44(rhesus-31 and common langur-13) were used for analysis after truncation. Based on model averaging, there were an estimated 11.9 primates per $km^2$ (SE= 3.9, 95%CI=6.4-12.3, P=0.8, χ2=0.8, df=3, Table 4.3) which is an estimated 7,304 primate's (95%CI=3,905-13,661, Table 4.5) in CNP's 612 $km^2$. Uniform model with cosine series best fitted the data for primate combined in CNP.

**Detection probability curve (half normal cosine) for rhino in Chitwan National Park.**




**Detection probability curve (uniform cosine) for primate in Chitwan National Park.**



Summing the point estimates from each species that was analyzed separately (does not include gaur – 7 observations, wild elephant – 1 observation), results in an estimated 27,434 main wild prey animals in CNP. This is within the point estimate and the confidence interval of the overall estimate of 31,624 wild prey animals (95% CI=26,293-38,036) in CNP's 612 $km^2$.

## 4.6 DISCUSSION

### 4.6.1 Density of wild prey

#### 4.6.1.1 All species in Protected Areas

The density (Animals per $km^2$) of wild prey greatly varies between PAs ranging from 7 in PWR to 145 in SWR.

In SWR, the density (animals per $km^2$) of wild prey was slightly increased, from 108 in 2006 (Yadav 2006) compared to present study. The estimation by Yadav (2006) did not include common langur and rhesus macaque but the combined density of rhesus macaque and langur was 14.8 in present study. Compared to Yadav (2006) density of chital (56 vs.79) and hog deer (6.5 vs. 21.6) has increased but swamp deer (37.0 vs. 30.0) has declined nominally.

In BNP, an increase in density of chital (animals per $Km^2$) from 31.8 to 190.8 was documented by Wegge et al. (2009) into small 11.8 $Km^2$ area of KFP between 1976 (Dinerstein 1980) and 1998 (Wegge et al. 2009). The density of chital in 105 $Km^2$ area of KFP between 1998 (Wegge et al. 2009) and 2009 (Malla 2009) was similar (84.7 vs. 85.3) but there is decline of density to 50.5 chital per $Km^2$ in the same area of KFP, BNP (Table 4.2).

**Table 4.2: Comparison of density of main wild prey species (animal/$Km^2$) in Bardia National Park, Nepal.**

| | Dinerstein 1976 (1980) | Wegge et al. 1998 (2009) | Wegge et al. 1998 (2009) | Malla 2009 | | | 2009 present study (BNP 326.1 $Km^2$) |
|---|---|---|---|---|---|---|---|
| | (11.8 $Km^2$-part of KFP) | | (105 $Km^2$ KFP) | KFP+ | Babai | BNP | |
| Chital | 31.8 ±3.7 | 190.8 ±16.6 | 84.7±7.9 | 85.3±24.9 | 25.5±5.3 | - | 50.5±8.4 |
| Barking deer | 1.7 | 2.6 ±0.4 | 2.3±0.4 | 3.1±1.9 | 2.5±0.8 | - | 1.24±0.32 |
| Hog deer | 3.2±1.2 | 6.9±0.8 | 13.2±1.5 | - | - | 5.0±4.0 | 0.65±0.31 |
| Wild pig | 4.2±0.6 | 1.0±0.2 | 2.2±0.4 | 3.1±0.7 | 1.2±0.7 | - | 1.67±0.53 |
| Swamp deer | 0.5 | 0.2±0.1 | 0.4±0.1 | - | - | - | - |
| Sambar | - | - | - | - | - | 4.1±1.2 | 1.37±0.33 |
| Blue bull | 5.0 | 0.1±0.1 | 0.3±0.1 | - | - | - | - |

+KFP=Karnali Flood Plain.

Our estimate of density for all species in KFP of BNP was comparable (103.7) with 91.5 by Malla (2009) as we have incorporated rhesus (10.6 SE 2.8) and common langur (9.2 SE 2.3) in our estimation.

Chital density obtained from this study (19.2 vs.25.5) is comparable with Malla (2009) in Babai valley, BNP. All species density estimate compared to Malla 28.8 SE 5.5 (2009) in Babai valley was higher in the present study (37.3 SE 6.6) as the present study includes the contribution by primate species. Our result is consistent with Dinnesrtein (1977) and lower to Wegge and Storass (2009) but their intensive area was smaller (11.8 $Km^2$) core habitat compared to present study area in KFP (105 $Km^2$).The lower density in her study could be due to the foot method used by

Malla (2009) compared to present study on elephant back. Malla (2009) did cover more areas incorporating sloppy hills in Babai valley that could have lowered the density compared to present study. Present study was limited to low lying valley with comparatively higher wild prey species abundance.

Compared to Tamang (1982), the density of chital (16.9 vs. 32), wild pig (2.9 vs. 3.4) and sambar (2.7 vs. 3.5) has increased but the density of hog deer (7.9 vs. 2.7) and barking deer (6.6 vs. 2.1) has declined in CNP. We covered larger area and the higher density of hog deer and barking deer was likely in Tamang's study area due to better flood plain habitat for these species. The comparison of the overall density (individuals per $km^2$) with some PAs of India including tiger Reserves shows SWR in the upper range, BNP and CNP in the middle range, whereas the PWR is in the lowest range (Figure 4.1).

Since there is selective poaching of tigers due to their high commercial value in East and South East Asia, it is possible to deplete tigers from forests that have good prey base (Check 2006, Gopal et al. 2010, Chundawat et al. 2010). Thus, the corresponding tiger number could have been higher provided the habitat management focusing prey species need coupled with reduction of human induced mortality in BNP and SWR whereas PWR needs focused program to improve prey condition including introduction/re-introduction of wild prey species.

**Figure 4.1 Comparison of density of ungulate species (Indi./km$^2$) with select PAs in the region.**

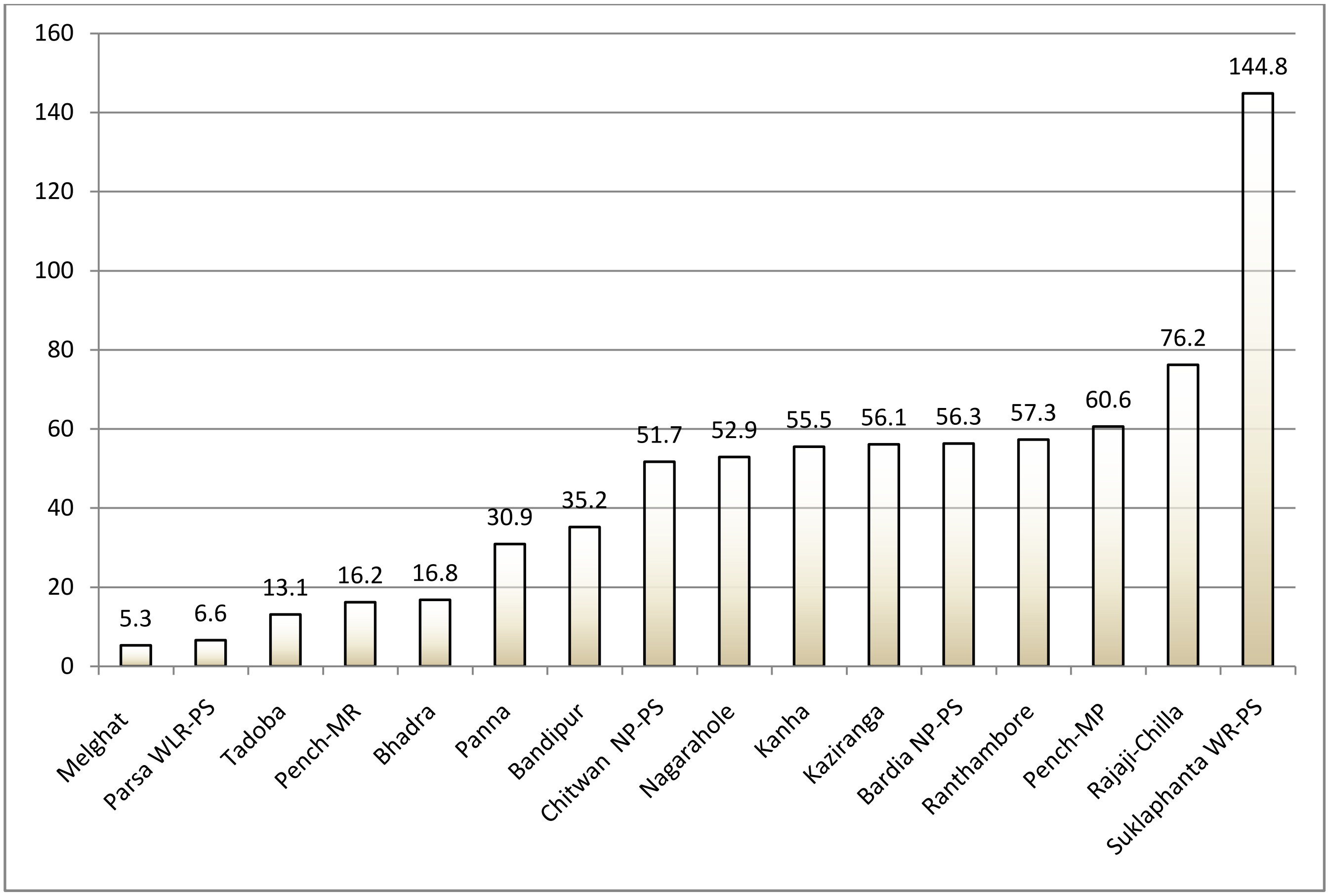


**Table 4.3 Density of tiger's prey species (Indi./km2) in Parsa and SWRs, and Bardia and CNPs, Nepal.**

| Species | Species model | ESW (SE) | Cluster size (±SE) | DS(±SE)/ $Km^2$ | D(±SE)/$Km^2$ | Encounter rate (±SE/Km) | Total Effort | 95%CI | Cut point L,R(m) |
|---|---|---|---|---|---|---|---|---|---|
| **PWR-T.** | **Unif,S.P.** | **41.4 (3.3)** | **1.6(0.2)** | **4.6(0.7)** | **6.6(1.1)** | **0.4(0.04)** | **132** | **4.8-9.1** | **59.6** |
| **SWR-T.** | **HN,Cos.** | **26.4 (1.6)** | **10.7(1.9)** | **25.1 (3.1)** | **144.8 (22.8)** | **1.3(0.1)** | **195.69** | **106.3-197.2** | **80.4,1** |
| Chital | HN,Cos. | 34.3(3.1) | 12.5(2.4) | 7.3(1.3) | 79.0(19.0) | 0.5(0.07) | 195.69 | 49.5-126.0 | 109,0.5 |
| Sw.deer | Uniform | 58.5(7.3) | 29.5(10.2) | 1.8(0.6) | 30.0(16.1) | 0.2(0.06) | 195.69 | 11.0-81.7 | 120 |
| Hog deer | Half N. | 26.6(2.0) | 2.6(0.2) | 9.5(1.8) | 21.6(4.4) | 0.5(0.1) | 195.69 | 14.5-32.1 | 70 |
| Primate | Half N., | 38.1(5.6) | 6.0 (0.9) | 2.1(0.5) | 14.8(4.6) | 0.2(0.04) | 195.69 | 8.1-27.2 | 76 |
| **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** | **45.0-70.5** | **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 | 81.4-132.2 | 85,0.2 |
| Foot Hill | Unif.,Cos. | 37.6(2.7) | 7.4(1.1) | 3.7(0.8) | 22.2(6.5) | 0.3(0.06) | 273.08 | 12.6-39.0 | 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 | 26.3-50.0 | 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 | 22.0-39.1 | 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 | 36.4-70.1 | 87 |
| Ch-FH | Uni,Cos. | 39.5(6.1) | 10.5(1.6) | 2.2(0.7) | 21.8(8.4) | 0.2(0.05) | 273.08 | 10.5-45.4 | 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 | 11.4-32.4 | 82 |

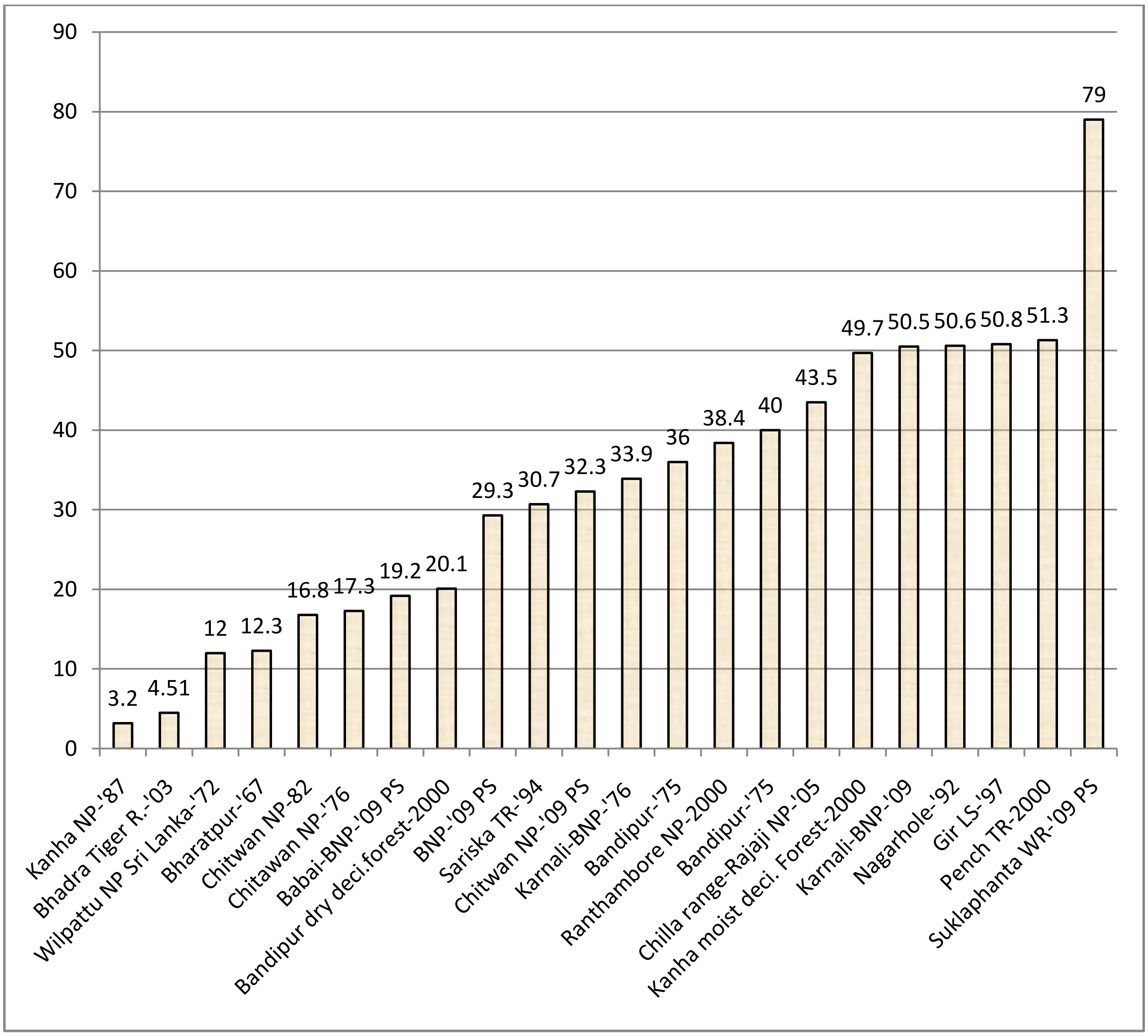
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sambar | Half N. | 41.7(4.9) | 2.3(0.2) | 1.3(0.3) | 3.0(0.7) | 0.1(0.02) | 559.16 | 1.8-4.8 | 67 |
| Wildpig | Halfn,cos. | 40.6(6.8) | 2.2(0.3) | 1.0(0.2) | 2.4(0.6) | 0.08(0.02) | 559.16 | 1.4-4.0 | 98.1 |
| Bk.deer | Unifo.Cos | 31.8(3.4) | 1.2(0.07) | 1.1(0.2) | 1.4(0.3) | 0.07(0.01) | 559.16 | 0.9-2.1 | 54 |
| Langur | Uniform,S.P | 53.6(3.2) | 7.6(0.8) | 1.4(0.3) | 9.2(2.3) | 0.1(0.02) | 559.16 | 5.7-14.9 | 77.7 |
| R.Monkey | Unif.,Cos. | 44.8(3.6) | 8.5(1.0) | 1.2(0.2) | 10.6(2.8) | 0.1(0.02) | 569.12 | 6.3-17.8 | 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 | 1.5-3.4 | 65.4 |
| **CNP_T.** | **Unif.,Cos.** | **26.8(1.5)** | **3.6(0.2)** | **14.1(1.03)** | **51.7(4.9)** | **0.75(0.04)** | **720** | **42.9-62.1** | **75** |
| Chital | HN,Cos. | 34.6(3.7) | 12.7(1.1) | 2.7(0.4) | 32.3(6.3) | 0.19(0.02) | 712 | 22.1-47.3 | 75 |
| Sambar | HN,Cos. | 24.3(3.0) | 1.8(0.1) | 2.4(0.4) | 3.5(0.7) | 0.1(0.02) | 712 | 2.4-5.0 | 59.5 |
| Bk.Deer | HN,Cos. | 34.5(5.0) | 1.2(0.4) | 1.8(0.3) | 2.1(0.4) | 0.1(0.02) | 712 | 1.4-3.0 | 67.7 |
| Hog Deer | Unif,cos. | 37.1(1.7) | 1.8(0.1) | 1.6(0.2) | 2.7(0.5) | 0.1(0.02) | 712 | 1.9-3.7 | 70.7 |
| Wildpig | HN,Cos. | 16.1(2.5) | 1.8(0.2) | 2.2(0.5) | 3.4(0.8) | 0.07(0.01) | 712 | 2.2-5.4 | 41.9 |
| Rhino | HN,cos. | 51.6(6.8) | 12.4(1.5) | 0.9(0.2) | 0.9(0.2) | 0.05(0.01) | 712 | 0.5-1.4 | 118 |
| Primate | Uni,cos. | 33.6(3.5) | 12.4(1.5) | 0.7(0.4) | 11.9(3.9) | 0.06(0.01) | 712 | 6.4-12.3 | 57.3 |

ESW = Effective Strip Width, cluster = average cluster size, DS = group density, D = Individual density, CV% (DS) and CV%(D) = coefficient of variance on estimate of Ds and D respectively, 95%CI= 95% confidence interval on the estimate of individual density.

#### 4.6.1.2 Chital density

Density of chital ranges from 29 in BNP to 79 in SWR (Figure 4.2).

