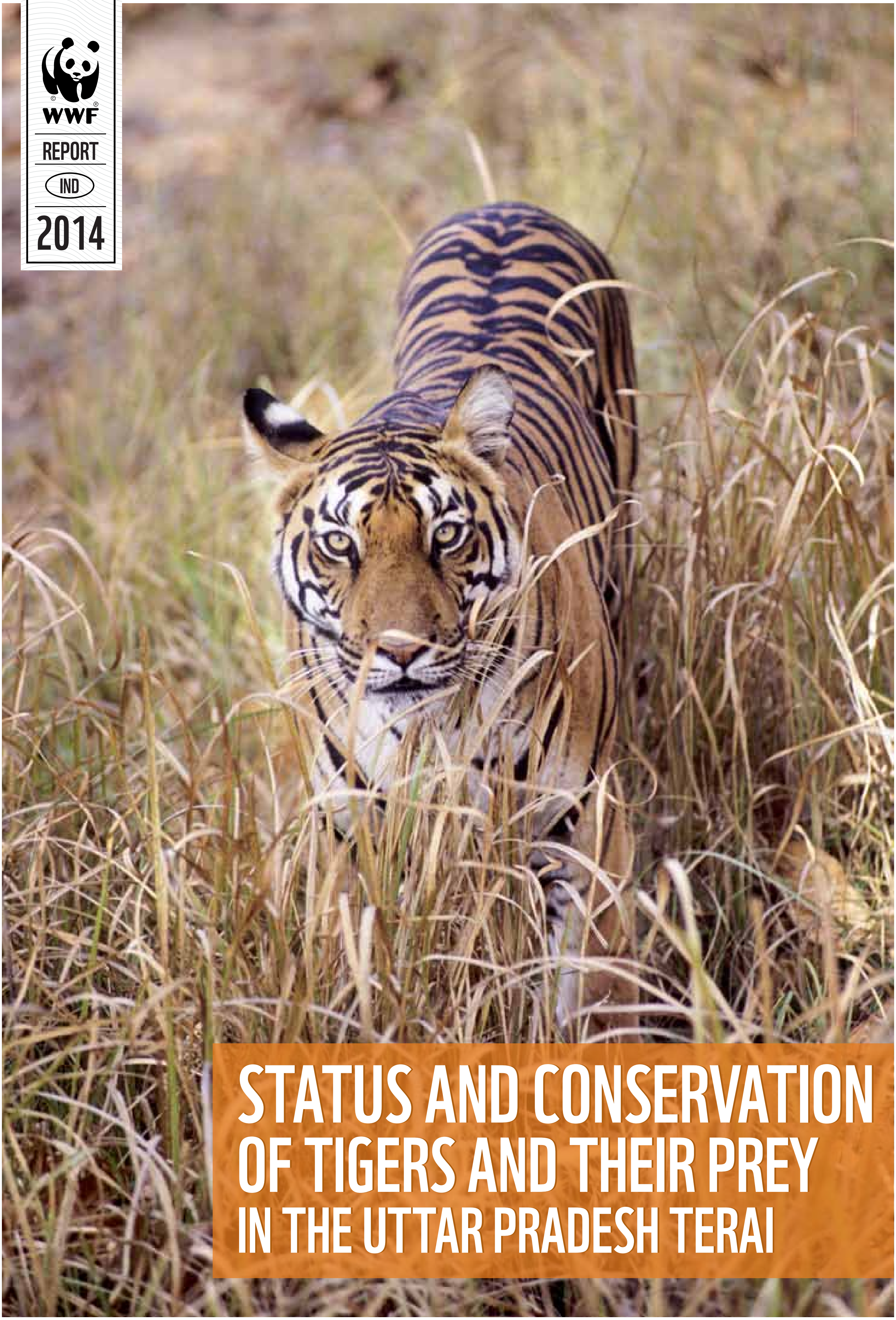

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REPORT

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2014

STATUS AND CONSERVATION OF TIGERS AND THEIR PREY IN THE UTTAR PRADESH TERAI

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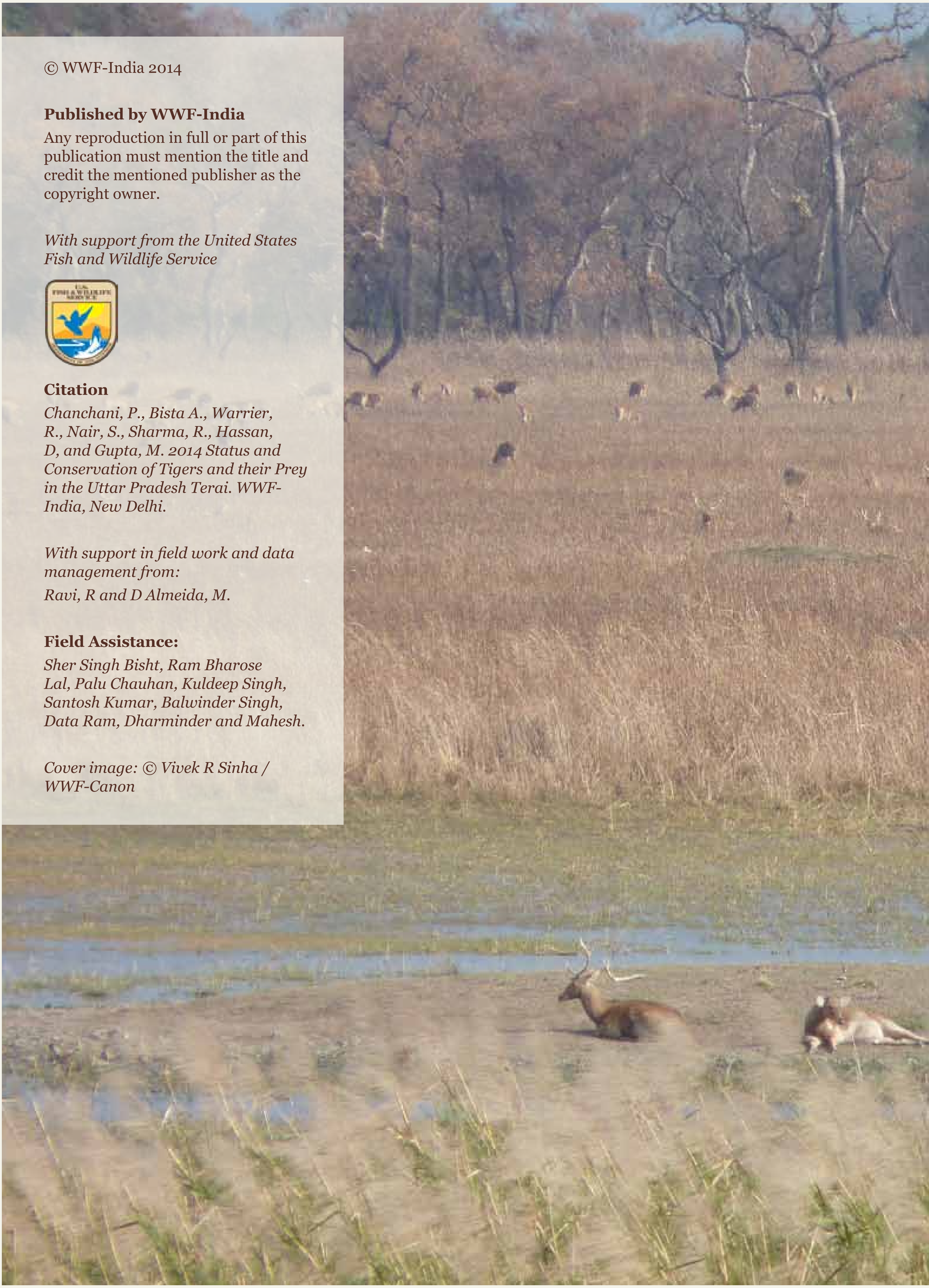

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This timely and well analysed report provides important information on the status and ecology of tigers and their prey from the 'Central Terai Landscape' comprising of the forests of Pilibhit Wildlife Sanctuary (now Tiger Reserve), Dudhwa Tiger Reserve, the Reserved Forests of Kheri and Sohelwa Wildlife Sanctuary. These forests are surrounded by a very productive agriculture landscape with a large and growing human population and a major challenge is how tigers can be sustained and recovered in landscapes with high human densities.

In its intensity and coverage of the UP Terai, this report is a unique scientific exercise. Camera traps were deployed in over 1000 locations over multiple years and the sampling effort was substantially greater than previously conducted surveys in this region and elsewhere.

Besides providing robust estimates of population sizes for tigers and their prey, the report also delves into other relevant aspects such as turnover of populations, and identifying recovery sites based on multiple year data. The report also reviews habitat conservation, management and land use practices and touches upon measures that allow tigers, their prey and humans to co-occur in a highly fragmented forested landscape. It probes to ascertain if the current habitat and prey base will allow tigers to reach optimal densities in potential recovery sites and touches upon the challenges for dispersing tigers that move between forest patches through the predominantly agricultural matrix in the Terai.

Tigers and their prey utilizing the agricultural landscape that surround Protected Areas in this region is discussed, along with the need for appropriate policy and conservation interventions to address human-wildlife conflict. Monitoring tiger populations is extremely relevant to provide insight on the above aspects and discuss solutions and is the focus of this important and well researched report.

Tiger recovery and conservation in this trans-boundary section of the Terai is also affected by the management of forests along the Nepal border and I hope this report further aids recent efforts to restore key corridors between forests in India and Nepal that can lead to recovery of populations in suitable habitats on both sides.

I commend the authors and WWF for this collaborative study with the UP Forest Department with generous support from several organizations, institutions and individuals. The results will guide us in implementing appropriate measures to ensure an interconnected and viable tiger population in the UP- Terai.

17/7/14
(Dr. Rupak De)

EXECUTIVE SUMMARY

This report presents information on the ecology and status of tigers and wild ungulates in a portion of the Terai Arc Landscape that lies between the town of Pilibhit in Uttar Pradesh and Suhelwa WLS in Balrampur District of Uttar Pradesh, referred to as the Central Terai Landscape. The study (2011 -2013), carried out in association with the Uttar Pradesh Forest Department, was focused on studying populations of tigers and their principal prey species in Dudhwa Tiger Reserve, Pilibhit Forest Division, and the North and South Kheri Forest Divisions. These surveys for wildlife were the most intensive of their kind to date, and the findings of two years of field-sampling have been analyzed and presented in this report. With the greater purpose of generating reliable information on the occurrence and abundance of tigers and their prey in order to inform conservation planning and wildlife management, at both the landscape and local scales, this study addressed several major objectives.

The first was to intensively sample tiger populations using camera-traps to estimate population sizes and density. The second was to make available preliminary information on the dynamics of tiger populations and to describe the population structure in detail. The third objective was to quantify the abundance of key prey species, and to develop an understanding of prey density and distribution relative to the environment. The fourth was to extend tiger monitoring efforts to the Suhelwa Wildlife Sanctuary and report on the status of tigers at this site which has received little conservation attention. Methodological details and study findings have been discussed in detail, in the context of current conservation issues.

Ultimately, the report reveals that tiger and prey-populations in large-contiguous habitat patches are faring better than those in fragmented forest-islands, irrespective of Protected Area status. Furthermore, this study reveals that several of the region's tiger populations are precariously small, and recovery may be aided by enhanced protection and the restoration of some important corridors.

An important feature of sampling in this study was to maximize spatial coverage while intensely sampling their habitats with camera traps. This study design was to maximize the probability of all adult tigers in sampled sites being exposed to motion-triggered cameras, and to ensure that sampling encompassed the full gradient of habitat types and human disturbance in the study area. Data collected from cameras enable the accurate mapping of variations in tiger density across the landscape. In all, camera trapping involved the deployment of cameras at 1086 locations over the two years for a total of 18,636 trap nights, and approximately 2500 km^2 of tiger habitat was sampled. Sampling effort was between 40% and 300% greater than in the previously conducted All India Tiger Monitoring Exercise. Likewise, while sampling for prey species using variable distance line transect sampling, an effort was made to distribute transect lines to maximize the spatial extent of sampling, and nearly 100 transect lines were sampled repeatedly over two sampling seasons in Dudhwa Tiger Reserve. Analysis of these camera-trap data, using contemporary spatial capture-recapture models, has yielded estimates of the population size, population density and the capture probability. These data have also been been partitioned and analyzed in a manner that facilitates the

Swamp deer, Jhadi Tal,
Kishanpur WLS, Uttar Pradesh

comparison of population estimates with previous estimates from the All India Tiger Monitoring Project (2008 and 2010). Data from line transects have been analyzed using conventional distance sampling and analysis estimates for five ungulate species have been provided. Maps depicting variations in the density and abundance of tigers and their prey across the Central Terai Landscape have also been generated from camera trap and line transect data.

The estimated population size for tigers in Pilibhit Forest Division was 23 - 26, Dudhwa National Park 14 - 22, Katerniaghat WLS 17 – 24, and Kishanpur WLS 16 – 18 individuals. The density of tigers (number per 100 km^2) ranged between 2 in Dudhwa National Park and 5 in Kishanpur WLS. The sex ratios (number of adult male tigers: adult female tigers) were even 1:1 in Dudhwa and Katerniaghat and biased towards females in Pilibhit and Katerniaghat. In two years of sampling, the turn-over of individual tigers in each of these populations ranged between 20% and 30%, and the turnover was particularly high for adult and transient (dispersal age) males. Prey density values ranged from 4 ungulates/ km^2 in the forested areas of Katerniaghat WLS to 35 ungulates/ km^2 in the grassland-dominated Seed Farm area of Katerniaghat. Kishanpur WLS Pilibhit, Kishanpur and South Kheri are all part of one contiguous forest patch and have a tenuous connectivity with Shuklaphatna WLS (Nepal) and Nandhour WLS (Uttarakhand). Katerniaghat WLS is connected with the Royal Bardia National Park in Nepal via the Khata corridor. Forest connectivity between Dudhwa National Park and adjacent forests in Nepal appears to be completely severed. In Suhelwa WLS, recent surveys indicated that the Sanctuary may no longer support a resident tiger population, and that ungulate prey populations are greatly depleted. The recovery of tigers on Suhelwa will depend on population recovery in the adjacent and connected forests in Nepal, and by increasing protection of wildlife habitats.

Tiger populations in the Uttar Pradesh Terai are observed to occur at relatively high densities in Kishanpur WLS and some ranges of Pilibhit Forest Division, underscoring the importance of habitat connectivity. At other sites, we believe that tiger density and abundance is low because of relatively low prey-densities. Prey occur in high densities at some sites, typically those associated with grasslands and primary-succession riparian forests. Large mammal populations may also be low on account of anthropogenic pressure and hunting, particularly in areas close to the India-Nepal border. The recovery of some populations (most notably in Dudhwa National Park) will be aided by intensified patrolling and enforcement efforts, appropriate management of grassland habitats, and greater collaboration with local communities reliant on forest resources. Efforts to restore key corridors between forests in India and Nepal are expected to lead to significant increases in tiger populations by facilitating recolonization of unoccupied suitable habitats. Lastly, because tiger and their prey utilize agricultural lands that surround Protected Areas, there is need for policy and conservation interventions to address human-wildlife conflicts and to extend conservation efforts into the agricultural land around tiger occupied Protected Areas and Reserve Forests.

Elephant herd on the Dudhwa - Dhangadi road, Dudhwa National Park
© Ruchir Sharma / WWF-India

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At the onset, we would like to thank the Uttar Pradesh Forest Department for granting us necessary permits to undertake these studies. The department is also thanked for extending logistic facilities to the field teams, and facilitating the work in many ways. We are grateful in particular to Dr Rupak De for his support for our work. The Field Director of Dudhwa, Mr Sailesh Prasad, has encouraged us to expand sampling efforts and we thank him for his keen interest and involvement throughout the study. Mr Ganesh Bhatt, DFO Dudhwa provided key support and engaged closely with the field teams. We appreciate his enthusiam, for extending crucial logistic support, and for directing our attention to remote areas within the park that needed additional surveys. We are also grateful to DFO's of Katerniaghat, Mr. R.K Singh, Pilibhit Mr A.K. Singh and South Kheri, Mr. Neeraj Kumar for facilitating and supporting our work. Mr Manish Mittal was very supportive of our surveys in Suhelwa WLS. We also thank Mr V.K. Singh for his keen interest in conservation and research over the years.

We gratefully acknowledge the support from the Wardens and Range Officers who worked with us to ensure that the camera trapping exercise was conducted efficiently. In particular, we would thank Mr Anand Kumar (Warden, Belrayien), Mr A. Jaiswal (Warden Dudhwa), Mr K. Gautam (Warden Kishanpur), Mr C.K.P Choudhary (Dudhwa Range), Mr Suresh Kumar (Kishanpur Range), V.K. Tiwari (Mailani Range), Mr M.K Shukla (Katerniaghat Range), Mr. S.K. Chaudhary (Nishangara Range), Mr K.L. Meena (Bankati Range), and Mr T. Dhoora (Gauriphanta Range) for leading from the front and working tirelessly with their staff to keep cameras safe. We are also grateful to the many foresters, forest-guards and beat watchers who accompanied us on camera-installation forays and afterwards worked energetically, through rain, knee-deep-slush, leeches and elephant-perils - to keep cameras safe. For their committed effort over the years, we were rewarded with captures of tigers and other animals.

We are also thankful for the guidance provided by the Late Billy Arjan Singh during the initial stages of WWF-India's work in the Terai of Uttar Pradesh. We are deeply indebted to Dr Barry R. Noon whose interest, involvement and earnest passion for science and conservation has motivated this study and enabled its growth. Dr Noon's contribution of grant funds to the project, and review comments on sections of this report are also greatly appreciated.

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A tigress explores her territory inside the rhino rehabilitation area in Dudhwa National Park.
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INTRODUCTION

The last remnant tiger-occupied forests in North India lie in the bhabar and Terai tracts that abut the outer Himalayan and Shivalik ranges in Uttar Pradesh and Uttarakhand, adjacent to Nepal. This report details the status of tigers and their prey species in the Terai tract of Uttar Pradesh that is loosely bound on the west by the Sharda River and on the East by the Karnali-Girwa-Ghaghara river system. This area has been described as tiger habitat blocks (THB) IV, V and VI by Johnsingh *et al.*, (2004), henceforth referred to as the Central Terai landscape (CTL) or the Uttar Pradesh Terai. Dudhwa Tiger Reserve and other forests located within this region have long held a reputation for supporting large numbers of tigers which have variously been described as being "fierce" and, "wily and sophisticated" (Chaturvedi 1928, cited in Strahorn 2009), and "tolerant of humans due to force of circumstance" (Singh 1970). The Terai's forests, grasslands and swamplands, habitats for its tigers have no less a reputation of being dangerous on account of large mammals (Sunquist and Sunqusit 1988, Arnold 2006); sparsely populated and extremely unhealthy (Hamilton 1828) because of humid weather and swarming malarial mosquitoes and unwholesome swamps. Following over 150 years of colonization and transformation, tiger populations in the CTL are now largely restricted to the forests of Dudhwa Tiger Reserve in Lakhimpur-Kheri and Bharaich districts and in Reserve Forests in Pilibhit district. The areas around forests are comprised of productive, well irrigated agriculture fields tended by a large and growing human population.

Given the global decline of tigers as a consequence of habitat loss and fragmentation, prey depletion and poaching (Dinerstein *et al.*, 2007, Check 2006, Seidensticker *et al* 1999), the forests of the Uttar Pradesh Terai are in many ways a crucible in which the existing paradigms and formulas for tiger conservation are being tested (see debate on alternative tiger conservation paradigms in Waltson *et al* 2010; Wikramanayake *et al* 2010; Carter *et al.*, 2012; Harihar *et al.*, 2012). The challenge is to recover depleted tiger populations and to sustain existing ones in forest sites that are fragmented and disturbed by human activities and can support only small, local populations. A major research question is whether tigers can be recovered and sustained in landscapes with high human use and the effectiveness of existing reserves to conserve tiger populations over the long-term. These and other questions are pressing, given that Terai's human population has grown exponentially with a 130% increase between 1881 and 1981 (Semwal 2005). In a region where rural communities are predominantly agricultural, there is great pressure on forest resources as a result of extraction of fuel wood and grass from villages and towns located near these forests, both in India and Nepal (Johnsingh *et al.*, 2004, Semwal 2005). Mammals in the Terai's forests are also vulnerable to being hunted, with pressure stemming both from India and Nepal (De 2001, Basnet 2003).

What combination of land-use (e.g., timber harvest), habitat conservation, and management practices will allow tigers, wild ungulates and humans to co-occur or co-exist in a highly fragmented forested landscape? Within the current altered Terai landscape, will tigers be able to return to the high densities of the past? Will the current habitat and prey base allow the growth of tiger populations to reach regional and global objectives - such as WWF's Tigers Alive Initiative (WWF-2013). And are tigers able to disperse successfully between the Terai's forest patches through the predominantly agricultural matrix? A significant step towards answering these and other questions is to monitor populations in order to provide reliable estimates of population sizes for tigers and their prey. This is the primary concern of this report.

The word "status" as used in this report refers to a set of demographic parameters such as estimates of the population size of tigers and ungulate prey species ($\hat{N}$), density ($\hat{D}$) and measures of relative abundance such as species encounter rates. The current status of many species can be measured against baseline data such as that of Jhala *et al* (2008, 2010), and older Project Tiger data (www.projecttiger.in). Sampling methods and analytical tools to estimate demographic parameters for tigers and other large mammals have advanced rapidly over the past decade. In addition, recent sampling efforts are far more intensive than in the past. In some cases, current and former estimates of population size are not strictly comparable, but changes (positive or negative) in the status of these populations can be deduced. A formal analysis of population growth rates, survival and other demographic parameters will be enabled by continued monitoring in the future (see Karanth *et al.*, 2006).

Organization of this report

This report is organized into three sections. The first is a detailed introduction that discusses the context of tiger conservation in the Terai landscape from a national and global perspective. This introductory section describes historical, geographical, and cultural factors that have influenced Terai wildlife and their habitats, particularly in recent centuries. The introductory section also lays out our research objectives and broad research methodologies. The succeeding three sections (chapters 2, 3 and 4) describe the methods used to estimate demographic parameters for tiger and prey populations from camera trap and variable distance line transect data. These chapters also elucidate key ecological and anthropogenic factors that are likely to influence the occurrence and abundance of tiger populations in the CTL. Chapter 5 summarizes the findings of recent occupancy surveys conducted in Suhelwa Wildlife Sanctuary. The final section (chapter 6- Conclusion), summarizes previously described processes and variables that are likely to affect, positively or negatively, the growth of tiger populations and highlights the study's most significant findings. These findings are the basis of specific recommendations for management, conservation and future monitoring that are provided at the end of this final chapter. Additional details pertaining to data analysis, pictures of individual tigers photographed and relevant maps are in the appendices.

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Endangered garhials in the Girwa River, Katerniaghat Wildlife Sanctuary.

1.1 THE TAMING OF THE TERAI: COLONIZATION, LAND-CONVERSION AND CONSERVATION IN THE 19TH AND 20TH CENTURIES

Over the past two centuries, the Terai landscape has experienced a rapid transformation in land cover —formerly, the region was a malarial jungle, sparsely populated and on the fringe of civilization. Currently, the Terai is a densely human populated landscape dominated by agricultural fields of wheat, rice and sugarcane (Atkinson 1882, Strahorn, 2009). What remain of natural habitats are small islands of remnant forests, swamp and wilderness that have been extensively altered by current and past rulers and inhabitants of the Terai. Over the past two centuries, human denizens of the region have included two or more generations of British administrators, pioneering Sikh agriculturalists, migrants from East Bengal and indigenous communities including the Tharus and Buxas. Detailed anthropological information and other accounts of the indigenous Terai groups can be found in the writings of Srivastava *et al.*, (1958) and Conway *et al.*, (2000).

In colonial India, the demand for timber, most notably for railroad construction, attracted foresters and British administrators to the Terai. Historical records from eastern areas of the Terai indicate that by 1800's, sal and other valuable timber products were being transported all the way to Calcutta (Poffenberger 2002). The imperial forestry operation was well entrenched in the Terai by the mid 1800's and sal forests in some areas of the Terai were showing signs of severe exploitation wherein sal trees >5 feet in girth were seldom encountered (Sivaramakrishnan 1999). By the turn of the nineteenth century (1885-1905) meter-gauge railway lines had been laid in the frontier districts of the Indian Terai bordering Nepal. Trains connected the remote forests of Bharaich, Balrampur, Gonda, Lakhimpur and Pilibhit to Bareilly, Lucknow and by extension the great ports of Calcutta and Bombay. The most significant felling of the Terai forests occurred in the colonial era, with marked increases in timber extraction around the periods of the two great wars.

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Established to serve imperial forestry operations, The narrow gauge line from Barielly to Gonda passes through the forests of Pilibhit, Kishanpur, Dudhwa and Katerniaghat.

In the years following India's independence, the processes and forces that led to the 'normalization' of the Terai, or the transformation of its physical terrain into a 'preferred-landscape' for humans are many (Stahorn 2009). Foremost was the state government's sharply directed policy to transform the Terai's "wasteland" into productive cropland. The post-independence years were characterized by the introduction of forest-clearing, swamp-filling bulldozers, the government-mediated arrival of pioneering agriculturalists from Punjab (and displaced Sikhs from Pakistan), Hindu refugees from Bangladesh and elsewhere. These settlers of post-Independence Terai were offered attractive settlement packages and their efforts to transform the Terai's wilderness were supported by massive malaria eradication programs funded in part by World Health Organization, and by international support for agricultural development. In the colonial era and early decades after independence, forestry operations and agricultural expansion often resulted in the slaughter of tigers and other wildlife, usually in the form of organized sport hunting ordained and coordinated by maharajas or forest administrators (Stahorn 2009). With increasing dominance of the landscape by agriculture, a number of ungulates associated with Terai grasslands reportedly witnessed drastic declines (Davis 2005). Forestry operations were formalized in Dudhwa and other sites in the Terai by Brandis in the 1860's and a series of working plans evolved thereafter which prescribed felling practices and means of enhancing sal regeneration, often by clearing the understorey of other plant species (De 2001). These working plans have not been operational in Dudhwa National Park and other PA's since their creation, but continue to guide forestry operations in South Kheri, North Kheri and Pilibhit.

In the 1970s, heightened awareness about forest and environmental degradation and the decline of tiger populations brought about regulations on hunting and forest clearing practices. WWF and International Union for the Conservation of Nature (IUCN) created a strategic plan for the creation of tiger conservation programs and supported and funded Government efforts to conserve tigers and their habitats (Strahorn 2009, Greenough 2003). With the establishment of Dudhwa National Park and Kishanpur Wildlife Sanctuary in the 1970s, there was a marked shift in the government's focus away from hunting, logging

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A winter morning in the farmlands of Kishanpur village, nestled within Kishanpur Wildlife Sanctuary.

and land conversion towards protecting wildlife habitats and attempts to increase tiger populations in some reserves. The veteran conservationist Billy Arjan Singh (1917 - 2010) actively championed the cause of tiger conservation in Dudhwa and other sites in the Terai for nearly 40 years and published widely on his jungle experiences and threats to wild tigers (see Singh 1973, 1993). Billy Arjan Singh lived on a farm adjacent to the Suheli River along Dudhwa National Parks's southern boundary for several decades, and is perhaps best remembered for the zoo-born tigress, Tara, he reared in his home, and reintroduced into the forests of Dudhwa National Park.

Tigers have been a dominant factor in the decisions, ambitions and frustrations of current and former administrators, foresters and cultivators whose overriding goal is to transform the Terai into a productive, habitable landscape for human use. By occasionally attacking and killing agricultural settlers and their livestock, tigers impinged on the colonial state's designs to neutralize and tame the Terai. For a period in time, shikaris were well rewarded for ridding or diminishing forests of these 'vermin' (Rangarajan 2012). Elsewhere, tigers were the prized bounty of exalted hunts on elephant back. There are many well documented accounts of dozens of tigers being shot as trophies by a hunting expedition lasting a few days or weeks in wildlife reserves that were under the exclusive control of maharajas or imperial administrators (Rookmaaker *et al.*, 2005, Stahorn 2009). In current times, managers are challenged by tigers that injure or kill humans and cattle or take up temporary residence in farmlands (Singh 1970, Greenough 2003, Shukla 2013). Ostensibly, conservation measures to increase vulnerable tiger populations may in some cases exacerbate human-tiger conflict (Sunquist and Sunquist, 1988), and this has led to a polarized debate on tiger conservation in India (Narain *et al* 2005, Karanth 2011), particularly with regard to the presence of human settlements within tiger habitats, and access of the public to forest resources.

1.2 CONTEMPORARY CONSERVATION ISSUES IN THE UTTAR PRADESH TERAI

The forest tracts between the Sharda and Girwa support an estimated 100 - 120 tigers (Jhala *et al.*, 2008, 2011). Tiger conservation in the Uttar Pradesh (UP) Terai and elsewhere in India is complicated: in addition to conserving and protecting tigers and maintaining large contiguous landscapes, management must also pay heed to historical, legal and livelihood concerns of local human communities (Rastogi *et al* 2013). Five themes spanning social -ecological issues that are strongly linked to tiger conservation in the Terai have been outlined in the paragraphs that follow. Data from present and future monitoring programs can help inform management and policy interventions that intersect with these issues.

First, several proposals have been put forth to extend the current Protected Area network by including adjacent forest patches or complexes which support or could support tiger populations, by granting Protected Area status to such sites. One example is Pilibhit Forest Division better known for its status as a working forest with forestry operations focusing on the selective extraction of sal (*Shorea robusta*), and less known for the substantive tiger population it harbors (Johnsingh *et al* 2004, Chanchani *et al.*, 2011). Local populations extract fuelwood and other forest resources as head loads and bicycle loads from all the CTL's forests, though these pressures are considerably higher in reserve and buffer zone forests (De 2001). Moreover, management practices in PA's and reserve forests may vary widely and little is known about the effects of specific management practices such as burning and 'assisted natural regeneration' on herbivore populations or the distribution of tigers (but see studies of Kumar *et al.*, 2002, and Shrestha 2004). In 2014, Pilibhit Forest Division was granted the status of Tiger Reserve, in recognition of its supporting one of the most significant tiger populations in North India. While this forest's management status has changed, significant challenges lie ahead to plan and implement new conservation strategies and to ascribe a new set of access rights for the region's local residents.

A second related theme pertains to the co-occurrence of tigers and humans in forests of the UP Terai (Fig 1-3). Given the large human populations that live close to and utilize forests and their resources, wildlife ecologists are debating whether, and to what extent, tigers are tolerant of human beings in their habitats (Carter *et al.*, 2012, Harihar *et al.*, 2012). This discussion is particularly relevant given that human communities residing in forests are increasingly claiming their rights to land and livelihoods under the Recognition of Forest Rights Act of the Government of India (2006, www.fra.org.in). By mapping the current distribution and density of tigers and their prey in the CTL, this study will enable managers to re-examine forest demarcations and inform the delineation of core, buffer and critical wildlife habitats.

The third theme is centered on conflict between humans and wild mammals. Human - tiger conflict arises periodically in the CTL. Usually, conflict implies tigers preying upon cattle, or more rarely involves an attack on a human being - sometimes resulting in a fatality. On occassion, affected people retaliate and provoke, injure or kill tigers that are believed to threaten their livelihoods. Every year tiger encounters occur both in forests and in sugarcane fields outside of forests where tigers take refuge. There is no consistent strategy to redress conflict or to provide compensation to humans adversely affected by tigers. Neither is there an official policy to protect dispersing tigers that take up residence in or pass though farmlands, or to safeguard the lives of people who live in close proximity to tigers. Estimating population sizes for tigers and their prey and mapping their distributions across the landscape will allow us to better identify the causes of conflicts in the CTL.

Shared space
A family resident in a forest-interior village cycles past a camera trap in Kishanpur WLS. A tigress passes by the same spot at night. Such occurrences are common-place, and sometimes separated by minutes.

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Tharu women and their livestock from Nepal (huts in background) near the forests of Katerniaghat Wildlife Sanctuary. An open border between Indian and Nepal presents many opportunities and challenges for wildlife conservation.

A fourth theme that is relevant to the persistence of tigers in the Terai is habitat connectivity. Connectivity in the UP Terai is critically compromised today because of extensive habitat fragmentation. For example, the largest forest patch in the UP Terai, the Pilibhit-Surai-Kishanpur-South Kheri forest complex, shares no forest connectivity with Dudhwa National Park and only tenuous connectivity with Shuklaphanta in Nepal. Large forest tracts were transformed into disjoint patches in the British era, but forest connectivity has been significantly reduced as a consequence of increasing development and encroachment into swampy grasslands and river courses which served to connect tiger habitat patches (eg. the Mohana River between Dudhwa and Katerniaghat). These data on tiger populations in Dudhwa Tiger Reserve and other sites in the CTL have allowed us to monitor individual tigers over the past three years. These data can be incorporated into models of habitat connectivity to model dispersal, corridor functionality and the influence of fragmentation on tiger populations (Royle *et al.*, 2013).

Lastly, tiger conservation success in the UP Terai is strongly affected by the management of forests along the Nepal border (eg. Dudhwa National Park, Katerniaghat Sanctuary and Pilibhit Forest Division). An open border between India and Nepal consisting of fragmented forests patches presents an opportunity for tigers to disperse between habitat patches but also necessitates coordinated conservation and wildlife management efforts across this border. (Fig.1-4). While the un-fenced border permits animal movement, wildlife populations along the international border face a persistent threat from poaching, and and hunters from Nepal have been apprehended in Dudhwa Tiger Reserve (De 2001). Political instability and insurgency in Nepal over the past decade have severely undermined wildlife conservation in the TAL (Wikramanayake *et al*., 2010). The international border, which intersects key tiger habitats, has encouraged increased collaboration between forest authorities and tiger researchers in India and in Nepal but much additional work needs to take place to jointly define and implement realistic conservation targets, reduce hunting and restore habitat connectivity. Recently, there has been an increased emphasis to collaborate and jointly monitor tiger populations and to facilitate data sharing. Towards this end, WWF-India, WWF-Nepal and other agencies have initiated efforts to standardize data collection and analysis protocols. Collectively, these groups in the two countries sampled nearly 10,000 km^2 of tiger habitat with camera traps in the TAL between November 2012 and June 2013.

1.3 GEOGRAPHY AND VEGETATION

Geographical characteristics of the Terai and descriptions of Study Sites

The Terai, by definition, is a flood plain. The physiognomy of this landscape has for millennia been moulded by water that flows through in large, flood-prone rivers, or collects in innumerable ponds, wetlands and ox-bow lakes, some of which are located within forests. Over the past century, the Terai has increasingly been claimed and 'tamed' by agriculturalists to cultivate sugarcane, wheat and rice that rival the agricultural production of the Punjab plains. In the process of converting the Terai's wilderness to agriculture, particularly between 1900 and 1965, many rivers have been dammed and an elaborate network of canals and reservoirs has been devised to divert perennially-flowing water deep into the plains of UP, especially in Pilibhit and adjacent districts. Meanwhile, many swamps and river banks have been claimed for agriculture (Strahorn 2009). The Terai's grasslands were maintained by annual flooding which brought rich alluvium and promoted early-succession riparian vegetation communities. Altered rivers flows and the reclamation and development of wetlands have severely impacted the grasslands (Dinerstein 2008, Peet *et al*., 1999 b). By some estimates, intact Terai grassland habitats are now only 2% of their original extent (Dinerstein 2008). A number of the remnant tall-grass patches lie within the protected areas of Dudhwa, Kishanpur and Katerniaghat.

Katerniaghat Wildlife Sanctuary (~500 km2, established 1976) is the easternmost area of Dudhwa Tiger Reserve. The northern boundary of this forest lies along the Nepal border which it follows for nearly 50 kilometers. A defining feature of Katerniaghat is the Girwa river (Karnali in Nepal), which has been dammed by a large barrage situated in the western portion of the Sanctuary. The Girwa supports sizable populations of muggers (*Crocodylus palustris*), gharials (*Gavialis gangeticus*) and Gangetic dolphins (*Platanista gangetica*), species which have largely disappeared from several other river systems in North India. The dam resulted in the formation of a large reservoir surrounded by the forests and grasslands of Katerniaghat Range. A portion of Katerniaghat Range (~60 km^2), including the Trans-Girwa and Koudiyala beats, lie to the North of the reservoir and river. The northern portions of Katerniaghat along the Girwa-Karnali river are connected to Bardia National Park in Nepal through the Khata and Karnali-Cheddia corridors. The central and eastern portions of Katerniaghat consist of a narrow, linear (east-west oriented) forest which is neatly bisected by a grid of forest roads including the east - west oriented State highway and the railway line from Palia to Nanpara and Bharaich.

The southern extension of the sanctuary to the south of Katerniaghat in Nishangada Range is an area often referred to as the seed farm. This area was long owned by the central government and was managed for agricultural production, horticulture and fisheries. In 2010, following a prolonged legal battle, the central state seed farm was transferred over

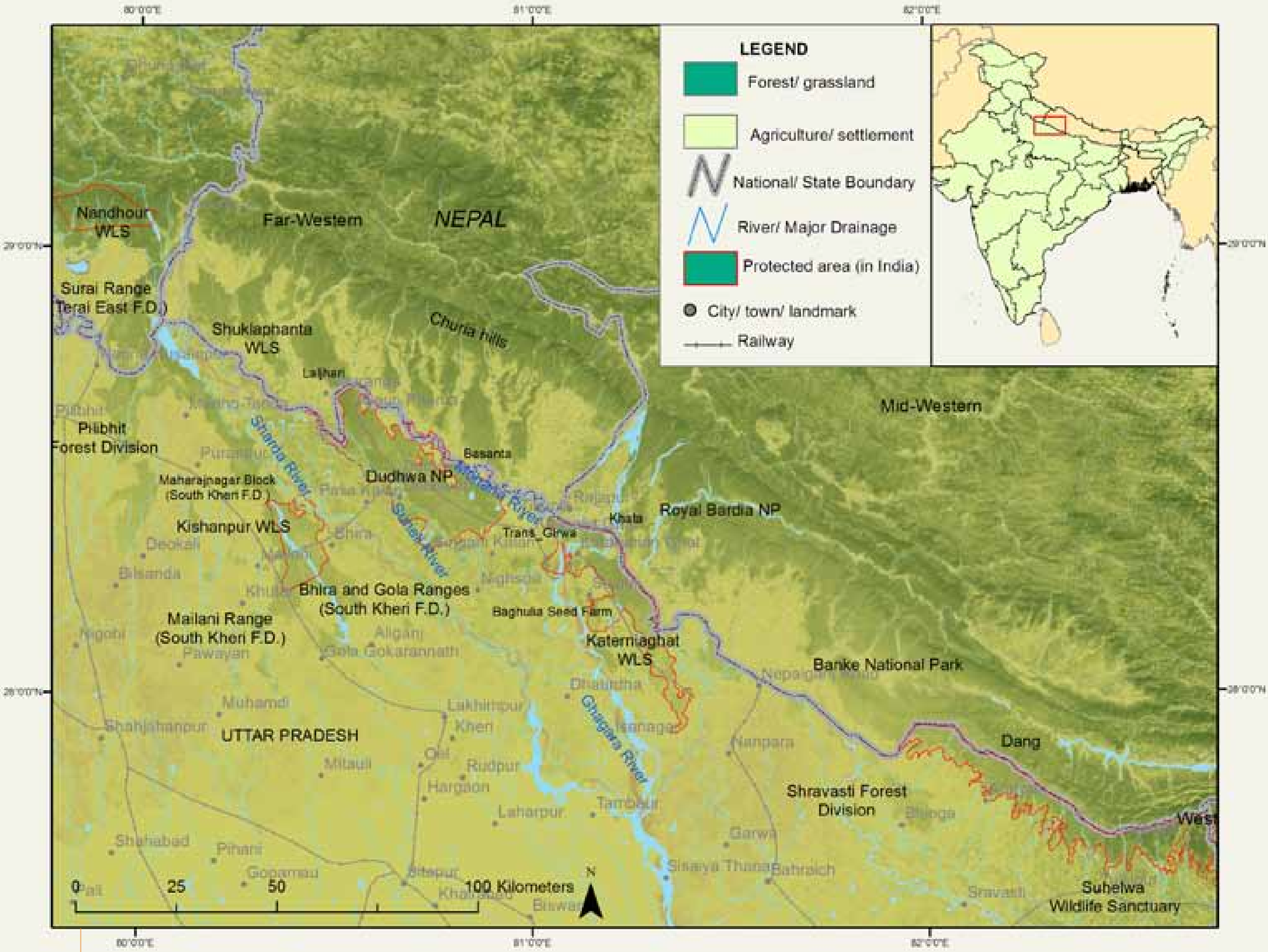


Figure 1.1
Map of the Central Terai Landscape showing Protected Areas in India and adjacent forests in Nepal.

to the Uttar Pradesh Forest Department and is now an integral portion of the Sanctuary, even though a large part of this land is still fallow, and ground cover comprises of various grass species and exotic weeds. Today, the seed farm is intensively grazed by cattle, which by some estimates number over 10,000 heads. Katerniaghat Sanctuary has over 13 villages within it populated by Tharu, Muslim, Hindu and Sikh communities. Katerniaghat has been in the news in recent years on account of elevated conflict between humans and large carnivores, particularly leopards.

The 680 km^2 Dudhwa National Park (DNP) lies to the west of Katerniaghat and is separated from it by about 15 kilometers of farmland. The Northern boundary of Dudhwa (also the border with Nepal) is defined by the Mohana River. A large enclave of forest-villages inhabited by the Tharu community is situated along the Park's Northern boundary and connected by road to the towns of Palia-Kalan and Dhangadi (Nepal). The forests adjacent to these villages and other edge-regions of the park have been categorized as the buffer zone whereas the core comprises of the more central areas of DNP. To the south of these villages are extensive tracts of sal forests, interspersed by tall-grasslands, large wetlands and seasonal streams. The southern boundary of the park is generally defined by the meandering Suheli River. Dudhwa has tenuous connectivity with the community managed Basanta and Laljhari forests in Nepal through corridors that are now predominantly under human land use. The Park is also bisected by a meter-gauge railway line which runs through its central portions. Dudhwa is prone to flooding in the monsoons when the rivers to its north and south breach their banks and inundate low lying grasslands and forests (Midha 2008). The park is also well known for its small population of reintroduced Rhinos, numbering 30 or less, and restricted to a fenced enclosure in the Suheli river flood plain. The complex grassland communities and woodland-grassland mosaics of Dudhwa (such as those found in Kakraha and Sathiyana) are a defining ecological feature, and they are the last representative sites of habitats that may have been more widely distributed in the Terai historically. De (2001) reports in the park's management plan that around 40,000 cattle graze in the peripheral areas of Dudhwa and Kishanpur each day.

The largest contiguous forest complex in the UP Terai includes within it Kishanpur Wildlife Sanctuary (200 km^2, KWLS, administered under Dudhwa Tiger Reserve), the Reserve forests of Pilibhit Forest Division (PFD, 700 km^2) and South Kheri Forest Division (SKFD, 300km^2) to the south. The forests of Surai Range (Terai East Forest Division, Uttarakhand) lie immediately to the north of PFD and are wholly connected with Mahof Range of PFD. A unique feature of the geography of this forest complex is its narrowness and the lack of a well-defined core area that is insulated from human activity. The Sharda River flows along the eastern boundary of these forests and separates Pilibhit from Shuklaphanta Wildlife Reserve in Nepal. While KWLS is a premier wildlife Sanctuary, known for its large swamp deer (*Rucervus duvaucelii*) populations, SKFD and PFD are worked forests which yield many thousand cubic meters of timber each year. Another defining feature of this forest complex is the distribution of an extensive network of unpaved canals stemming from the Sharda River and the Sharda Sagar reservoir. These canals offer a number of benefits to the region's wildlife including a perennial water supply. The periodically regulated water flow in some canals (weekly cycles) allows wildlife to ford these canals which otherwise fragment the forest. Portions of this habitat block exist as patches of grassland along the Sharda and other rivers. Kishanpur and Haripur Range of Pilibhit FD are proximate to the Shuklaphanta Wildlife Reserve and the movement of rhinos (*Rhinoceros unicornis*) from Nepal has been noted in this corridor area. The banks of the Sharda River also support numerous cattle camps, and there are several thousand buffaloes grazing in these areas. Human use of forest resources is notably high in this region, both from several thousand villages adjacent to the forests, and from the larger settlements including Pilibhit, Majhola, Puranpur, Mailani, Gola and Mohammadi in Pilibhit and Lakhimpur-Kheri districts. Roads, highways and a railway line between these settlements bisect the Pilibhit, Kishanpur and South Kheri forests.

The forests of North Kheri Forest Division (NKFD) are predominantly located along the Sharda River in a series of fragmented patches comprising of forests of Khair (*Acacia catechu*), silk cotton (*Bombax ceiba*), sihsham (*Dalbergia sissoo*) and *Zizyphus spp*. interspersed with patches of grass dominated by *Saccharum spontaneum*. Some of these forest patches (eg Paraspur in Palia Range) are in close proximity to forests of Pilibhit and Kishanpur, while others like Majgai are adjacent to the Dudhwa forests. Certain patches (eg Lagdhan) are altogether isolated. The forests of North Kheris represent a dynamic riverine-flood plain ecosystem which is prone to significant annual changes mediated by monsoon floods. Changes in the river course cause forests to be lost to the river, and occasionally result in the formation of new wilderness patches. Several patches of the North Kheri forests such as those located between Dudhwa and Katerniaghat are thought to serve as stepping-stones for dispersing tigers, while some other patches of the North Kheri forests such as Paraspur and Majgai are known to be occupied by tigers. Like SKFD and PFD, the North Kheri forests are worked for timber with selective felling and an emphasis on the extraction of dead wood. NKFD also has extensive cattle-grazing and its forest patches are all very disturbed. Given the complex nature of forest boundaries that flank the flood-prone Sharada River, significant portions of forest lands have been encroached predominantly by Sikh sugarcane cultivators with large land holdings.

Herd of wild elephants in a sal forest. Chandpara Block, Dudhwa National Park

Suhelwa Wildlife Sanctuary, in the districts of Balrampur and Shravasti, is a narrow linear, forest patch, adjacent to the India-Nepal border in the north. Suhelwa is contiguous with the forests of Dang in Nepal, and is connected to Banke National Park, which is part of the Bardia forest complex. The habitat in this sanctuary is typified by elements of the *bhabbar* zone typified by porus rocky riverbeds (*raus*) and undulating terrrain along the Himalayan foothills. Terai habitats, such as wetlands and tall-grass stands are absent in Suhelwa. A lengthier description of the geography and ecology of Suhelwa WLS can be found in chapter five of this report.

Vegetation characteristics of the Terai

Tiger habitats in the Terai can broadly be thought to exist in the form of three charactersitic vegetation communities: deciduous forests (wet and dry), alluvial grasslands and tropical swamp forests. Vegetation communities described by Kumar *et al.*, (2002) and Johnsingh *et al.* 2004 are sal (*Shorea robusta*) forests, sal mixed forests, moist mixed deciduous forests, tropical seasonal swamp forests, tropical seasonal evergreen forests, Khair (*Acacia catechu*) and sissoo (*Dalbergia sissoo*) forests, and plantations. Three grassland communities have also been identified namely upland grasslands, lowland grasslands and *Tamarix* scrub.

Sal forests in the CTL have been extensively 'worked' by the forest department, and some continue to be under silvicultural management today. Sal is a predominantly mono-dominant species in these forests, or the dominant species with associates such as *Mallotus philippensis, Millusa velutina, Lagerstromia parviflora, Teriminalia alata* and *Syzygium cumuni*. Primary understory shrub associates are *Clerodendron viscosum, Tiliacora acuminata, Ardisia solanacea* and *Flemengia microhylla* whereas *Themeda arundinaceae, Imperata cylindrica, Saccharum bengalense* and *Desmostachya bipinnata* are the major grass associates. Nearly 75% of the tiger habitat in the CTL is within sal forests. The mixed-moist deciduous and tropical seasonal swamp forests of the Terai are dominated by introduced teak (*Tectona grandis*), *Termanalia alata, Trewia nudiflora*, *Ficus racemosa, Acacia catechu* and *Mallotus philippensis* in the canopy whereas *Clerodendrum viscosum, Ardisia solanacea* and *Glycomis pentaphylla* are dominant in the understorey.

Upland grasslands occur as mosaics that are often embedded within moist sal forests. These grasslands are associated with well drained soils and areas that are not severely water logged. Grasses such as *Imperata cylindrica, Phragmytes karka, Arundo donax, Sclerostachya fusca, Themeda arundinacea, desmostachya bipinnata, Saccharum spontaneum* and *Cymbopogon jwarancusa* are typically found to occur in upland grasslands. Lowland grasslands, by contrast, occur in water-logged and low-lying areas that are associated with alluvial soils. In addition to species found in upland grasslands, *Saccharum narenga* is widely distributed and abundant in such grasslands. Tree species associated with these grasslands (and scantily distributed within them) include *Bombax ceiba, Butea monosperma, Albizia lebbeck, Scheleichera oliosa* and *Syzygium cumini*. The Tamarix scrub community is found to occur in unstable, erosion prone sand banks along the Sharda river. In addition to the dominant scrub *Tamarix dioica,* associated species such as *Ziziphus mauratiana, Saccharum spontaneum*, *Acacia catechu* and *Dalbergia sissoo* are also commonly encountered in sandy riverine habitats (Kumar *et al.*, 2002).

The structural characteristics of forest and grassland habitats and the species composition of vegetation influence the distribution of wild ungulates. For example, data from studies in Nepal indicate that several ungulates may achieve their highest densities in alluvial flood-plain and grassland habitats whereas sal forests, with relatively limited understory vegetation, are less productive habitats for grazing species (Shrestha 2004). Some species of deer have highly specialized dietary and habitat requirements and select tall-grass habitats dominated by *Saccharum spontaneum* (Wegge *et al.*, 2006; Odden *et al.*, 2005). Ungulate-

Above: A tusker at the water's edge in Chaurela tal in Dudhwa National Park. Nagra tal, Bilrayien Range, Dudhwa National Park. Animals congregrate at such wetlands, especially in the summer months

Below: Nagra tal in Dudhwa National Park is frequented by tigers, elephants and swamp deer habitat relationships are often influenced by management actions. For example, canopy openings in sal and mixed forests are thought to promote vegetation used by populations of chital and other herbivores (Shrestha 2004). A regime of cutting grasslands succeeded by their burning attract chital herds and may result in more forage being available during the hot-dry months (Kumar, 2002; Moe and Wegge 1997). Tigers appear to seek out areas with a well-developed understory (Sunarto *et al.*, 2012), and grasslands are preferred hunting areas in the Terai (Sunquist and Sunquist 1988).

1.4 SUMMARY OF RECENT WILDLIFE SURVEYS IN THE UTTAR PRADESH TERAI

This study broadly builds on the three previous surveys that ascertained the status of tigers and other mammals in the CTL. The first of these was conducted by Johnsingh *et al* (2004). In this pioneering landscape-scale study, A.J.T. Johnsingh and his colleagues rapidly surveyed tiger habitats in the entire TAL in India by walking transects that followed rivers, canals, ridges and forest trails. The overall survey effort was about 1000 kilometers, and surveyors recorded encounters of signs of tigers and other mammals, collected information about vegetation characteristics and ranked human disturbance along the survey routes. These surveys described the occurrence and abundance of large mammals at the landscape scale, identified distinct tiger habitat blocks and delineated important wildlife corridors within the landscape. These studies cautioned that several tiger populations appeared to be small and vulnerable, likely on account of severed habitat connectivity, habitat degredation and hunting.

Kanagaraj *et al* (2011) refined analyses for data from these and other similar surveys and built habitat suitability models for tigers, while also identifying 'source and sink' sites within the Terai Arc Landscape. Recent work by these authors on landscape connectivity (Kanagaraj *et al.*, 2013) reveals that while some of the Terai's major wildlife corridors appear to provide structural and functional connectivity for tigers, the loss of forest cover is likely to have severely affected tiger-use in several other corridors.

As a part of Phases I, II and III of the All India Tiger Monitoring Project (conducted by the National Tiger Conservation Authority, the Wildlife Institute of India and WWF-India and other NGO's -- see reports by Jhala *et al.*, 2008 and 2011), extensive Terai-wide surveys were carried out to sample tiger and prey species populations and statistically estimate site occupancy and species abundance. The first step of field sampling involved extensive foot surveys in all forest beats associated with historical tiger presence. Three hundred and eighteen 100 km^2 grids were surveyed to estimate site occupancy for tigers and other wild mammals in the Terai. Ungulate encounter rates along survey trails, wild ungulate dung density, the normalized differential vegetation index, elevation and road density were environmental factors that were identified to influence tiger occurrence in the TAL.

These occupancy surveys were followed by camera trap and line transect sampling in key sites, with the objective of estimating tiger and ungulate population sizes. Based on capture-recapture analysis, Jhala *et al* (2008) estimated that there were 95 (80-110) tigers in a portion of the CTL (Pilibhit, South Kheri, and Dudhwa Tiger Reserve), whereas the estimate from the 2010 surveys was 112 tigers (106-118). These results are based on camera trap surveys with a cumulative effective trapping area of approximately 1000 km^2, which is about 40% of the overall forest area in the CTL. Line transect sampling involved 742 km of survey effort over 93 transect lines. The densitiy estimate (number/km^2) of ungulates for all forest patches in the UP Terai and Valmiki Tiger Reserve in Bihar were 13.0 (2.17) for chital; 0.14 (.10) for sambhar; 0.41 (0.17) for hog deer; 3.02 (0.81) for nilgai; and 1.99 (0.55) for wild pigs. Figures in brackets are standard error values.

Population estimates for tigers in the CTL, from pugmark survey data that preceeded the aforementioned camera trap surveys can be found in the Dudhwa Tiger Reserve Management Plan (De 2001). Between 1985 and 1999, there were an estimated 64 - 80 tigers in Dudhwa National Park, and 14 - 33 in Kishanpur Wildlife Sanctuary. Dudhwa, Kishanpur, Mailani and Bilrayien Ranges, situated within these Protected Areas, were reported to be Ranges with high tiger use whereas Gauriphanta Range, a buffer zone area in the Northern end of Dudhwa National Park was reported to be devoid of tigers.

Other notable ecological research in the Central Terai Landscape include studies of swamp deer populations (Sankaran 1989 and Qureshi *et al.*, 2004), grassland ecology and management (Kumar *et al.*, 2002), forest-fragmentation and river dynamics (Midha and Mathur 2008) and Arachnid diversity and conservation (Hore and Uniyal 2008). Detailed studies on various aspects of the ecology and conservation of tigers have been carried out in other regions of the Terai Arc Landscape both in Nepal and India and readers are referred to the studies by Seidensticker 1976, Sunquist 1981, Smith *et al.*, 1998, Shrestha 2004, Harihar *et al.*, 2009, 2012 (b), Johnsingh *et al.*, 2004, Mann *et al.*, 2012., and Barber-Meyer *et al.*, 2012.