**Figure 4.2: Chital density (Indi./km$^2$) compared with the select PAs in the region.**




(PS = present study) Tiger R/TR = Tiger Reserve, deci. = deciduous, NP = National Park, LS = Lion Sanctuary, BNP = Bardia National Park

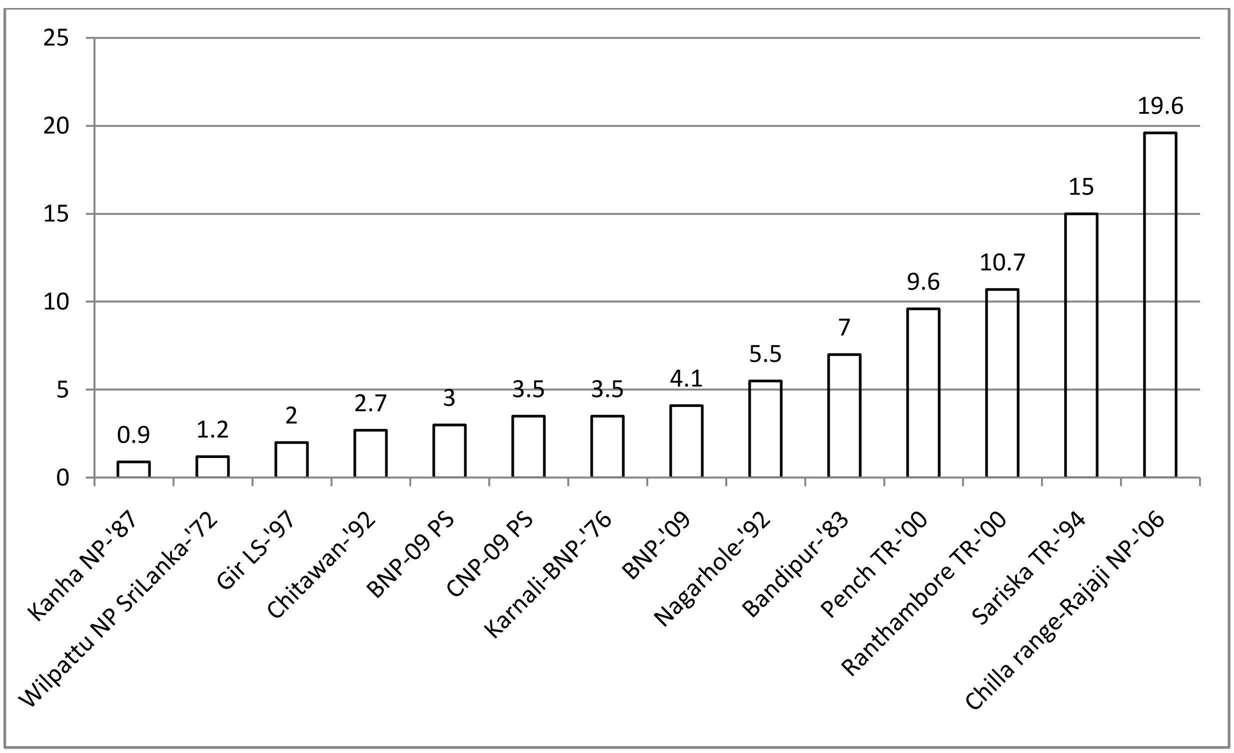
### 4.6.1.3 Sambar density

Density of sambar ranges from 3 in BNP to 4 in CNP. The sambar density (3.0 SE 0.7) was slightly lower compared to 4.1 SE 1.2 by Malla (2009) in BNP.

The sambar density was 3.5 ind. per $Km^2$ in CNP in the present study and was slightly less (2.7 ind. per $Km^2$) than earlier study (Tamang 1982) which may be due to the area covered by Tamang (1982) was limited to lowland which is only medium quality habitat for sambar compared to Churia.

Sambar density is towards the medium to low range while comparing with the some of the available densities in PAs in South Asia (Figure 4.3).

**Figure 4.3. Sambar Density (Indi./$km^2$) compared with select PAs in the region.**



Except the Chilla range of Rajaji NP (higher range, 33-86 in 2005 and 2006, Harihar et al. 2006), the density of sambar ranged from medium to lower side in BNP and CNP (Figure 4.4) whereas it was not observed sufficiently in SWR for analysis.

#### 4.6.1.4 Barking deer

Density of barking deer ranges from one in BNP to two in CNP. Barking deer has shown nominal decrease (1.4 ind. Per $Km^2$) compared to earlier studies 1.7, 2.6. 3.1 (ind. Per $Km^2$) by Dinnerstein (1980), Wegge et al. (2009) and Malla (2009) respectively in BNP. The present estimation is for whole BNP (612 $Km^2$) whereas the study area of Dinnerstein (1980) and Wegge et al. (2009) was part of our study area in KFP.

**Figure 4.4. Barking deer density (Indi./km2) compared with select PAs in the region.**

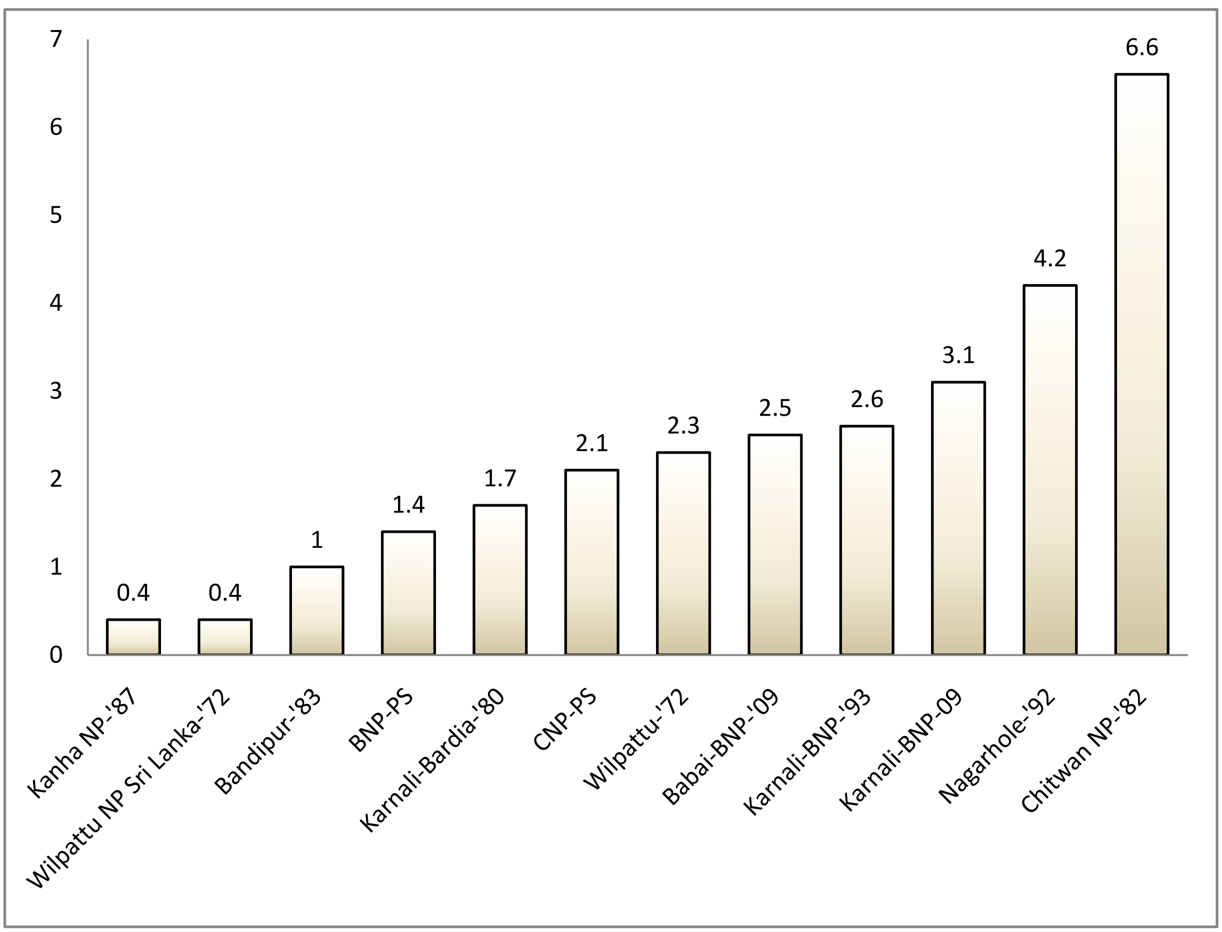


**Table 4.4. Density comparisons (Indi./km$^2$) of hog deer and swamp deer in different PAs in the region.**

| Species | Location /Area | Number | Ecological density (N/km$^2$) | Source |
|---|---|---|---|---|
| Hog deer | Karnali-BNP | 25-50 | 2.1-4.2 | Dinerstein 1980 |
| | | | 3.2 | Wegge et al. 2009 (1993) |
| | BNP | | 4.9 | Malla 2009 |
| | Chitwan | | 35.0 | Seidensticker 1976 |
| | CNP | | 2.7 | Present Study |
| | SWR | | 21.6 | |
| | Gorumara NP | 3580 | 37.3 | Bhoumik and Chaudhary 2001 |
| Swamp deer | Karnali-BNP | 6 | 0.5 | Dinnerstein 1980 |
| | | | 0.2 | Wegge et al. 2009 (1993) |
| | | 91 | 4.6 | Parajuli 2001 |
| | | 73 | 3.7 | Ghimire 1996 |
| | SWR | 908 (32 km$^2$) | 28.4 | Schaaf 1978 (1976) |
| | | 2250(51.1km$^2$) | 43.7 | Mehta 1987 |
| | | | 30.0 | Present Study |
| | Kanha NP, India | | 5.2 | Schaller 1967 |
| | Kaziranga NP, India | | 2.52 | Vasu 2003 |

#### 4.6.1.5 Swamp deer

Swamp deer has shown slight decline while comparing for 22 years between 1976 and 1998 in BNP. The swamp deer is forming second dense prey species after chital in SWR but not figuring in sufficient data points for BNP due to their narrow distribution range in the Khauraha-Baghaura-Lamkauli grasslands on KFP (Table 4.4).

#### 4.6.1.6 Hog deer

Density of hog deer ranges from 3 in CNP to 22 in SWR. Hog deer appears to be third dense wild prey in SWR and CNP but their medium body size and restricted distribution in tall flood plain grasslands (Table 4.4) may restrict its availability to tiger.

#### 4.6.1.7 Wild pig

Density of wild pig ranged from 2 in BNP  to 3 in CNP. Wild pig was comparable (2.4 vs. 2.2 ) with Wegge et al. (2009) but showed slight decline compared to 4.2 Dinnerstein  (1976) and 3.1 Malla (2009) in BNP. The difficulties in detecting the wild pig from elephant, shyness and flash behavior may have reduced the expected density in tall to medium grassland and dense forest areas of Nepal's tiger bearing PAs.

#### 4.6.1.8 Langur/Macaque

Density of primate ranges from 12 in CNP to 20 in BNP. These primate are also forming part of the tiger diet (Maharjan 2011, Wegge et al. 2009), contributing 5.8% each by langur and rhesus in PWR (Maharjan 2011). Langur was found to be 5.7% in items of relative number of tiger kill (Wegge et al. 2009) in BNP. In BNP, the density of common langur and rhesus macaque combined was 16.73 SE 6.6 (Malla 2009) whereas we estimated rhesus macaque 10.6 SE 2.8(6.3-17.8) and common langur 9.2 SE

2.3 (5.7-14.9) respectively (Table 4.3). Combined density of rhesus macaque and common langur was estimated to be 14.8 SE 4.6 (8.1-27.2) and 11.9 SE 3.9 (6.4-12.3) in SWR and CNP respectively (Table 4.3) in this present study.

### 4.6.2 Abundance of wild prey

The abundance of main wild prey ranges from 1,639-3,095 in PWR to 26,684-39,262 in CNP (Table 4.5). Pellet group abundance (number of pellet groups per plot) was found higher for Chital 1.35 (65%), followed by sambar 0.28 (12%), swamp deer 0.19 (8%), wild pig 0.08 (3%), blue bull 0.07(0.2%), barking deer 0.07 (3%), hog deer 0.05 (2 %), four-horned antelope 0.02 (1%), langur/macaque 0.06 (3%) and livestock 0.07 (3%) by Shrestha (2004) for the TAL's PAs of Nepal.

In PWR, the abundance of main wild prey species was low 1,591 (1,639-3,095) and the estimated number of tiger was similarly low 4 (4-4). The Churia and outer foot hills do not hold water during the dry periods. The Reserve does not have sufficient grasslands intermixed with water sources in spatial scale. The attempt to create grasslands and construction of ponds to provide water has been continued. The relocation of chital from the musk deer research center, an artificial rearing center in Kathmandu, are under regular monitoring to evaluate their performance in the wild (Bhattarai 2009) where predators are around and their performance are not much encouraging (pers. com. BR Yadav, then CCO). The resettlement of Rambhori and Bhata villages in 2010 is providing the habitat for ungulate as the abandoned agricultural fields are being converted to grasslands as a first assemblage in succession. The ponds constructed by the earlier village lord for fish farming are providing water and the area has potential for an appropriate habitat of chital and other wild prey species including rhino.

In rest of the three PAs, the numbers of main wild prey were reasonably high. Prey density is a suitable predictor of tiger (Karanth et al. 2004) and the decline of wild prey do not seems to be a main problem and their recovery can be made if the human induced pressure (encroachment, poaching, etc) is controlled.

High abundance of prey species was also reported by Wegge and Storass (2009 ) and further argued that better protection from poaching probably contributed only marginal increase of tigers; prior to establishment, the area was used as a Royal Shikari (hunting) Reserve with deployed forest guards to prevent killing of tigers (Bolton, 1976) in BNP.

Thus, it is essential to focus management on maintaining and/or increasing wild prey in addition to appropriate protection.

Chital and hog deer was contributing higher in numbers in CNP, SWR and BNP. Sambar, wild pig and Barking deer were higher in number in CNP followed by BNP. Primate was higher in CNP followed by BNP and SWR (Table 4.5).

The swamp deer is restricted in only two meta-populations in Nepal, about 83 (Malla 2009) in BNP and 1,674 (Khadka 2007) in SWR.  The swamp deer population in BNP has grown from only 15 individuals in 1977 (Dinnrstein 1979). The Suklaphanta population estimates ranges between 805 in 1975 (Schaaf 1978) and 2,291 in 2004 (Bhatt 2004). Ghimire (1996) has recorded few individuals of swamp deer in Babai valley and suggested management of open grassland patches to attract them. There used to be swamp deer in CNP until early 1960 (Mishra 1982, Gurung 1983) mainly north of Rapti river which was settled by farmers from the south of Rapti river.

**Table 4.5 Status of the tiger's wild prey (Indi./km$^2$) in Parsa and SWRs, and Chitwan and BNPs.**

| PAs | Wild prey type | Abundance | | Wild prey type | Abundance | |
|---|---|---|---|---|---|---|
| | | Animals | 95% CI | | Animals | 95% CI |
| PWR* | All | 1,591 | 1,154-2,192 | | | |
| CNP | All | **31,624** | **26,293-38,036** | Sambar | **2,113** | **1,554-3,073** |
| | Chital | 19,775 | 13,507-28,953 | Barking deer | 1,275 | 872-1,862 |
| | Wild pig | 2,107 | 1,338-3,318 | Rhino | 528 | 323-863 |
| | Hog deer | 1,636 | 1,171-2,284 | Primate | 7,304 | 3,905-13,661 |
| BNP | All | **18,356** | **14,661-22,983** | Karnali FP | **15,901** | **12,480-20,260** |
| | Foot Hills | 2,553 | 1,452-4,487 | Babai valley | 2,153 | 1,515-3,059 |
| | Chital | 9,596 | 7,180-12,743 | Wild pig | 784 | 469-1,309 |
| | Barking deer | 454 | 297-696 | Sambar | 964 | 596-1,558 |
| | Hog+Bk. deer | 746 | 501-1,109 | Rhesus | 3,448 | 2,051-5,798 |
| | Langur | 3,012 | 1,868-4,855 | | | |
| SWR | All | **25,548** | **20,963-38,879** | Chital | **15,563** | **9,749-24,844** |
| | Hog deer | 4,252 | 2,856-6,329 | Swamp deer | 5,909 | 2,167-16,112 |
| | Primate | 2,924 | 1,596-5,357 | | | |

* = analysis performed for all species, Bk. = Barking deer, FP = flood Plain

There were records of about 60 individuals of blue bull in the BNP's KFP (11.8 km$^2$) area (Dinerstein 1980). Later estimate ranges form 57- 86 (Khatri 1993) and between 36 - 45 (Subedi 2001) individuals in BNP. Malla (2009) recorded bull in four occasions and researcher (Dec. 2008) saw two bulls in Lamkoili phanta. The habitat has been changed in to dense forest cover and they have started to move outside PAs in BZ forest. The possible reason of the decline of blue bull could be the unsuitable habitat in PAs, conflict with local people due to crop raiding and hunting outside PAs.

35-47 individuals of blue bull were estimated in SWR and 29-35 individuals in PWR (Subedi 2001) whereas only few records are available in CNP. The larger sized prey, blue bull, could have contributed significantly to the diet of tiger in Nepal but their existence in CNP and BNP is now in question. Further habitat management and people's participation for their protection in BZ are essential to keep them alive in CNP and BNP.

Only seven observation of gaur was made in the line transects in CNP but 296 individuals of gaur were recorded in 2007 (DNPWC 2008). Though no observation could be made in line transect in PWR, direct count revealed 37 gaurs (28 were direct sightings and 9 were indirect counts) in effectively sampled area of about 170 $Km^2$ in earlier survey. Of 37, 8 were male, 11 were female and 18 unknown. Of 37, 17 were adults, 2 were sub-adults, 9 were calf and gender could not be assessed for rest 9 (DNPWC 2007). Except during the April - May, gaur are restricted to Churia area in CNP and PWR (Chetri 1994). The gaur might be supporting diet for tiger in CNP and PWR particularly in the Churia. The distribution of tiger in Churia area of CNP supports this prediction. One four horned antelope was seen by Malla (2009) twice and camera trap has recorded some photographs in BNP. We did not recorded wild elephant in line transect. There are 80 individuals of wild elephant in BNP (Pradhan 2007) of which 50 are estimated in KFP and 30 in Babai valley with the density is 0.2 elephant in KFP of BNP (Pradhan 2007). There were only 10 - 15 elephants in 1970's (Uprety 1994) and reduced to 3 individuals till 1992 (pers. Obs. 1992/93).

# CHAPTER FIVE : ESTIMATING TIGER ABUNDANCE THROUGH CAMERA TRAP IN TERAI ARC LANDSCAPE, NEPAL

## 5.1 INTRODUCTION

Tigers have been serving as flagship species to generate worldwide conservation attention for Asian forest biodiversity. Ironically, tigers are now in peril as their current global population is comprised of <5% of what was estimated just a century ago (Dinnerstein et al. 2007).

The Royal Bengal tiger was once widespread across south Asia and are now restricted to Bangladesh 440, Bhutan 75 (67-81), India 1,706 (1,502-1,909), Myanmar (85), Nepal 155 (124-229 adults) (GoN. 2010, GTRP 2010, Jhala et al. 2011).

Historically, tigers were distributed continuously across the lowland Himalayan forests in Nepal. Surveys, between 1987 and 1997, documented only three isolated tiger populations, remained in Nepal-Chitwan, Bardia and Suklaphanta (Smith et al. 1998). These are major source population for Nepal and part of northern India and have the potential to recover over the next 10 years, given adequate conservation effort (Dinnerstein et al. 2007).

Knowledge about the abundance is crucial for conservation and management of the concerned species. Estimation of animal abundance has now become a very specialized branch of research in field techniques and biostatistics (William et al. 2002). In Nepal, the oldest population estimates of tiger come from CNP. The estimates in the past were based on either radio-telemetry (Sunquist 1981, Smith 1993, Smith et al. 1999) or pugmark surveys (McDougal 1999). Although they provided an estimate, these methods did not explicitly deal with the two key issues of animal population estimation: incomplete spatial sampling of the area of interest and incomplete detection of animals even within the area that was sampled. It is now clearly recognized that 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).

In this study camera trap based mark-recapture framework was used to obtain abundance estimates of tigers across all population in Nepal.

## 5.2 OBJECTIVE

To estimate the density of tigers in Nepal's TAL PAs.

## 5.3 STUDY AREA

The study was focused mainly in BNP, CNP, SWR, and PWR of TAL, Nepal. The details of the area are described under chapter two section 2.3.2. Camera traps were deployed in the lowland areas of the PAs.

## 5.4. METHODS

Camera trapping was employed to estimate tiger abundances inside PWR, CNP, BNP and SWR.

### 5.4.1 Survey Design

After reconnaissance survey the study area was divided into 5, 6, 12 and 20 sampling blocks in PWR, SWR, CNP and BNP, respectively. In BNP, four groups operated simultaneously by using 12-13 pairs of camera each. In CNP, two groups with 25 pairs of camera operated simultaneously. Camera traps were rotated between blocks to cover the entire areas. Cameras were deployed for total of 85 days in BNP, 114 days by first group and 125 days by second group in CNP, 108 days in PWR and 106 days in SWR using 15 day sampling periods in each of the camera locations.  25 pairs of camera each in PWR (Figure 5.1) and SWR (Figure 5.4) and 50 pairs of camera each in BNP (Figure 5.3) and CNP (Figure 5.2) adequately covered PAs in the stipulated period of time. Trap distance between two trapping stations (Wegge et al. 2004) was 2 km for PWR and 1.5 Km for rest of three PAs. Care was taken not to leave any potential holes in the sampling area of interest.

Limitation of the work was survey restricted to the lowlands in all four PAs, and South and south eastern areas (Dhaka, Jhilmila, etc) of SWR.

### 5.4.2 Field Methods

Survey was conducted between December 2008 and March 2009 by employing Stealth Cam (Stealth Cam, LLC,Bedford, TX, USA) and Moultrie (Moultrie Feeders, 150 Industrial Road, Alabaster, AL35007) passive camera traps. The traps were placed along the forest roads, river and stream beds, salt-licks, waterholes, ridge lines and trails that are frequently used by tigers. Camera traps wherever feasible were camouflaged with natural vegetation, and no impression pads were made close to the camera stations (Wegge et al. 2004). If trap shyness was detected (tiger tracks showing avoidance of cameras), the camera location was changed by 50-100 m. Due to the possibility of camera theft during day time, the camera were placed during late afternoon (around 16:00 hours) and removed by late morning (after 09:00 hours) to minimize temporal overlap with human activity in forests and maximize temporal overlap with tiger active phase (Tamang 1982). The sampling period was maintained at approximately 14 hrs for each sampling occasion. New travel routes were made at strategic points by clearing vegetation to ease placement of cameras for trapping tigers where natural trails were not available.

**Figure 5.1. Camera trap locations in Parsa Wildlife Reserve, Nepal**

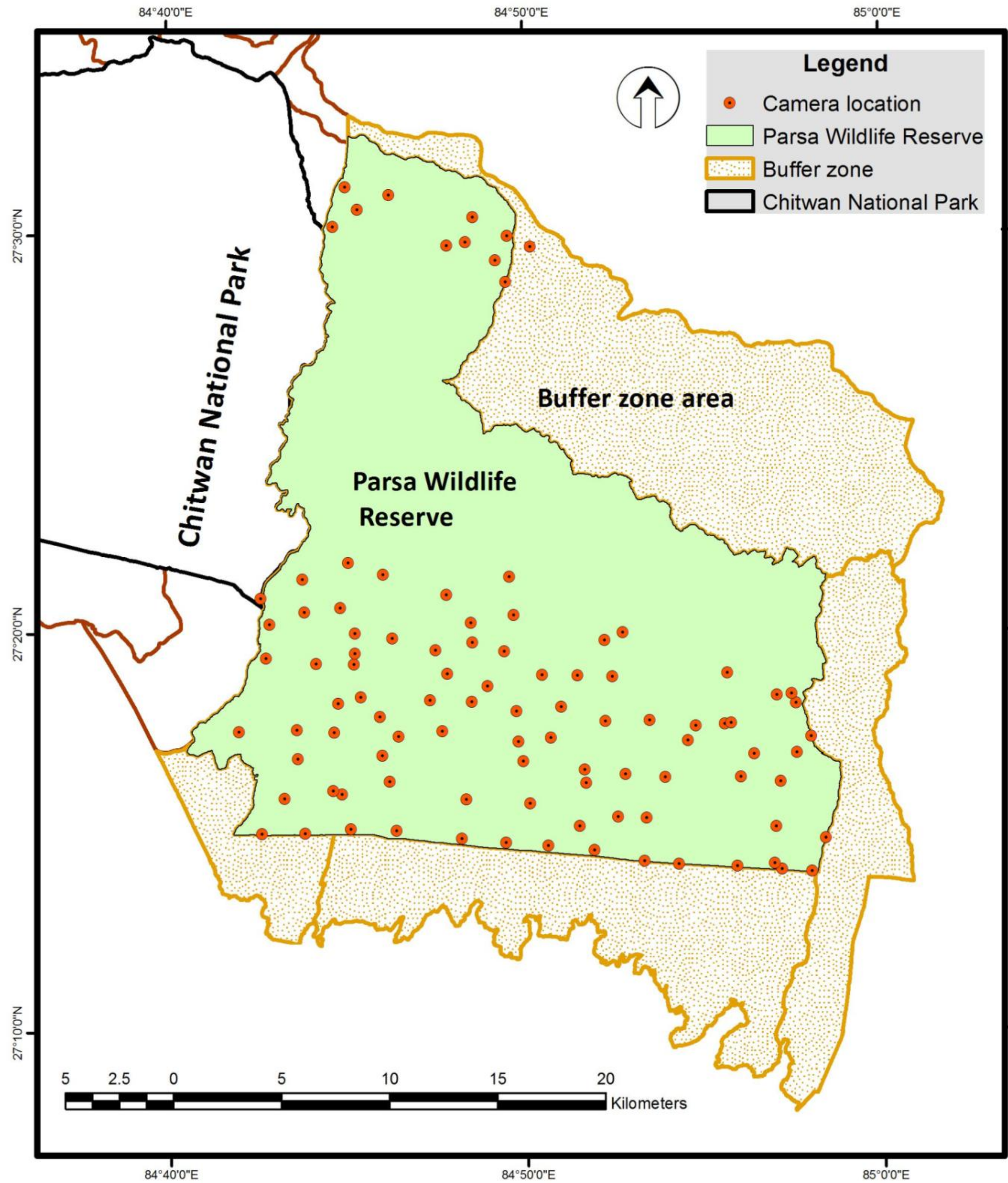


**Figure 5.2 Camera trap locations in Chitwan National Park, Nepal**

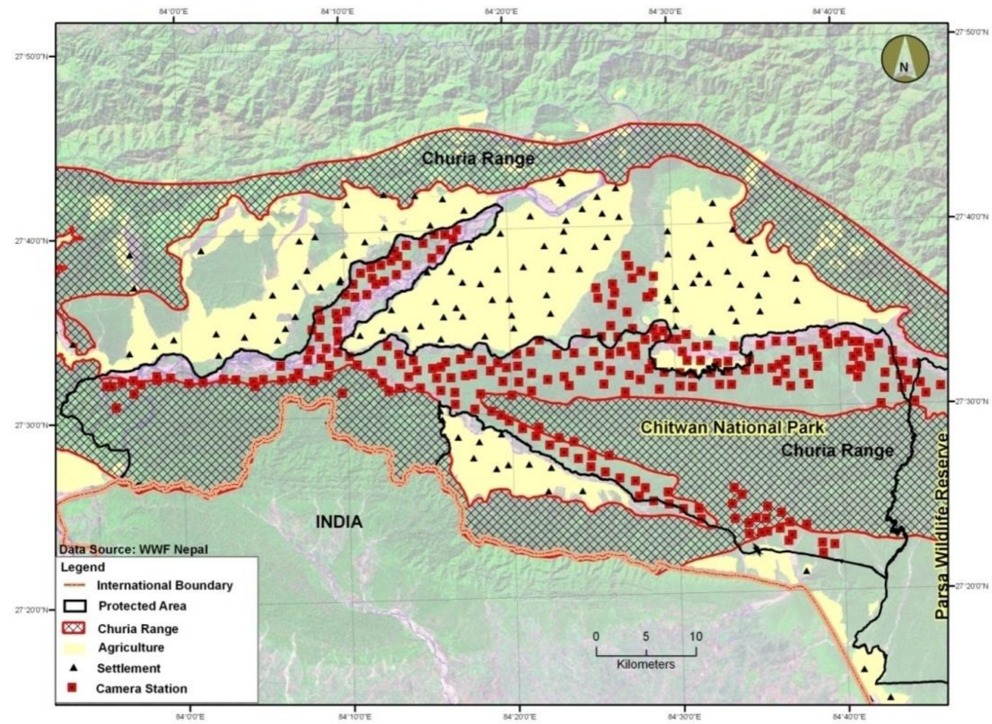



**Figure 5.3. Camera trap locations in Bardia National Park, Nepal**

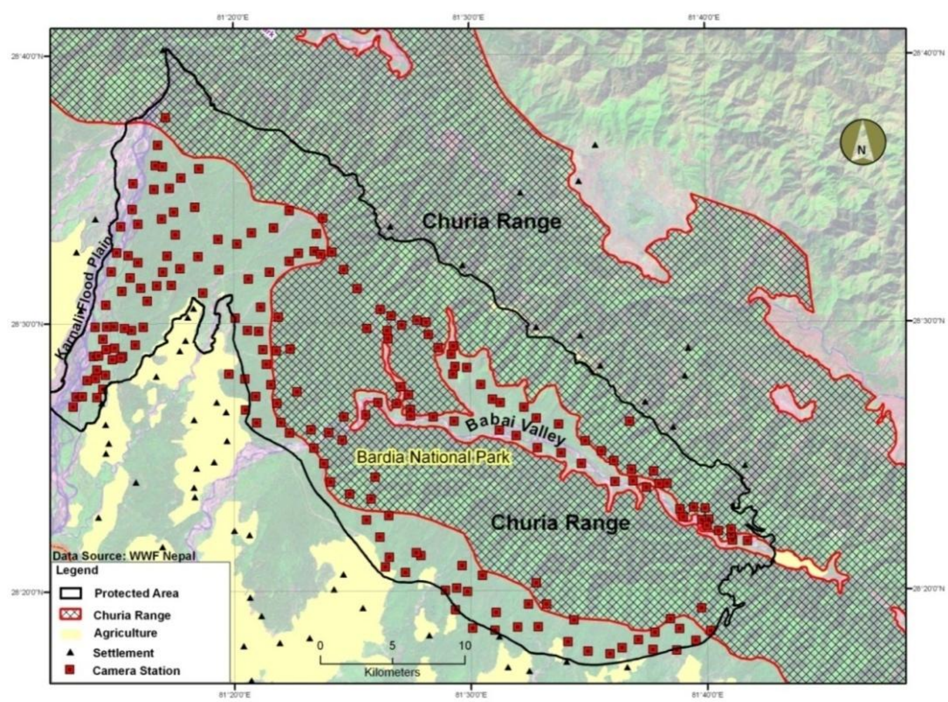
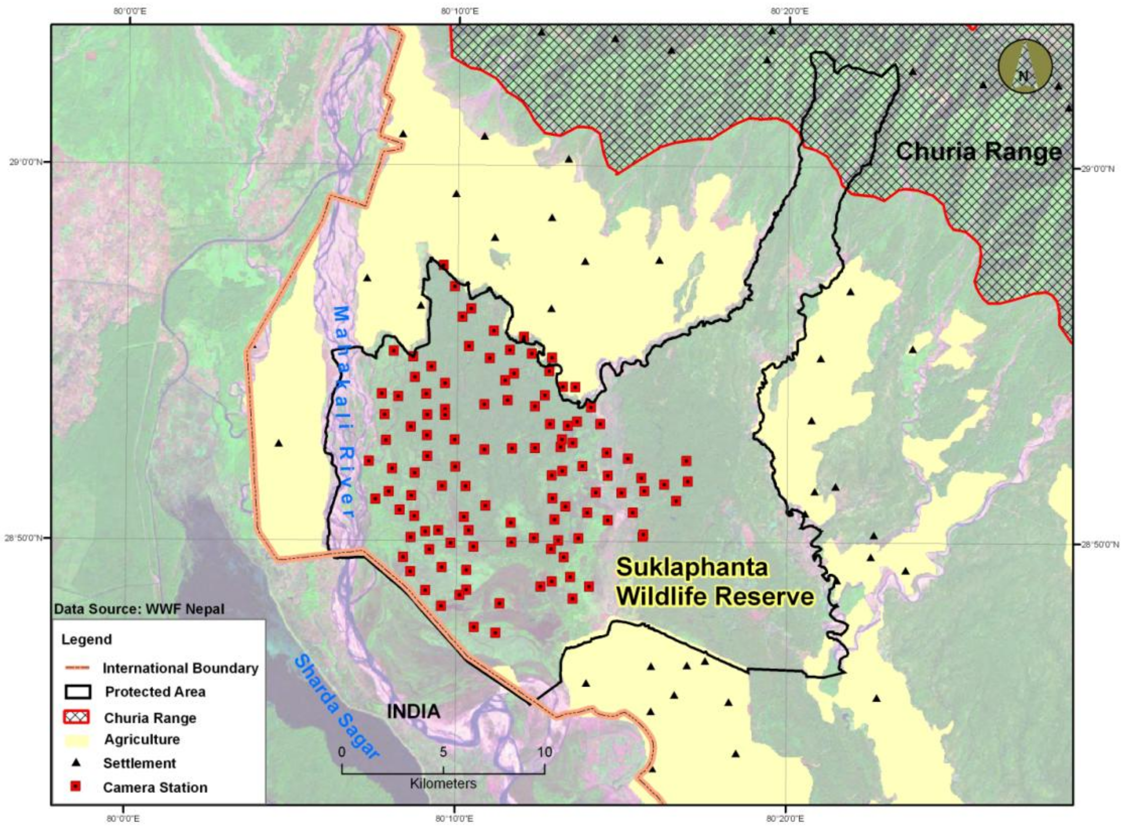


**Figure 5.4 Camera trap locations in Suklaphanta Wildlife Reserve, Nepal.**




## 5.4.3 Analytical Methods

Camera trap mark-recapture analysis (Karanth and Nichols 1998; Pollock et al. 1990) was undertaken to estimate tiger population parameters. Capture histories (X matrix) were developed by identifying every tiger captured on the basis of the stripe pattern on the body flanks, and legs (Karanth 1995; McDougal 1977; Schaller 1967). Capture histories are simply strings of 1's and 0's indicating capture and no capture, respectively, at each specific sampling period. For example, a capture history of 01001 indicates that the animal was captured only on sampling periods 2 and 5 of a 5-occasion study. Data were analyzed using the program CAPTURE 2 interface (Otis et al. 1978; Rexstad and Burnham 1991; White et al. 1982). Comparing life span of tigers and a larger spatial coverage, we considered the tiger population as demographically and geographically closed (Karanth 1995; Karanth and Nichols 1998; Otis et al. 1978) during the camera trap period.

Model selection was guided by the Discriminant Function Test that scores all plausible models between 0.0-1.0, with a higher score indicating a relatively better fit of the model to the set of observed capture histories. However this model selection routine of program CAPTURE has tendency to default to selection of Mo in instances when sample sizes are low, thus we also considered the between-model goodness of fit tests and other relevant parameters while selecting the best model.

The density (D) of tigers in the study area was estimated as the population size (N) divided by the effectively sampled area (A(W)). $\hat{A}(W)$ was computed by adding a buffer width $(\hat{W})$ to the polygon connecting the outermost camera-trap stations, on a (GIS) platform, and removing those areas which were under land uses that do not support tiger presence (e.g. agricultural fields, settlements). The buffer width, $\hat{W}$, an estimate of half the home range length, was estimated as half the average of maximum distances moved by animals captured at least twice (½ MMDM) (Karanth and Nichols 1998; Wilson and Anderson 1985). The mean of the maximum distance moved between captures for each individual tiger (MMDM) is an estimate of the average home range diameter, and attaches a buffer strip width of half this home range diameter around the polygon formed by outermost camera traps to estimate the area sampled.

Following this method, if $d_i$ is the maximum distance moved between recaptures for animal *i*, and *m* the number of animals captured at least twice during the study, the mean and variance of the maximum distance moved are:

$$\hat{\bar{d}} = \frac{\sum_{i=1}^{m} d_i}{m} \qquad \hat{\mathrm{var}}(\hat{\bar{d}}) = \frac{\sum_{i=1}^{m} (d_i - \hat{\bar{d}})^2}{m(m-1)}$$

The boundary strip, *W*, and its variance are:

$$\hat{W} = \frac{\hat{\bar{d}}}{2} \qquad \hat{\text{var}}(\hat{W}) = \frac{\hat{\text{var}}(\hat{\bar{d}})}{4}$$

Density and its variance are then estimated as:

$$\hat{D} = \frac{\hat{N}}{\hat{A}(W)} \qquad \hat{\text{var}}(\hat{D}) = \hat{D}^2 \left[ \frac{\hat{\text{var}}(\hat{A}(W))}{\hat{A}(W)^2} + \frac{\hat{\text{var}}(\hat{N})}{\hat{N}^2} \right]$$

The same capture history was used in the program DENSITY version 4.4.1.6 (Efford 2011) and Spatially Explicit Capture Recapture (SECR) algorithm in program DENSITY was used to estimate density of tigers.

## 5.5 RESULTS

### 5.5.1 Parsa Wildlife Reserve

A total of 97 trap locations (Figure 5.1) were sampled accounting for a total sampling effort of 1,762 trap nights. This revealed four individual tigers, 2 males and 2 females in PWR. All four tigers were recaptured more than once (Figure 5.5) with a mean maximum distance between two captures of 8.3 km (SD 2.2). Trapping results showed that no new tigers were trapped after 12$^{th}$ night, while total number of captures tends to stabilize after the 13$^{th}$ nights (Figure 5.6).