1.5 STUDY METHODS AND OBJECTIVES

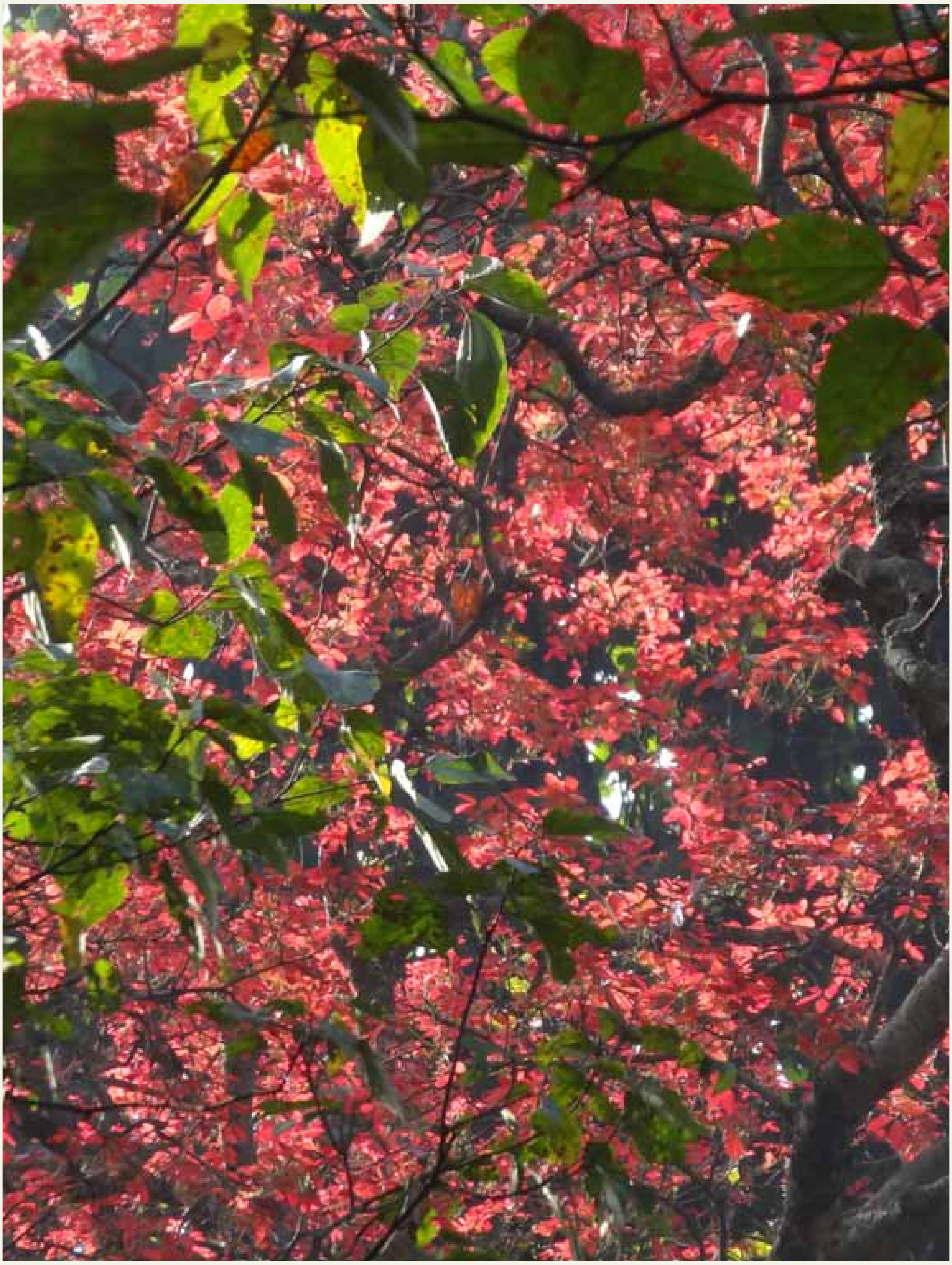
The present WWF-India led surveys - the subject matter of this report - have been informed by and build on the aforementioned surveys. Similar to the monitoring program of Jhala *et al* (2010), an important objective of the present surveys was to reliably estimate the abundance of tigers and their prey. Multi-year estimates of animal abundance can be used to determine population trends. A point of departure for our surveys from the previously mentioned studies is the intensity of sampling effort. While the surveys conducted by Johnsingh *et al* (2004) and Jhala *et al* (2011) were a part of larger regional or national studies, our surveys were intensively focused on Dudhwa Tiger Reserve and surrounding tiger habitats.

Whereas mark-recapture sampling for tigers has traditionally been designed to be focused on relatively small areas of forest patches with known tiger occupancy (eg. Jhala *et al.*, 2011, 2011), the present study emphasized a more uniform coverage of the entire study area, irrespective of prior knowledge of high-and-low occupancy areas. This design had two advantages (a) it allowed the 'true' spatial heterogeneity in tiger density to be ascertained; and (b) this design enabled the research team to monitor the ranging patterns of large individual tigers across the landscape. The lay-out of line transects was designed to be similar in spatial coverage as the camera trap sampling. A greater number of line transects were sampled by this study than had been sampled before.

This study was also designed to provide insights into the effects of various intrinsic and extrinsic variables on tiger population occurrence, abundance and persistence in the CTL. Data from camera traps has been analyzed using both frequentist and Bayesian formulations of contemporary spatially explicitly capture recapture models. These models are theoretically sound and statistically advanced and provide reliable estimates of population parameters (Ivan *et al.*, 2013). Where relevant, a subset of site-specific capture-recapture data have been analyzed separately to compare these results with previous studies, which sampled smaller trapping grids. For clarity, statistical nomenclature used in this report are consistent with Royle *et al.*, (2009 B), Efford el al., (2009) (for SECR models), Karanth and Nichols (2002) for closed-population mark-recapture models and and Buckland *et al.*, (2001) for Distance sampling analysis.

To provide information of relevance to managers, the specific objectives of this report are: (i) provide estimates of tiger densities for various Protected Areas and reserve forests in the CTL, based on two years of sampling across the CTL. (ii) estimate densities of major prey species at the landscape scale; (iii) describe tiger capture dynamics over the study period; (iv) report on the occurrence of tigers in Suhelwa Wildlife Sanctuary; and (v) describe and discuss key determinants of tiger and prey abundance in the CTL and associated relevant management and conservation actions.

Leopard caught on camera in Dudhwa



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Schleichera oleosa adds colour to the spring in the Terai's forests.

A tigress accompanied by three juveniles in Kishanpur WLS.

ESTIMATING TIGER ABUNDANCE AND DENSITY FROM CAMERA TRAP DATA IN THE UTTAR PRADESH TERAI

Accurate and unbiased estimates of the population parameters abundance ($\hat{N}$) and density ($\hat{D}$) are fundamental to wildlife monitoring programs. How these state variables change over time and space, and their relationships with habitat factors and management are the building blocks of wildlife conservation plans. These parameters are generally estimated through the collection of a representative sample of wildlife populations in the area of management interest, based on random samples taken throughout the management area. The data collected in well designed surveys provides reliable and science-based inference about the status of wildlife populations. Because of variability of data in space and time, and the fact that stochastic variation is often inherent in sample data, all estimates are subject to sampling variability (Williams *et al.*, 2002).

Given the elusive and nocturnal nature of tigers and the fact that individual animals can be recognized by their pelage patterns, abundance is commonly estimated using photographic "capture - recapture" of uniquely identifiable animals in target populations. Capture-recapture methods are a robust analytical tool to estimate abundance when the population is not subject to losses or gains within the sampling period (Williams *et al.*, 2002, Karanth and Nichols 2002, Otis *et al.*, 1978). The second parameter of interest in this study, density, is broadly described by the canonical estimator $D=N/A'$, where N is an estimate of population abundance and A' is the area over which the sampled population is distributed. In addition to the parameters $\hat{N}$ and $\hat{D}$, this report provides estimates of other associated parameters such as the capture probability (p), and the animal 'movement' parameter σ. Capture probability (p) must be estimated from the data in order to adjust the naïve estimate of N upward to account for animals that are present in the study area, but are unobserved.

This chapter details results from capture-recapture sampling in Dudhwa Tiger Reserve, its buffer forests, and in Pilibhit Forest Division for the years 2012 and 2013. Site specific estimates of abundance and density are provided for the two years. In addition, a 'density surface map' has been created to characterize in a spatial context how tiger density varies across the landscape and within the regions various Protected Areas and Reserve Forests. These data allow (a) accurate descriptions of the status of tigers based on repeated sampling of populations in the Uttar Pradesh Terai, and (b) the development of data-supported hypotheses for explaining local variations in tiger abundance and distribution. These hypotheses have ecological underpinnings such as the distribution and density of prey, and they also pertain to management actions such as protection and grassland burning. The conservation implications of population estimates presented here have been addressed in detail in the discussion section of this chapter.

2.1 SAMPLING FRAMEWORK AND DATA COLLECTION

In order to extend tiger monitoring and conservation efforts in this important tiger conservation landscape – which consists of both PA's and Reserve Forests – tracts of tiger habitat that support resident tiger populations in the Uttar Pradesh Terai Arc Landscape were comprehensively sampled. In all, our surveys involved sampling in over 2000 km^2 of tiger habitat, and many sites within the landscape were re-sampled over the two year period.

Sampling in 2012 and 2013 was carried out between October and June and was restricted to the pre- and post-monsoon periods. The sampling design within each patch of suitable tiger habitat was determined by (a) the size of the patch so as to address the population closure assumption (see Appendix 5) and (b) availability of camera-traps and trained field personnel. Given the objective of sampling patches in their 'entirety', camera trapping was carried out using multiple sampling blocks within most sites (design IV, Karanth and Nichols, 2002, Royle *et al.*, 2009). This sampling framework offered the dual advantages of being able to maximize spatial coverage to expose a large number of individual tigers to camera traps while also adhering to the assumption of population closure (population size is unlikely to be influenced by births, deaths, immigration, or emigration for a sampling period < 8 weeks). Various aspects of our camera-trap sampling design are likely to have resulted in reliable population estimates including the maintenance of inter-trap spacing of < 2 km, the operation of two camera traps simultaneously at all sites, and careful selection of camera trap sites - often at trail intersections and water edges in order to maximize capture probabilities. By sampling large habitat blocks, with few large 'holes' or gaps in the camera trap grid, our surveys were designed to provide reliable estimates of population parameters (Sollmann *et al.*, 2012).

Sites for camera trap stations were selected based on our prior knowledge of the sampling block from extensive sign surveys conducted by trained observers who extensively searched each site for tiger signs - spoor, pug marks, scrapes, scent sprays etcetera. These surveys were along forest roads, minor trails, river courses, canals, reservoirs and water holes, and were guided by detailed maps and satellite imagery. Surveyors were accompanied by forest department field staff who were knowledgeable of the area. Sites for camera traps were typically 'marked' a few days in advance (by trimming the understory within the viewing angle of cameras) in the presence of forest department staff. Cameras were deployed 4 to 7 meters away from road and trail edges and were secured to trees or wooden posts, approximately 45 cm above the ground. To deter theft and vandalism and reduce elephant damage, cameras were encased in specially-fabricated metal boxes that were secured to wooden posts or trees with chains and padlocks. Camera trap stations were selected to minimize 'holes' in the trapping grid, and trap placement was broadly guided by a 2 km x 2 km grid overlaid on a map of the study area. In general, grid cells in close proximity to forest

**Site	Sampling period	Trap nights	ESA	Trap stations	Sampling blocks	Mean inter-trap spacing (km)	Trap nights, ETA, (number of traps) from Jhala et al 2011	% increase in trap nights, sample locations (2013) **
Dudhwa	Feb - Apr '12	2626	706	159	3	1.78	1088, 265, (32)	346%, 531%
Dudhwa	Feb - Apr '13	4861	779	202	2	1.42		
Katerniaghat	Apr - Jun '12	2190	373	82	2	1.37	1800, 306, (40)	103 %, 178%
Katerniaghat	Nov - Jan '13	3663	734	111	2	1.52		
Kishanpur	Dec - Feb '12	2648	384	63	1	1.63	1920, 306, (48)	38%, 40%
Kishanpur	Apr - May '13	2655	330	67	1	1.53		
Pilibhit	Apr - Jun '13	2814	762	171	3	1.96	1200, 258, (30)	134%, 470%
Pilibhit +	Dec '10 - May '11	2739	685	157	8	2.05		
SKFD	Apr '13	739	-	44	1	1.39	Not sampled	-
Surai	Jun '13	462	-	30	1	1.24	Not sampled	-
TOTALS		**18636**	**0**	**1086**	**16**	**1.59 (mean)**		

* ESA density: 15 km buffer around sites. See definition of ESA in table 2.2.

** % increase in survey effort in 2013 over 2010 All India Tiger Monitoring Program Surveys (Jhala *et al.*, 2011).

+ Survey by Chanchani *et al.*, 2011.

Table 2.1
Camera trap deployment details for 2012 and 2013. The last two columns on the right summarize the sampling effort of the All India Tiger Monitoring surveys conducted in 2010.

edges were more likely to go unsampled than sites in the forest interiors, because of the increased risk of camera theft or damage.

Digital cameras used in these surveys were predominantly Cuddeback Attack 1179, (Non Typical Inc., USA). These cameras triggered rapidly when confronted by a mobile animal or object, and provided pictures that were usually well centered within the frame with little blurring. In darkness, pictures were taken with the aid of a conventional flash installed on the cameras, except when infra red cameras (Reconyx Hyper-fire) were used. Details of camera trap installment across sites and years are in table 2.1. In all, we sampled ~ 2500 km^2 of tiger habitat in the Uttar Pradesh Terai with camera traps in the year 2013, and about 1500 km^2 in 2012. A notable feature of our camera trapping in 2013 was that a large (> 1100 km^2) block of continuous forests encompassing Pilibhit Forest Division, Kishanpur Wildlife Sanctuary and South Kheri Forest Division, Surai range of Terai East Forest Division was sampled within a 60 day period (Figure 2.1, table 2.1).

In order to sample each site within the target 'closure' period of ≤ 60 days, decisions on camera deployment were made in advance. At the beginning of the trapping period, multiple teams (WWF field personnel accompanied by forest department staff) would travel to camera stations and deploy camera traps. Our goal was to deploy a camera trap block rapidly (within 4 days), even when the number of sites was large (80 - 120 locations). Cameras were checked regularly to ensure their functionality and to download data. At the completion of the trapping period for a 15 – 25 day sampling block, cameras were removed and re-deployed in the next sampling block. Forest department staff routinely patrolled their beats to keep cameras safe, particularly in buffer zone areas with high human use.

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Cane forests along a minor tributary of the Girwa (Karnali) river in the Trans-Girwa area of Katerniaghat WLS. This site is close to the Khata corridor, and is used by a number of tigers, some of whom frequently swim across the river.

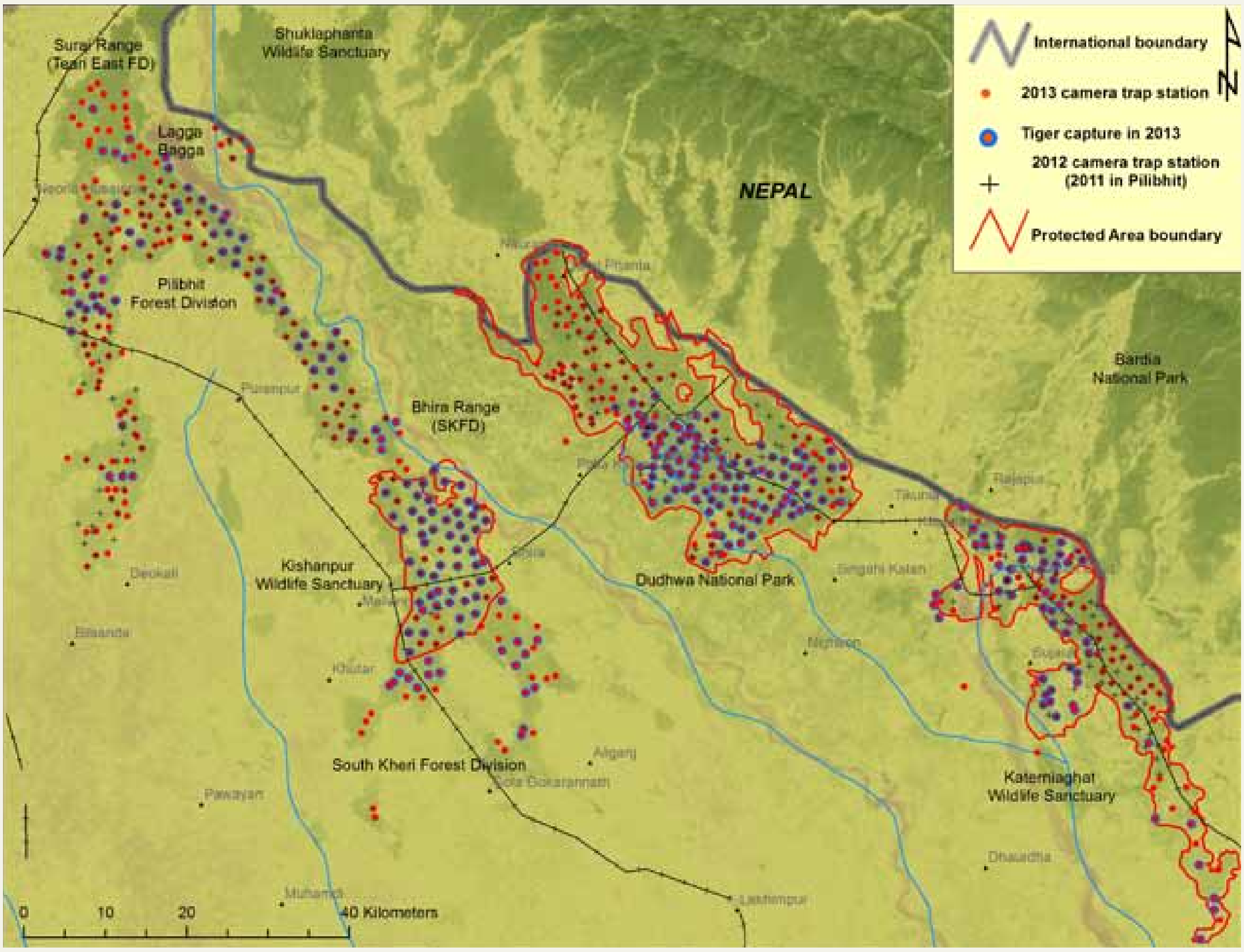

Figure 2.1
Locations of camera traps in the Uttar Pradesh Terai in the December 2011 - June 2012 and November 2012 - June 2013 sampling periods. Blue dots indicate sites with tiger captures.

2.2 DESCRIPTION OF STATISTICAL MODELS AND ESTIMATED PARAMETERS

Capture-recapture models based on capture histories obtained from camera-traps provide reliable estimates of population size for large carnivores (Karanth and Nichols, 1998, O'Connell *et al.*, 2011). Key steps for analyzing tiger related capture-recapture data from camera-traps are (i) the unambiguous identification of individual tigers based on pelage stripe patterns (ii) the formulation of a capture history matrix detailing sampling occasions, capture locations and identities of tigers captured over the sampling period; (iii) analysis of capture history data using probability equations in conjunction with maximum likelihood or Bayesian estimators to derive estimates of the parameters $\hat{N}$ (population size) and p (capture probability). Key assumptions of classical capture-recapture models are: (a) no changes in population size (demographic and geographic closure), (b) correct identification of marked animals, and (c) all animals are equally likely to be captured in each sample (or variations in capture probabilities are suitably modeled). Given adequate sample sizes, it is possible to estimate as a function of animal behavior, temporal heterogeneity in captures and other covariates that may have influence on the capture process or on the distribution of animals (Otis *et al.*, 1978). Detailed descriptions of closed population capture-recapture models, estimators and assumptions can be found in Karanth and Nichols, 1998; Williams *et al.*, 2002; Cooch and White 2011; O'Connell *et al.*, 2011; Chao and Huggins, 2005 and Royle *et al.*, 2013).

Parameter	Description
$\hat{D}$	Density of tigers, expressed as individuals/100 km². This is a derived parameter. The area (denominator) in the density equation is variously described by the ETA (closed-capture recapture models) or the ESA (MLSECR models).
$\hat{N}$	The 'superpopulation', or number of activity-centers distributed in the state space S, within which animal activity centres are thought to be distributed (for the sampled population).
σ	Spatial scale detection process away from the centre of the home range, typically modeled by a half normal detection function.
$\hat{N}$	Estimate of population size for the target population that was exposed to camera traps.
λo	Baseline encounter intensity, or the capture rate in a trap for an individual having S located precisely on a trap location.
Ψ	The data augmentation parameter. This parameter is estimated in lieu of parameter N under data augmentation and is related to N as follows: N ~ Bin (M, ψ).
p_1	Probability of encountering individual tigers that have not been previously encountered (secr).
p_2	Probability of encountering tigers subsequent to their initial encounter (secr).
p	Estimated probability of capturing a new individual tiger on each sampling occassion
c	Estimated probability of capturing an individual, subsequent to inital capture on a camera trap.
p^*	Estimate of capture probability for an individual at least once over the sampling period.
ESA	Or the Effective Sampling Area is given by $D=n/\hat{a}$, where $a= \int p.(X:\theta)dX$ (Borchers and Efford 2004). This is reported and used in MLSECR estimates.
ETA	(Aw) Describes the area over which tigers caught on camera traps are thought to be distributed, often defined by adding a buffer strip width (eg 1/2 MMDM or MMDM) to a polygon bounding the camera trap array.

Table 2.2
Brief descriptions of key parameters estimated from conventional closed population capture recapture and SECR models.

We have adopted the use of both likelihood and Bayesian analytical approaches in this report (see Appendix 6 for more details). Maximum likelihood SECR approaches have been used in the analysis of the all-India tiger monitoring program data (Jhala *et al.*, 2008, 2011), which serve as baselines for our studies. Hierarchical Bayesian SECR models have been developed and tested extensively using camera trap data for tigers (Royle *et al.*, 2009, Gopalaswamy *et al.*, 2012), and these models continue to be developed to make them more robust and versatile (see Royle *et al.*, 2013).

2.2 DATA ORGANIZATION AND MODEL PARAMETERIZATION FOR ANALYSIS OF TAL-UP DATA

2.2.1 Identifying Tigers

Images of individual tigers from camera traps are identified by pelage patterns which are unique to each animal. When complete and sharp images of right and left flanks of an individual are obtained, identification is a relatively simple task, especially for an experienced observer. However, not all pictures are of a high quality and tigers are sometimes photographed at an angle to the camera, and thus not all stripes are clearly visible. In such situations, it may be difficult to unambiguously identify a tiger, particularly

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Riparian areas such as the banks of the Suheli river in Dudhwa National Park are the preferred habitat of hog deer, swamp deer and tigers.

if a single observer is involved or even when using pattern-recognition software. We identified tigers by using two or three experienced observers to independently compare and assign identities to right and left flank tiger pictures. Data from photo captures were only included in the analyses when all observers assigned a common identity to an animal. Disputed pictures (captures) were excluded from the capture-history matrices used in capture-recapture models. The picture -library of tigers was also processed in Extract Compare (Hiby *et al.*, 2009) a software that compares stripe patterns, and this further confirmed that the tigers we had identified visually were indeed unique individuals. Photos of juvenile tigers (<2 years) were omitted from the capture-history datasets. Juvenile tigers may reach adult size by about 2 years, and are typically accompanied by their mothers and siblings.

2.2.2 Estimation of Population Size

Population estimates were from traditional capture-recapture models (Otis *et al.*, 1978), implemented in program MARK (White 2014). These estimators compare the relative proportions of marked and unmarked animals from actual sightings or photo captures over a series of successive occasions. For one sampling event, the estimator can therefore be described as $\hat{N}=n/\hat{p}$ where n is the number of unique individuals that were encountered and $\hat{p}$ is the probability of encountering any individual animal in the target population on each capture occasion given that it was present in the population. We also compute p^*, the capture probability associated with detecting an individual at least one time over the entire trapping period, which was computed as $1-(1-p)^x$, where p is the per-occasion capture probability and x is the number of sampling occasions. The use of camera traps in blocks, wherein each block of traps was only functional for a sub-period of the overall sampling duration, necessitated the use of a nuanced method of constructing a capture history matrix for analysis in program MARK (White 2014). Following Karanth and Nichols (2002), we determined the total number of captures on each occasion (e. g., occasion 5), by summing captures on occasion 5 in each sampling block.

The Huggins closed C-R model was used to estimate tiger abundance, and N is a derived parameter and is not estimated as part of the likelihood function in this model. Separate estimates of tiger population size for Dudhwa, Kishanpur and Katerniaghat for 2012 and 2013 have been provided. The abundance of tigers in Pilibhit in 2013 has also been estimated. A minimum of four models were evaluated in terms of their relative fit to the data to determine if there were variations in capture probabilities arising from behaviour, time (t) or individual heterogeneity (h), or a combination of behaviour (b) and heterogeneity in captures (model M_{bh}). The fifth model was the null, or M_o.

Estimates of the parameter N_{super} from SECR analysis have not been reported here because the superpopulation estimate pertains to large area, defined by the state space *S*, which may be several times larger than the area sampled with camera traps, often including tiger habitats in proximate and sometimes un-connected forests. While this parameter may be of interest in inferring abundance at the landscape-scale, tiger abundance, N_{super} is difficult to interpret, and of limited relevance when the primary parameter of interest is the population size of animals in 'bounded' sites, such as National Parks. Finally, details of closure tests we performed are provided in Anexure 5, and more detailed description of the statistical theory underlying spatial capture recapture models are in Appendix 6.

2.2.3 Density Estimation

Density ($\hat{D}$) estimates are derived from Bayesian and ML-spatial capture-recapture models. We developed an encounter history for every adult tiger captured while omitting juvenile tigers (< 2 years) from analysis. These data were entered as a I x J x K index matrix where I indexes the trap location, J the identity of the trapped individual, and K the sampling occasion on which individual J was trapped at location I. Because not all traps within a site were operated simultaneously (Table 2.1), and because some traps malfunctioned or were stolen or destroyed during a trapping session, trap-functionality was specified in the models in order to make adjustments for number of sampling occasions at each camera trap station. We used a Bernoulli formulation of a hierarchical random effects GLM model and Bayesian analysis to analyze these data. Analysis was carried in RGui, using the package SPACECAP (Gopalaswamy *et al.*, 2012).

Data analysis for all sites across the two years was also carried out using maximum likelihood SECR analysis using program DENSITY (Version 5, Efford 2012), and an associated package *secr* in R. The data structure for animal captures and trap deployment details was similar to the one previously described. We assumed a binomial point process model with a 15 kilometer buffer around the camera trap array. Detection models were fit by maximizing the conditional likelihood to estimate the density and other parameters (Table 2.2). Based on our *a priori* knowledge of the geography of tiger habitats in the study area, we believed that a 15 km buffer for SECR density estimation was likely a large enough area to capture the movements of tigers whose territories may only partially overlap the camera trap grids. This is particularly true for Kishanpur, Katerniaghat and Pilibhit, all of which are contiguous with other tiger occupied patches. In all sites, our multi-year camera trap data have revealed the movement of individual tigers, particularly territorial males, over considerable distances beyond the administrative boundaries of the forest units, which

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Team members and forest department staff on their way to a camera trap in Dudhwa National park. Rain water is retained by the Terai's clayey soil and causes roads to become severely water logged.

justified the use of 'large' buffers. To determine whether the assumed buffer helps delineate an adequately large state space area, *S*, a series of models with different buffer extents were tested. These procedures are described in Section 2.2.4.

To accurately describe the putative area over which tiger activity-centers of the sampled population are likely to occur, both the Bayesian and ML analyses require that habitat and non-habitat areas be delineated using forest boundary GIS files or other equivalent spatial data that delineates 'habitat' boundaries. For these analysis, a habitat-mask was created wherein only forested areas (habitat) were included within the area state space *S*, while non-habitat areas were masked out (Efford *et al.*, 2009, Royle *et al.*, 2009, Jhala *et al.*, 2011). Bayesian models were similar to Royle *et al.*, (2008, 2009) and involved the generation of evenly spaced points within the area demarcated for analysis, such that each point (potential tiger activity centre) represented an area of 0.336 km^2, a grain size which is sufficiently small in comparison to the average home range size of tigers (Royle *et al.*, 2013). Interestingly, for all sites except Kishanpur WLS, a buffer >5km around the camera trap array would include tiger habitats (forested areas) that extend beyond the international border of Nepal. Notably, forest tracts such as portions of Shuklaphanta Wildlife Sanctuary, Bardia National Park and Basanta appear in the buffered areas in these models. The purple and dotted black lines in Figure 2.2 depict habitat areas that were included in each analysis for ML-SECR and Bayesian SECR models. SECR models make the assumption that animal activity centers are uniformly distributed across the areas delineated as habitat. Data augmentation values were described to be roughly 10 times greater than the number of captured individuals at each site (M_{t+1}). In Bayesian analysis, the MCMC algorithm was run

Team members setting up a camera trap in the cane forests of Katerniaghat Range.

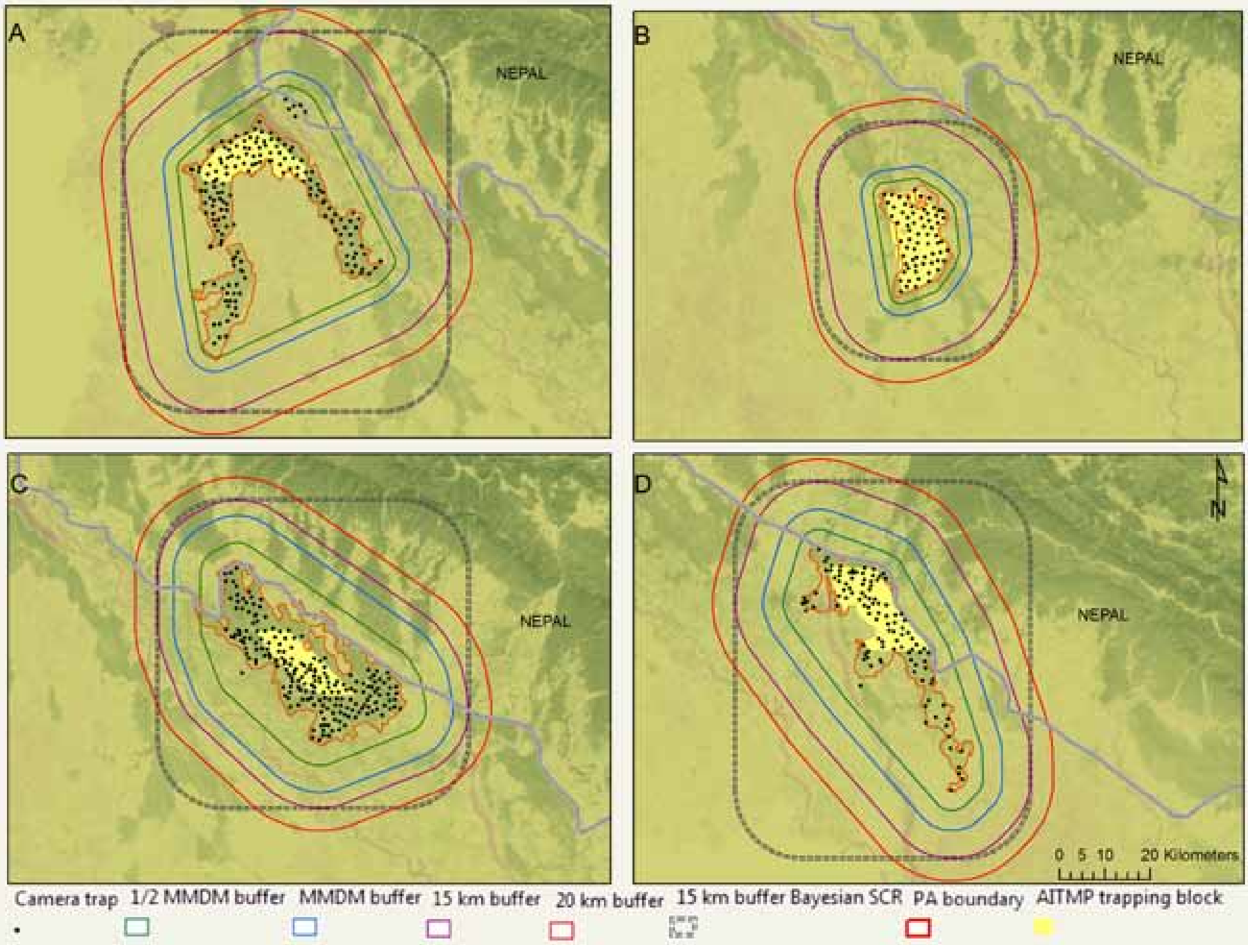

Figure 2.2
Depictions of varying buffers around camera trap arrays used in density estimation. Polygons representing the outer boundary (MCP) of camera-trap blocks in the AITMP surveys (Jhala *et al.*, 2011) are depicted in yellow.

for 52,000 iterations, with a burn-in value of 2000. Analysis took 60 to >250 hours on a PC with 8 GB RAM. Posterior summaries from Bayesian estimators and ML-SECR estimates of model parameters and associated 95% error intervals are provided in Table 2.4 and Figure 2.3.

2.2.4 Effect of Varying 'Buffer Sizes' or Effective Sample Area on Density Estimates

An important decision in the estimation of tiger densities from capture-recapture data is the extent of the buffer (in ETA-based estimators), or of the state space *S* in spatial capture-recapture models. While the MMDM estimators are generally known to be associated with significant positive bias (Obbard *et al.*, 2010, Ivan *et al.*, 2013, Blanc *et al.*, 2013), density estimates from SECR models are invariant to the extent and size of the state space *S*, if the area described is adequately large (Royle *et al.*, 2013, Efford, M., Density Forum on http//phidot.org). These authors place an emphasis on the selection of a suitable *S* beforehand, so that it includes all tigers that have even a low probability of encountering a camera trap over the sampling period. Given the uncertainty associated with assigning a single value for S beforehand, in conjunction with ML-SECR analysis, multiple buffer sizes were specified around each camera trap array to describe the state space, *S*. Analysis for all sites (2013 data) were initially performed with 'large' buffers which extended to a distance of 20 kilometers beyond the trap array (Royle *et al.*, 2009, Gopalaswamy *et al.*, 2012). This was approximately 4 to 8 times the values of σ (parameter that scales the detection process as a function of distance from animal activity centres). For the 2013 data, we also used 1/2 MMDM and full MMDM values to describe buffers for each site. The analysis with a 15 km buffer around the camera trap array (described previously) represents a fourth buffer size. Based on the estimated values of σ and our knowledge of the regions geography, it was expected that density estimates would be fairly insensitive to changes in buffer size beyond the full MMDM or 15 km buffers. ML-SECR estimators implemented in program DENSITY were used for these analyses because processing time by maximum likelihood methods is considerably faster (minutes) relative to Bayesian analysis using MCMC chains (multiple days).

2.2.5 Comparison with 2011 (All India Tiger Monitoring Estimates)

By partitioning data for 2013 (the most recent and extensive surveys to date), abundance has also been estimated for cameras traps situated within the minimum convex polygon of the all-India Tiger Monitoring Program (AITMP, Jhala *et al.*, 2011) for Dudhwa, Katerniaghat and Pilibhit. This was achieved by identifying camera trap locations from 2013 that were situated within the polygon that described the extent of the trap array in the AITMP surveys (yellow polygons in Figure 2.2). Tiger capture information for these sites was translated into capture history matrices that allowed both the traditional closed capture recapture analyses as well as spatially explicit analyses. These data were used to estimate population size within each site in the above mentioned areas.

For consistency, density was also estimated for each site by replicating the analytical approach of the AITMP surveys. Site specific population estimates were derived using the Huggins closed capture estimator in program MARK. Density for the subset data was then estimated in two ways: (i) ETA method: a 1/2 MMDM buffer strip to the sampled area to define the effective trapping area (Karanth and Nichols, 1998, Jhala *et al.*, 2011) - standard errors associated with these density estimates were calculated using the delta method approximation detailed by Karanth and Nichols (1998), and Williams *et al.*, (2002). (ii) ML-SECR models, implemented in program DENSITY. The effective trap area for the ML-SECR analyses were defined by setting buffer values to coincide with those used in the AITMP analysis. Details of sampling effort and tiger captures relevant to these analyses have been provided in Table 2.5. The area sampled with cameras traps in Kishanpur during the AITMP surveys and the present survey were very similar, and the camera trap array extent was identified by the Sanctuary's boundary. The estimates for the years 2012 and 2013 (reported in tables 2.5 and 2.6) for Kishanpur are directly comparable with the results of the AITMP surveys (Jhala *et al.*, 2011).

Closure tests were not carried out for for the aforementioned subset analyses because these data have been partitioned from the larger data sets which were tested for population closure (see Appendix 5). The partitioned datasets are a fraction of the larger trap arrays, i.e. they are a subset of the entire capture history in each site; they are also drawn from a smaller time-window for each site.

2.3 RESULTS

In Dudhwa National Park (DNP) 14 (12, 131) tigers were photo captured in the year 2012, and 14 (13, 274) tigers in 2013. Numbers in brackets indicate the number of individuals with recaptures, and the total number of usable adult tiger captures for each year. Captures of juvenile tigers (< 2 years) were not incorporated into the capture-recapture data files, and details on these age classes can be found in chapter 3 of this report. In Kishanpur WLS 19 (16, 264) tigers were captured in 2012, and 16 (15, 256) tigers in 2013. In Katerniaghat WLS, 18 (15, 88) tigers were captured in 2012 and 16 (15, 265) in 2013. In Pilibhit, 23 (17, 94) tigers were photo-captured in 2013. In Dudhwa National Park, tigers were captured in 42% and 55% of total camera trap stations in 2012 and 2013. Corresponding values for Kishanpur are 87% and 79%, Katerniaghat 52% and 54%, and Pilibhit 31% (2013) (Figure 2.1).

Site (year)	Mt + 1	Number recaptured	$\hat{N}$ (SE), CI	p, SE (model Mo),	p*	Model selected (AIC_c weight)	Trap success (No. captures/100 trap nights)
DNP '12	14	12	14 (0.73) 14 - 18	0.26 (0.02)	0.99	M_h (0.68)	5.0
DNP '13	14	13	14 (1.48) 14- 22	0.40 (0.03)	1.00	M_{bh} (0.72)	5.6
Kishanpur '12	19	16	19 (0.58) 19 - 23	0.20 (0.01)	0.99	M_h (1)	9.7
Kishanpur '13	16	15	16 (0.35) 16 - 18	0.22 (0.01)	0.99	M_h (1)	9.6
Katerniaghat '12	18	15	18(0.55) 18 - 21	0.12 (0.01)	0.95	M_o (0.64)	4.0
Katerniaghat '13	17	16	18 (1.35) 17- 24	0.26 (0.02)	0.99	M_h (1)	6.9
Pilibhit '13	23	17	23 (0.93) 23- 28	0.13 (0.03)	0.93	M_t (0.41)	3.3

Table 2.3
Site and year-specific summaries of tiger capture events, and estimates of population size from closed capture-recapture analysis. Best supported models based on AIC_c scores are also reported.

2.3.1 Estimates of Population Size

Under the assumptions of population closure, mark-recapture models for camera-trap data of tigers provide site specific estimates of abundance and density for adult (>2 year old) tigers in the Central Terai Landscape. The estimated population sizes, the associated 95% confidence-intervals, the most supported model, and its AIC weight are reported (Table 2.5): Dudhwa National Park 2012 14 (14 -18), 2013 14 (14 - 22); Kishanpur 2012 19 (19 - 23) 2013 16 (16 - 18); Katerniaghat 2012 18 (18 - 21), 2013 18 (17 - 24); Pilibhit 2013 23 (23 - 28). In general, owing to the large number of sampling occassions and high rates of recaptures, estimates of population size are close to the count of unique tigers (Mt +1) encountered on camera traps at each site. In general, model Mh, (individual heterogeneity in capture probabilities), was the most supported model for most sites (Table 2.5).

2.3.2 Site-wise & Year-wise Density Estimates from SECR Models

Tiger densities were estimated from camera trap data for 2012 and 2013 using Bayesian SERC models (Royle *et al.*, 2009, Gardner *et al.*, 2011, Royle *et al.*, 2013). Density estimates were obtained by standardizing the estimated population size from SECR analysis by incorporating the area of the state space S (camera trap grid plus habitat areas within a 15 km buffer around the trap array) while also including spatial information derived from capture loactions. All values are expressed in individuals/100 km², and values in brackets are 95% credible intervals (Table 2.6).

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Forest department staff and personnel of the SSB border security force on a joint patrol in Katerniaghat WLS

The mean posterior density estimates, number of tigers > 2 yrs old/100 km², for DNP are 2.05 (1.41 - 2.75) and 1.89 (1.27 - 2.54); Kishanpur 4.14 (3.06 - 5.34) and 4.96 (3.37 - 6.58); Katerniaghat 4.72 (3.19 - 6.64) and 2.22 (1.50 - 3.00) for the years 2012 and 2013 respectively. The estimates for Pilibhit for 2013, 3.44 (2.33 - 4.54) are lower than previous estimates based on comparable methods 4.22 (1.89 - 6.49) (Chanchani *et al.*, 2011).

The posterior mean of the data augmentation parameter (ψ) is concentrated away from the boundary (ψ = 1) for all our estimates suggesting that the posterior estimate of N was not a result of too few all-zero encounter histories (described by the data augmentation value). The posterior mean values for the parameter which scales the distance function (σ) ranges from 1.75 to 6, but estimates are consistent across years for each site. The posterior mean values for the expected number of captures in a trap given that the activity-centers baseline encounter rates λo range between 0.01 and 0.04, (i.e. the expected number of captures in a trap given that the activity-center is situated at the same location as the camera-trap). The values p_1 and p_2 refer to the posterior means for pre- and post-initial encounters. Density, p_1, and p_2 are derived parameters in the model. Figure 2.5 illustrates the fine-scale variation in tiger densities across the landscape.

In the 2013 data, there is considerable overlap in the state space S over which densities are estimated for the Kishanpur WLS and the Pilibhit Forest Division. These two analyses were carried out separately. In 2013, our tiger captures reveal that one male tiger ranged in Haripur Range of Pilibhit FD and the Tarkoti area of Kishanpur wildlife sanctuary, and was a member of both data sets. Several other individuals were photo-captured in Bhira Range

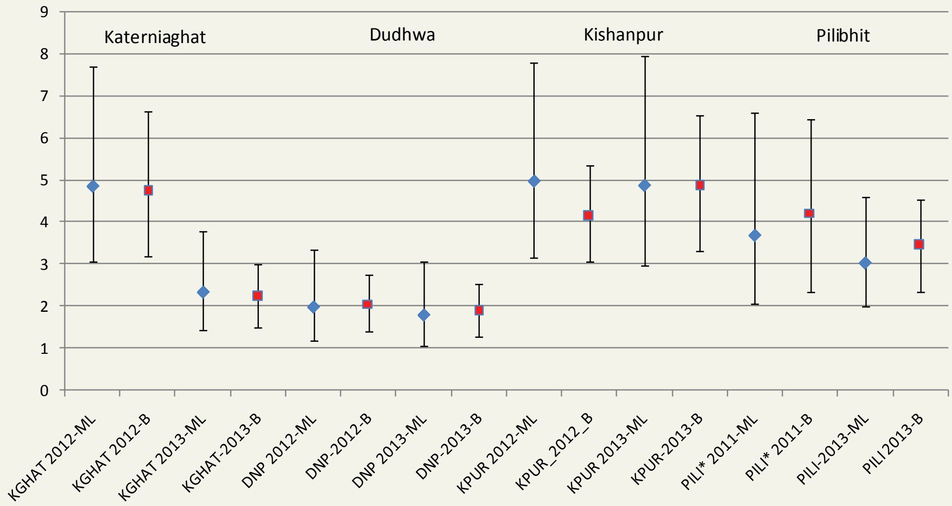

Figure 2.3
Estimates of density (tigers/100 km²) from Bayesian (B) and ML-SECR (ML) models for Katerniaghat, Dudhwa, Kishanpur and Pilibhit from the years 2012 and 2013. Error bars on the Bayesian SECR point estimates are 95% posterior intervals whereas the errors on the ML-SECR models are 95% confidence intervals. Pilibhit 2011* estimates are from the CSU/WII survey (Chanchani *et al.*, 2011).

of South Kheri Forest Division which lies between Pilibhit and Kishanpur. However, over the trapping period in each year, these individuals were either captured in Kishanpur or in Pilibhit (in addition to Bhira Range), but not in both areas. The forest block consisting of Pilibhit, Kishanpur, South Kheri and Surai Range of Terai East Forest Division was sampled within a 60 day period providing a separate estimate of density for the entire forest block, thereby eliminating ambiguity attributable to overlapping areas and common individuals in density estimation (Table 2.6) .

Tiger densities were also estimated using ML-SECR models (Borchers and Efford 2008) which are similar to those from Bayesian SERC analyses (Figure 2.4). The possible convergence of estimates from these approaches has been reported previously (Gerber *et al.*, 2011, Noss *et al.*, 2012, Gopalaswamy *et al.*, 2012, Royle and Gardner 2010)—however, in our study the estimates from the Bayesian models were more precise than those associated with the ML-SECR estimates.

2.3.3 Invariance of Density Estimates to Varying Buffer Sizes (ML-SECR Analysis)

Density estimate, across primary sites with camera-traps surveyed in 2013, were largely independent of buffer size for ML-SECR analyses (Figure 2.4). For all sites, with the exception of Katerniaghat, the addition of the smallest buffer to define the state space S appears to be adequate to estimate density with low bias and high precision.

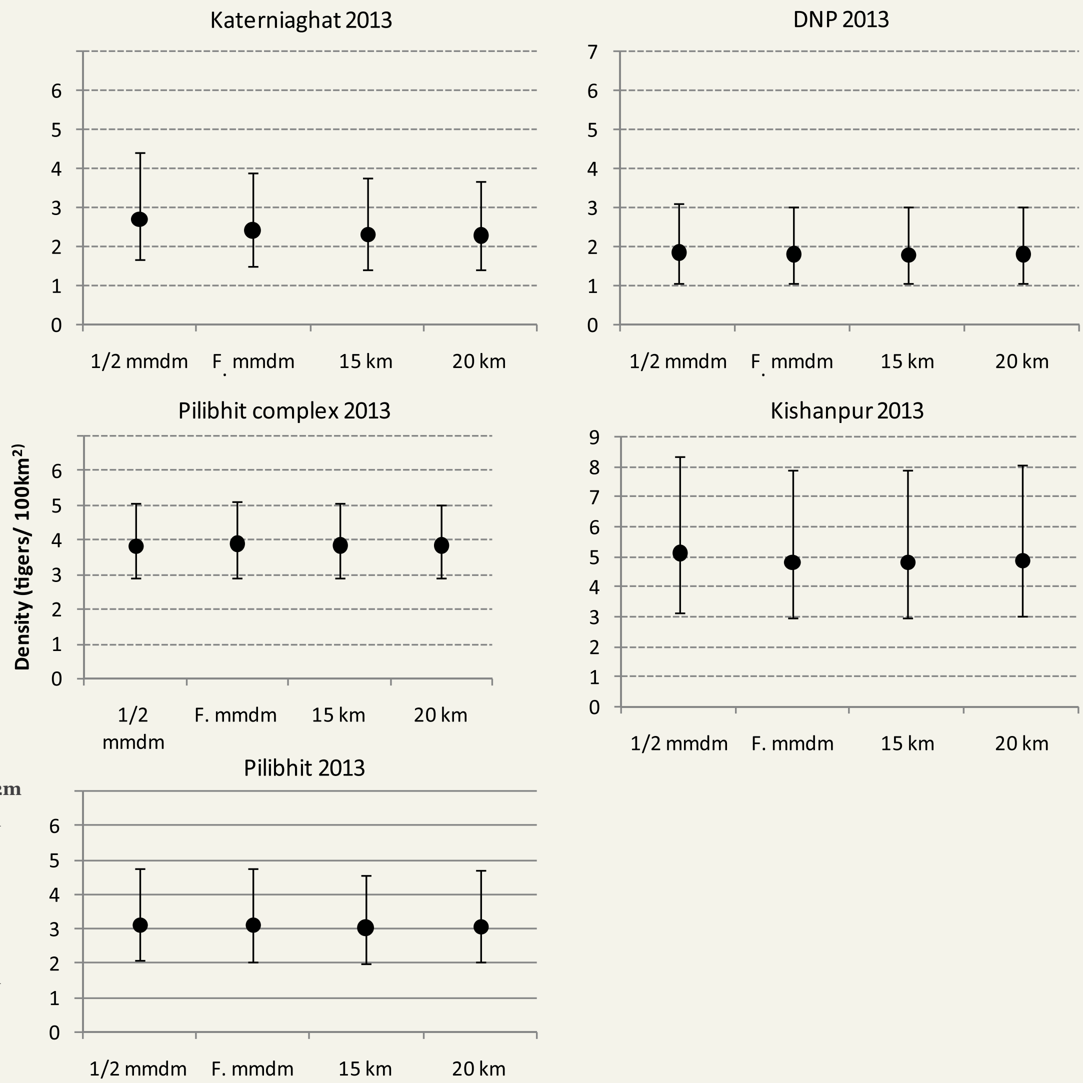

Figure 2.4
MLSECR estimates for density (and for confidence intervals) for sites sampled in 2012-2013. The X-axis indicates the buffer size specified for these analyses, namely half the mean maximum distance moved by tigers, the mean maximum distance moved (F.mmdm), 15 kilometers and 20 kilometers.

Pilibhit complex comprises of Pilibhit Forest Division, Surai Range (Terai East Forest Division), Kishanpur WLS and South Kheri Forest Division.

1/2 MMDM Katerniaghat = 4422m
F. MMM Katerniaghat = 8843 m
1/2 MMDM DNP = 5571 m
F. MMDM DNP = 11542 m
1/2 MMDM Pili. complex = 2789
F. MMDM Pili. complex= 5577
1/2 MMDM Kishanpur = 2635 m
F. MMDM Kishanpur = 5271 m
1/2 MMDM Pilibhit =3086 m
F. MMDMPilibhit = 5271 m

2.3.4 Monitoring Density and Abundance: Comparing 2011 and 2013 Estimates (from restricted area analyses)

When data were partitioned to only include a subset of sites that were within the minimum convex polygon that defined the trap array of Jhala *et al.*, (2011), captures of 9 (8) tigers in DNP (subset); 13 (11) in Katerniaghat(subset), and 9 (5) tigers in Pilibhit (subset) were obtained. Numbers in brackets are the number of individuals in the subsetted data that were recaptured. The values for Kishanpur are the same as those reported above 16 (15) because the areas for both surveys are very similar. Estimates from the partitioned datasets are referenced by the subscript "(subset)".

The estimated population size for DNP (subset) is 8 (8 - 9), for Katerniaghat (subset) 12 (12 - 16), and for Pilibhit (subset) 9 (9- 15). The 1/2 MMDM subset estimate for tiger density (animals/ 100 km^2) for 2013 for Dudhwa (2013) is 2.37 (0.3), Kishanpur it is 4.5 (0.39), Katerniaghat it is 3.00 (0.69) and for Pilibhit it is 5.07 (0.34). The effective trapping areas (km^2) A(w) for each site are listed in table 2.7. Densities for tigers within the subsetted areas have also been estimated using ML-SERC models in program DENSITY and the results are listed in Table 2.5.

Site	year	Density (sd)	95% PI	σ (sd)	95% PI	Λo(sd)	95% PI	Ψ (sd)	95% PI	p1 (sd)	95% PI	p2 (sd)	95% PI
DNP	2012	2.05 (0.38)	1.34 - 2.75	4.54 (0.32)	3.93 - 5.16	0.02(0.003)	0.01 - 0.03	0.17 (0.04)	0.09 - 0.25	0.02 (0.003)	0.01 - 0.03	0.63 (0.09)	0.46 - 0.79
DNP	2013	1.89 (0.34)	1.27 - 2.54	1.76 (0.15)	1.47 - 2.05	0.03 (0.003)	0.01 - 0.03	0.17 (0.04)	0.09 - 0.24	0.02 (0.003)	0.01 - 0.03	0.65 (0.04)	0.56 - 0.74
Kishanpur	2012	4.66 (0.67)	3.52 - 5.96	3.88 (0.27)	3.40 - 4.41	0.02(0.002)	0.02 -0.02	0.12 (0.03)	3.35 - 0.17	0.02 (0.002)	0.013-0.02	0.80 (0.03)	0.75 - 0.86
Kishanpur	2013	4.92 (0.88)	3.37 - 6.58	2.38 (0.14)	2.13 - 2.66	0.03 (0.01)	0.02 -0.04	0.17 (0.04)	0.09 - 0.24	0.03 (0.01)	0.02 - 0.04	0.67 (0.05)	0.57 - 0.76
Katerniaghat	2012	4.72 (0.92)	3.19 - 6.64	2.39 (0.22)	2.01- 2.86	0.03 (0.01)	0.02 -0.04	0.45 (0.10)	0.28 - 0.64	0.02 (0.01)	0.02 - 0.04	0.47 (0.14)	0.19 - 0.74
Katerniaghat	2013	2.22 (0.40)	1.50 - 2.96	6.39 (0.47)	5.47 - 7.30	0.02(0.002)	0.01 - 0.02	0.9 (0.04)	0.11 - 0.27	0.01 (0.002)	0.01 - 0.02	0.71 (0.04)	0.62 -0.80
Pilibhit *	2011	4.22 (1.17)	2.22 - 6.49	1.46 (0.50)	0.64 - 2.47	0.02 (0.04)	0.01 - 0.02	0.22 (0.07)	0.11 - 0.36	0.01 (0.004)	0.01 - 0.02	0.81 (0.08)	0.66 - 0.92
Pilibhit	2013	3.44 (0.58)	2.32 - 4.54	3.65 (0.36)	3.00 - 4.40	0.01 (0.003)	0.0 - 0.02	0.22 (0.04)	0.14 - 0.31	0.01 (0.003)	0.01 - 0.02	0.74 (0.08)	0.57 - 0.87
Pilibhit complex	2013	4.05(0.45)	3.16 -4.91	3.11(0.14)	2.84 -3.38	0.18 (0.002)	0.01 -0.02	0.41 (0.05)	0.30 - 3.38	0.018 (0.002)	0.01 - 0.02	0.76(0.03)	0.70 - 0.81

Table 2.4
Site and year-specific summaries of posterior mean values and associated 95% posterior intervals for density (tigers/100km^2) and associated parameters from Bayesian-SECR analysis. These parameters are defined in table 2.2. The Pilibhit-complex comprises of Pilibhit Forest Division, Kishanpur Wildlife Sanctuary, South Kheri Forest Division and Surai Range (Terai East FD) and covers an area of nearly 1200 km2.