**Figure 5.5. Total captures of each identified tiger in Parsa Wildlife Reserve.**

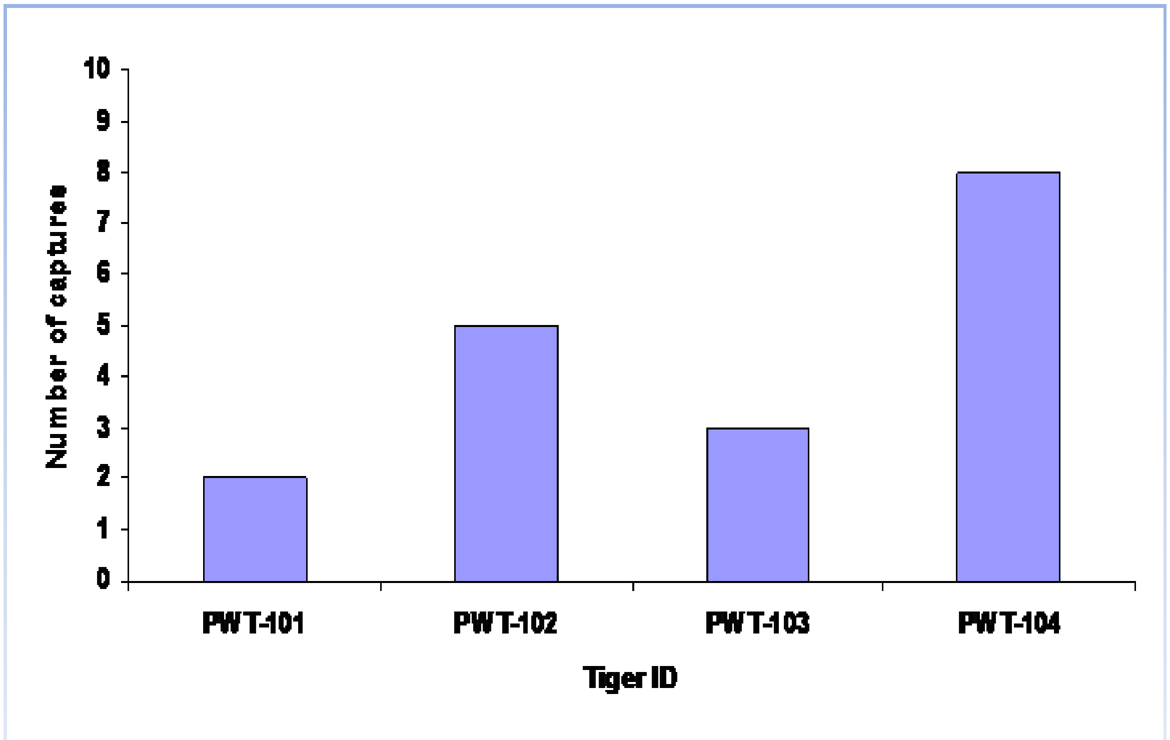
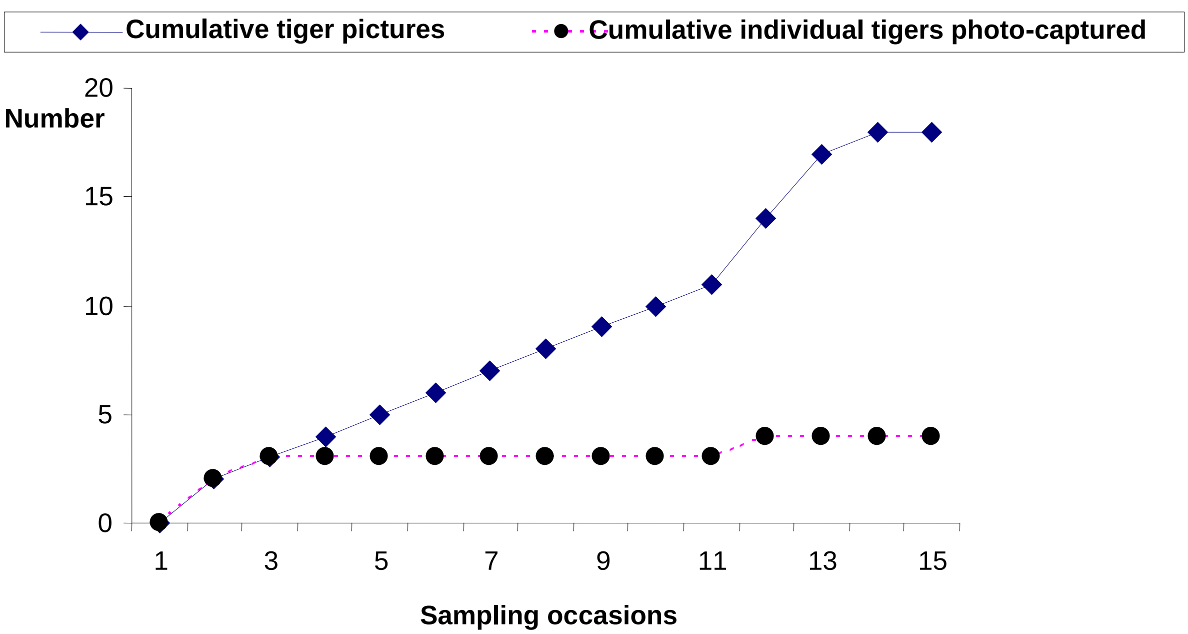



**Figure 5.6. Capture-recapture pattern of camera-trapped tigers in Parsa Wildlife Reserve.**



Model Mth was selected in CAPTURE. The estimated tiger number ( $\hat{N}$ ) was 4 (SE 0.47).The density of tiger was 0.15 (SE 0.01) tigers/100 $km^2$ and 0.11(NA) from the program DENSITY for ½ MMDM and MMDM respectively (Table 5.1). The density from Spatial Explicit Capture-Recapture of Maximum Likelihood (SECR ML) provided only 0.10 whereas the SPACECAP (no buffer, 4 Km grid) provided slightly higher density 0.87(0.04). Number of tiger from SPACECAP also came to 4 with SE 0.16 and ranging 4-4 tigers (Table 5.1). Habitat mask was used in the density providing density 0.61 (SE 0.32) 95% CI 0.23-1.62, 353.1 $Km^2$.

**Table 5.1: Population and density estimates of tigers in PWR in 2009 using different models for population and density estimation.**

| Models | Mo | | Mth | |
|---|---|---|---|---|
| | CAPTURE | DENSITY | CAPTURE | (Chao Cov.1)DEN |
| N | 4 | 4 | **4** | 4 |
| SE | 0.035 | 0 | **0.47** | 0 |
| CI (95 %) | 4-4 | 4-4.4 | **4-4** | 4-NA |
| Wt.(CAPTURE) | 0.76 | - | **1.0** | - |
| P-hat | - | 0.4 | 0.144 | 0.4 |
| RPSV (m) | | 3,631 | - | 3,631 |
| D±SE/100 $km^2$ (MMDM /2), ETA($Km^2$) | - | 0.15(0.01)2613.7 | **0.15(0.02)2613.7** | 0.15(NA) |
| D/100 $km^2$ (MMDM), ETA ($Km^2$) | - | 0.11(0.01)3582 | **0.11(0.02)3582** | 0.11(NA) |
| D(SE) 95% CI/100$km^2$ (ML SECR) | - | 0.1018(+) | **0.1018(+)** | 0.1018(+) |
| D(SE) 95% CI/100$km^2$ (IP SECR) | - | NA | NA | NA |
| D(SE)/100 $km^2$, 95%CI (MLSECR), Mask area ($Km^2$) | | | 0.61 (0.32) 0.23-1.62 , 353.1 | |

+Error floating point division by zero? (Thus analysis was not performed in DENSITY)

### 5.5.2 Chitwan National Park

A total of 263 trap locations (Figure 5.2) were sampled that yielded a total sampling effort of 3,920 trap nights. A total of 59 individual tigers, 14 males, 27 females and 18 individuals whose gender could not be assessed, were identified from 314 photographs.

Over 60% of 59 tigers was recaptured more than once (Figure 5.7) with a mean maximum distance between two capture events of 8.9 km (SD 7.9). About 70% of the total individual tigers were recorded in first five days of the pooled (across blocks) 15-day sampling occasions (Figure 5.8).

**Figure 5.7. Total captures of each identified tiger in Chitwan National Park.**

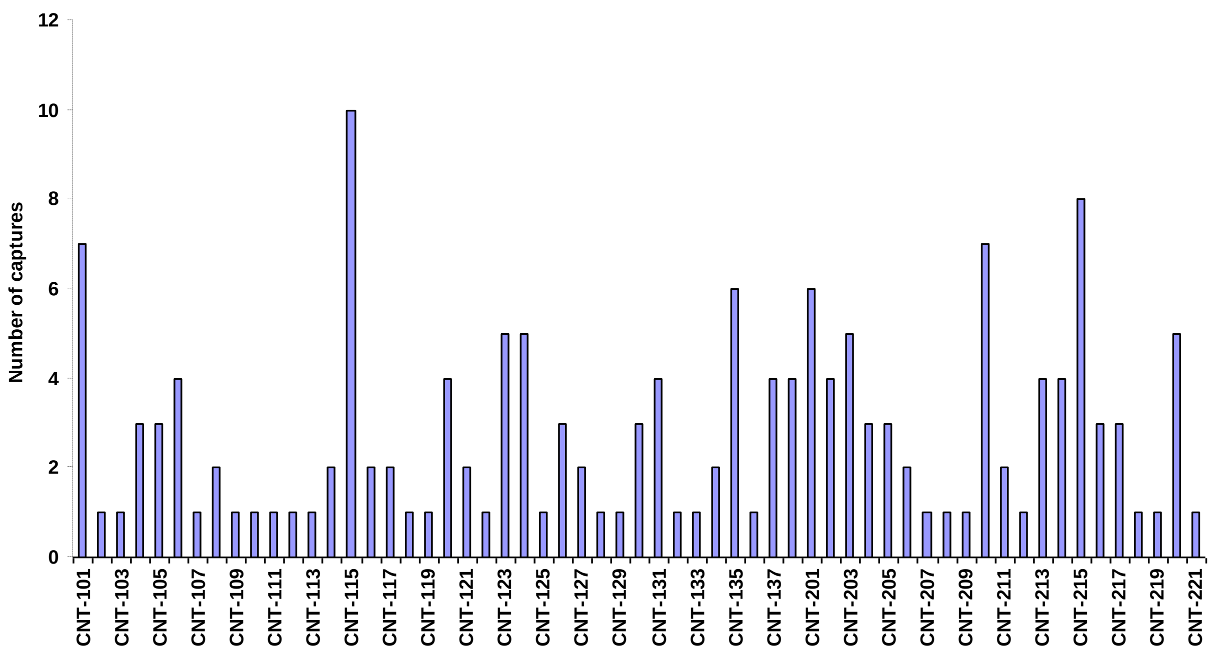
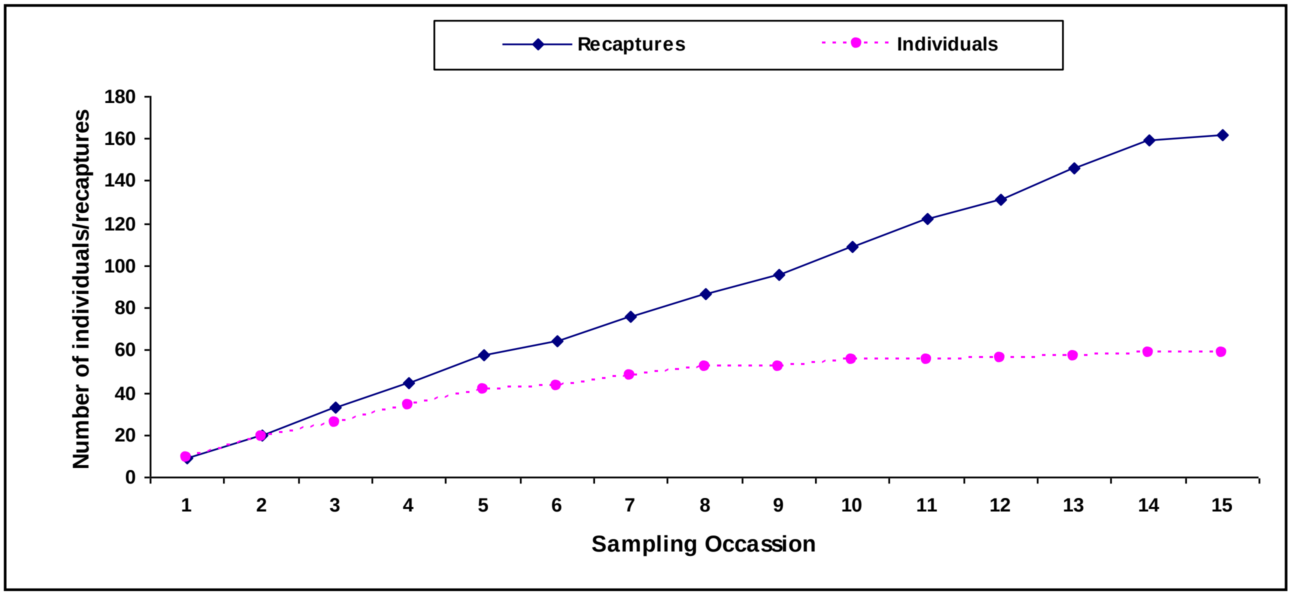


**Figure 5.8. Capture pattern of camera trapped tigers in Chitwan National Park.**




Because there was significant time variation in trapping probabilities (Chi-square = 27.52, df = 14, P = 0.02), assumptions required under model Mo were violated thus selected the 2$^{nd}$ ranked model, Mh Chao, as justified by goodness of fits tests results which indicated Mo was not a sufficiently better fit than Mh (Mo vs. Mh; Chi-square = 29.30, df=4, P < 0.01) and that Mh did sufficiently fit the data (Mh vs. Not Mh; Chi –square = 16.74, df = 14, P = 0.27). Because Mh is robust to violations (except for the very extreme) this model can reliably be used as the apparent time violation is caused by only one of the pooled capture days and the results (including all sampling occasion days) based on Chao's Mh point estimate (91 tigers) was very similar to the results when the last sampling occasion was removed (88 tigers) indicating the model's robustness.

Estimated tiger number was 91 with SE of 17.8 ranging from 71-147 from model Mh Chao from CAPTURE. The ½ MMDM density of tigers were 2.88 (SE 0.62)/100 km$^2$ and MMDM density of tigers were 1.91 (0.4) form program DENSITY (Table 5.2). The habitat mask density was 2.3 (SE 0.31) 95% CI 1.77-2.99 with the area of 1,987 Km$^2$. The density from Spatial Explicit Capture-recapture of Maximum likelihood provided only 1.63 (0.24) ranging from 1.23 to 2.16.

**Table 5.2. Population and density estimates of tigers in Chitwan National Park in 2009 using different models for population and density estimation.**

| Models | Mo | | Mh (Chao) | |
|---|---|---|---|---|
| | CAPTURE | DENSITY | CAPTURE | DENSITY |
| N | 62 | 58 | **91** | 85.4 |
| SE | 2.12 | 1.9 | **17.79** | 16.6 |
| CI (95 %) | 60-69 | 56-63.1 | 71-147 | 66.5-138.4 |
| Wt.( CAPTURE) | 1.0 | - | 0.92 | - |
| P-hat | | 0.19 | - | 0.12 |
| RPSV (m) | | 6559.7 | | |
| D(SE)/100 km$^2$ (MMDM/2), ETA (Km$^2$) | - | 1.96(0.2) 2961 | - | **2.88(0.62)** 2961 |
| D/100 km$^2$ (MMDM),ETA (Km$^2$) | | 1.28(0.19) 4521 | | **1.91(0.4)** 4521 |
| D(SE)95%CI/ 100km$^2$ (ML SECR) | | 1.63(0.24)1.23-2.16 | | **1.63**(0.24)1.23-2.16 |
| D(SE) 95%CI/ 100km$^2$ (IP SECR) | | Failed | | Failed |
| D(SE)/100 km$^2$, 95%CI (MLSECR), Mask area (Km$^2$) | | 2.3(0.31) 1.77-2.99, 1,987 | | |

### 5.5.3 Bardia National Park

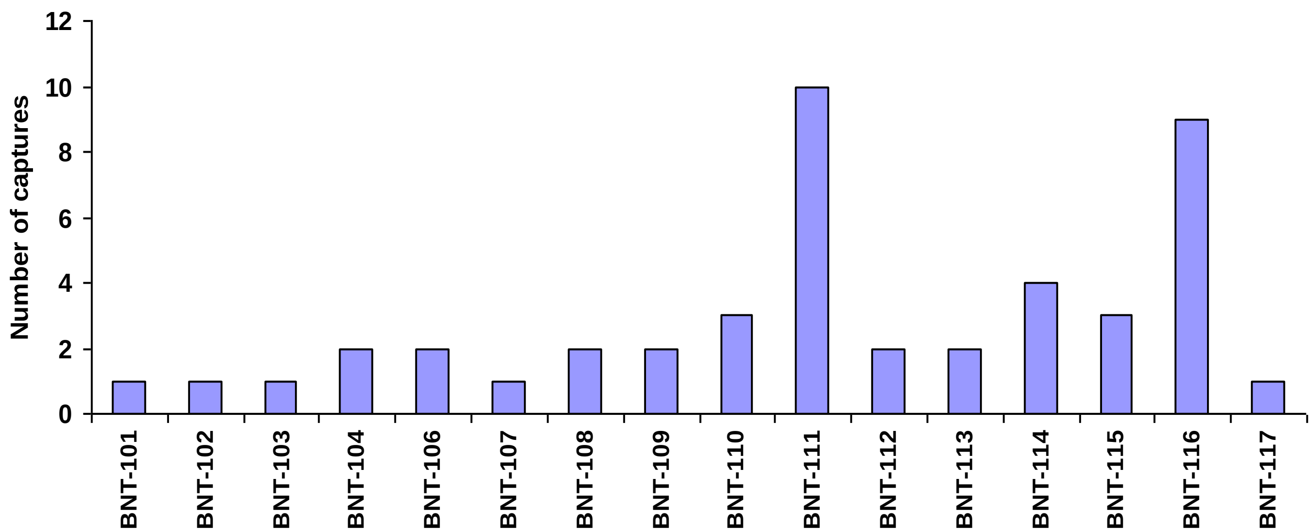
Camera trapping was carried out in the 197 trap locations (Figure 5.3) accounting for the total sampling effort of 2,944 trap nights.

A total of 16 individual tigers, 5 males, 8 females and 3 whose gender could not be assessed, were photo-captured by 162 photographs.