* Estimates from Chanchani *et al.*, 2011.

Site	Cam sites	trap nights	MT +1	No. of captures	Density - half MMDM				ML-SECR			
					ETA (1/2 MMDM)	Density	SE	CV (5)	ESA (Density)	Density	SE	95% CI
$\text{DNP}_{\text{subset}}$	58	1428	9	108	338	2.4	0.3	12.5	416	2.17	1	1.9 - 5.8
$\text{Kishanpur}_{\text{subset}}$	67	2558	16	231	355	4.5	0.39	11.5	317	5.63	2.1	2.8 - 11.3
Katerniaghat- subset	60	2223	13	161	400	3.0	0.69	13.6	398	3.36	0.8	1.1 - 4.2
$\text{Pilibhit}_{\text{subset}}$	48	628	9	23	198	5.1	0.34	8.6	161	5.05	1.3	3.9 - 8.2

Table 2.5
Site-specific summaries of tiger captures from partitioned data for 2013, denoted by the subscript $_{\text{subset}}$. Partitioned data are from camera traps within the same area as the MCP's that bound camera traps in the AITMP surveys of 2010. Density estimates from a 1/2 MMDM estimator and ML-SECR estimator are provided separately for each site with associated errors. Errors for the 1/2 MMDM estimator were generated using the delta method approximation (Karanth and Nichols 1998).

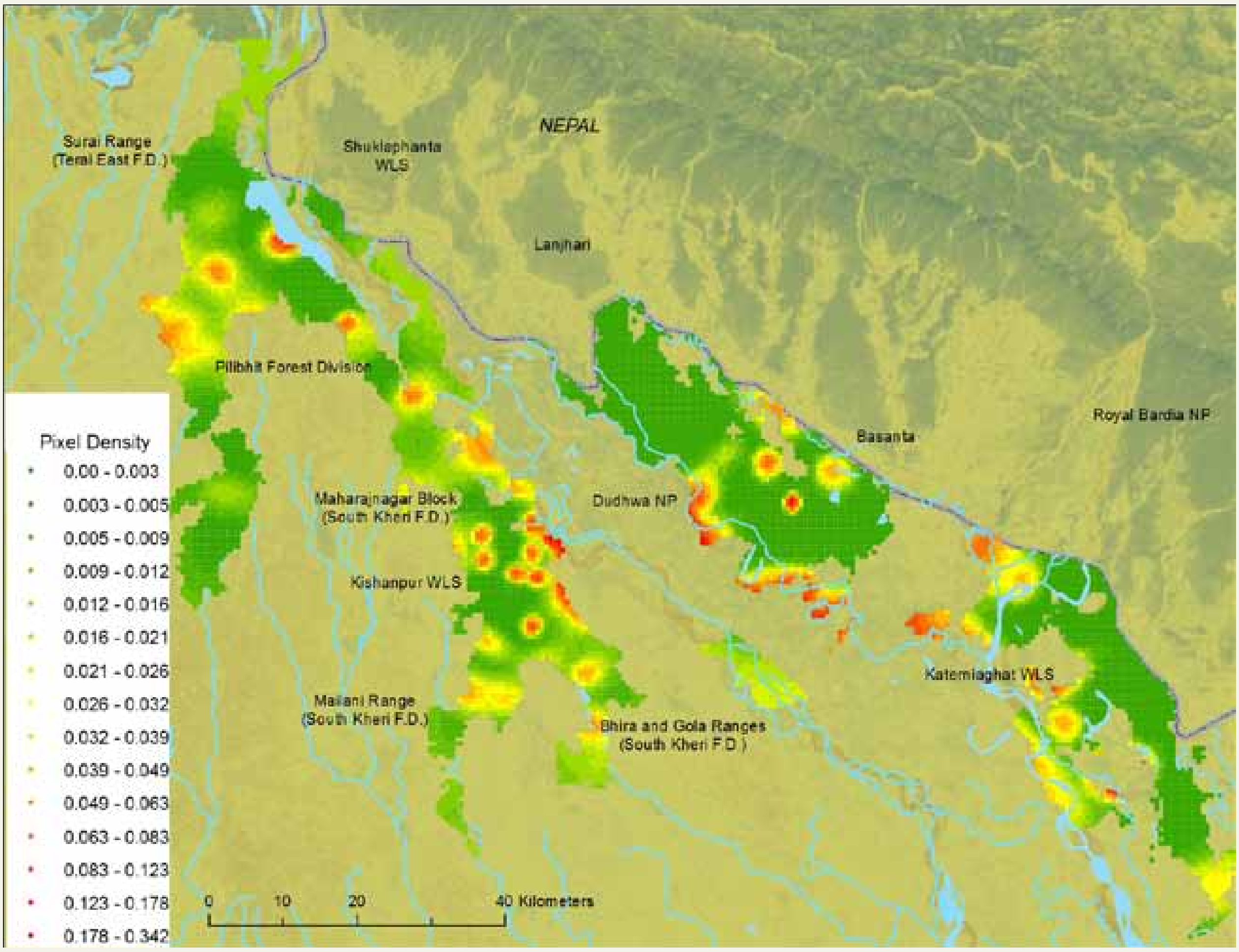

Figure 2.5
Pixel-specific tiger densities (tigers/0.336 km²) for the Central Terai Landscape of Uttar Pradesh (based on data collected in the 2012 - 2013 sampling season). Each pixel represents an area of 0.336 km². Values have been clipped to the boundary of India. These results are derived from Bayesian SECR models, for which summary results have been listed in Table 2.5

2.4 DISCUSSION

From November 2012 to June 2013, we sampled 2200 km² of tiger habitat in the Uttar Pradesh Terai including three Protected Areas, two entire Reserve Forests, and portions of other Reserve Forests. Across all sites, we photo-captured 76 adult tigers and 25 cubs/ sub-adults (< 2 years). For the areas previously sampled in 2011-2012, our results are similar, although fewer cubs were captured in the first sample season. Of these tigers (adults + juveniles), 57 % were captured in Protected Areas, 35% were captured in Reserve Forests, and the remaining 8% were captured in PA's and in adjoining RF's (e. g. Kishanpur Wildlife Sanctuary and South Kheri Forest Division). These estimates of population size and density for are likely to be precise and reliable because capture probability over the sampling period (p*) was consistently high.

In the sections that follow, we: (a) interpret the results of the various analyses used to estimate tiger and prey populations; (b) discuss the relevance of these results from mark-recapture and distance analysis in the light of model assumptions and limitations of these analyses; (c) examine the findings of this study in the context of previous studies of tigers in the Terai and elsewhere; and, (d) propose working hypotheses about underlying causal factors affecting the distribution and abundance of tigers in the CTL.


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Tigers often spend the day-time hours resting in muddy wallows and streams, especially in the summer.

2.4.1 Tiger Abundance

Estimates of $\widehat{N}$ using closed capture-recapture models (Otis *et al.*, 1978, Karanth and Nichols 1998) were precise with small standard errors and narrow confidence-intervals. Precise estimates reflect high capture rates (p* > 0.95) for adult tigers over the 'closed' trapping period in each site and each year. The number of sampling-occasions in each of of the study areas sites was also high (total of ~60 occasions), but at any one time cameras were typically operated in 2-3 spatially and temporally unique blocks. As a result, a tiger present in one of the sampling- blocks was potentially exposed to camera-traps for ≥15 days. When a tiger's movements, over an area, were described by two or more sampling-blocks, the probability of capture is likely to have been even higher. Even though trap-densities were moderate (25 - 35 cameras/100 km^2), the coverage of large areas (>400 km^2) resulted in high capture-rates over multiple sampling periods in each site. Previous studies have shown that trap-densities < 25/100 km^2 often result in low recapture rates for tigers and imprecise estimates of density (Contractor 2007, Harihar *et al.*, 2009). Even though capture probabilities per-occasion were generally low (<0.5), p*, or the capture probability across the sampling period in each site (47 - 60 occasions) is nearly 1. As a consequence, the abundance estimates in the full likelihood parameterization of closed capture-recapture models for most sites were the same as M_{t+1} or the actual count of unique tigers from camera-traps (see similar conclusions in Scherer 2008). When p* is estimated to be ~1, estimates from closed-population capture-recapture models can be interpreted as a 'near census' of the sampled population (Gerber *et al.*, 2014).

These data suggest that capture rates may be lower in summer (May - June) than in other months. We had lower numbers of captures in the two sites that were sampled in summer, (i.e. Katerniaghat in 2012 and Pilibhit in 2013). During these months, day-time temperatures were often >40^o C which may have led to a shift in tiger habitat use and movement (e.g., increased use of riparian zones), and possibly higher rates of camera malfunction during the day. Our data suggest that given adequate sampling effort (high spatial- coverage, multiple trap-nights, camera-densities ~25/100 km^2), the number of individuals caught on camera traps (M_{t+1}) are similar in the summer and winter. However, on an average, recapture rates for individual animals tend to be lower in the summer resulting in less precise estimates. An additional pattern observed was that estimates of initial capture-probability (p_1) were consistently lower than subsequent recaptures (p_2) in our Bayesian-SECR. These results may be an artifact of non-independence among encounters (Royle *et al.*, 2009 b), and not be indicative of a true behavioral response to the camera traps.

Ecological and Conservation Inferences

Estimates of N in Dudhwa, Kishanpur and Katerniaghat are similar across the two years of sampling (2012 and 2013). The largest extant tiger population in Uttar Pradesh is in the forests of Pilibhit Forest Division, Kishanpur WLS and South Kheri Forest Division (linked to forests in Uttarakhand through Surai Range). Estimates for 2013 indicate that this area supports ~50 adult tigers. Our estimates of population size in other sites (DNP and Katerniaghat) are considerably lower (15 - 20 individuals). These estimates are also significantly lower than population sizes reported from other Protected Areas in the Terai (e.g., Corbett National Park and Chitwan National Park).

It appears that that current tiger populations in DNP and in Katerniaghat Wildlife Sanctuary are lower than the habitat-based carrying capacity of these areas. A possible contributing factor is the low densities and the non-uniform distribution of prey species, especially chital. Although chital, swamp-deer and hog-deer were found to occur at high densities at some locations within these sites, (e.g., Kakraha in the fenced rhino enclosure, the

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Interspersed short-and-tall grasslands such as these are the preferred habitat of hog and swamp deer. Animals congrate in large numbers in grasslands following annual burning.

Sathiyana Range in DNP and the Sadar beat of Katerniaghat WLS), overall their densities were very low. In addition, ungulates that congregate in wetlands or grasslands over long time spans provide prey only for resident tigers but are likely to be unavailable to tigers whose territories do not include these habitats. Moreover, sambhar, a dominant species in the tiger's diet in the Terai (Harihar *et al.*, 2011), are rare in the CTL. Estimated prey densities of chital, hog deer and wild pigs in DNP were ~11/km^2. These values correspond with tiger densities <5/100 km^2 based on the model of Karanth *et al* (2004). Fine scale pixel density estimates for tigers (Figure 2.5) reveal distinctly elevated densities in prey rich areas (such as Jhadi Tal in Kishanpur and the Rhino enclosure and the Maholi Block in DNP). In general, there appears to be an association between complex habitats (forest-wetland-grassland mosaics) and high ungulate prey densities, whereas extensive tracts of sal forest monoculture support only lower densities of these prey species (Seidensticker *et al.*, 2010).

In addition to prey limitations, camera trap data indicate that current densities of tigers in the CTL may also be influenced by skewed sex ratios. Specifically, in 2012 in Dudhwa Natonal Park and Katernighat WLS, 9 adult males and only 5 adult females were recorded (sex ratio 1 male: 0.55 females). With the addition of two young adult females into the population in 2013 (and the non-detection of some males), the sex ratio was 1:1 in 2013. The birth of several cubs in 2012 - 2013, at least 3 of which may be females, may foster a recovery of the female population. Given that tigers exhibit polygynous reproductive behavior, some studies have indicated that the ratio of breeding male to female tigers in stable populations is ~ 1: 3 (Sunquist 1981). Sex ratios skewed in favor of males can result in low rates of population growth (Sunquist *et al.*, 1999; Singh *et al.*, 2013) even when suitable

An agricultural enclave embedded in a sal forest. Croplands such as the one pictured above attract wild ungulates, and tigers may pass through or rest in them unnoticed.

habitat is not limiting. For example, based on two years of sampling in the Sathiyana Range of Dudhwa, we have only detected a single male tiger who occassionally visited this forest range. Prey densities in Sathiyana are amongst the highest in the landscape. The likely absence of a breeding female in the area over the duration of this study may explain its relatively low use by tigers during the study period, as female tigers are thought to be the limiting factor in the persistence of tiger populations (Horev *et al.*, 2012).

It is hypothesized that the presence of humans in forests, when restricted to day-light hours, has a lesser effect on tiger abundance than the availability of ungulate prey. This hypothesis is supported by the observation that Pilibhit Forest Division, which experiences high day-time disturbance (human pressure in the form of fuel-wood and grass collectors, traffic on major roads that bisect the forest and timber harvesting by the Van Nigam), has similar or higher abundance of tigers than other sites in the TAL that experience lower human disturbance. Human-tiger co-occurrence may be the result of a habitat refuge that provides tigers undisturbed space during the day-time hours when human beings are widely distributed across the forests. In the UP Terai, it seems that refugial habitat exists in the form of dense patches of tall-grass and riparian habitats dominated by species such as *Themeda* and *Saccharum Sp.* where tigers may retreat in the day-time hours.

Further, these results suggest that two key factors may set limits to the size of tiger populations in the UP-TAL. First, the densities of key prey species (chital, sambhar) are considerably lower in the CTL than in Rajaji and Bardia NP (Harihar *et al.*, 2009b; Wegge *et al.*, 2009). The functional relationship between prey availability and tiger densities is well established (Karanth *et al.*, 2004). Second, certain habitat types known to support high tiger densities (Wikramanayake *et al.*, 2011; Ranganathan *et al.*, 2009; Sanderson *et al.*, 2006) are uncommon in the CTL. For example, the rolling hills and valleys of Chitwan and Corbett may provide a more diverse array for habitats for tiger-prey- species than the sal forest dominated areas of the UP Terai. Homogenous sal forests are generally associated with lower densities of tigers and key prey-species (Kumar *et al.*, 2002, Shrestha 2004), and grasslands constitute a relatively small proportion (<15%) of the overall habitat area within the CTL.

2.4.2 Tiger Density

The density estimates presented in this report describe the current status of tiger populations in the Central Terai Landscape and will serve as a baseline for future monitoring efforts. These estimates are likely to be reliable because: (a) sampling using camera-traps was comprehensive and not limited to an *a priori* selection of areas with known tiger-occupancy; and (b) we used state-of-the-art estimation methods (e.g., SECR models) shown to have relatively low bias (Ivan *et al.*, 2013) when compared with earlier MMDM estimators which are known to be biased high (Obbard *et al.*, 2010, Ivan *et al.*, 2013).

It is likely the differences between earlier and current (from this study) estimates of tiger densities in Katerniaghat Wildlife Sanctuary (for 2012 and for 2013) and in Dudhwa National Park (2012 and 2013) arise from two key factors. First, an extension of the trapping grids in these sites by 100 - 200 km^2 (in 2013) resulted in an increase in the overall trap area. Although trap area was increased in 2013, we recorded few (1-2) tiger captures in these newly added areas (Gauriphanta Range of DNP and Motipur Range of KWLS). Thus, while the area sampled with camera traps was significantly increased between the two years there was a small corresponding increase in the count of tigers. Second, the estimates of the 'movement parameter', σ are also different between years and are likely to influence the density estimates. The estimate of σ is considerably higher for Katerniaghat in 2013 than it is in 2012. This may be an artifact of the movement of four adult male tigers over unexpectedly large areas in 2013, including three individuals who may have held territories on both sides of the Girwa River. Extending the extent of the camera-trap-array in 2013, allowed us to more accurately record and model tiger movement in sampled sites.

In light of these factors, the difference in density-estimates between 2012 and 2013 in Katerniaghat and DNP may not necessarily reflect actual population declines, but rather reflect the increased area sampled by cameras in 2013 and a more representative documentation of tiger movement. Of these surveys, the 2013 surveys are the most extensive and it is suggested that these results be considered the most reliable density-estimates for Dudhwa and Katerniaghat. In contrast, survey efforts in Kishanpur and Pilibhit Forest Division between 2010 and 2013 are comparable and it appears that the tiger population in PFD has declined since 2010.

Similar to the findings of several previous studies, density estimates from ML-SECR and Bayesian SCR models were very similar (Noss *et al.*, 2012, Gerber *et al.*, 2011, Gopalaswamy *et al.*, 2012 and Ivan *et al.*, 2012). In general, it was observed that the posterior mean summaries for Bayesian estimators were very similar to the maximum likelihood estimates when the priors in the Bayesian models were non-informative (Kery and Schaub 2012). We defaulted to using uniform priors for our Bayesian analysis in program SPACECAP. The similarity of estimates between the two methods suggest that both Bayesian and ML-SECR models provided comparable and reliable estimates of tiger densities. While hierarchical Bayesian models using data augmentation algorithms are the method of choice for complex data structures and small-sample size scenarios, these analyses may have high computation times for large capture-recapture datasets. With the relatively simple data structures in this study, estimation time for all our ML-SECR models were < 1 hour.

Ecological and Conservation Inferences

An important product from this study, and one of interest to managers, is the 'density-surface' for tigers in the CTL (Fig 2.5). As expected, tiger-densities varied among sites (resulting, for example, from low landscape connectivity, differences in habitat quality and variable prey densities). An unexpected finding however, and one of conservation concern, is the sharp difference in predicted tiger densities, and in some cases unrelated with any obvious declines in habitat quality. For example, in the Dudhwa Tiger Reserve, study results from 2012 and 2013 reveal a clear east-west gradient in tiger densities, with high values in the south-eastern and central areas of the Park along the Suheli River and markedly lower values in the western parts of the Park (comprising Dudhwa, Sathiyana, Bankati and Gauriphanta Ranges). Some of these areas (eg. Bankati and Gauriphanta Ranges) have been associated with low tiger use for at least one decade (De 2001), whereas the decline in the density of tigers in Sathiyana Range and Chandpara Block of Dudhwa Range appear to be more recent. Similar gradients in densities are also seen in Katerniaghat (low values in Murtiah, Dharmapur and Kakraha Ranges), and in the Pilibhit Surai complex (sharp density-gradient between Mahof range of Pilibhit and Surai Range of Terai East FD). While these gradients in tiger-densities may reflect spatial-variation in prey-densities, they may also be indicative of areas that are exposed to high hunting pressures along the Nepal border and face disproportionally high hunting pressure in DNP(De 2001). The meat of several wild ungulate species contribute significantly to the diets of people who reside in and around the Churia Hills of Nepal (Paudel 2012). Moreover, a number of people from villages within India around these forests have routinely been booked in wildlife crime cases (De 2001).

In addition to the effects of prey availability, habitat loss and human disturbance, an additional factor affecting the distribution and abundance of tigers is habitat connectivity (Seidensticker *et al.*, 1999, *et al.*, Crooks *et al.*, 2011). These findings suggest a ‘connectivity-effect’ on some tiger populations in the CTL. For example, Kishanpur Wildlife Sanctuary (~200 km^2) supports >15 adult tigers, whereas Lalpur-Deoria Range of Pilibhit Forest Division (~200 km^2) has <5 adult tigers (Chanchani *et al.*, 2011, present study). Kishanpur is nested within a large (~1200 km^2) habitat block, whereas the Lalpur-Deoria forest fragment is disjoint from other tiger occupied forests (a stretch of farmland, 1.5 km at its narrowest section separates Garah Block of PFD from the Lalpur-Deoria patch). Similarly, population and demographic attributes of tigers in DNP, possibly the most ‘isolated’ tiger-habitat patch in the CTL, may be influenced by low rates of tiger-immigration into the National Park from other areas.

2.4.3 Varying Buffer Sizes on Density Estimates for 2013 Data

The estimated tiger-density values did not change significantly when buffer sizes were varied over multiple distances. Correspondingly, the effectively sampled area (ESA) in ML-SECR showed only minor changes when the buffer sizes were varied. In the ML-SECR analyses, density is estimated as $\hat{D} = N/\hat{a}$. The effective sampling-area (ESA = $\hat{a}$) is greater than the geographical area represented by the camera-trap array (Aw) and the associated ‘user-defined’ buffer. When the buffer area is large relative to the half-normal distribution (as is the case in our analyses), Borchers and Efford (2008) explain that increases in the ESA will be small, even if the buffer area is increased.

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Teliocora acuminata, a weedy climber, dominates the understorey - particularly in moist and closed-canopy forests. This species is most abundant in Dudhwa and appears to be browsed on infrequently for most deer

Ecological and Conservation Inferences

The relative 'insensitivity' of tiger-density estimates to changes in buffer size is an artifact of the way the effectively sampled area is estimated in MLSECR models (see description above). It is ultimately a reflection of the sampling-design (area-sampled with camera traps relative to the area-available to the population being sampled), the peculiar geography of the study region, and the movement of tigers in the sampled populations. Seemingly, the smaller buffers (represented by full and half MMDM distances) may have adequately described *S*, particularly for sites that were sampled exhaustively, and when these sites had 'hard' boundaries (wilderness areas surrounded by other land use types).

The use of small buffers in these analyses may be appropriate for certain 'island-like' sites (e.g., Dudhwa National Park) which are sampled almost in entirety with camera traps. This is because the 'super-population' of tigers exposed to camera traps is likely restricted to the forest-boundaries, comprising of the park's core and buffer zones. Although tigers may occassionally venture into human land use area beyond these boundaries, tiger populations are largely restricted to forest and grassland habitats. There are a few notable exceptions. Some tigresses accompanied by young cubs were located in farmlands at significant distances (10 - 15 km) from forest patches, and these animals had taken up residence in sugarcane fields for several months. The existence of 'farmland tigers' such as these is public knowledge because farm-owners commonly encounter such animals or their signs.

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Village women collect fuel-wood in a buffer zone forest area that is frequented by tigers.

2.4.4 Estimates from Restricted Analysis (NTCA Trap Area)

Estimates of tiger population-size from the restricted area analysis were similar to estimates from the AITMP surveys in 2010 in all sites other than DNP and PFD. For density-estimates, both from buffer-strip-width (MMDM) estimators and from ML-SECR, the 2013 estimates were either higher or lower than the previous estimates.

Differences in estimates of $\widehat{N}$ from closed population capture-recapture models could be on account of a number of factors. In sites where fewer individuals were captured in 2013 than in 2010, lower estimates were expected. However, the precision of the abundance and capture-probability estimates is greatly influenced by the recapture probability of "marked" individuals. In general, sites with high numbers of recaptures have more precise estimates than sites with lower-recapture rates (e.g., Pilibhit in 2013). The estimates and their associated confidence-intervals may have been influenced by the estimating model (Huggins or full - likelihood parameterization). In the Huggins model (used for 2013 data), $\widehat{N}$ is a derived parameter whereas it is an estimated parameter in the likelihood function in the standard parameterization. The annual estimate of abundance at each site represents the number of adult tigers whose territories wholly or partially overlapped the camera trap grid. The 2010 surveys established a single camera-trap block which remained active for a period of 30 - 50 days. By contrast, the 2013 surveys (at all sites but Kishanpur) had multiple-trapping blocks within a site, each of which was 'active' for a duration of 15 - 25 days. Trap-densities were higher in all sites in 2013 than in 2010.

Because $\widehat{D}$ is a derived parameter, its estimates are a function of the estimated population size and the effective trapping-area (Aw) or the effective sampling-area ($\hat{a}$). The area-term is estimated as the 1/2 MMDM buffer around traps or scaled by animal movement around home-range centers (related to the parameter in ML-SECR models), and is an outcome of animal movement and capture locations. As a result, the sampled areas in 2010 and 2013 are different for all sites, and are scaled by the movement of animals in the trapping-blocks in each year. Estimates for cameras located within the AITMP trapping-area, (2010 and 2013 surveys excluding Kishanpur WLS), are not necessarily applicable to the entire Park, but rather to some smaller area within the Park represented by the trapping block + buffer area. Therefore, observed differences in tiger-abundance / density between 2010 and 2013 allow only limited inference to population change. Inferences are limited to some subset of the Park or Reserve Forest areas that were sampled and do necessarily allow inference about Park-wide changes in the status of tigers.

Ecological and conservation interpretation

The 2013 surveys were separated from the 2010 surveys by ~30 months. Natural populations are in constant flux as consequence of birth, death, immigration and emigration processes. Further, not every individual in a sampled population is captured on camera-traps. Individual tigers, males in particularly, disperse from their natal territories at 2 to 3 years of age, and females breed and produce their first litters at a similar age (Sanderson *et al.*, 2006). Territoriality is a characteristic tiger behavior and there is frequent turnover in territory location and occupancy. All of these processes are likely to have led to changes in the distribution, and in some cases, abundance of tigers between 2010 and 2013.

Comparisons of estimates between years should be made with caution. Even though the trap areas are the same, differences in animal movement, trap-duration, trap-density and study period, can all influence population estimates. Nonetheless, these data suggest that there were fewer tiger individuals within the AITMP trapping-areas in 2013 than in 2010, at three sites (DNP, Katerniaghat and Pilibhit). While there are indications of declines, the short time duration of this study precludes firm conclusions about longer-term population trends.

An adult male tiger spray-marks his territory in Katerniaghat WLS.

Tiger with chital carcass, Dudhwa National Park
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TIGER CAPTURE DYNAMICS AND INTER-YEAR POPULATION ATTRIBUTES

3.1 INTRODUCTION

As described in Chapter 2, monitoring tiger populations with camera traps provides estimates of population parameters such as density and abundance. The primary objective of the current chapter is to use the capture-recapture data to document the 'fates' of individual tigers over the study period and to estimate the age and sex structure of tiger populations in the Central Terai Landscape (CTL).

Monitoring population 'structure' and changes in the age and sex-class distributions from year-to-year, provides insights into population dynamics (growth or decline). Specifically parameters such as the ratio of young to old animals, age at first reproduction, and age at which breeding senescence occurs in male and female animals, and changes in these metrics over time, can provide important insights into population trends. Because tigers are a territorial species with a polygamous mating system, the age distribution and sex ratio of a population also influence the behaviour of individual animals in the population. Territory sizes and boundaries, ranging patterns, timing and direction of dispersal, harem sizes of male tigers, and behaviour such as cub-infanticide by hostile non-parent male tigers are related to sex ratio and age-class distribution. Knowledge of population structure, and an understanding of tiger-habitat relationship (i.e. how tigers distribute themselves across the landscape in response to spatial variation in the distribution of resources such as water, prey and cover), provide insights to long-term population dynamics. Simultaneous monitoring of changes in the abundance and population structure of tigers, and the endogenous and exogenous drivers hypothesized to drive temporal and spatial variation in their demography, provide the key information needed to implement effective conservation strategies.

These studies, carried out over 2 sampling-seasons (over a 3 year period), provide annual estimates of tiger population size, age distribution, and sex ratio. Because the full extent of tiger habitat within the study area was sampled, it has been possible to generate a comprehensive estimate of population structure in terms of number of territorial adult tigers, number of transient (i.e. non territorial young adult), and juvenile tigers, separately for males and females. One question that has been explored in this chapter is whether there is evidence of an association between the age-sex structures of tiger populations and environmental factors and measures of human use of the CTL. Evidence for putative causal relations between tiger demographic attributes and environmental factors allow the development of informed management strategies to conserve tiger populations.

3.2 METHODS

The capture process has been described by plotting the cumulative number of captures as a function of sampling effort (number of camera trap sampling occasions) over the 'closed' sampling period. Specific details on trap deployment are described in chapter 2. Using pie diagrams, the age-and-sex distribution of tigers in each of the study populations over the sampling period has been reported. Each 'captured' tiger has been classified as belonging to one of the following categories: adult males (territorial males > 3 years); transient males (2 to 3 year old males that are dispersing, or staking out new territories); adult females (territorial females > 3 years); lactating females (adult females that are visibly lactating, even though no cubs are observed); transient females (2 to 3 year old females assumed to be searching for or establishing a territory); juveniles (1 to 2 year old tigers, accompanied by their siblings and mother); cubs (tigers < 1 year old, accompanied by siblings and their mother); and unknown (tigers in the aforementioned categories to which we are unable to assign gender based on camera trap data). A post-breeder category was not created because it was difficult to unambiguously identify such animals from camera trap data.

To describe the transition of individuals among age-classes and years, and provide insight to the entry and exit of animals from our study area, we use diagrams similar to a population-stage-structure diagram. The circles in these diagrams represent an age-class to which individual tigers captured over the two years have been assigned to one of three age classes: young (cub + juvenile), transient (sub adult) and adult. These are similar to the juvenile, transient and breeder categories described by Chapron *et al.* (2008). Tigers in each age-class are reported as counts, followed by a 'm', 'f', or 'unk' suffix to reference males, females and animals with unknown gender. Arrows between boxes and associated numbers indicate tigers captured in both years, or individuals known to have transitioned from one age class to another. Red arrows leading out of the circles and associated numbers refer to animals that were in the population during the first year of sampling (2012), but were not subsequently captured in 2013. When the fates of animals are known (e.g., identifying a dead animal by means of a photographic match between pelage patterns on the carcass and in our photo-database), these are indicated by specific notations in the diagrams. In all other cases, the absence of an animal in our 2013 sample, given capture in 2011-2012, could be on account of (i) non-detection on camera traps in 2013 even though the animal was present in the study area; (ii) temporary immigration or permanent immigration out of study area; or (iii) mortality between the sampling periods in 2012 and 2013.

These data have not been subjected to open-population capture-recapture analysis, as was done by Karanth *et al.* (2006). Such analyses will provide estimates of annual survival rates. It is uncommon to estimate survival and immigration-emigration parameters from short-term studies such as ours (but see Gardner *et al.*, 2010 for a recent application of open-population models).

Curious cats: tigers are often intrigued by camera traps and other foreign objects in their reign. Often they approach them closely. Pictured here is the Kakraha male in Dudhwa National Park.

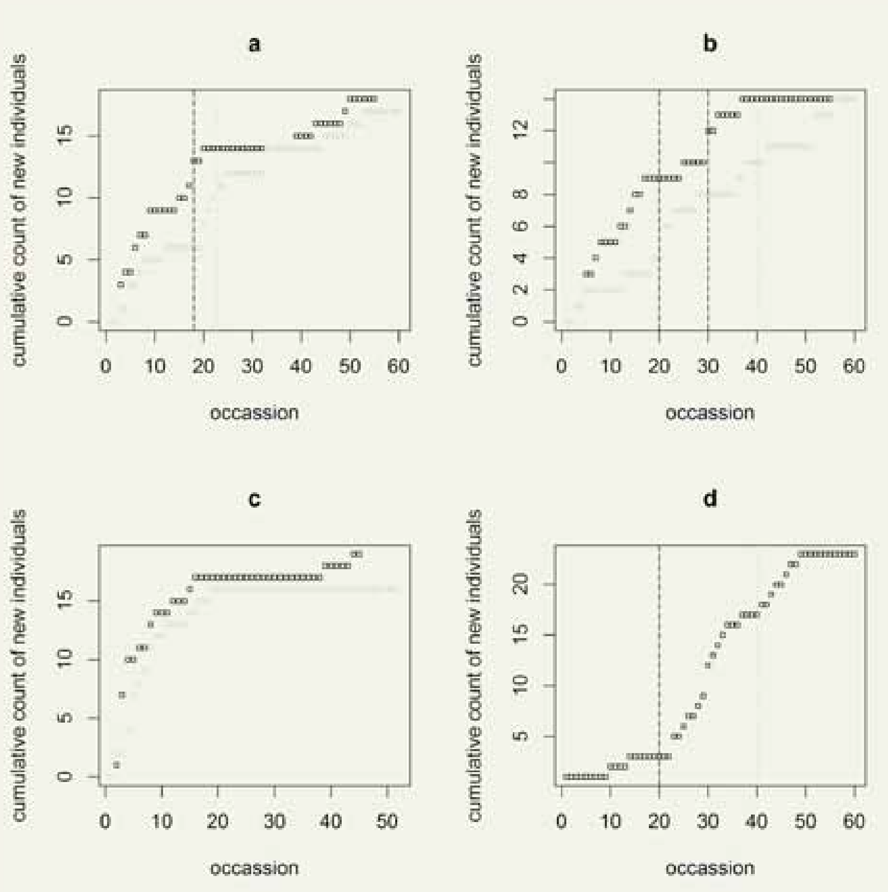
Figure 3.1
Plots depicting cumulative captures of new tigers at four sites in UP Terai. Black squares are plots for 2012 whereas grey squares are for 2013. The dotted vertical lines mark approximate period for camera transitions between sampling blocks, the black dotted line represents 2012 and light grey dotted line represents 2013.

(a) Capture accumulation curve for new tigers encountered on camera traps in Katerniaghat Wildlife Sanctuary in 2012 and 2013. Each occasion refers to a 24 hour period In 2012. Block 1 included camera trap locations in Katerniaghat Range and some areas of Nishangara Range, whereas Block 2 included the Bagluia Seed Farm area of Nishangada Range, and portions of Murtiah and Dharmapur Ranges. In 2013, Block 1 sampled Motipur, Kakraha, Murtiah and Dharmapur Ranges and the Bagluia Seed Farm Area. Block 2 included locations in Nishangara Range, Katerniaghat Range in its entirety and a few locations in North Kheri Forest Division.

(b) Capture accumulation curve for Dudhwa National Park. In 2012, the first sampling block included the Belrayien Range in eastern DNP. The second block was located in Dudhwa, North and South Sonaripur Ranges, and the third was in Dudhwa, Sathiyana and Bankati ranges. In 2013, there were only two sampling blocks, the first covering Gauriphanta, Bankati, Sathiyana and Dudhwa Ranges while the second included locations in South Sonaripur, North Sonaripur and Bilrayien.

(c) Capture accumulation curves for Kishanpur Wildlife Sanctuary for 2012 and 2013. Kishanpur was sampled by a single trapping block in each of the two years.

(d) Capture accumulation curve for Pilibhit Forest Division for 2013 which was sampled in three blocks, the first included a portion of Haripur Range, the second included Haripur, Barahi and Mahof Ranges in their entirety, and the third Mala and Deoria Ranges.



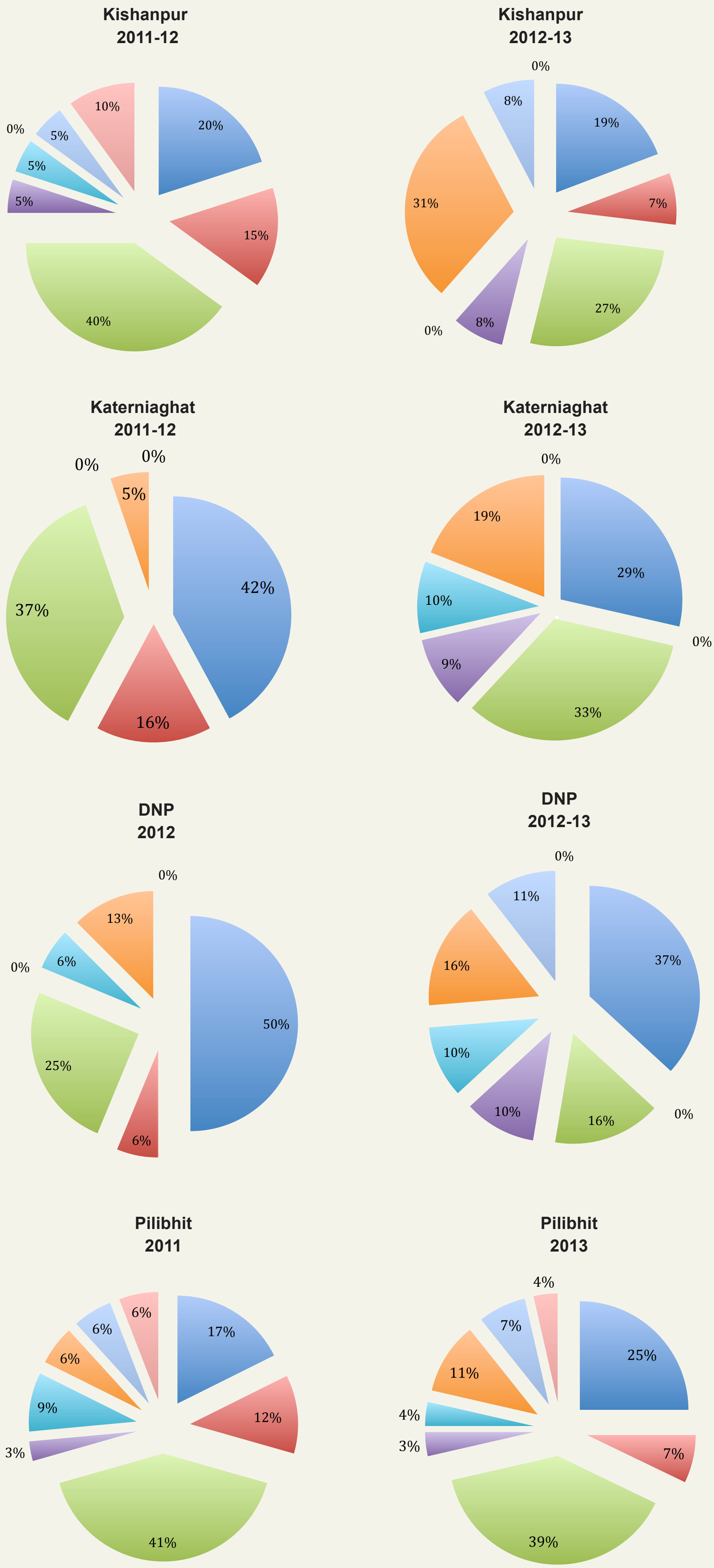
3.3 RESULTS

3.3.1 Katerniaghat WLS:

A: Capture accumulation curves

The cumulative capture curves for 2012 and 2013 in Katerniaghat WLS (Figure 3.1 a) illustrate the non-random spatial distribution of tigers which likely reflects spatial heterogeneity in habitat quality and extent. For example, sampling-block 1 had multiple tiger captures and sampling-block 2 had areas with multiple captures. Sampling-block 1 contained productive riparian grasslands and successional forests along the Girwa River and the Koudiyala Rivers. Sampling-block 2 contained the Bagluia Seed Farm area of Nishangara Range a productive area for tigers. In contrast, Murtiah Range and Dharmapur Range within block 2 had no tiger captures or pugmark records during the study period. Of the tigers captured in Sampling Block 2, 33% had previously been captured in sampling block 1 in 2012, and 21% in 2013. In terms of spatial coverage, the order of camera trapping was ‘reversed’ in 2013, and we installed the first block of camera traps in Murtiah and Dharmapur Ranges, the Bagluia Seed Farm in Nishangara Range and Kakraha and Motipur Ranges (the last two had not been previously sampled with camera traps). Consistent with the 2012 data, east-lying areas of the Sanctuary added few individual tigers to our total count, as compared with the western areas of the Sanctuary, i.e. Katerniaghat and Nishangara Ranges (Block 2 in 2013). The mean number of recaptures (standard deviation in brackets) for adult male tigers in 2012 and 2013 were 6 (4.1) and 14 (14.5) respectively, and for females, 3 (2.0) and 11 (8.9). It is noteworthy that sampling in 2012 occurred in the peak summer when day-time temperatures frequently rose above 40^{o} centigrade, whereas 2013 sampling was restricted to the winter months with near-freezing temperatures.

Figure 3.2
Age-and-sex structure of tiger populations in Katerniaghat WLS, Dudhwa NP, Kishanpur WLS and Pilibhit Forest Division. Data are presented as percent of captures of each age and sex category from camera traps in two years of sampling (2011 data for Pilibhit FD is from the study of Chanchani et al., 2011).



During the day, tigers often retreat into dense vegetation such as this patch of *Phragmytes sp.* and cane on the islands on the Girwa River in Katerniaghat. An adult male and female tiger are pictured above.

(B) Population characteristics: (sex and age-structure)

The ratio of adult male tigers:adult female tigers for the years 2012 - 2013 were 1 : 0.63 and 1 : 1.57 respectively (figure 3.2). Fewer transient-age males were recorded in 2013 than in 2012, particularly in areas along the Girwa River near Khata corridor. In 2011, a single tigress accompanied by a cub was photo-captured in the Manjhara block forests of Katerniaghat Range. Manjhra is a peripheral forest patch near the Girwa reservior and bordering small forest tracts of North Kheri Forest Division. Two “new” adult females were captured in 2013 . One of these females (accompanied by two young cubs) occupied a territory dominated by Teak plantations and dense Zizyphus and cane understorey in the disturbed eastern tip (Motipur Range) of the sanctuary. The other was captured in the Seed Farm area (Sujuali in Nishangara Range). Two females in the ‘transient’ age class were also first recorded in 2013 in Katerniaghat Range of the Sanctuary. In addition, two juvenile tigers (approximately 1 year old) were captured near the boundary of Murtiah and Dharmapur Ranges in 2013.

(C) Inter-year dynamics:

Even though the area sampled in 2013 was >35% greater than the area sampled in previous years (2012, WWF-India), the number of tigers captured in Katerniaghat over the past three years was nearly identical--17 (2011, Jhala *et al.*, 2011), 18 (WWF 2012) and 16 (WWF 2013). Fifty percent of the individuals captured in 2011 (Jhala *et al.*, 2011, photos available in WWF -India database) were also photo-captured in 2012 (representing a comparable trapping extent between the two years, but a two-fold increase in trap densities in 2012). In contrast, 12 individuals (or 71% of the captured animals captured in 2012) were also captured in 2013, whereas the remaining 29% were represented by animals that were previously unrecorded. Of the new adult individuals only one adult female was from an area not previously sampled (Motipur female with two cubs). Gender and age-specific details of captures and transitions of individuals between age-classes for 2012 and 2013 are presented in Figures 3.2 and 3.3.

3.3.2 Dudhwa National Park

(A) Capture accumulation curves:

Similar to Katerniaghat, the capture accumulation curves for Dudhwa NP in 2012 reveal marked differences in the numbers of individual tigers captured in each of the three sampling blocks (Figure 3.1 b). Captures of 14 individuals were obtained from the first two blocks covering Belrayien, North and South Sonaripur and Dudhwa Ranges. Block 3, covering the western ranges of the park, yielded no tiger captures. This is not reflected in the capture accumulation curve for sampling in 2013, when the park was trapped in 2 sampling blocks, of approximately the same area. A number of male tigers in DNP exhibited significant east-west ranging movement (>30 kilometres) between Dudhwa and Bilrayien Ranges and were captured in >1 sampling block. The mean and standard deviation for recaptures for adult male tigers in 2012 and 2013 were 10 (9.4) and 26 (30.0), and for adult female tigers 9 (3.4) and 13 (9.4) for the two years. In the 2012 sampling period, 50 % of the adult tigers encountered in the second sampling block had previously been encountered in the first block. One hundred percent of the individuals in the third sampling block had been encountered in other blocks. In 2013, there were only two sampling blocks, and 50% of the adult tigers captured in sampling Block 2 had been previously captured in Block 1.

(B) Population characteristics:

Based on camera trap data from Dudhwa National Park, a male-biased sex ratio was observed in 2012 (1:0.55), and an even ratio for adult male and female tigers in 2013 (1:1). The appearance of two young females (2 to 3 years old) in the Kila area of Belrayien range and a young adult female in the rhino enclosure, as well as the absence of a few males recorded in the previous year - resulted in the even sex ratio in 2013. The presence of 5 juveniles and cubs (< 2 years old) and two lactating females in 2013 may help repopulate areas of the Park and that the sex ratio may change significantly if the 5 cubs and juveniles present in the Park in April 2013 (2 to 3 of which are females) survive to become breeding adults.

(C) Inter-year dynamics:

Although the area sampled in 2012 was considerably greater than the area sampled in 2010 (Jhala *et al.*, 2011), we recorded 57% of the individuals photo-captured in 2012 to be 'new', and only 43% of the individuals captured in 2010 were subsequently recaptured in 2012. A much higher percentage (71%) of individuals photo-captured in 2012 were subsequently 'recaptured' in 2013 (Figure 3.4). Between 2010 and 2012, one young male dispersed out of Dudhwa and subsequently occupied an area of semi-wilderness on the outskirts of Lucknow. This tiger was tranquilized and captured, and released into Dudhwa National Park in 2012 shortly after the camera trapping exercise for that year had been completed.

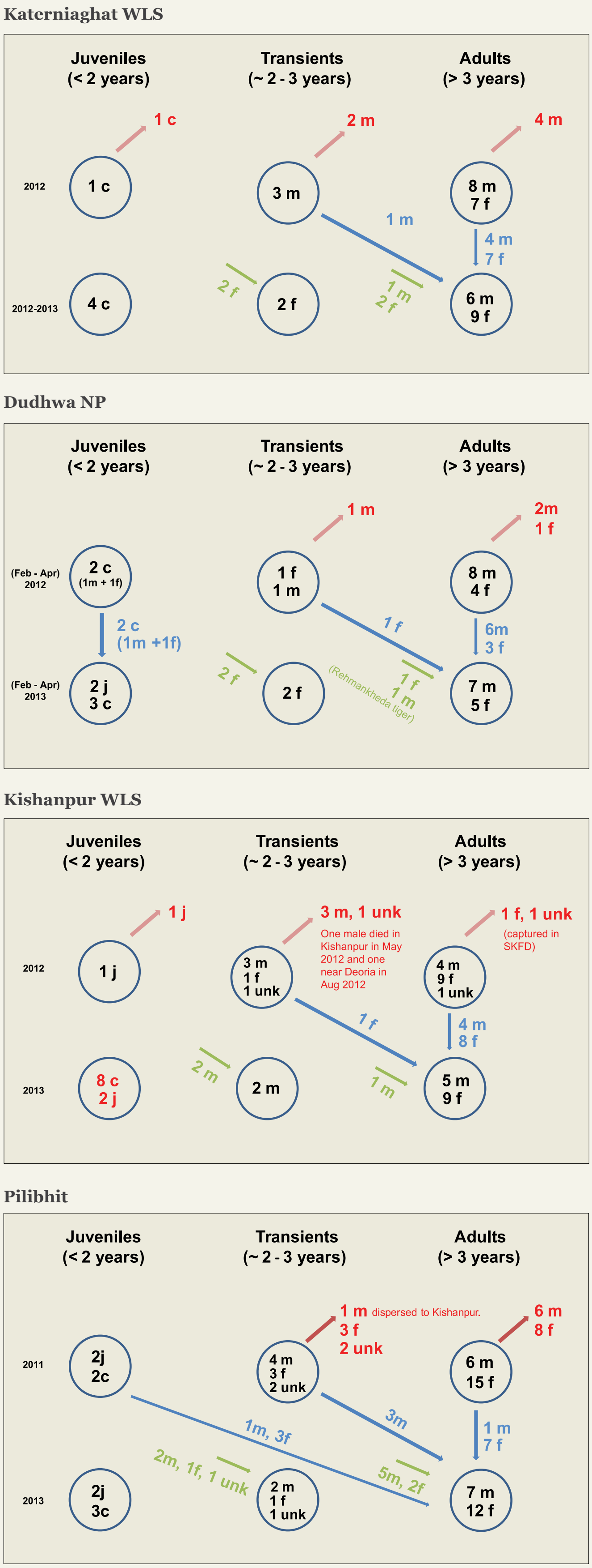


Figure 3.3
Age and sex characteristics, and stage transitions recorded for the four tiger-occupied areas sampled in the Uttar Pradesh TAL for 2012 and 2013 from camera trap data. The upper row indicates the population composition (by age and gender class) during the 2011-2012 sampling period, and the bottom row describes population composition for the 2012-2013 sampling season. The circles represent three age classes, and the numbers inside circles are a count of individuals in each of the age classes at the time of sampling, indexed by gender (m = male, f = female). Within the juvenile category, c indexes cubs (< 1 year) and j represents juveniles (1-2 years). Animals indexed with a j in 2012 will transition to the transient category in 2013 (if detected), whereas those labelled c in 2012 will stay in the same 'stage', but will be indexed by a j in 2013 to indicate that they are older cubs. The blue arrows represent transition of individuals from one age class to the next (eg. juvenile - sub-adult) between 2012 and 2013. Numbers associated with the arrows indicate the count of individuals photo-captured in 2012 that we recaptured in 2013 in the same (adults) or some other age-class. Red arrows and associated numbers reference individuals that were recorded in 2012, but were not captured in 2013 because of: non-detection on camera traps, immigration or mortality. Green arrows and associated values indicate animals that were captured in 2013 but were not captured in 2012 (These are animals that were either not detected by cameras in 2012 or those that emigrated between the 2012 and 2013 sampling sessions.

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A rusty spotted cat in the Terai forests

3.3.3 Kishanpur WLS:

(A) Capture Accumulation Curves:

Kishanpur was camera trapped in a single 45-50 day camera trap block in 2012 and 2013. The cumulative count of new individual tigers reached an asymptote at around 20 days for both years. However, the appearance of two transient males between the 30th and 45th sampling occasions in 2012 caused the count to rise beyond the 20th day in that year. The mean numbers of recaptures and their associated standard deviations were 18 (19.8), 15 (15.0) for males and 14 (7.7), 17 (14.9) for females in 2012 and 2013 respectively.

(B) Population characteristics:

The adult male to adult female sex ratio for tigers captured on our camera traps were 1: 1.42 in 2012 and 1 : 1.5 in 2013. Four adult males in the population appeared to have stable territory locations over the study period, and two of these had territories that extended into Bhira range of SKFD. A fifth adult male captured in 2013 appeared to have a large portion of his territory in Mailani range in the South Kheri FD, and this tiger made forays into the Sanctuary primarily along the Kheri canal in Mailani Range. In 2013, 6 of the 9 females captured were either accompanied by cubs, or were lactating. Of these, two had litters of 3 and 2 small cubs respectively (2-3 months old). A third female was accompanied by three cubs that appeared to be approaching an age of 1 year. A fourth female was accompanied by 1-2 older juveniles (1-2 years old). We also recorded the presence of two females that were lactating but no accompanying cubs were photo-captured.

(C) Inter year-dynamics:

A significant proportion of the transient and adult individuals were captured across sampling periods, with 72% of the individuals captured in 2012 being ‘recaptured’ in 2013. Three tiger mortalities were recorded in Kishanpur WLS during the 2011 - 2013 period. An adult female was killed on the Mailani - Palia highway in 2012 by a speeding truck, prior to sampling. The carcass of a young male (2 to 3 years old) was recovered from Kishanpur Range in May 2012. Another young male died of unknown causes and its carcass was recovered from the Hardoi Canal near Deoria Range of Pilibhit Forest Division in August 2012. Three adult males (two of which appear to be transients), previously un-recorded, were photo-captured in Kishanpur WLS in 2013.

Capturing tigers: A team member tests a camera trap in Kishanpur WLS. Three young cubs gaze curiously at the cameras.

3.3.4 Pilibhit Forest Division:

(A) Capture Accumulation Curves:

The capture accumulation curve for PFD for 2013 (Figure 3.1 d) reveals fewer new individual tigers were encountered in sampling Blocks 1 and 3 than in Block 2. Block 1 included 15 camera locations in Haripur Range (the remaining cameras were deployed in Kishanpur WLS and in South Kheri Forest Division). Block 2 included portions of Haripur Range, and Barahi and Mahof Ranges in their entirety. Block 3 included locations in Surai Range (Terai East Forest Division) and Mala and Deoria Ranges in PFD, both locations with few tiger detections from earlier surveys (Chanchani *et al*., 2011). In Mala Range, fewer tigers were captured on camera traps in 2013, than in 2011, and tiger use of the two Garah Blocks was considerably lower than in 2011. The mean number of recaptures for males (standard deviation) in 2013 was 3.07 (1.89), and the mean for females was 5.88 (4.25). Six percent of the individuals recorded in Block 2 had previously been recorded in Block 1, and 28% of the individuals captured in Block 3 had been previously captured in Block 2.

(B) Population characteristics:

Chanchani *et al*. (2011) reported the sex ratio for adult male: female tigers to be 1:1.8. Based on the 2013 sampling, we recorded a sex ratio of 1:1.4. We captured 4 juveniles (1-2 year old animals) in 2011, and 3 young cubs and 2 juveniles in 2013.

(C) Inter-year dynamics:

Of the 34 individuals captured during 2010-2011, 18 (50% of population in 2011) were not captured in 2013. However, the presence of several tigers in our databases from 2011 and 2013, with only single flank pictures, made it difficult to match some individuals between the two sampling periods. Fifty percent of the adult males captured in 2011 were not recaptured in 2013, and 55% of the adult and sub-adult females captured in 2011 were not captured in 2013. Camera trap data yielded information on the the fates of all four sub-adults males recorded by camera traps in Pilibhit FD in 2011. Three of these established territories in PFD, and one dispersed to Kishanpur WLS. In addition, in 2013 a WWF-India and forest department team established that a female tiger (captured previously in Mahof Range 2011) had temporarily migrated out of Pilibhit Forest Division and took up residence in sugarcane fields along the Deva River, near Amariya village on the Uttarakhand - Uttar Pradesh state border.

In the PFD, several tiger mortalities were documented between 2011 and 2013. The carcasses of 2 adult males were recovered from Haripur Range in May 2012. These animals were thought to have died after feeding on a poisoned buffalo carcass near the Sharda river. The skins and coats of these tigers were considerably degraded and it was impossible to establish the identities of these individuals with those in the photo database. In November 2013, an adult male, ~ 4-5 years in age, (individual W in the Annexure of a report on Pilibhit's tigers - see Chanchani *et al*., 2014) was found dead in Barahi Range, and reportedly died of canine distemper. An adult tigress was reportedly poached in Mahof Range soon after the monsoon period in 2013, based on the confession of some poachers who were arrested. In 2013, surveys revealed the presence of 8 "new" adult tigers in the Pilibhit Forest Division population. Of these, one was a large adult male whose territory extended into Bhira Range of South Kheri Forest Divsion and Kishanpur Range of the Sanctuary.

An adult tigress confidently strides forward in the Kila area of DNP.

3.4 DISCUSSION

Capture accumulation curves suggest extensive spatial heterogeneity in the abundance and distribution of tigers, even within a single contiguous forest area (e.g., Pilibhit Forest Division). The likely causes for such heterogeneity are variation in habitat quality and extent reflecting spatial variation in prey availability and refuge areas for minimizing interactions with humans.