**Capture and recapture pattern of tigers**

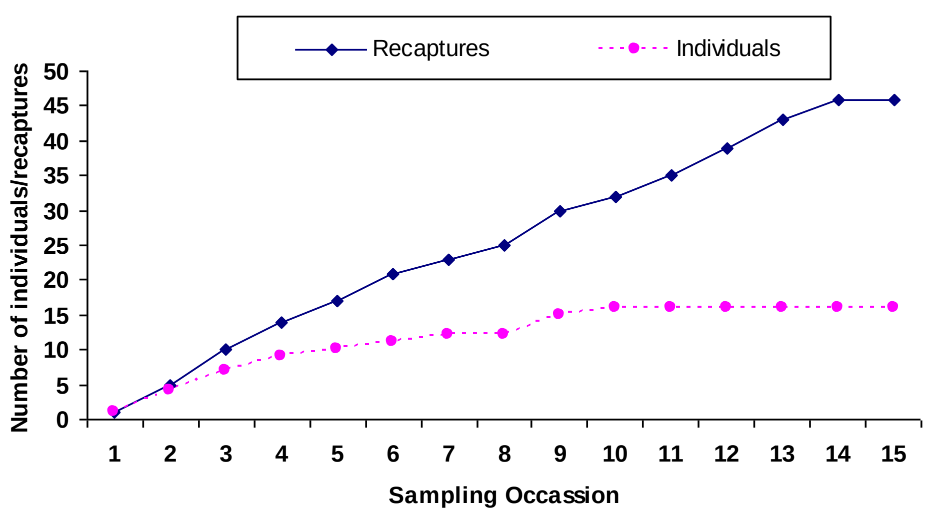
About 70% of tigers was recaptured more than once (Figure 5.9) with a mean maximum distance between two capture events of 8.9 km (SD 10).

**Figure 5.9. Total captures of each identified tiger in Bardia National Park.**




Trapping results showed that no new tigers were trapped after the 10$^{th}$ night (pooled across blocks), while the total number of captures increased steadily until the 14$^{th}$ night (pooled across blocks). Nearly 65% of the total individual tiger captures were made during the first five days of camera trapping (Figure 5.10).

**Figure 5.10. Capture pattern of camera trapped tigers in Bardia National Park.**



There was clear heterogeneity in the capture histories as demonstrated by far greater capture rates of tigers BNT–111 and BNT–116 compared to other animals (Figure 5.9). Also, between occasions 1 and 2 there were 4 times as many animals captured than on day 1. In magnitude, 3 additional animals is not a lot – but because it is relatively assessed by CAPTURE, this is not considered merely 3 animals captured but as 4 times more animals captured and this can cause results that appear as if potential immigration occurred. Similarly, on the last day no animals were captured and this was different than all other days and could suggest potential emigration to CAPTURE (see closure test results below). Because of these potential issues, we chose Mh as the most appropriate model due to its robustness and model selection score (Goodness of fit test Mh vs. Not Mh; Chi –square = 13.62, df = 14, P = 0.48). Furthermore, running the analysis without two days that were likely causing any closure issues (day 1 and 15) did not reduce the number of animals captured but did cure the potential closure issue. Because the results were the same with or without these pooled days using model Mh, our selection of Mh is robust.

Estimated tiger number was 19 with SE of 1.7 (range 18-35) from 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 5.3). The density from Spatial Explicit Capture-recapture of Maximum likelihood provided 0.61(SE 0.15) 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.

**Table 5.3: Population and density estimates of tigers in BNP in 2009 using different models for population and density estimation.**

| Models | Mo | | Mh (Jacknife) | |
|---|---|---|---|---|
| | CAPTURE | DENSITY | CAPTURE | DENSITY |
| N | 17 | 17 | 19 | **19** |
| SE | 1.118 | 0.8 | 3.17 | **3.3** |
| CI (95 %) | 17-24 | 17-19.6 | 18-35 | 17.2-36 |
| Wt.( CAPTUR) | 1.0 | | 0.98 | - |
| P-hat | | 0.04 | - | 0.04 |
| RPSV (m) | | 6271.5 | | |
| D±SE/100 $km^{2}$(MMDM/2),ETA($Km^2$) | - | 1.17(0.21)1456 | - | **1.31** (0.32) |
| D/100 $km^2$ (MMDM),ETA ($Km^2$) | | 0.78(0.21) 2182 | | 0.87 (0.28) |
| D(SE)95%CI/100$km^2$(MLSECR) | | o.61(0.15)0.37-0.99 | | 0.61(0.15)0.37-0.99 |
| D(SE)95%CI/ 100$km^2$(IPSECR) | | Failed | | Failed |
| D(SE)/100 $km^2$, 95%CI (MLSECR), Mask area ($Km^2$) | | 0.94 (0.23) 0.58-1.52 , 1,896 | | |

### 5.5.4 Suklaphanta Wildlife Reserve

Camera trap surveys were undertaken in 113 trap locations (Figure 5.4) for a total effort of 1,679 trap nights. A total of seven individual tigers, 2 males, 2 females and 3 individuals whose gender could not be assessed, were identified from133 photographs (Table 5.4).

Among 7 individual tigers, approximately 90% was recaptured more than once (Figure 5.11) with a mean maximum distance of 6.6 Km (SD 3.4) between two capture events. Trapping results showed that no new tigers were trapped after $4^{th}$ pooled night, while the total number of captures increased steadily in the following sampling occasions (Figure 5.11). All indentified individual tigers captured were encountered in the period between first five days of the pooled 15-day sampling occasion (Figure 5.12).

**Figure 5.11. Total captures of each identified tiger in Suklaphanta Wildlife Reserve.**

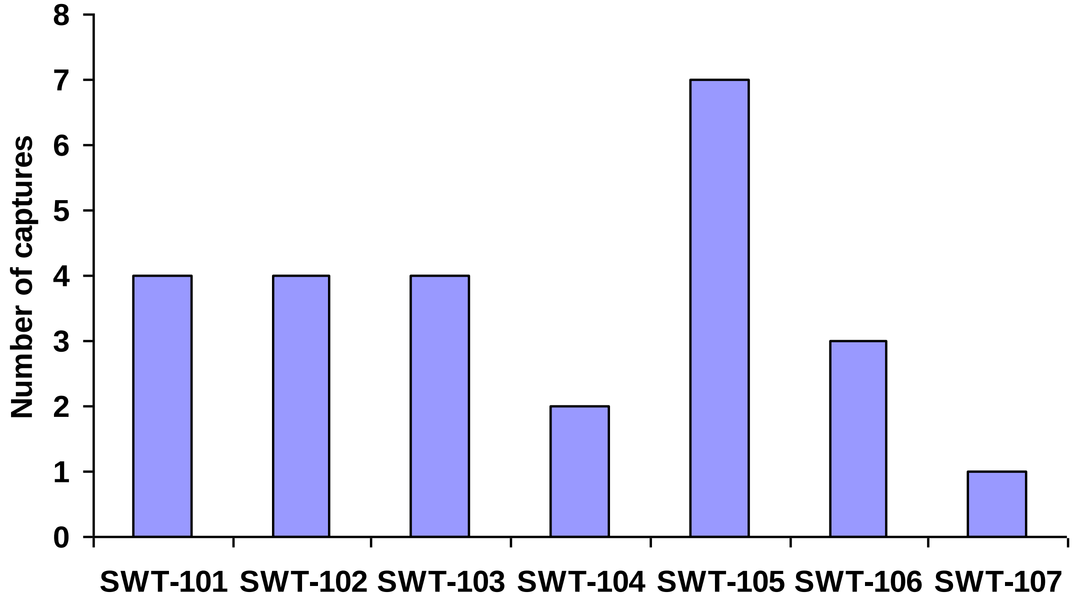
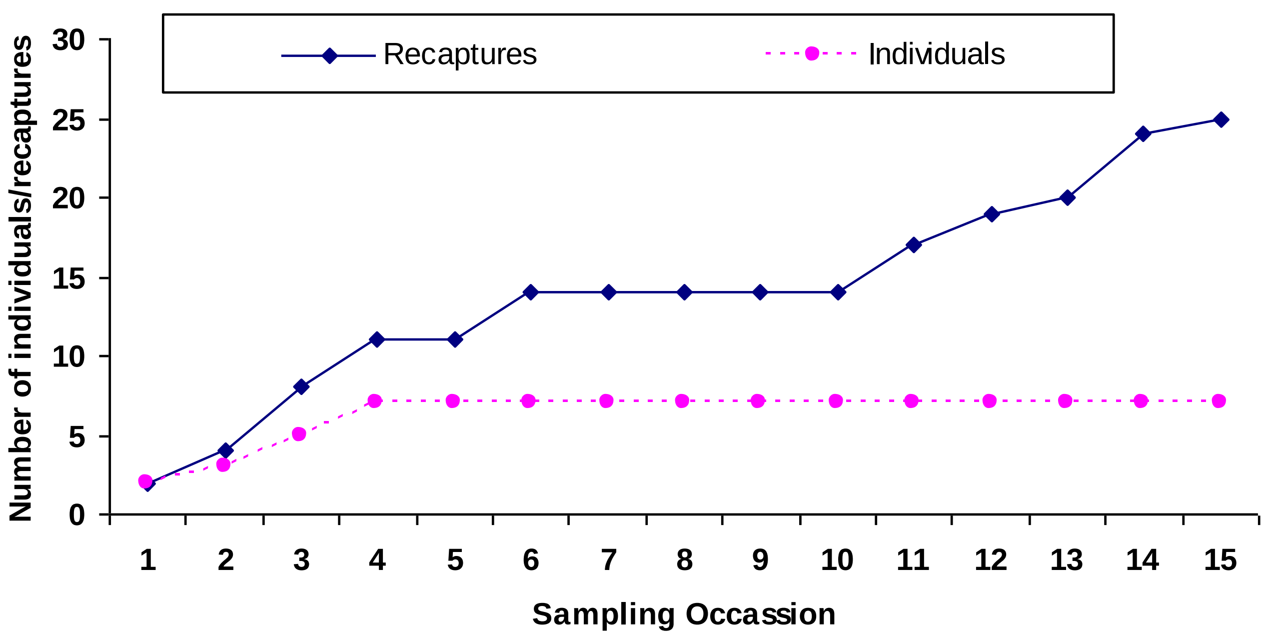



**Figure 5.12. Capture pattern of camera trapped tigers in Suklaphanta Wildlife Reserve.**



Model selection routine in CAPTURE suggested Model $M_0$. Estimated tiger number was 7 with SE of 0.2. The density from Spatial Explicit Capture-recapture of Maximum likelihood provided 1.42 (0.57) ranging from 0.59 to 2.74 whereas the SPACECAP (no buffer, 4 Km grid) provided similar density of 1.46 tigers with SE (0.08) (Table 5.4) and number (NSuper) (compared to our null model result) 7.13 with SE 0.37 ranging from 7-8. Habitat mask was performed in DENSITY to remove the non-tiger habitat area where the density was estimated at 2.1 (SE 0.8) 95% CI 1.0-4.4 with an masked area of 443.9 Km$^2$.

**Table 5.4: Population and density of tigers in SWR using different models**.

| Models | Mo | | Mh Jackknife | |
|---|---|---|---|---|
| | CAPTURE | DENSITY | CAPTURE | DENSITY |
| N | **7** | 7 | 7 | 7 |
| SE | **0.22** | 0.3 | 0 | - |
| CI (95 %) | **7-7** | 7-7.9 | 7-7 | 7-NA |
| Wt.(CAPTURE) | 0.98 | | 1.0 | |
| P-hat | - | 0.05 | - | 0.05 |
| RPSV (m) | | 2962 | | |
| D(SE)/100 km$^2$(MMDM/2),ETA(Km$^2$) | | 1.15(0.16)610 | | 1.15 |
| D/100 km$^2$ (MMDM),ETA (Km$^2$) | | 0.73(0.15)959 | | 0.73 |
| D(SE)95%CI/100km$^2$ (ML SECR) | | **1.42**(0.57)0.66-3.05 | | 1.42(0.57)0.66-3.05 |
| D(SE) 95%CI/ 100km$^2$ (IP SECR) | | 1.27(0.52)0.59-2.74 | | 0.95(1.39)0.12-7.80 |
| D(SE)/100 km$^2$, 95%CI (MLSECR), Mask area (Km$^2$) | | | 2.1 (0.8) 1.0-4.4, 443.9 | |

## 5.6 DISCUSSION

In Nepal, a total of 121 adult tigers (100-191) were estimated in four PAs, 4 in PWR, 91 in CNP, 19 in BNP, and 7 in SWR in 2009. A nominal increase in tiger population in Nepal seems to have occurred in a decade considering the mid value of 1999/2000-2008/09, pronounced mainly in Chitwan from 55 to 91 (Table 5.5, DNPWC 2005).

SWR clearly showed the declining trend since 2000 from 20 individuals in 2000 (Regmi 2000), 17 individuals (Jnawali et al. 2001), 27 in 2004/05 (WWF/N 2006), 10 in 2005/06 (Poudel et al. 2008) and 7 in 2007/08 (Mishra et al. 2008) to current 7 individuals. Dudhwa-Kheri-Pilibhit tiger population with occupancy in about 2,110 $Km^2$ with an estimated tiger population between 106-118 individuals (Jhala et al. 2011) probably forms the source to SWR.

In BNP, during 1990's, there were 28 tiger estimated based on the study 1994-96 by ITNC and DNPWC (cited in Basnet et al. 1998). As a result of continuous camera trap monitoring from 1998 to 2001, 42 individual tigers have been identified from BNP (Bhatta et al. 2002). Similarly, 19 tigers in 100 $Km^2$ of KFP, BNP (Pokharel 2002) have been documented. The 2008 estimation in Karnali Flood Plain showed 13 tigers in 2007 and 16 (5 male, 5 female, 5 cubs) in 2008 (BNP 2008). These estimates mentioned above were minimum individuals identified from the captured photographs. There seems decline of tigers in BNP compared to that of earlier estimations. The possible explanations of reduction in number are likely to be the civil unrest that Nepal went through in the past decade and subsequently resulted in heavy poaching of tiger and its prey base (Check 2006, Gopal et al. 2010, Karki et al. 2008, Chundawat et al. 2010). The moderate quality of habitat of Babai valley and south eastern flank are supporting fewer tigers. The recent declaration of BaNP that connects to these parts may continue a viable link. BaNP through the Mahadevpuri corridor which connects to Suhelwa Wildlife Sanctuary, India, may provide further genetic connectivity between these bordering areas in Nepal and India.

In CNP, the earlier three estimates of tigers prior to year 1998, 26-34 tigers (1976-1978, Tamang 1982), 65 tigers (45 females and 20 males, Smith et al. 1987b), 69 tigers (Smith et al .1998) and 55 adults (50-60, in 2000 and 2005, Poudel et al. 2008) are less than the current estimates of 91 individuals. The earlier studies have covered smaller areas and the estimates were the actual photo-captured individual tigers whereas the current numbers are based on the estimates by capture recapture analysis.

The density of tiger in TAL PAs ranges from 0.61 to 2.3/100 $Km^2$ with the lowest in PWR (0.61 tigers/100 $km^2$) and highest in CNP (2.88 tigers/100 $km^2$) and medium for BNP (1.31 tigers/100 $km^2$) and SWR (1.42 tigers/100 $km^2$).

The non spatial density (4.2) estimated tiger habitat is improved even from the area of 1987 and this could be the more achievable for the future. This would even go higher when a manual estimation by using tigers (125 individual) in area (2085 $Km^2$) is estimated (5.99).

Tamang (1982) estimated density of one tiger/43 $km^2$ area (2.33 tiger /100 $km^2$) in CNP which is close to the current estimate of 2.88.

In BNP, the density of 13.3 to 19.3 individuals/100 $km^2$ in 1998-2001 (Wegge et al. 2009, table 5.3) for KFP is not attained now (1.31 Indi./100 $km^2$ and only 0.94 Indi./100 $km^2$ from mask ML SECR) while considering the additional Babai valley as well but approaching towards 2.7 as estimated by Smith et al. 1998. Earlier studies were more focussed on estimating tiger based on either sign or camera trap to estimate minimum number of tigers and whereas the current study used the ½ MMDM for estimation of density and compared with the ML SECR by removing the non-habitat areas from the estimation.

In SWR, the earlier densities were 5 (1987) and 14.7 (2001) during 1987 and 2000 (Smith et al. 1987 b, Regmi 2000), which is higher than the current estimate of 2.1 (Table 5.5).

Nepal shows potential hope to meet the commitment of global community to double the tiger number by 2022 - from estimated 121 (2010) to over 250 adult tigers by the Year 2022 (NTRP 2010) in Nepal. Tiger can recover its earlier status in BNP and SWR where a clear decline has recorded in last one decade. This requires the control of poaching, management of habitat, and management of wild prey species including the introduction/re-introduction. In PWR, the habitat improvement will help increase wild prey species and tiger can grow as there is good source population in CNP. The transient tigers may be able to use the tiger-empty area available in PWR.

**Table 5.5. Status of tiger recorded in different studies in Nepal**

| | **1998[1]/(areakm[2])in complex** | **Density[3]/ 100 km$^2$** | **'98/99[4] (no/den)** | **2000/01[4] (no/den)** | **1999/2000 (no)** | **2005 (no)** | **2009 (no)** | **2010 (no)** |
|---|---|---|---|---|---|---|---|---|
| CNP | 50(1921)[2]/69 | 2.7 | | | 50-60 | 50-60 | 91 | 125 |
| BNP | 25/50 | 2.7 | 14/13.3(2.1) | 22/19.3(2.2) | 32-40 | 32-40 | 19 | 18 |
| SWR | 16(320) | 5.0 | | 20 (14.7)[5] | 16-23 | 16-23 | 7 | 8 |
| PWR | Included in CNP | | | | | | 4 | 4 |
| **Total** | **91/135** | | | | **98-123** | **103-130** | **121 (100-191)** | **155 (95-185)** |

[1]Smith et al 1998.[2.] Also includes PWR, [3] Smith et al 1987b, [4] Wegge et al 2009, [5].Regmi 2000

The presence of adequate prey species is imperative to maintain the high number of tigers and other predators in CNP. CNP has already experienced local extinction of wild water buffalo and swamp deer by 1960. The feasibility assessment report has identified Sukhibhar as appropriate habitat for swamp deer and ample habitat for wild water buffalo is available in CNP. Thus, a reintroduction of wild water buffalo and swamp deer in CNP should be considered.

# CHAPTER SIX : ABUNDANCE OF TIGER IN CHITWAN NATIONAL PARK, NEPAL

## 6.1 INTRODUCTION

Camera trap survey of 2009 revealed the presence of 121 adult tigers in Nepal of which Chitwan National Park (CNP) alone contributed 91 individuals thereby making CNP a PA with the highest population and density of tiger (2.88 adult tiger/100 $km^2$) in Nepal (Karki et al. 2009).

During the 2008/09 camera trap, Churia range was not included because of logistic constraints and assuming that all tigers would move to water rich lowlands during the dry season when camera trapping was conducted. In a high density population, transient tigers were also likely to occupy and use suboptimal habitat like the Churia hills as well (Barlow et al. 2009). We therefore, carried out a reconnaissance sign survey in Churia on December 2009-January 2010. The sign survey depicted the presence of tiger, leopard (*Panthera pardus*) and their prey including sambar, wild boar, chital, barking deer, serow and gaur in Churia range. Realizing the importance of Churia range as tiger habitat, we developed a survey design, covering both the Churia hills and lowlands (1,261.16 $km^2$) with the objective of estimating the total number of tigers and distribution pattern throughout CNP.

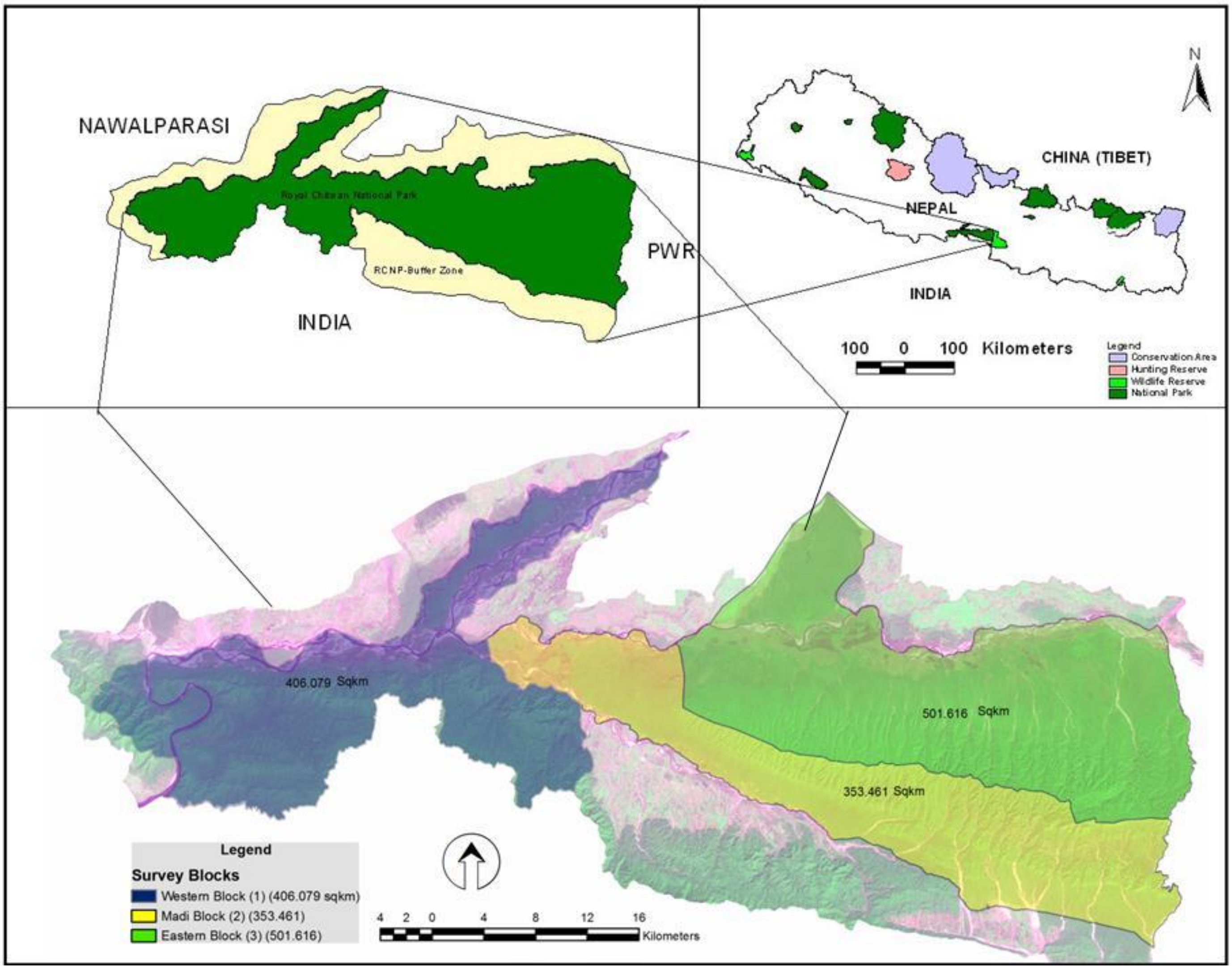
## 6.2 OBJECTIVE

To estimate the tiger population, density and distribution within the CNP.

## 6.3 STUDY AREA

The present study was carried out between 20$^{th}$ January to 22$^{nd}$ March, 2010 in CNP, Nepal (27.34–27.69°N, 83.87–84.75°E). The Chitwan valley consists of subtropical forests with Sal forests and grassland covering 70% and 20% of the park respectively. It supports more than 50 mammalian species, over 525 birds, and 55 amphibians and reptiles. The intensive study area (1,261 $km^2$) covers the entire CNP including lowland, Barandabhar BZ forest, and Churia (Figure 6.1).

**Figure 6.1. Map of the study area a) location of CNP in Nepal, b) boundary of CNP and its BZ, c) CNP with three blocks where camera trap was conducted**.



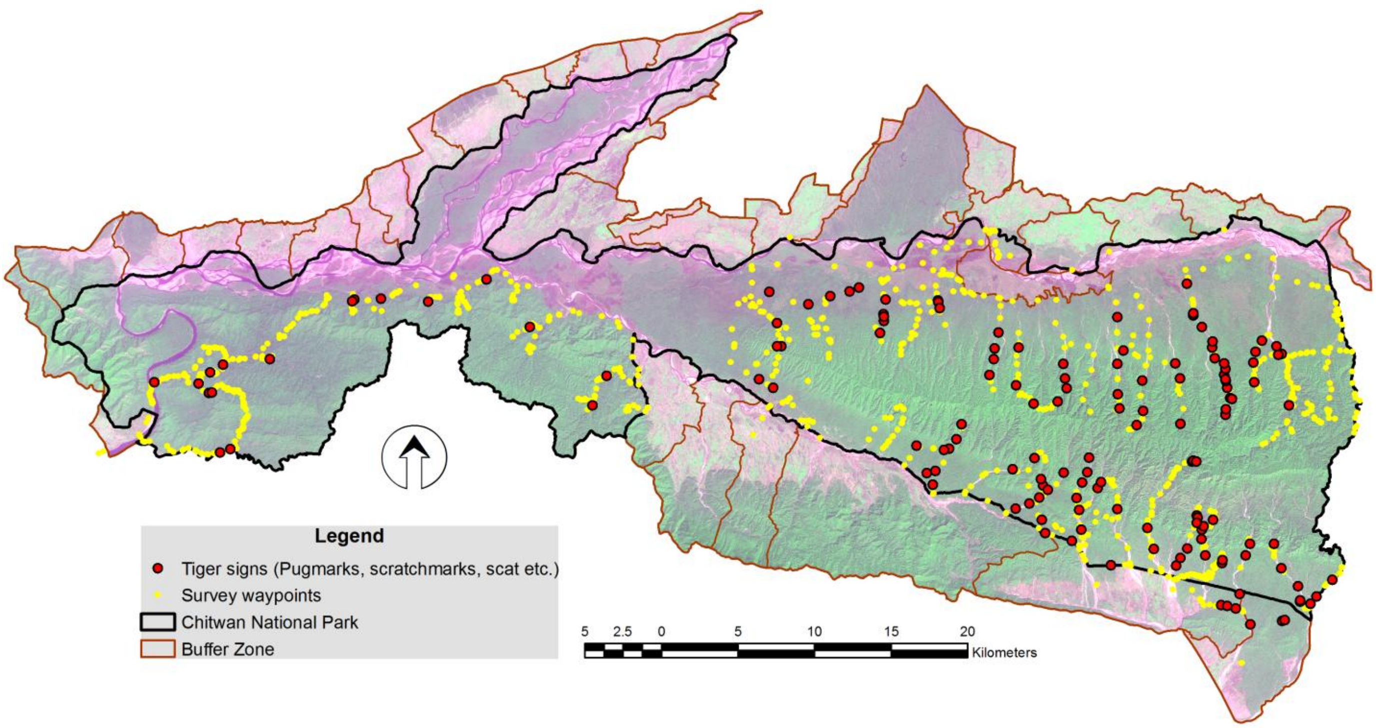
## 6.4 METHODS

### 6.4.1 Field Methods

#### 6.4.1.1 Reconnaissance survey

We designed camera trapping for CNP following tiger monitoring protocol, Nepal (DNPWC, 2009). We conducted an intensive carnivore and their wild prey sign survey across Churia of CNP prior to the actual placement of cameras. We thoroughly searched all the potential sites especially along the major streams and its branches to record tiger pug marks, scats, scrape marks and scent marks. Similarly, we also looked for footprints, pellet/dung and other evidences of wild prey species (Figure 6.2).

**Figure 6.2. Area surveyed and the tiger signs recorded in Chitwan National Park.**



We divided park into three blocks: Block I. Western (West of Reu river, Narayani Island and Triveni area), Block II. Eastern (Northern slope of Churia and lowland east of Kasara) and Block III. Madi (Southern slope of Churia west of Shikaribas, lowland east of Reu river to Kasara) (Figure 6.1).

Sign survey from the western block started on 7th December, 2009. The survey of the western and Madi block was completed by the end of December 2009. The eastern block was surveyed on the last week of December 2009 to first week of January 2010.

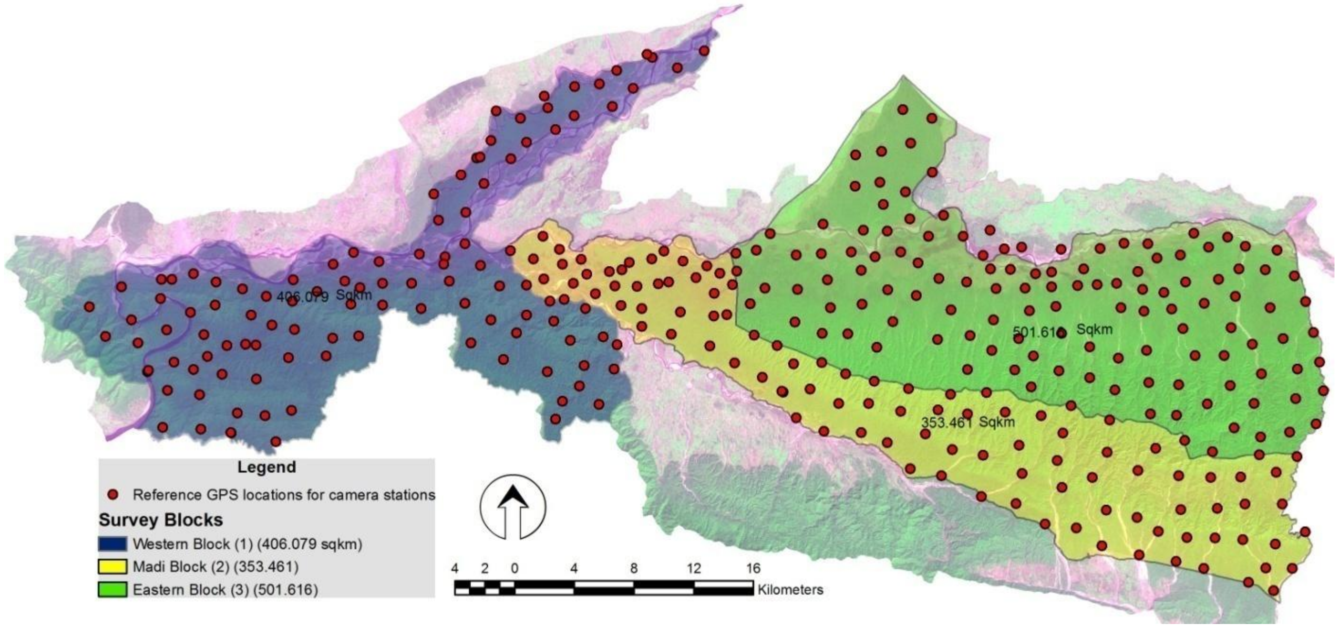
#### 6.4.1.2 Camera Location Finalization and Map Preparation

Based on the sign survey on Churia and camera locations of 2009 from lowland in CNP, camera locations for 2010 were proposed. Survey team consisted of officials from DNPWC, CNP and BNP staffs, National Trust for Nature Conservation (NTNC)-Biodiversity Conservation Center (BCC) technicians, wildlife trainees, student volunteers from Universities, nature guides, Nepal Army and local communities (cooks, assistants, guides, and boat man). Team received two days field orientation training prior to the field work. From these trained personnel, 11 field teams of mixed composition were formed for 11 different camps within each block and worked independently.

#### 6.4.1.3 Field execution

We uploaded the recorded GPS locations from sign survey on GPS unit to be handled by the field teams for the easy placement of cameras. A distance of 1.5 km between two camera trap locations was maintained so as to cover every 2x2 $Km^2$ grid by at least one camera. The total period of camera trapping in all the three blocks was of 62 days duration with 4,793 camera trap nights, including 3,582 man days and 170 elephant days. Camera traps were placed in a total of 310 locations (Figure 6.3). Continuous monitoring and technical support was provided through visits to the different camps by researcher along with CNP officials, NTNC-BCC and WWF Nepal's technical team.

**Figure 6.3. Camera Locations for Tiger Monitoring in Chitwan National Park 2010**




### 6.4.1.4 Camera types and placement

Moultrie and Stealth Cam passive digital camera traps were used for 299 locations and Trail Master® 1550 (Goodson Associates Inc. Kansas, USA) active camera trap was used for 11 locations. Camera traps were placed along the park road, fire-line, river and stream beds, trails and animal movement paths along the Churia ridge. We operated the cameras for 24 hours, except at Barandabhar where they were set at dusk and removed by dawn owing to their proximity to surrounding villages and higher chances of theft. Cameras were camouflaged with natural vegetation to minimize trap shyness. Wherever trap shyness was detected, cameras were moved about 50 to 100 m to or fro, from the station. To reduce the risk of fire in some of camera locations in block III, vegetation of about 2 m. radius was cleared around the trap location. The basic guidelines for operation of camera trap provided by Karanth and Nichols (2002) were followed.

### 6.4.2 Analytical methods

We printed all the tiger photographs and separated individual tigers based on position and shape of stripe pattern on head (face), body flanks, tail and other parts as available from the photograph (Schaller 1967, McDougal 1977, Karanth 1995 and Franklin et al. 1999).

After identification of individual tigers through stripe patterns, capture history for each individual was generated in an X matrix (Otis et al. 1978; Nichols 1992; Karanth 1995). The 24 hour cycle (morning 00:01 to mid night 24:00) was used as one day while preparing the capture day in matrix.

We performed photographic capture-recapture analysis (Karanth and Nichols 2002) to estimate the tiger population parameters. We assume that the capture population was demographically and geographically closed (Karanth 1995, Karanth and Nichols 2002, Pollock et al. 1990, Otis et al. 1978) during the effective sampling period of 62 days due to the full area coverage and short time span of sampling in comparison to the life span of tigers. The number of tigers was estimated from Program CAPTURE (Karanth and Nichols 2002). The same model used by CAPTURE was used in the program DENSITY Version 4.4.1.6 (Efford 2011) for population and density estimates. Spatially Explicit Capture Recapture (SECR) algorithm in program DENSITY was used to estimate density of tigers also by removing tiger non-habitat area through habitat mask. Density was verified with the program SPACECAP (Singh et al. 2010) by adopting Bayesian approach (Royle et al. 2009).

We segregated data from lowland (same as the 2009 survey area) with that of Churia (outside the 2009 area) and performed a separate analysis and compared for lowland’s 2010 results with that of 2009 results.

## 6.5. RESULT

### 6.5.1 Photo capture of tigers

Of 1,32,000 photographs obtained from camera trapping, 11,589 were of animals including 367 photographs of tigers. Among 367 tiger photographs, 162 were of left flanks, 182 were of right flanks and 23 were of cubs with poor picture quality. We identified 70 individual tigers, of which only 62 were used in our analysis (by using the photographs of the left flanks) because of the possibility of 8 individual tigers being double counted from only right flank photographs. Among the 62 adult individual tigers 41 were females, 15 were males while 6 couldn't be identified to the gender level. We used photographs of tigers >about 18 months for further analysis. We separated rest of the 8 photographs of right flanks and did not include for further analysis as they could be represented by the individuals identified from left flanks. We captured 12 tigers (3 males, 9 females) in Block I (area 406.079 $km^2$); 22 tigers (2 males, 15 females, 5 unknown gender) in Block II (area 353.461 $km^2$) and 25 tigers (8 male, 16 female and 1 unknown gender) in Block III (area 501.616 $km^2$). One male tiger was captured from Block I and II, and one male and one female tigers were captured from Block II and III.

Out of 310 camera stations, tigers were captured on 106 locations which included 23 locations in Churia not covered in 2009 camera trapping (Figure 6.4).

### 6.5.2 Trapping effort and capture pattern of tigers

Tigers were captured from 1$^{st}$ to 20$^{th}$ day of the camera installation (Figure 6.5). Many new tigers were captured even after 15$^{th}$ day.