The territorial behaviour of tigers is well documented: female home ranges in the Indian sub-continent vary between ~15 to 30 km^2, and male home ranges can be larger than 150 km^2 and usually encompass 1 or more female home ranges. In Chitwan in the Nepal Terai, Sunquist (1981) estimated the ratio of adult male: female tigers to generally be 1:3. Variation in female home range size is believed to be primarily associated with variation in prey availability. In contrast, males select home range areas on the basis of access to females (Smith 1993). Sunquist (2010) suggests that "females, rather than food, are the most sought after resources for males". In the CTL the male: female sex ratio was found to be <1:3, and even male-biased in some sites. For example, across these four study sites, we found more females than males only in Kishanpur in both years and in Pilibhit in 2011. In contrast, Dudhwa and Katerniaghat had male-biased or even sex ratios, with the male bias being most pronounced in DNP. This leads us to posit that sites with greater habitat connectivity (Kishanpur, Pilibhit, and Katerniaghat) are more likely to maintain female-biased sex ratios than more isolated sites (eg. DNP). However, variation in landscape connectivity is unlikely to be the sole factor contributing to the observed variation in sex ratios among our study sites. The observed sex ratios may also be a consequence of human-induced mortality (Horev *et al.*, 2012). Of key significance is the fact that sex ratios skewed in favor of males may significantly elevate the risk of local extinction (Chapron *et al.*, 2008).

Previous studies suggest that imbalances in the sex ratio (even or male-biased) may result in increased intra-specific male-male aggression and higher rates of infanticide (Smith, 1993; Sunquist 2010). In addition, biased sex ratios may cause transient young males to disperse into farmlands in search of new territories and potential mates. It is also possible that male biased sex ratios may cause some female tigers to raise young cubs in the relative safety of sugarcane plantations outside of forests, away from hostile males.

Results from these capture-recapture studies for tigers indicate an annual turnover of ~20% to 50% in the composition of tiger populations in the study area (for data collected in the 2010 - 2013 period). Adult males and sub-adult males (transients) had the highest turn-over rates among all age-sex classes. Previous studies have shown that resident adult males and females have annual survival rates >80%, whereas dispersers (sub-adults) may have survival rates of ~70% (Kenney *et al.*, 1994). In our study, 'turnover' among sampling periods was most pronounced in DNP and Katerniaghat WLS. Both these study sites lie along the Nepal border and are 'connected' to forests in Nepal through narrow corridors that may serve as conduits for tiger dispersal and movement (Wikramanayake *et al.*, 2010). Although a turnover of ~50% was documented in PFD, this figure is from a two year interval between sampling. It is noteworthy and of concern that a disproportionately high number of adult females could not be accounted for (in our camera trap study) in 2013, suggesting an urgent need to enhance anti-poaching efforts in PFD.

Camera trap data indicates that several male tigers with few captures in the Trans-Girwa and Kaudiyala areas of Katerniaghat occupy habitats both in India and the Khata area of Nepal. While corridors leading in and out of DNP (from Nepal) are characterized by extensive fragmentation, minimal-disturbance crop cultivation in farmlands along these corridors may allow occasional tiger movement between these forests. There is evidence of tigers moving up to ~ 200 km through agricultural areas in the Uttar Pradesh Terai (e.g., the dispersal of the 'Rehmankheda tiger' from Dudhwa to the outskirts of Lucknow in 2012). Other investigators have documented tigers dispersing over large distances via forest corridors, and occasionally through the non-forest matrix (Reddy *et al.*, 2012, Singh *et al.*, 2013, Patil *et al.*, 2011), suggesting that tigers do occasionally disperse through farmlands. The likelihood of movement through the matrix between forest patches will be strongly affected by the intensity of agricultural practices. Empirical data from a radio telemetry study involving dispersal-age tigers Smith (1993) suggests that tigers are unlikely to move through agricultural landscapes in Nepal, where cropping patterns are considerably different from the better-irrigated Indian Terai.

In all the sites surveyed, we observed only a small number of females accompanied by cubs, with the exception of Kishanpur in 2013. Based on our estimates of tiger density, the northern areas of Kishanpur Wildlife Sanctuary represent high quality tiger habitat. The Sanctuary's proximity and connectivity with Pilibhit (and likely with Shuklaphanta in Nepal), the presence of prey-rich riparian habitats, and natural boundaries (including the Sharda River and Kheri Canal) that limit human presence in the forest interior may explain this area's large tiger population.

There is sparse information on annual 'turnover' in tiger populations from other regions of India and Nepal to compare these findings with. Based on an analysis of long-term capture-recapture data, Karanth and Nichols (2006) estimate that the tiger population in Nagarhole increased by 3% per year even when 23% of the population was annually lost to emigration and mortality. Naive estimates of emigration + mortality rates from our short-term Terai study appear to be considerably higher than those reported for Nagarhole. In general, historical information on tiger hunts in the Terai of India and Nepal suggest that tiger populations are able to recover from significant population loss due to hunting because of their high reproductive potential (Sunquist 2010). However, most populations are now small and fragmented, and modeling studies have shown that poaching pressures

Fast growing! A cub in the Banke Tal area of Dudhwa National Park in early 2012. The cub was recaptured at a nearby site one year later (~1.5 years old in the right picture). Cubs generally part ways from their mother at 2 - 2.5 years of age.

may greatly enhance the probabilities of such small populations going extinct over relatively short time-spans (Kenney *et al.*, 1994; Chapron *et al.*, 2008, Horev *et al.*, 2012). Small populations have also been associated with high rates of inbreeding depression (Smith and McDougal., 1991). Smith's (1993) study in Chitwan NP has established that young (dispersal age) males face aggression from older tigers prompting them to disperse. Tigers in this age group are especially vulnerable to threats originating both from tigers and from humans. To arrest tiger population declines and increase population growth, we believe there is an urgent need for increased anti-poaching patrols and law enforcement efforts in and around the tiger habitats of the Uttar Pradesh Terai and in neighbouring Nepal.

Finally, a few practical recommendations to guide future camera trap sampling in the CTL can be prescribed from these studies.

(i) Design sampling protocols that encompass the range of spatial heterogeneity in tiger densities and habitats to obtain reliable estimates.

(ii) Maintain trapping blocks for a minimum of 15 to 20 days when camera trap spacing is ~1 - 2 km. This design appears to expose most resident adult tigers to camera traps and provides multiple recaptures for individuals, particularly in winter-time sampling.

(iii) Researchers should be aware that capture rates may be considerably lower in the hot summer months (end April - July) than in the winter period (October - March). Lower capture rates may arise because of decreased movement in hot weather, and also because some cameras traps appear to be more likely to malfunction in the hot summer than the cool winter months. By sampling the study sites in their ‘near-entirety’, using a block design, this study yielded estimates of capture probabilities for the entire sampling period (p*) that ranged between 0.93 and 1.0, resulting in a near census of these populations (Table 2.5 Chapter 2). Sampling large areas of remnant tiger habitat in the landscape, and reducing the spacing between camera traps results in higher capture probabilities and provides reliable estimates.

Vigilant chital on a forest road, Kishanpur WLS.

THE OCCURRENCE AND ABUNDANCE OF UNGULATE PREY IN THE CENTRAL TERAI LANDSCAPE

4.1 INTRODUCTION

This chapter details survey methodologies and reports the density estimates for major tiger prey species (wild ungulate fauna) in Dudhwa National Park, Katerniaghat WLS and Kishanpur WLS (DTR). While previous studies have provided estimates of tiger densities for these sites (Jhala *et al.*, 2008, 2011), additional information on the status of ungulate prey is needed to better understand their influence on the distribution and dynamics of tiger populations. The current study provides systematic baseline estimates for ungulate prey densities in DTR based on robust sampling techniques (Karanth and Nichols, 2002). Densities of major prey species have been estimated for Kishanpur WLS, Dudhwa NP and Katerniaghat WLS using data from variable distance transect sampling conducted over two years (2011-2013).

This chapter begins with an overview of current scientific evidence on the role of ungulates in ecosystems, and more specifically in the food-chains of large carnivores. The importance of monitoring ungulate populations and the theory underlying a commonly employed density estimation strategy using line transect sampling have been emphasized. The sampling, analytical methods and results from this study have then been presented. The chapter concludes with a detailed discussion and recommendations for the management of ungulate fauna in DTR, based on available literature and studies from similar sites elsewhere in the landscape.

4.2 THE ROLE OF UNGULATE PREY IN SUSTAINING CARNIVORE POPULATIONS

Variation in animal density and distribution patterns across a landscape principally reflect changes in the availability of key resources. Therefore, a thorough understanding of how changes in resource availability over space and time affect the species that consume these resources is key to devising successful conservation and management measures. Where carnivores are concerned, the availability of prey is thought to be the most important factor determining their spatial distribution across habitat types and their overall abundance (Hairston *et al*. 1960, Carbone and Gittleman 2002).

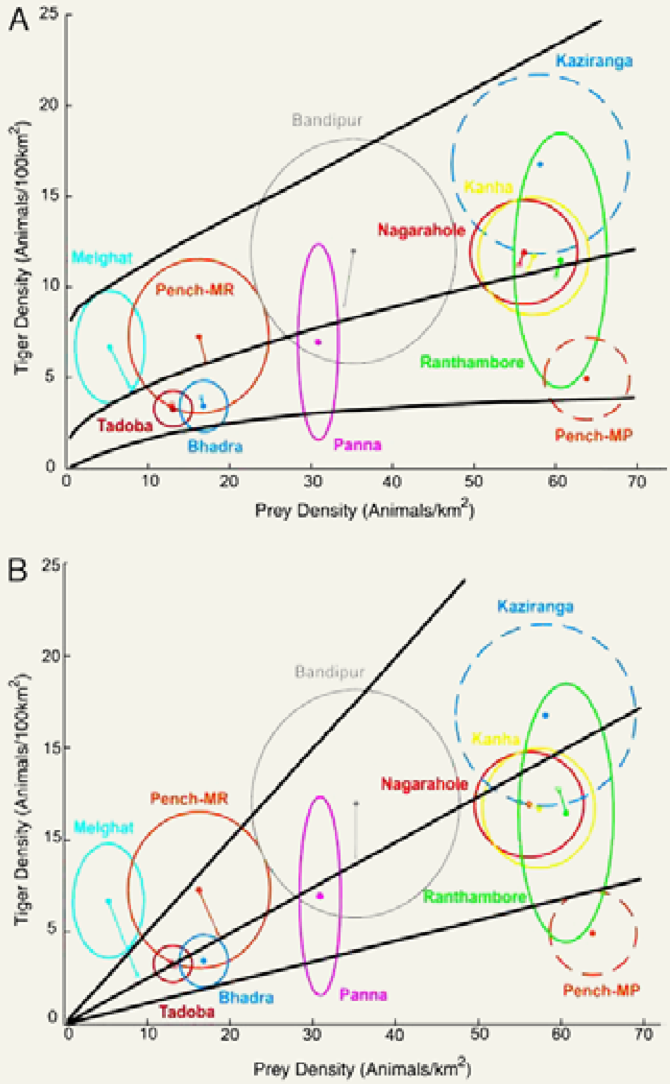


Figure 4.1
Relationship between prey and tiger densities based on data from 11 tiger reserves in India (image sourced from Karanth *et al*. 2004).

The density and distribution patterns of large predators, like tigers, are primarily governed by the availability of ungulate prey (Harihar *et al* 2012, Karanth *et al* 2011, Karanth & Nichols, 1998). Karanth and Nichols (2004) derived a model describing tiger densities as a function of ungulate-prey densities (Figure 1). They tested their model using data collected from 11 tiger reserves that represented a diversity of ecosystem types and found that the model was broadly supported suggesting a general, positive functional relationship between tiger and prey biomass.

Species	Habitat preference	Status (IUCN)
Chital (Axis Axis)	Forest, grassland, shrubland	Least Concern
Hog Deer (Hyelaphus porcinus)	Savanna and alluvial grasslands	Endangered
Swamp deer (Rucervus duvaucelli duvaucelli)	Grasslands and wetlands	Vulnerable
Nilgai (Boselaphus tragocamelus)	Forest, shrubland, farmland	Least Concern
Wild boar (Sus scrofa)	Forest, shrubland, farmland	Least Concern
Sambar (Rusa unicolor)	Forest, savanna	Vulnerable
Barking deer (Muntiacus muntjak)	Forest	Least Concern
Blackbuck (Antelope cervicapra)	Grassland , scrubland	Near Threatened
Four horned antelope (Tetracerus quadricornis)	Grassland, scrubland	Vulnerable
One horned Rhinoceros (Rhinoceros unicornis)	Forest, grassland, wetland	Vulnerable

Table 4.1
Ungulate species found in the Central Terai Landscape and their current IUCN status

The important role of maintaining abundant prey populations to sustain viable tiger populations is well recognized and unsurprising. Consequently, securing and managing ungulate prey populations has been repeatedly identified as an important measure to promote tiger populations at key tiger conservation areas (e.g., Sanderson *et al.*, 2010, Chapron *et al.*, 2008, Walston *et al.*, 2010). Examples of dramatic recoveries of tiger populations in Rajaji and Bardia National Parks in the Indian and Nepal Terai, respectively, lend support to these recommendations. Tiger numbers have steadily increased in the Chilla Range of Rajaji National Park since the relocation of the buffalo-herding Gujjar community out of the Park in 2002 (Harihar *et al.*, 2009, Harihar *et al.*, 2011. The increase in tiger densities has been attributed to two factors: first, improvements in chital recruitment rates in Rajaji resulting from a release in competitive pressures from domestic ungulates; second, the landscape connectivity between Rajaji with Corbett National Parks providing a source population for immigration of tigers into Rajaji. Similarly, in Bardia National Park, Wegge *et al.*, (2009) demonstrated an increase in the resident tiger population in tandem with an increase in chital densities following ten years of protection and improved law enforcement.

The density and diversity of prey species available at a site also determines whether smaller sympatric predators such as leopards and wild dogs can co-occur with tigers (Karanth and Sunquist 1995, Andheria *et al.*, 2007, Odden *et al.*, 2010). Previous studies suggest that areas that support high densities of large and medium sized prey can support sympatric populations of tigers and leopards (Karanth and Sunquist, 1995). Whereas, in the absence of large bodied prey, leopards tend to be outcompeted by tigers and relegated to lower quality habitats (Harihar *et al.*, 2011). Besides their direct role in structuring carnivore communities, as primary consumers ungulates significantly affect plant community composition and contribute to nutrient cycling, thus affecting ecosystem functioning (Sankaran *et al* 2013, Hobbs 1996, Moe and Wegge 2008).

Despite the important role of ungulates in ecosystem processes and as primary prey for large carnivores, few studies of ungulate ecology and behavior have been conducted in South and South-East Asia. Habitat loss, poaching and other factors have affected populations of several ungulate species which are now imperiled all over India (Karanth *et al.*, 2010). The Terai landscape, for example, historically supported abundant and widely distributed populations of at least 10 ungulate species (Table4.1). Some species, such as the one horned rhino and the four horned antelope, have become locally extinct from most sites in their historic range. Habitat specialist species such as hog deer and the swamp deer now occur only in small remnant fragmented populations (Dinerstein 2008). Species such as chital, nilgai and wild boar, though ubiquitously distributed, now occur in densities much lower than reported historic levels.

4.3 ESTIMATING UNGULATE PREY DENSITIES

A crucial first step towards devising conservation strategies for any species is obtaining reliable estimates of their abundance and geographic distribution. Estimating abundance is not as simple as counting observed animals because many species are cryptic, rare, or difficult to observe. The non-detection of animals present within a sampling unit is usually the largest source of bias in reliably estimating density. Most density estimation techniques are therefore focused on accounting for, and correcting this source of bias called 'detection probability' or 'p'. The parameter p can be defined as the fraction of the sampled population that was detected during sampling such that:

$C = N*p$,

where,

C = Count of animals obtained during sampling

N = True number of animals actually present within the sampling unit

p = probability of detecting an animal present within the sampling unit.

Thus, if a sample unit has a true abundance of 100 individuals of a species, but a detection probability of 50%, only 50 of these individuals would be detected , thereby biasing low our estimates of density in the area. Non-detection can result from a variety of factor such as cryptic behaviour, dense vegetation, observer error etc. An additional factor that affects whether an animal is detected or not is the distance of the animal from the observer. This simply means that animals that are present close to the observer are more likely to be detected than animals present at a further distance. This idea is central to estimating detection probability using a method called Distance sampling (Buckland *et al.*, 1993, 2005) which accounts for the decline in detection probability as an animal is located further from the observer. Distance sampling and the analysis of distance data, are among the most commonly employed methods to estimate the densities of wildlife populations. The technique involves generating data on perpendicular sighting distances by walking multiple transect lines, and recording the distance from the observer on the transect line to the animals detected Fig 4.2 is a diagrammatic representation of the distance sampling process.

When animals are detected while walking a line transect, observers record the sighting distance to the animal and also the angle of detection 'θ' using a range finder and a compass, respectively. From the sighting angle and distance it is straightforward to compute the perpendicular distance of the animal from the transect line. Perpendicular distance values generated over many such animal observations, across multiple transect lines, are then fitted to functions that model how detection probability declines with distance from the transect. The function is estimated using computer programs such as Distance 6.0 (Thomas *et al.* 2009) in order to estimate the detection probability, and subsequently to estimate density using the formula

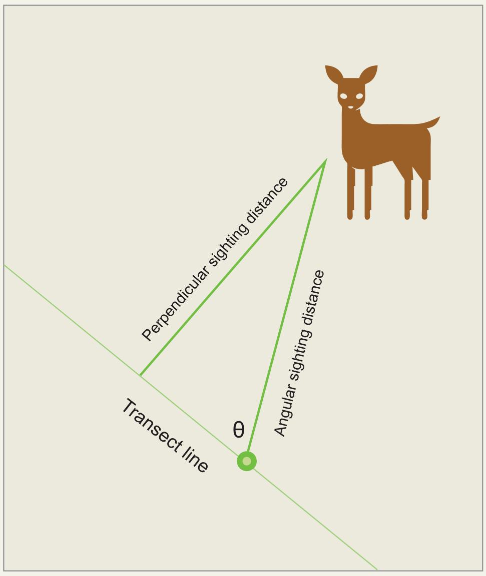


Figure4. 2
Perpendicular distances are calculated using the angular sighting distance and detection angle θ using the formula ' Perpendicular Distance= Sin θ * Angular sighting distance

$$\text{Density} = \frac{\text{Number of animals detected}}{\text{Detection probability } (p) \text{ *Area sampled (A)}}$$

4.4 SAMPLING DESIGN AND DATA COLLECTION

While distance sampling is a powerful tool, reliable inferences from the technique are dependent on several critical assumptions including:

a) Transects are placed randomly in the area of interest; b) Animals occurring on the transect line are not missed; c) Animals are detected at their original location; d) Distance to sighted animals are measured accurately.

The sampling design and protocols for the estimation of ungulate density in DNP strictly complied with these assumptions. As a first step, a grid (~3.5 x 3.5 km) was overlaid on a map of the study area and we quantified the ratio of forest:grassland habitat within each grid cell from a classified vegetation map. Then grid cells for sampling were systematically selected, while ensuring that a sufficient number of cells were picked to include both forest-dominated and grassland-dominated areas. In the final step of designing these surveys, a random start point was picked for a transect within each of the selected cells. Randomly placed line transects, were sampled multiple times in 2011-12 and 2012-13 by foot or from elephant-back in tall grassland habitats. Each square transect was 4 kms long (3.2 kms in Dudhwa), and the average length of a straight line transect was 2 kms in Katerniaghat WLS.

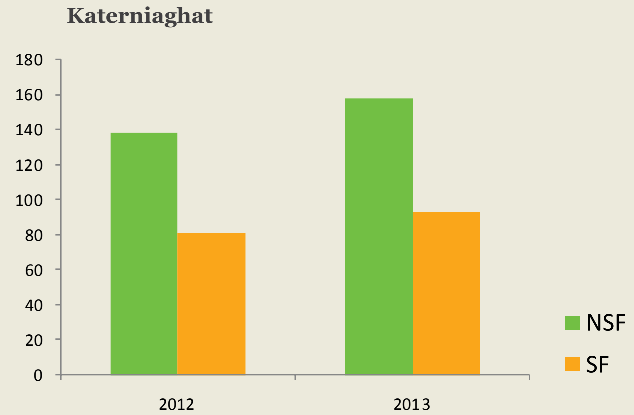
Square transects were employed in Duhwa and Kishanpur because they offer many logistical advantages especially when using elephants. Data from square transects are dealt exactly as data from straight line transects. Also, transects were placed in a manner so as to ensure adequate spatial coverage (Fig 4.3). In Dudhwa and Katerniaghat, sampling efforts were increased in the second year so as to increase spatial coverage. During the second year in Katerniaghat, transect sampling was extended into Kakraha Ranges, while in Dudhwa, additional transects were added at multiple locations in the park. In 2012, sampling of the tall grasslands in Dudhwa and Kishanpur was carried out using elephants due to the impenetrable nature of the grasslands before they are reduced by intentional and controlled burning. In 2013, however, a majority of the transect sampling in Dudhwa and Kishanpur was carried out after the grasslands were burned. Consequently elephant-back transects were carried out only within the Rhino enclosure in Kakraha and in the grassland patches of Sathiana. Between 2011 and 2013 over 1400 kms of transects were sampled to estimate ungulate densities within DTR (Figure 4.3).

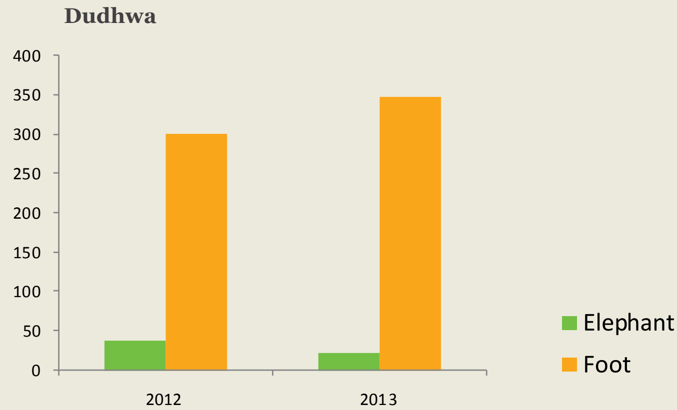
All transects were walked in the early morning and late evening hours by two or three trained observers. To generate adequate detections, each transect was sampled 2-3 times. When animals were detected, details such as species, group size, age and sex were noted. All distance and angle measurements to the detected animals were made using range finders and compasses in order to reduce measurement error in recording detection distances.

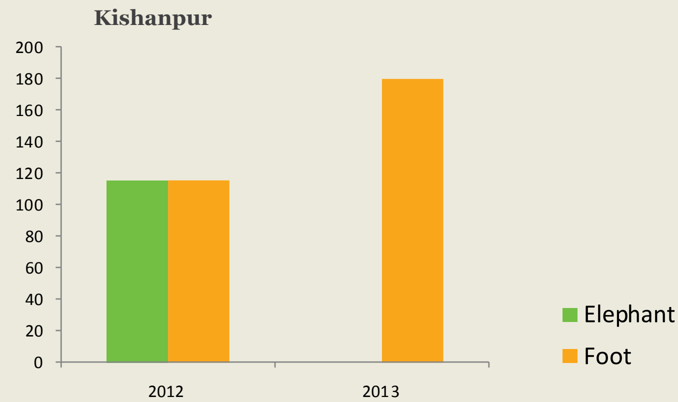
4.5 ANALYSIS

4.5.1 Descriptive Statistics

The transect data were initially summarized to determine the total number of detections for each species at each site. For species that can occur in groups, total number of detections for each species is the total number of animal-clusters of a particular species, encountered during transect sampling at a site.







	2011-12 Effort kms. (#Transects)	2012-13 Effort kms. (#Transects)
Katerniaghat	220 (31)	251 (33)
Dudhwa	338 (39)	370 (51)
Kishanpur	232 (17)	180 (16)
Total	**790**	**701**

Figure4. 3
Transect effort in DTR during the years 2012 and 2013. For Dudhwa and Kishanpur the green columns indicated transect effort when elephants were employed for sampling. For Katerniaghat the green and orange columns indicate the two habitat strata NSF- Non seed farm or forest strata and SF- Seed farm strata comprising of Sujauli and Bagluia seedfarms which are dominated by grasslands, wetlands and fallow fields.

4.5.2 Encounter Rates and Interpolation

Encounter rate for a species is the total number of animals detected per unit transect effort.

$$\text{Encounter rate} = \frac{\text{Total number of clusters of a particular species detected}}{\text{Total sampling effort}}$$

Since encounter rate calculations do not correct for detection probabilities, they are simple indices of relative abundance of a species. These indices provide estimates of population trend only if the assumption that the proportion of animals detected is constant across time and species holds true. Since this assumption is seldom met, encounter rate indices are not reliable estimates of species abundance and they are of limited utility in monitoring population trends. We calculated group encounter rates for each species, i.e. the total number of groups of each species detected per unit transect effort per site. These estimates can be interpreted as the relative probability of encountering any species during transect sampling at a site.

To predict the abundance of tiger prey across the entire landscape based on the line transect data, the Inverse Distance Weighted (IDW) spatial interpolation algorithm was used. This method estimates the density value for each unmeasured cell in a raster map by averaging the density estimates from transects located in the neighborhood of the focal cell (Bivand *et al.* 2008). With the Inverse Weighted Distance algorithm data from transects closer to the focal cell will have more weight (influence) on the averaging process than from transects that are more distant. The weights are proportional to the inverse of the distance between a transect and the focal cell raised to a power value p. Weights assigned to data sources

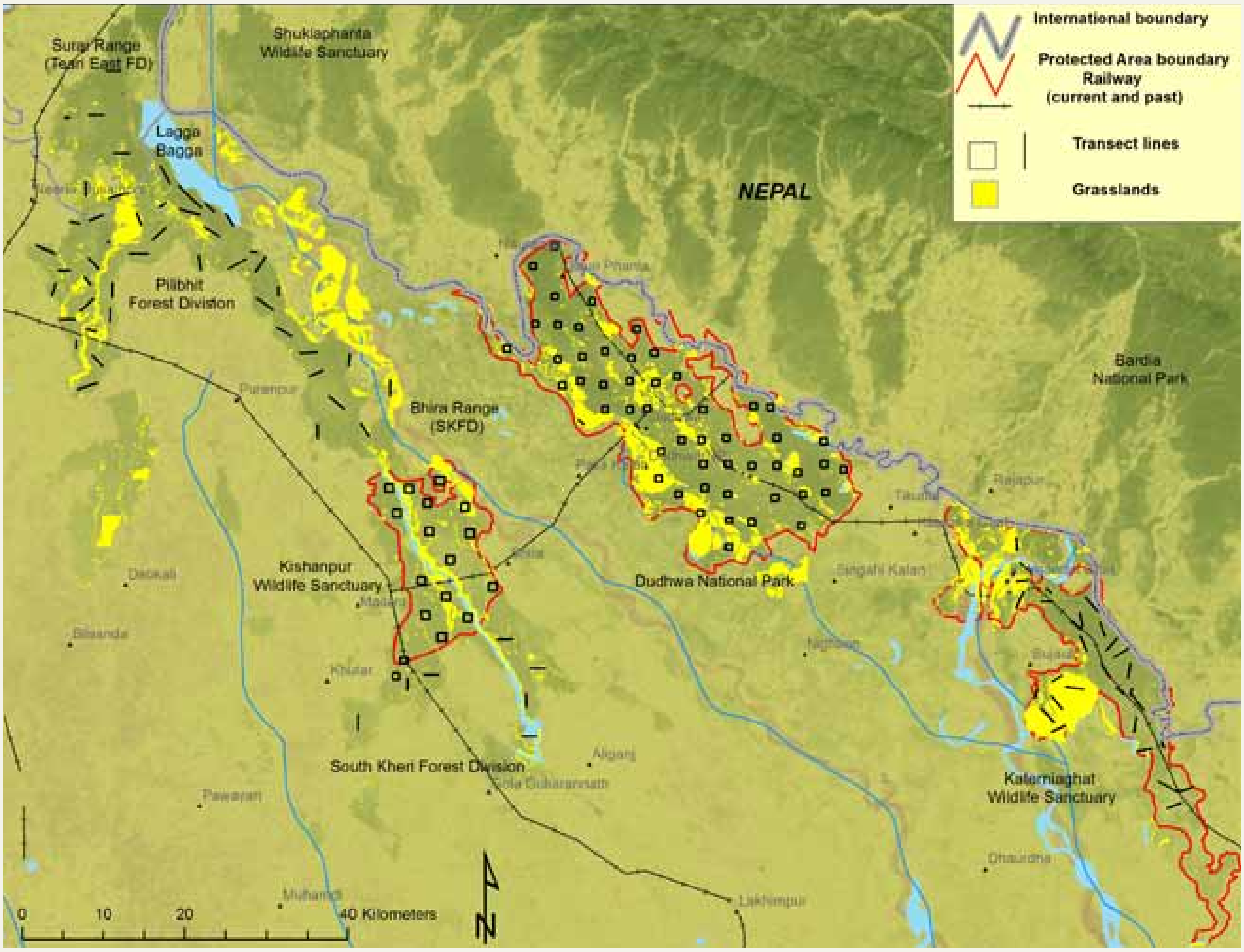


Figure4.4
Distribution of transects (black lines and squares) in the Central Terai Landscape. Yellow polygons represent grasslands. Transects in Pilibhit Forest Division were sampled by Bista (2011).