**Figure 6.4 Tiger trapped locations in Churia and lowlands of Chitwan National Park.**

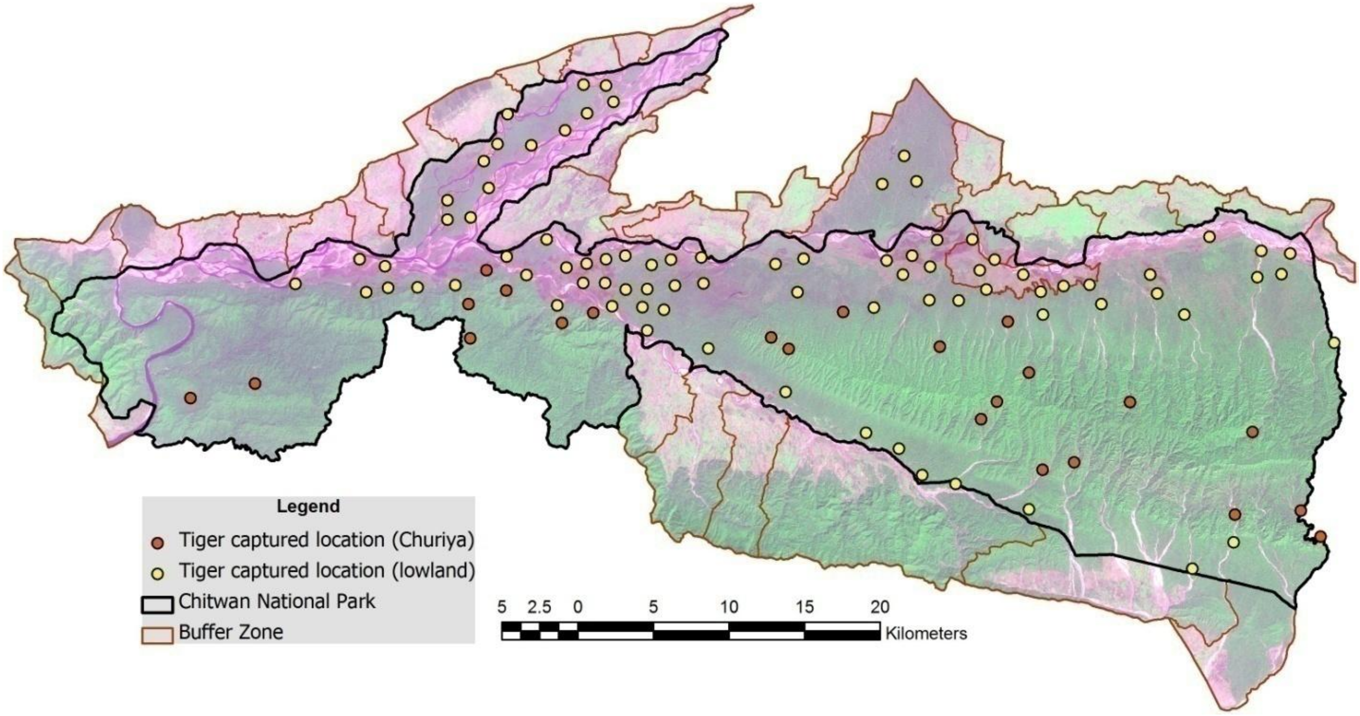
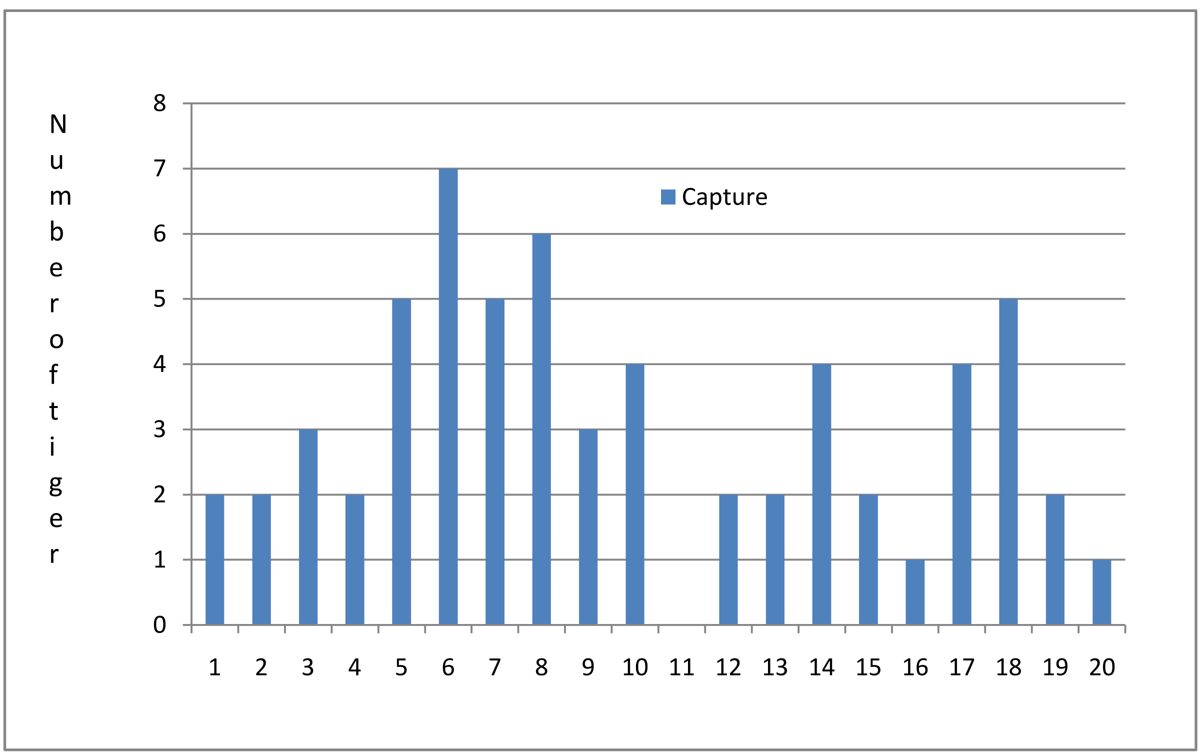


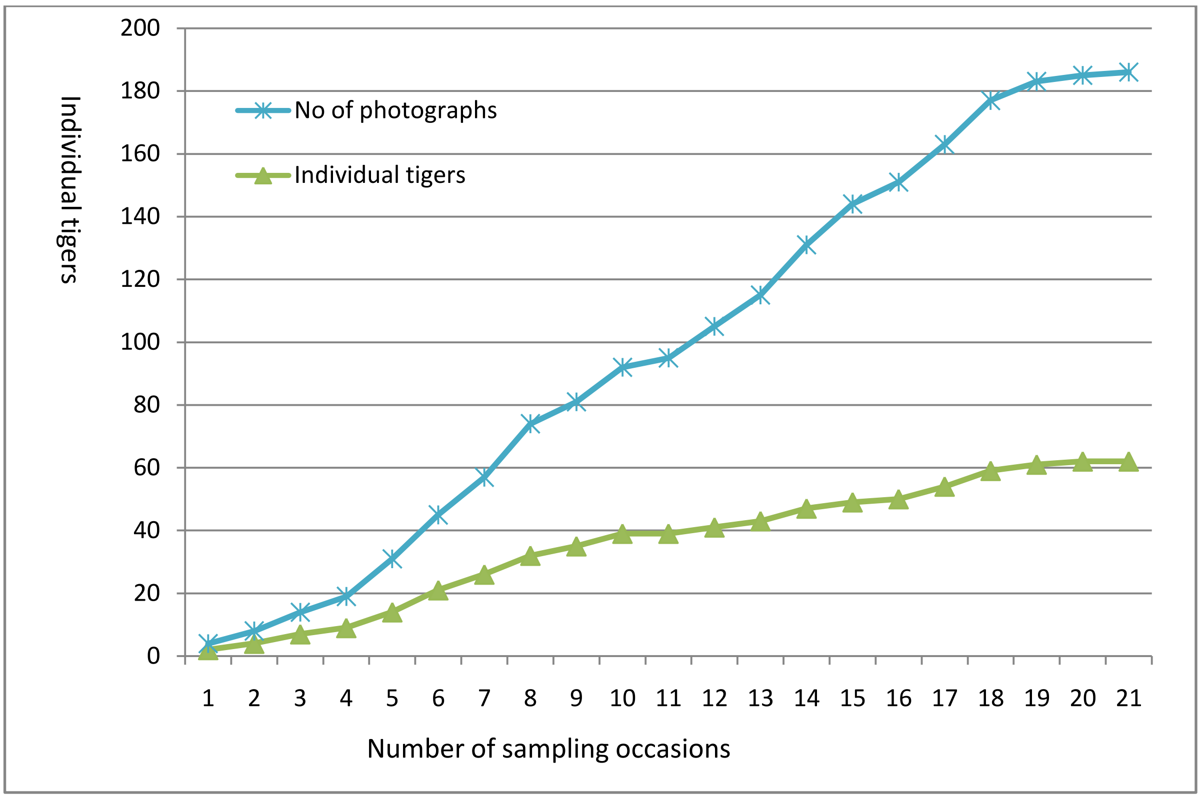

**Figure 6.5: Number of tigers Captured over the 20 days occasions in all three block in CNP.**



### 6.5.3 Recapture patterns of tigers

The number of new tigers being captured tends to stabilize after 18th days but the capture still tends to show slight increase indicating that few more days may be required for stabilizing the capture of tigers (Figure 6.6).

**Figure 6.6 Capture pattern of tiger over twenty two day occasions in Chitwan National Park.**




### 6.5.4 Estimation of Tiger population for CNP

After preparing the capture matrix from the individually identified 62 tigers, program CAPTURE was run to estimate the number of tigers. The estimated number of tigers 125 (SE 21.8, 95%CI: 95-183) using model Mh (Jacknife) was selected as best fit model.

Program DENSITY was used to verify the number and density of tigers. The ½ Mean Maximum Distance Moved (MMDM) and MMDM, Maximum Likelihood (ML) and Inverse Prediction (IP) in Spatially Explicit Capture-

Recapture (ML SECR) algorithms were used for this purpose. We have used the habitat mask in density and estimated the density of 2.74 (SE 0.37) 95% CI 2.1-3.6 , with the habitat mask area of 2085.8 $Km^2$. Thus, the density of tiger was 4.61 (SE 0.84), 3.51 (SE 0.7), 2.74 (SE 0.37), 2.31 (SE 0.32) from ½ MMDM, MMDM, ML SECR (Habitat mask) and ML SECR respectively (Table 6.2).

The density from program SPACECAP (Singh et al. 2010) was estimated to be 4.5 (SD 0.35) while using one $Km^2$ grid size and five kilometer buffer width (Table 6.1). The density has not changed much when the buffer area was changed to 10 Km.

**Table 6.1. Density of tigers from SPACECAP analysis using Bayesian approach in CNP.**

| **50,000 iteration-10Km buf_4 $Km^2$ grid** | | | | | **50,000 iteration-5Km Buffer-1 $km^2$ grid** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameters** | **Posterior _Mean** | **Posterior _SD** | **95%_HPD_Level** | | **Posterior _Mean** | **Posterior _SD** | **95%_HPD_Level** | |
| | | | Lower | Upper | | | Lower | Upper |
| **Sigma** | 1.725 | 0.245 | 1.2883 | 2.2121 | 1.7589 | 0.2479 | 1.3004 | 2.2405 |
| **lam0** | 0.0059 | 0.0009 | 0.0042 | 0.0075 | 0.0057 | 0.0009 | 0.0041 | 0.0077 |
| **Beta** | 2.4126 | 0.2013 | 2.0005 | 2.7924 | 2.4355 | 0.2139 | 2.0111 | 2.8477 |
| **Psi** | 0.2593 | 0.0351 | 0.1937 | 0.3297 | 0.1484 | 0.0188 | 0.1115 | 0.185 |
| **Nsuper** | **145.30** | 16.75 | 114 | 178 | **82.72** | 6.48 | 71 | 95 |
| **Density** | **4.16** | 0.48 | 3.26 | 5.10 | **4.50** | 0.35 | 3.87 | 5.17 |
| **p1** | 0.0059 | 0.0009 | 0.0042 | 0.0075 | 0.0057 | 0.0009 | 0.0041 | 0.0076 |
| **p2** | 0.9086 | 0.0185 | 0.8706 | 0.9424 | 0.9104 | 0.0196 | 0.8718 | 0.9454 |
| **25,000 iteration-10Km buf_4 km2 grid** | | | | | **20,000 iteration -5 Km Buffer-1km2 grid** | | | |
| **Sigma** | 1.6706 | 0.2152 | 1.2847 | 2.1028 | 1.7203 | 0.2185 | 1.3337 | 2.1786 |
| **lam0** | 0.0061 | 8.00E-04 | 0.0047 | 0.0076 | 0.0059 | 8.00E-04 | 0.0042 | 0.0075 |
| **Beta** | 2.3774 | 0.1884 | 2.0114 | 2.752 | 2.3965 | 0.2082 | 1.9581 | 2.7988 |
| **Psi** | 0.2612 | 0.0347 | 0.1946 | 0.3283 | 0.1481 | 0.0185 | 0.113 | 0.1847 |
| **Nsuper** | **146.32** | 16.54 | 114 | 177 | **82.46** | 6.28 | 70 | 94 |
| **Density** | **4.19** | 0.47 | 3.26 | 5.07 | **4.49** | 0.34 | 3.92 | 5.23 |
| **p1** | 0.006 | 0.0008 | 0.0046 | 0.0076 | 0.0059 | 0.0008 | 0.0042 | 0.0075 |
| **p2** | 0.9056 | 0.0179 | 0.8701 | 0.9387 | 0.9069 | 0.02 | 0.8634 | 0.9421 |

**Table 6.2: Population and density estimates of tigers in CNP in 2010 using different models for population and density estimation.**

| Models | Mo | | Mt (Darroch) | | Mb (Zippin) | | Mh (Jacknife) | | Mtb(Burnham) | Mth | | Mtbh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CAPTURE | DENSITY | CAPTURE | DENSITY | CAPTURE | DENSITY | CAPTURE | DENSITY | CAPTURE | CAPTURE | (ChaoCov.2)DEN | |
| N | 70 | 68 | 69 | 68 | 101 | 97 | 125 | 119.6 | 104 | 127 | 122.3 | NA |
| SE | 3.33 | 3.2 | 3 | 3.1 | 29.02 | 26.2 | 21.8 | 20.7 | 58.29 | 23.59 | 16 | NA |
| CI (95 %) | 66-79 | 63-76 | 66-78 | 63.2-75.7 | 74-206 | 70-494 | 95-183 | 91.1-176.1 | 69-385 | 95-191 | 98.2-162.5 | |
| Wt.(CAPTURE) | 0.31 | - | 0.00 | - | 0.91 | - | 0.26 | - | 1.00 | 0.84 | | 0.85 |
| P-hat | - | - | - | 0.1043 | - | 0.0470 | - | 0.0593 | - | - | 0.0580 | - |
| RPSV (m) | - | 5639.7 | - | 5639.7 | - | 5639.7 | - | 5639.7 | 5639.7 | 5639.7 | 5639.7 | - |
| D±SE/100 km$^2$ (MMDM/2),ETA(Km$^2$) | - | 2.62±0.2,2596 | - | 2.62±0.2,2596 | - | 3.7±1, 2596 | - | **4.6±0.84,2596** | - | - | 4.7±0.7,2596 | - |
| D/100km$^2$ (MMDM),ETA (Km$^2$) | - | 2±0.22,3 3404 | - | 2±0.22,3404 | - | 2.9±0.8, 3404 | - | 3.51±0.7, 3404 | - | - | 3.6±0.6,3404 | - |
| D(SE)95%CI / 100km$^2$(ML SECR) | - | 2.31(0.32) 1.76-3.03 | - | 2.31(0.32) 1.76-3.03 | - | 2.31(0.32)1.76-3.03 | - | 2.3±0.32(1.76-3.03) | NA | - | 2.31(0.32)1.76-3.03 | - |
| D(SE)95%CI/ 100km$^2$(IPSECR) | - | 2.6(0.35)2.0-3.4 | - | 2.6(0.42)1.9-3.6 | - | Failed | - | Failed | NA | - | Failed | - |
| D (SE) 95 %CI/100km$^2$ ( ML SECR ), Mask Hab.Area (Km$^2$) | | | | | | **2.74** (SE 0.37) 95% CI 2.1-3.6,2085.8 | | | | | | |

### 6.5.5 Comparison of tigers in lowlands and Churia 2010

To maintain the data consistency and to make comparisons more effective, we segregated data from lowland (same as the 2009 survey area) with that of Churia (outside the 2009 survey area) and performed a separate analysis. We made comparisons for lowland's 2010 results with that of 2009 and observed the difference in population/density between the Churia and lowland.

Out of 62 tigers identified manually, 43 tigers were exclusively photographed in lowlands whereas seven were captured in both lowlands and Churia whereas remaining 12 were exclusively captured from Churia (Figure 6.4).

### 6.5.6 Population estimation for Churia

The total numbers of tigers captured exclusively in Churia were 12 and another seven tigers were captured both in Churia and lowlands.

As predicted by the Model M(h) (Jackknife) the number of tigers estimated was 25.8 SE 4.6 (21.0-41.6). We chose Model M(h) over Model M(o) because Model M(h) addresses inherent differences in capture probabilities of individual tigers. The model parameters are shown in Table 6.3.

**Table 6.3: Comparison of models and criteria from capture matrix for Churia of CNP.**

| **Models** | **Mo** | **Mh (Jacknife)** | **Mh (Chao)** | **Mh 2-Point mixture** | **Mth (Chao coverage 1)** |
|---|---|---|---|---|---|
| **N** | 20 | **25.8** | 27.1 | 28 | 33.7 |
| **SE** | 1.3 | **4.6** | 7.1 | NA | 5.6 |
| **CI** | 19.0-23.6 | **21.0-41.6** | 20.8-54.6 | 20.0-53.8 | 26.1-49.1 |
| **P-hat** | 0.1214 | 0.0941 | 0.0896 | 0.0867 | 0.0721 |
| **RPSV(m)** | 7402.3 | 7402.3 | 7402.3 | 7402.3 | 7402.3 |
| **Density(SE)(MMDM/2)/100Km$^{2}$, ETA (km)** | 0.67±0.09, 2967 | 0.87±0.19, 2967 | 0.91±0.26, 2967 | 0.94±NA, 2967 | 1.13±0.23, 2967 |
| **Density-MMDM/100Km$^{2}$, ETA (km)** | 0.47±0.1, 4239 | 0.61±0.16, 4239 | 0.64±0.21, 4239 | 0.66±NA, 4239 | 0.79±0.21, 4239 |
| **D-ML SECR (SE)95%CI)/100 Km$^{2}$** | | 0.57± 0.15 (0.34-0.96) | | | |

DENSITY software estimation "Model M(h)- Jacknife" for Churia revealed a density of 1.07 tigers per 100 km$^2$ with the effective trapping area of 2,419 km$^2$.

### 6.5.7 Population estimation for lowlands

Out of total 62 individually identified tigers, 43 were captured exclusively from the lowland areas (same as the 2009 area) and seven were captured from both lowland and Churia.

Model Mh (Jacknife) predicted a total of 90.4 SE 18 (67.5-143.1) individuals' tigers. The results derived from the different Models are presented in Table 6.4. Model Mh Jackknife using DENSITY software (MMDM/2) estimated the density of 3.38 tigers/100 km$^2$ area in lowlands with the effective trapping area of 2,673 km$^2$ (Table 6.4)

**Table 6.4. Comparison of models and criteria from capture matrix for lowland areas of CNP.**

| Models | Mo | Mb (Zippin) | Mh (2 point mix.) | Mh (Jacknife) | Mh (Chao) | Mth (Chao cov. 1) | Mth (Chao cov. 2) | Mt(Darroch) |
|---|---|---|---|---|---|---|---|---|
| N | 53 | 62 | 78.7 | **90.4** | 89.1 | 88.2 | 87.2 | 53.0 |
| SE | 2.2 | 9 | - | **18.0** | 21.8 | 13.6 | 13.4 | 2.1 |
| CI | 50-58.7 | 51.8-111.6 | 59.9-134 | **67.5-143.1** | 64.1-158.3 | 69.4-125.3 | 68.8-123.6 | 50.0-58.3 |
| P-hat | 0.12 | 0.07 | 0.08 | **0.07** | 0.07 | 0.07 | 0.07 | 0.12 |
| RPSV | 5706 | 5706 | 5706 | 5706 | 5706 | 5706 | 5706 | 5706 |
| Density (SE) (MMDM/2)/100 $km^2$ | 1.98±0.15 | 2.32±0.37 | 2.94±NA | **3.38±0.71** | 3.33±0.84 | 3.3±0.55 | 3.26±0.54 | 1.98±0.15 |
| ETA($km^2$)for MMDM/2 | 2673 | 2673 | 2673 | 2673 | 2673 | 2673 | 2673 | 2673 |
| D(SE) MMDM /100$Km^2$ | 1.48±0.16 | 1.73±0.31 | 2.2±NA | 2.53±0.57 | 2.49±0.66 | 2.47±0.46 | 2.44±0.45 | 1.48±0.16 |
| ETA for MMDM | 3574 | 3574 | 3574 | 3574 | 3574 | 3574 | 3574 | 3574 |
| Wt.criteria (CAPTURE) | 0.08 | 0.65 | NA | 0.00 | | | 1.00 | 0.17 |
| D(ML SECR) SE (95% CI) /100$Km^2$ | | | | 1.73(0.26) 1.29-2.32 | | | | |
| D (IP SECR) SE(95%CI)/ 100$Km^2$ | | | | 2.81(0.78)1.65-4.79 | | | | |

### 6.5.8 Comparison of tiger population between 2010 and 2009

Tiger population estimation in CNP in the year 2009 was done based on camera trapping on lowland areas only (Table 6.5). For the comparison same area from the 2010 year's data were selected for analysis.

The present study indicated almost similar number (91 in 2009 to 90.4 in 2010) and density 2.88 tigers/100 km$^2$ to 3.38 tigers/100 km$^2$ of tiger in the lowland areas.

**Table 6.5: Comparison of the number and density of tiger for lowland area of Chitwan National Park between 2009 and 2010.**

| Models | Mh (Jacknife) 2010 | Mh Chao 2009 |
|---|---|---|
| N | 90.4 | 91 |
| SE | 18.0 | 17.79 |
| CI | 67.5-143.1 | 71-147 |
| P-hat | 0.07 | 0.12 |
| RPSV | 5707.5 | |
| Density/100 Km$^2$ | 3.38 | 2.88 |
| ETA (km2) for ETA and MMDM/2) | 2962 | 2673 |
| D (ML SECR) SE(95% CI)/100Km$^2$ | 1.73(0.26) 1.28-2.32 | 1.63 (0.24)1.23-2.16 |
| D (IP SECR) SE(95% CI)/100Km$^2$ | 2.78(0.79) 1.61-4.82 | Failed |

### 6.5.9 Recapture of tigers from 2009 camera trap

Individually identified tigers of year 2010 to that of data from 2009 was compared. The comparison revealed repeated captures of seven male and 13 females in 2010. Out of 14 male and 27 female captured during 2009, 33.9 % (20 tigers) were recaptured in 2010 (Table 6.6). Out of total 62 tigers captured in 2010, 42 tigers (67.74%) were new tigers. Most of the common tigers were recaptured from the same area where they got captured in 2010 (Table 6.6).

The new 42 tigers captured in 2010 were possible as not all the tigers present in the area would be captured during the limited period of camera trap and that’s why the capture-recapture framework for estimating tiger number has been used.

**Table 6.6: Recaptured tigers (2009 and 2010) in Chitwan National Park.**

| SN | Tiger ID 2009 | Location of 2009 tigers | Location of 2010 tigers | Tiger ID 2010 |
|---|---|---|---|---|
| 1. | Male CNT-213 | Sukhibhar | Sukhibhar, Khoriamuhan | CNP_MAB 50 |
| 2. | Male CNT-220 | Khoriamuhan, Tamaspur | Ghatgain, Bhawanipur | CNP_MCC 61 |
| 3. | Male CNT-138 | Khagendramalli | Sunachuri | CNP_MCC 55 |
| 4. | Male CNT-124, 214 | Botesimara, Sukhibhar | Bankatta, Kasara, Ghatgain, Bhawanipur | CNP_MBC 53 |
| 5. | Male CNT-123 | Botesimara | Bagai, Sikaribash, Dipaknagar, Amuwa | CNP_MBB 52 |
| 6. | Male CNT-121, 137 | Botesimara | Bankatta, Botesimara, Ghatgain, Dhoba, Kasara | CNP_MBB 51 |
| 7. | Male CNT-201 | Dibyapuri | Island, Dibyapuri, Gideni | CNP_MAA 49 |
| 8. | Female CNT- 210 | Sukhibhar, Khoriamuhan | Tented camp | CNP_FAA 07 |
| 9. | Female CNT-204 | Dibyapuri | Dibyapuri with 2 cubs | CNP_FAA 05 |
| 10. | Female CNT-217 | Khoriamuhan | Tented camp | CNP_FAA 01 |
| 11. | Female CNT-215 | Khoriamuhan | Sukhibhar-Khoriamuhan-Temple tiger | CNP_FAA 02 |
| 12. | Female CNT-125 | Botesimara | Botesimara | CNP_FBB 13 |
| 13. | Female CNT-211 | Sukhibhar | Sukhibhar | CNP_FBC 26 |
| 14. | Female CNT-113,115 | Sukhibhar, Kasara | Sukhibhar, Kasara, Bankatta | CNP_FBB 14 |
| 15. | Female CNT-126 | Botesimara | Bagai | CNP_FBB 23 |
| 16. | Female CNT-135 | Dhedauli, Khorsor | Bhimpur, Sauraha with one cub | CNP_FCC 40 |
| 17. | Female CNT-105 | Dhedauli, Kasara | Bhimpur | CNP_FCC 42 |
| 18. | Female CNT-104 | Khorsor | Barandabhar | CNP_FCC 45 |
| 19. | Female CNT-106 | Dhedauli | Barandabhar | CNP_FCC 46 |
| 20. | Female CNT-102 | Sunachuri-CGL | Sunachuri (Harda Khola) | CNP_FCC 29 |

M=Male, A=Block A(I), B=Block B(II), C=Block C(III), CNT/CNP=indicates CNP's tiger

## 6.6. DISCUSSION

The use of camera trap to estimate tiger abundance was started from 1995 (Karanth 1995) improving its use (Karanth and Nichols 1998, 2000, 2002) for several individually identifiable carnivores (O'Brien et al. 2003, Trolle and Kerry 2003,Wallace et al. 2003, Karanth et al. 2004a,b, 2006., Silver et al. 2004, Wegge et al. 2004, Soisalo and Cavalcanti 2006).

The density estimation based on camera trap is based on the estimation of boundary strip width which is widely viewed as weak link (Karanth et al. 2006, Soisalo and Cavalcanti 2006) and overestimation by ½ MMDM (Dice 1938, Stickel 1954). Similar density was obtained using MMDM, home-range radius and spatial likelihood approach for tiger (Contractor 2007, Sharma et al. 2010), Jaguar (*Panthera onca*) (Siasalo and Cavalcanti 2006), and Ocelots *(Leopardus pardalis)(*Dillon and Kelly 2008). The argument of Royle et al. (2009a) to overcome key problems of individual heterogeneity in capture probabilities, movement of traps, presence of potential holes in the array and ad hoc estimation of sample area, by adopting Bayesian approach of analysis of the hierarchical model using data augmentation, is providing better results (Royle et al. 2009b). Moreover, Obbard et al. (2010) found consistently over estimate in black bear (*Ursus americanus*) suggesting the SECR models usefulness to overcome the geographical closure issue. The current study used the ML SECR model of the program DENSITY also by removing the non-tiger habitat through mask and verified by the Bayesian approach from the model SPACECAP (Singh et al. 2010).

Tigers have a complex social organization consisting of resident breeders that maintain home ranges and overlap between the two sexes. Some males are extremely dominant over the others, maintaining large home ranges. Besides, even some females have shown unusually large distribution in our study area. In addition, a proportion of the population consists of non-breeding floaters that do not retain a fixed home range (Sunquist 1981, Smith 1993).

These spatial patterns, as well as the locations of traps in relation to tiger movements and home range boundaries, were likely to cause capture probabilities to vary between individual tigers. Considering both ecological factors and the model comparison results reported above, we selected Mh as the most likely model for representing the underlying capture-recapture process that generated the tiger capture histories.

To generate parameter estimates under the Mh model, we used the jackknife estimator (Otis et al. 1978) in DENSITY, which had performed well in earlier photographic capture studies of tigers (Karanth 1995, Karanth and Nichols 1998). The result of population estimate showed the wide confidence interval 125 (95-183) which is mainly due to short duration of capture (i.e. 20 days) when asymptote is not reached.

Density was calculated using root pooled spatial variance (RPSV) which deviates from the conventional method of calculation of *A (W)* as it calculates effective sampling area (ESA) through root pooled spatial variance instead of adding a buffer strip to the intensively sampled area. The result of density did not remain the same while using the closed population and Maximum Likelihood SECR for density (ML-2.3 tigers/100 $Km^2$). The half mean maximum distance moved (MMDM) in Concave indicated 4.6 individuals of tigers per 100 $km^2$ whereas 3.5 individuals of tigers per 100 $km^2$ in MMDM (Table 6.2) but the ML SECR (Habitat Mask) density has reduced to only 2.7 tigers per 100 $km^2$.

Similarly, density of 4.2 tigers/100 $km^2$ was estimated from SPACECAP when using 10 Km buffer width and 4 $Km^2$ grid size in 50,000 iterations. The density increased slightly (4.5 tigers/100 $Km^2$) while reducing the buffer width to 5 Km and grid size to 1 $Km^2$.

Tiger Number estimated by Sunquist (1979) for early 1976 in smaller area (540 $km^2$) was 32 tigers (2-3 males, 12 females, 4 sub-adults, 10 cubs and three transients) (Sunquist 1979 cited in Tamang 1982). After one year in 1977, Tamang (1982) estimated 30 tigers (5 males, 16 females and 9 sub-adults) in slightly bigger area (910 $km^2$) (Tamang 1979). After one year in 1978, 28 tigers (13 adult and sub-adult males and 9 adult and sub-adult females, and six others based on track) were estimated by Smith in 910 $Km^2$ areas (Smith 1984). The density of tiger was estimated at 1 tiger per 43 $km^2$ area (2.33 tiger per 100 $km^2$) (Tamang 1982). The camera trap in CNP yielded 33 individual tigers from east and northern section (Chapperchuli, Khagendramalli, Amrite, Icharni, Bagmara, Barandabhar, Bhawanipur, forest patch I/II, Rapti river bank of Sauraha, Dumaria, Jarneli, Ghatgain, Tamortal, Kasara, Botesimara, and Dhoba post area) of CNP in 2000 (Jnawali et al. 2001). Additional 6 tigers were captured in the southern section of the park (Ghangar-2, Bagai-1 and Deepaknagar -3) during the same period (KMTNC/NCRTC 2001). The highest number of tiger estimated earlier to this study was 69 by Smith et al. (1998). The estimates of 2009 study had shown 91 tigers and 2010 study shown 125 tigers including in the Churia. It is clear that the tigers are constantly being maintained and we are able to estimate more precisely at present then earlier.

The density estimate of 6 resident female tigers/100 $km^2$ and the high overall abundance of 18 tigers recorded in the floodplain habitat of the CNP Terai was one of the best tiger habitats anywhere in the world as described by Sanderson et al. (2006). This was supported by previous work in Chitwan (McDougal 1977, Seidensticker 1976, Smith 1993, Smith and McDougal 1991, Smith et al. 1987a, 1998b, Sunquist 1981), and highlights the TAL’s potential as a long-term stronghold for tigers, and the need to reestablish breeding habitat and dispersal corridors across this region (Wikramanayake et al. 2004, Barlow et al. 2009). Moreover, there are only few areas in the tiger range states where the adult tigers are more than 100 individuals and thus CNP with the adjoining PWR and Valmiki TR (India) is very important area for tiger conservation. The Valmiki-Chitwan continuum spanning across parts of India and Nepal with 850 $Km^2$ tiger occupancy on the Indian side with 8-10 individual tigers and has weak connectivity to Sohagibarwa (Jhala et al. 2011).

### 6.6.1 Comparison with 2009

The number of tiger was found almost similar between 2009 and 2010. Good ungulate density of 62.6 animals/ $km^2$ (Karki et al. 2009) was available to support the tiger in CNP.

There was slight increase in the density of tiger, 2.88 to 4.61 tigers per 100 $km^2$ and this increase may be due to addition of tiger from Churia area as there were 12 tigers exclusively captured in Churia area. The rate of annual change of number may vary over years greatly (Karanth et al. 2006) and 3% annual increase has been documented in Nagarhole Tiger Reserve, India. Any such detected change may be a product of anthropogenic factors and natural temporal fluctuations in the population (Gibbs et al. 1998, Barlow 2009).

The current baseline provides an opportunity for a multiyear trend estimate for change in tiger population size and helps understanding population dynamics with higher level of precision and ability to detect change by considering the factors of variance on number and density over time. The factors could be minimized by deploying larger number of cameras for longer period in higher densities to capture more individuals with higher rates (Karanth et al. 2006).

### 6.6.2 Period of camera trapping in Churia

New tigers captured even after 15$^{th}$ days was consistent to the results from the earlier study in Corbett Tiger Reserve, Indian Terai suggesting that earlier trapping effort of 15 days may not be sufficient in case of CNP which is also supported by the studies in similar habitats in India (Contractor, 2007).

Pokhrel (2002) and Wegge et al. (2004) found all tigers captured in the lowlands of BNP in one Km spacing within the first five nights but later increasing trapping distance to two Km has captured only 86.1% of the tigers in 15 day session. The camera trap survey was not done so far in Churia and thus the 15 days session of earlier studies including 2009 and 20 days in 2010 was continued. In Bhutan, fifty days of camera trap was done in Jigme Wangchuk NP to capture tiger and Leopard (Wang and MacDonald 2009). The individual accumulation curve shows no signs of leveling out to reach an asymptote and the recapture patterns of tigers too don't stabilize even after 21 days. Similarly, the first capture and recapture have not reached to asymptote indicating requirement of longer period of camera placement particularly in the Churia and place like Chitwan with potential of having higher recruitment and mortality. These are the area of future research opportunity to continue monitoring this area where 125 adult tigers in Tiger Conservation Landscape Unit category I in Nepal exists.

Small-scale monitoring programs may have low power to detect trends, and if trends are detected they may not be useful to evaluate the effectiveness of conservation efforts. We recommend that tiger monitoring programs are designed to differentiate between the breeding and non-breeding sections of the population. Identifying the residents will increase power to detect change and improve inferences regarding population status and long-term viability. In general, resident animals can be identified through camera trapping when recorded in the same area for 2 consecutive years, or if there is evidence of cubs accompanying females. If residents cannot be identified, then monitoring should be carried out at a large enough scale that turnover of individual resident tigers will be unlikely to greatly affect detected changes in abundance. The size of survey area, in terms of the number of male territories and the length of time between samples, should be based on how much change needs to be detected for management purposes (Barlow et al. 2009).

# CHAPTER SEVEN: CONCLUSION, RECOMMENDATION, AND MANAGEMENT IMPLICATION

The TAL's potential as a long-term stronghold for tigers was indicated by its sign of presence in 10 of the 14 TAL districts and there were evidence of tiger occurrence in Bara forest, and Khata, Basanta, Laljhadi, and Mohana corridors, in the past. The occupancy in Mahadevpuri corridor (Banke district) showed higher probability of tiger use compared to the rest of nine districts. Part of this area was incorporated in to newly declared Banke National Park in 2010. There is strong need to re-establish breeding habitat and dispersal corridors across Nepal's BaNP-Mahadevpuri-community-national forests and India's (Suhelwa and Sohagi-Barwa WSs) forests in Terai belt of UP.

Tiger use of the Nepal's TAL PAs was higher in higher wild prey available areas with lower human disturbances. Prey depletion coupled with human disturbances and lack of functional corridor has been recognized as an important factor for the decline of wild tiger populations and hence a significant constraint on their recovery especially in outside forest in TAL. Therefore, to increase tiger occupancy, otherwise suitable areas that have depleted prey bases should be managed with focus on increasing the primary prey base. Monitoring occupancy of tiger in larger area was possible with a comparatively lower cost using existing experienced technicians with nominal training. This result clearly indicated the possible actions could be taken to improve the habitat conditions and reduce the human induced pressures in critical tiger movement areas.

Availability of ungulate indicates the possibility of tiger occurrence. The tiger abundance in CNP with effective protection showed stable tiger population in two consecutive years. CNP with more than 100 tigers is among the only few such areas in the tiger range countries and among the two within TAL after Corbet Tiger Reserve, India. This is the source population to PWR in Nepal and VTR in India. Exclusive use of Churia habitat by tiger was documented and is supported by the availability of wild ungulate. As tigers of CNP share the range with PWR, it is likely that the PWR would further receive tigers from CNP. The habitat management, waterhole development and stringent protection would improve the status of prey base, particularly in the newly relocated village sites and thereby the tigers in PWR.

The wild prey base is substantially high in SWR though about 60 % of tigers have declined in past 8 years. The potential reason could be poaching coupled with encroachment, and human induced impacts (Chundawat et al. 2010, Karki et al. 2008). The tiger use in the eastern and northern part of the Reserve was lower compared to the rest of the Reserve. Evacuation of the encroachment will help to restore the last remaining few tiger individuals in SWR. The improved protection has stabilized the tiger in recent years but there are very few breeding females for growth of population. The area is connected with the Reserve Forest of Pilibhit Forest Division and Kishanpur Wildlife Sanctuary in Uttar Pradesh, India and maintaining the forest condition linking them would help build the population in SWR for its long term sustenance.

Though the wild prey base is reasonably high in BNP, about 50 % of the tigers have declined over last one decade. The potential reason likely to be poaching and reduction of prey base (Check 2006, Chundawat et al. 2010, Gopal et al. 2010, Karki et al.2010) during the insurgency period that Nepal went through in the past decade. The overall improved protection, declaration of 180 $Km^2$ of BZ towards north in Surkhet district and establishment of BaNP towards east has increased the legal protection and provided the conservation opportunity with people. The upgraded status of Khata corridor as protection forest by Government of Nepal and functional use of the corridor by tiger to visit KTR has given immense hope that the tiger number could come back to what was there a decade ago. This would require consistent intelligence, networking and sustainability of youth involvement program in Khata corridor and recently upgraded community forests.

The assessment of the status of wild prey base in BaNP was accomplished recently. Mapping functional movement route of tigers from BNP to BaNP would help understand the tiger movement and constant use leading to the establishment of territory by breeding tigers in the newly declared BaNP.

Coinciding the monitoring of tiger with the trans-boundary PAs to gather the information on transient tigers would further strengthen the information for both the countries. The ongoing Monitoring System for Tigers-Intensive Patrolling and Ecological Status (MSTrIPES) of India is useful to explore its use in Nepal. Joint study in areas such as Khata-Katerniaghat, VTR (UP, India) - Kanamana valley (CNP), Dudhwa TR (UP, India) - Mohana and Laljhadi corridors in Kailali and Kanchanpur districts and BaNP - Mahadevpuri bottleneck - Suhelwa WLS (UP, India) should be initiated.

Improving the capacity and effectiveness of law enforcement in reducing poaching of tigers is an immediate priority to secure remaining wild populations in source sites (Stokes 2010). Due to this exercise that involved intensive trainings to PA and NTNC staffs, volunteers of universities and few local communities, the capacity to implement the camera trap and prey base monitoring in PA have been improved. Continuing such practice will help benefit the management by gaining local support and help exchanging the information with students, researchers and Academia.

MFSC, GoN has approved the tiger conservation action plan (2008-2012) as a means to provide the guidance for implementation and streamline the policy focus. The plan emphasizes on reliable ecological knowledge on population parameters that are crucial in improving the scientific management of tigers (GoN 2007). As this research program has created a baseline, repeated occupancy survey and camera trap every four year as recommended by the tiger monitoring protocol should be continued. The experience gained through this research is being used to renew the Tiger Conservation Action Plan by the team.

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