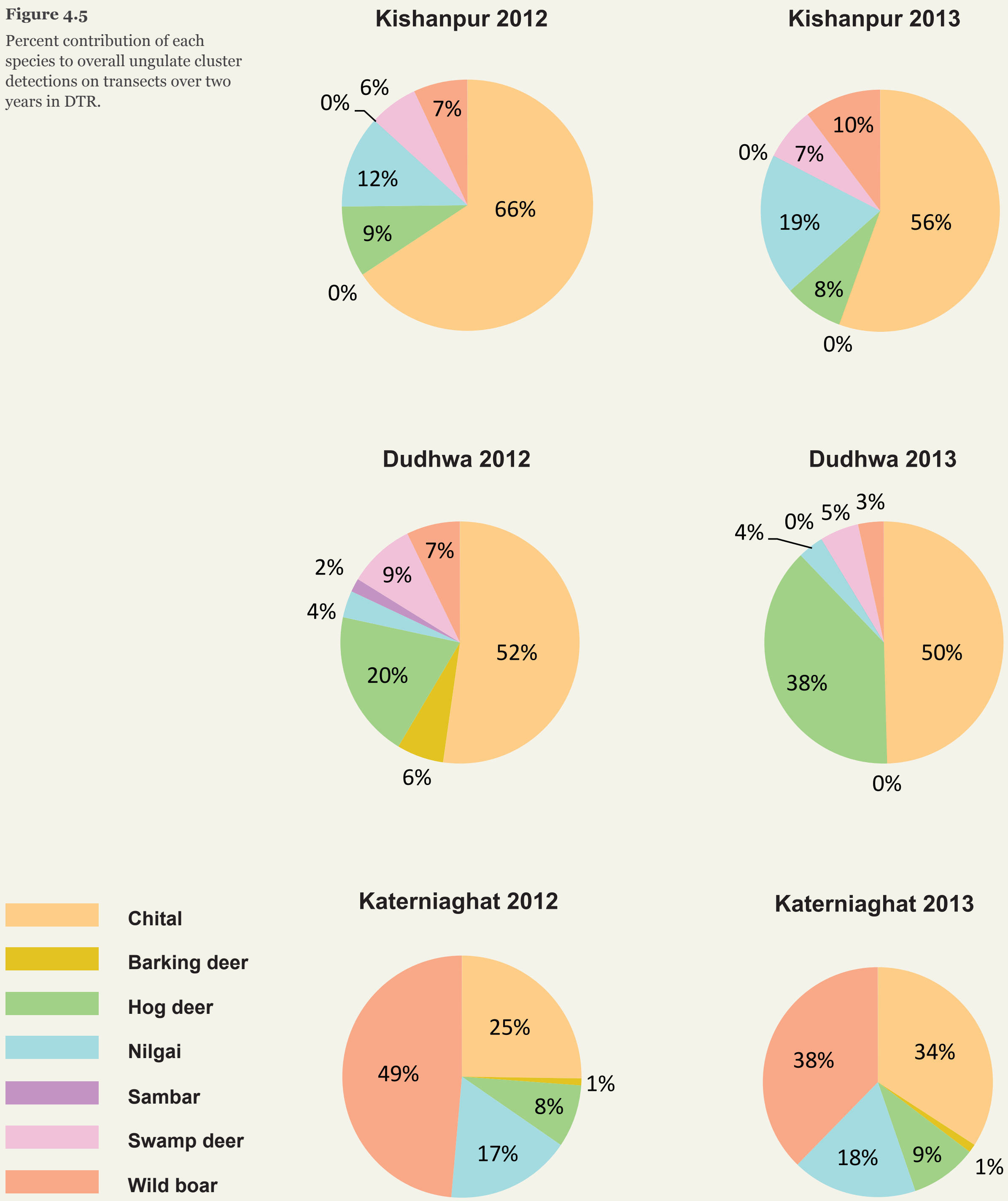
(transects) decline quickly with distance if p is a large number. In this case, estimates in the focal cell reflect measured values primarily from the immediate neighborhood.

An encounter-rate value (i.e. number of ungulate detections per transect /sampling-effort per transect, in kilometers) was assigned to the mid-point of each transect line (n=128) sampled in 2012 or 2013. Fifty-two percent of these transect lines were sampled one year, and 48% were sampled in two years. Where applicable, encounter rates were averaged across the two years. For Pilibhit FD, encounter rates from the study of Bista (2011) were used. The data were analyzed after determining the optimal power and number of neighbors that minimizes the Mean Squared Prediction Error (MSPE). The MSPE can be thought of as a statistic that minimizes the prediction error. The MSPE was plotted against various values o power (p = 1, 2 and 3), to determine which power value was associated with the lowest MSPE. Using these values, the IDW interpolation tool was implemented in Arc GIS (Version 10.1, ESRI 2010).

4.5.3 Density Estimation

Distance to detection data were analyzed in program Distance 6.0 (Thomas *et al.* 2009) to estimate detection probability and thus density separately for each site in each year. Prior to analysis, the distance data were checked for evidences of heaping and evasive movements of animals as prescribed by Buckland *et al.*, (2001). Heaping refers to an increase in

Figure 4.5
Percent contribution of each species to overall ungulate cluster detections on transects over two years in DTR.



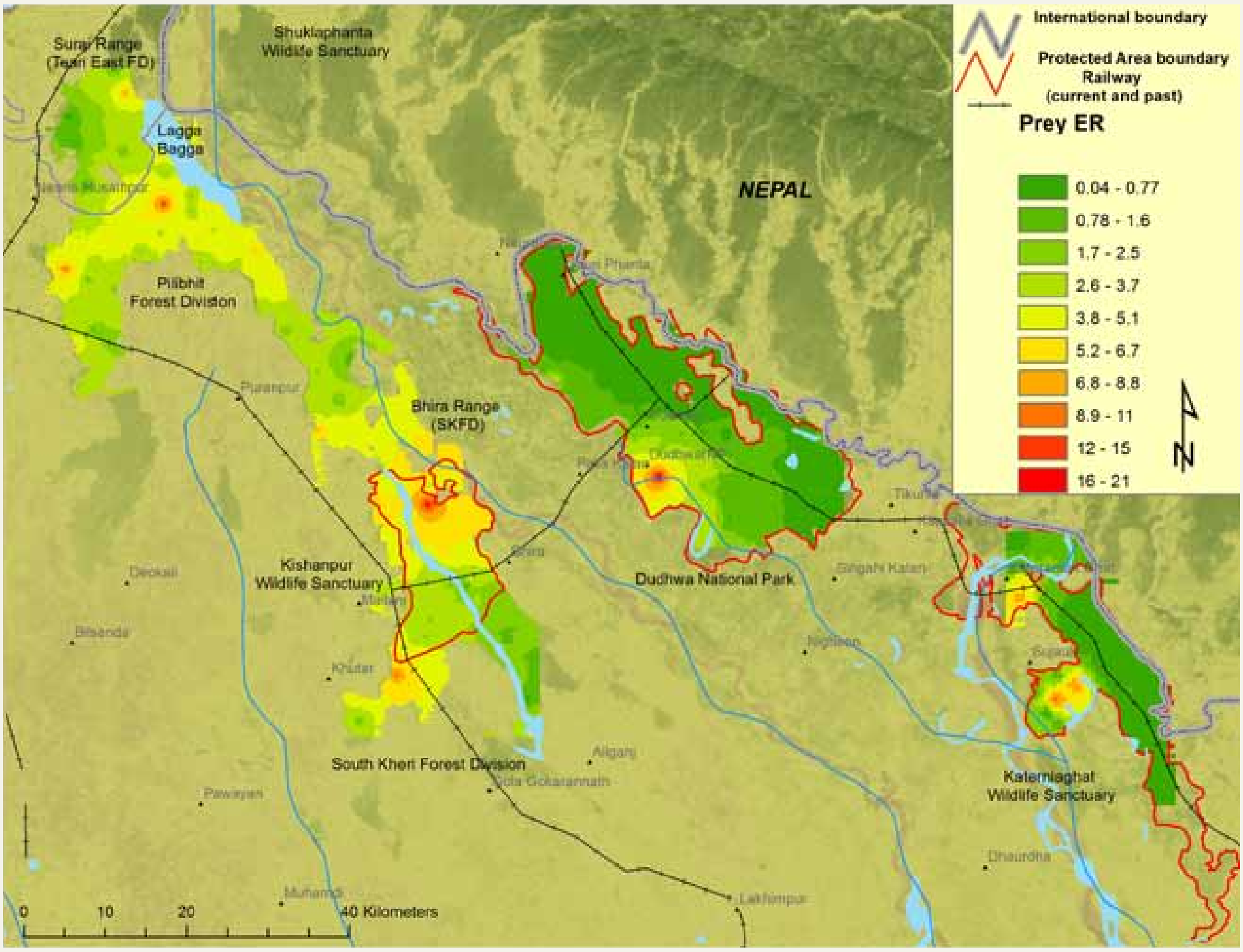


Figure 4.6
Interpolated map showing encounter rates in the CTL. (Data for Pilibhit FD is from Bista 2011).

the number of detections within certain distance-classes, and is a result of rounding or guessing distances to animals. Evasive movements prior to detection usually result in few detections near the line. Both of these problems can lead to biased estimates of the detection probability. A range of pre-defined detection functions and adjustments in program Distance were used to model these data. Right truncation was carried out to remove outliers (detections at very long distances from the line) that are generally uninformative but can significantly affect model fit. Visual examination and Chi square goodness-of-fit tests were used to assess the fit of the model to the data. Following this, the best model was selected using Akaike's Information Criteria (AIC) (Burnham and Anderson 2004). Across all years and sites, we analyzed data to obtain overall ungulate density estimates. For Katerniaghat, for both years, we used post-stratification to obtain stratum-specific ungulate density estimates according to the following strata: a) Seedfarm- Bagluia and Girijapuri seedfarm (short-grasslands); and b) closed canopy forests.

4.6 RESULTS

4.6.1 Descriptive Statistics

Despite substantial effort in line transect sampling across years, the total number of animal detected were low for all sites we sampled, relative to some other PA's in the Terai. The total number of animal detections within sites and across years were similar even though sampling effort varied between the two years. Table. 4.2 provides a summary of total number of animal detections in DTR in 2012 and 2 013.

Table 4.2
Total number of animal clusters detected on transects

	Kishanpur		Dudhwa		Katerniaghat	
Year	2012	2013	2012	2013	2012	2013
Total # detections	143	126	111	115	107	85

Across all sites we detected a total of eight ungulate species: chital (*Axis axis*), sambar (*Rucervus unicolor*), hog deer (*Axis porcinus*), swamp deer (*Rucervus duvaucelli duvaucelli*), barking deer (*Muntiacus muntjak*), nilgai (*Boselaphus tragocamelus*), wild boar (*Sus scrofa*) and the Indian one horned rhino (*Rhinoceros unicornis*). Rhinos were detected only on transects sampled within the rhino reintroduction area in Kakraha, (Dudhwa N. P.). In Dudhwa and Kishanpur, chital followed by hog deer were the most common species detected on transects. In Katerniaghat, detections were dominated by wild boar and chital. Swamp deer were detected only in Dudhwa and Kishanpur. Forest- obligate species such as barking deer and swamp deer were recorded only in Dudhwa in 2012. Fig. 4 summarizes species detections by location and year. Most of the species in the Terai occur in groups. Among the seven species recorded on transects, only sambar and barking deer are solitary. When species-groups were encountered we counted the total number of individuals within each group.

4.6.2 Encounter rates and Interpolation

We estimated species-specific encounter rates for all sites (Table). The % CV is a standardized measure of variation in the estimate. In this context low CV's would result when there are transect specific differences in species encounters. The low %CV values (e.g. Table 4.3, Chital in Kishanpur and Dudhwa) may therefore be interpreted to mean that the species was encountered in similar numbers across all transects . The swamp deer encounter rates may be interpreted to mean that relatively few groups of the species were detected on select transects in Dudhwa and Kishanpur.

The interpolated map of prey encounter rates (Fig4.6) reveals that the spatial distribution and abundance of tiger prey varies extensively across the Terai Arc Landscape. In general, a greater abundance of ungulate prey were encountered in Kishanpur WLS and Pilibhit Forest Division than in Dudhwa National Park and Katerniaghat WLS. 'Hot-spots' of high ungulate abundance are distributed patchily across the landscape, and are generally associated with grassland and primary-succession riparian habitats. Notable 'hot-spots' for high prey-encounter-rates were Kakraha (the rhino enclosure area) in DNP, Sharda-beat and the Jhadi-Tal area of Kishanpur WLS, the Chaugabe and Malsi grasslands in Mahof Range of PFD, and the Girijapuri and Bagluia seed farm areas, and Sadar beat of Katerniaghat

Site	Year	Chital	Barking deer	Hog Deer	Nilgai	Sambar	Swamp Deer	Wild Boar
Kishanpur	2012	0.41 (17.08)	0	0.05(40.33)	0.08(39.32)	0	0.01(96.33)	0.05(31.27)
	2013	0.39(17.12)	0	0.05(81.89)	0.13(26.62)	0	0.05(62.94)	0.07(33.83)
Dudhwa	2012	0.17(17.2)	0.02(40.43)	0.064(36.28)	0.011(59.93)	0.005(99.79)	0.029(61.8)	0.02(37.99)
	2013	0.15(16.76)	0	0.11(85.84)	0.01(47.41)	0	0.016(84.05)	0.01(47.87)
Katerniaghat	2012	0.122(33.55)	0.004(99)	0.04(47.78)	0.08(45.53)	0	0	0.23(51.39)
	2013	0.115(46)	0.003(100)	0.03(61.7)	0.059(45.81)	0	0	0.12(48.99)

Table 4.3
Species encounter rates in DTR. Percent CV (in parenthesis) is the % coefficient of variation in encounter rates

WLS. Sathiyana Range, parts of South Sonaripur, and Belrayien Ranges along the Suheli river were also found to support relatively high ungulate densities. High encounter rates in a number of these hot-spots were contributed by gregarious species that congregate in grasslands - most notably swamp deer and hog deer. Closed-canopy sal forests in Belrayien, Dudhwa and Bankati Ranges of DNP and Murtiah and Dharmapur ranges of Katerniaghat WLS were seen to be associated with low prey encounter rates (<2 animals/km). Although several hundred kilometers of transects were sampled in these areas, relatively few animals were encountered. Furthermore, though some areas of Dudhwa Range, for example Chandpara, had several large grasslands within them, prey encounter rates remain low indicating that factors other than the presence of grasslands are likely to have a bearing on ungulate distributions.

4.6.3 Density Estimates and Detection Probability

Estimated densities for all ungulate prey pooled across species for Kishanpur, Dudhwa and Katerniaghat are reported in Table.4.4.

Point estimates of detection probabilities across sites and years are presented in Fig.4.7. Except for Katerniaghat, detection probability was similar across sites and years. Overall detection probability in Katerniaghat was lower than Dudhwa and Kishanpur in 2012. In 2013 however, Katerniaghat was sampled in winter and there was a substantial improvement in detection probabilities in the Seed Farm strata.

4.7 DISCUSSION

4.7.1 Density Estimates

Dudhwa tiger reserve lies entirely in the rich alluvial floodplains of the Terai Arc Landscape. Historically, the mosaic of riparian forests, alluvial grasslands, and upland forests together supported a rich assemblage of ungulate species. Today however, following decades of habitat alterations and illegal poaching, ungulates occur in DTR only at very low densities. Relative to other prominent tiger habitats in India, densities of ungulates in DTR ranges are intermediate in Kishanpur (29.8/sq km) and the Seed Farm area of Katernaighat (35.4/sq km), but low in Dudhwa (13.6/sq km) and in the forested areas of Katerniaghat (4.4/sq km). These estimates are substantially lower than estimates from elsewhere in the Terai (Table 4.5), including Rajaji NP, Chitwan NP and Royal Bardia NP.

Despite differences in sampling season and overall effort, density estimates were similar for sites across years. However, these estimates represent combined ungulate density estimates (comprising of detection of at least 5 ungulate species) and as indicated by the CV's in Table 4.4 there is considerable uncertainty associated with them. We believe that this is largely a

Site	Year	Model	Ds(SE)	D(SE)	%CV($\hat{D}$)
Kishanpur	2012	Half Normal cosine	9.43(1.57)	26.61(4.80)	18.05
Kishanpur	2013	Uniform cosine	6.18(0.96)	29.81(5.69)	19.1
Dudhwa	2012	Half Normal cosine	4.26(0.77)	10.53(2.13)	20.22
Dudhwa	2013	Half Normal cosine	4.12(1.54)	13.64(5.28)	38.78
Katerniaghat (NSF)	2012	Hazard rate- Hermite polynomial	0.9(4.69)	4.3(2.40)	56
Katerniaghat (SF)	2012	Hazard rate-hermite polynomial	7.59(2.1)	35.40(10.5)	29.84
Katerniaghat (NSF)	2013	Hazard rate	1.83(0.57)	4.41(1.55)	35.19
Katerniaghat (SF)	2013	Half normal	4.05(1.23)	22.40(8.10)	36.17

Table 4.4
2012 & 2013 ungulate density estimates for DTR

'Ds' represents the density of animal clusters, and 'D' represents overall ungulate density.

result of sparse-data, and of some limitations in our sampling design.

For all the models, variation in encounter rates and the detection process was the largest contributor to the overall CV. This implies that the error in estimates is largely due to variability in encounter rates and unexplained variation in detection probabilities as a consequence of pooling data across species. Variability in encounter rates was highest for all species except Chital (Table 4.3). The variability is explained in part by the habitat preferences of the different ungulate species. Hog deer and Swamp deer are primarily distributed in tall grassland habitats, whereas species such as nilgai are edge species. Because of varying observability in different habitats, there is considerable variation in encounter and detection rates across species. In the future, allocating transects according to habitat strata (grasslands, riparian forests and sal), and /or incorporating habitat covariates to model detection probabilities (using the MCDS engine in Distance), may provide more precise density estimates. We also note that transect sampling should also

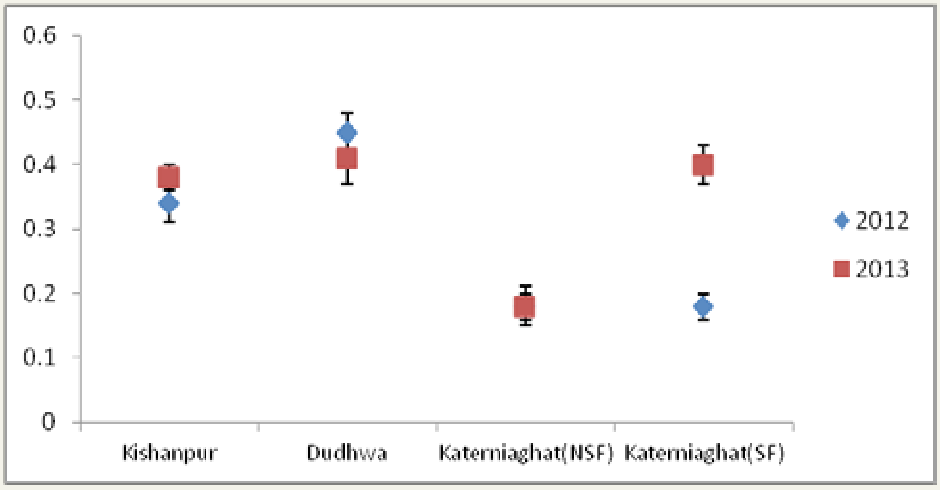
Table 4. 5
Combined ungulate density estimates from other ecologically similar sites

SITE	DENSITY ESTIMATE in sq km (SE)	SOURCE
Bardia National Park (Karnali River flood-plain)	200	(Wegge *et al.* 2009)
Chilla Range, Rajaji National Park	85	(Harihar *et al.* 2011)
Pilibhit Forest Division	40.5 (0.23)	(Bista 2011)
Kaziranga National Park	58.1(6.51)	(Karanth *et al.* 2004)

preferably be carried out in the pre-burning period when animals are better dispersed across the site and when large congregations are uncommon.

Given the overall low prey densities, we did not have sufficient detections to estimate species specific densities by conventional distance analysis. Pooling detections across species to estimate a detection probability assumes homogeneity in detection probabilities, an assumption likely to be false. In order to estimate species-specific densities transect effort will have to be significantly increased. Based on the species encounter rates (Table4.3) however, it is obvious that a substantial proportion of the

Figure 4. 7
Overall ungulate detection probabilities in DTR for 2012 and 2013



ungulate biomass in DTR is comprised of chital. This agrees with findings from other sites in the Terai where chital were the most abundant ungulate species (Wegge *et al*. 2009, Harihar *et al*. 2011). Simulations suggest that in order to generate sufficient detections for the most abundant species (chital), sampling effort will have to be approximately doubled at all sites. For a site like Dudhwa, this means that at least 600 kms of transect would be required to generate sufficient data to precisely estimate chital densities. Wegge and Storaas (2009) recommend that even for abundant species such as chital, at least 200 detections are required to generate point estimates with acceptable confidence limits. Consequently, for other species which are less abundant the necessary effort is several orders of magnitude higher than what is currently employed. Stratification can however, significantly reduce the overall effort required for habitat specialist species such as hog deer. For swamp deer, because of their tendency to form large aggregations, distance sampling may not be an appropriate strategy. For these species modified sampling and analytical methods (such as double sampling approaches) may yield better estimates.

Although considerable effort was made, some tall-grass habitats occupied by hog deer and swamp deer could not be sampled effectively because the availibility of elephants was limited to certain portions of the sampled habitats. Tall grassland habitats in Dudhwa and Kishanpur comprise approximately 10 - 15 of the overall suitable tiger habitat. Prior to burning, the grassland vegetation is so dense that they cannot be sampled by foot. Even though elephants were used to sample tall grassland habitats, ungulate detections were still insufficient to allow precise estimation of ungulate densities in grasslands. Therefore data from foot and elephant transects were combined to estimate 'overall' ungulate densities. This may have further contributed to the high variance in estimates since detection probabilities for species from elephant back and foot transects are likely to be dissimilar.

Contrary to our experiences in the Terai landscape, Wegge and Storaas (2004) recommend the use of elephants for estimating ungulate densities in subtropical forests. They however concede that this may not be a suitable method for estimating densities of rare species such as wild boar, barking deer and swamp deer. Wegge and Storaas recommend that for low prey density sites, monitoring should focus on preferred tiger prey species primarily in habitats where they are most abundant. Prey selection studies from the Terai suggest that chital and hog deer are the common component in tiger diets, but wild boar may be the most 'preferred' tiger prey species (Wegge *et al*. 2009, Hayward *et al*. 2012). We recommend that future transect efforts should be directed primarily towards estimating chital and hog deer densities. Swamp deer, in particular, are probably best monitored by conducting annual counts at congregation sites such as in Jhadi taal in Kishanpur and Kakraha in Dudhwa. Wild boar encounter rates were low in both Dudhwa and Kishanpur, primarily due to their nocturnal

A four horned antelope from the Terai forests

Table 4. 6
Effort required in Dudhwa National Park to estimate species-level densities at 20% CV

	Chital	Hog deer	Nilgai	Wild boar
Effort (km.)	650	847	6489	7737

activity patterns and preference for wooded habitats (Heibesen *et al* 2008). Methods such as mark-resight or mark-recapture may be better to estimate wild boar densities, provided that some individuals in these populations can be marked.

4.7.2 Ungulate Habitat Associations: grasslands and sal forests

Based on the interpolated encounter rate surface (Fig.4.5) it is evident that ungulate encounters were highest in the riverine forest and savanna grassland habitats across all sites. In contrast, sal forests had very low ungulate densities. This ungulate density distribution pattern holds true for most sites in the Terai. For example, densities of chital, hog deer, wild boar, swamp deer and nilgai in Bardia National Park, Nepal, (which lies a few kilometers North of Katerniaghat WLS and is connected to it by the Khata corridor), were 3 to 15 times higher in tall grass flood plain, savannah grasslands, and successional forests than they were in climax (sal-dominated) forests (Wegge *et al.* 2009, see also Dinerstein 1980). Although sal forests appear not to be 'preferred' chital habitats for most seasons of the year, a radio-telemetry study by Moe and Wegge 1994 revealed high use of sal forests by collared animals during the monsoons and early winter. This is explained in terms of increased forage availability in sal forests in these seasons on account of new grass growth in the forest understorey during the rainy season. Shrestha (2004) and Bhattarai and Kindlmann (2012) related relative abundance and density of ungulates to habitat attributes, and concluded that short-grasslands, mixed forests and riparian forests were preferred habitats for most large-bodied ungulate prey species.

In the Terai landscape, riparian grasslands are particularly important for hog deer. Odden *et al.*, (2005) studied the effects of annual fluctuations of food and of cover on hog deer habitat use in the Karnali River floodplains in Bardia NP. From a radio telemetry and block-count study, they concluded that hog deer were tall grass specialists (inhabiting grasslands composed primarily of *Saccharum spontaneum, Saccharum bengalensis*), and that they avoided other habitat types including later successional stages of flood plain riparian forests. Even though available tall grass-habitats were limited in the monsoons because of flooding, hog deer continued to use these patches almost exclusively. Further, no changes in habitat use or daily movements were recorded when tall-grass habitats were burned or cut by local villagers. Odden *et al.* (2005) note an "absence of trade-offs between habitat preference for food and for predator avoidance". This reflects the earlier findings of Dhungel and O'Gara (1991) who reported that 99% of hog deer locations were from within Saccharum dominated grasslands. These authors also reported hog deer to have small home ranges (mean of 80 and 60 hectares for stags and hinds respectively).

The availability of high quality forage plants may be the key factor governing ungulate habitat associations. Dinerstein's studies (1980) provided evidence of a strong relationship between habitat diversity and wild ungulate biomass. In particular he found, 'savannah' habitats with grass species such as *Imperata cylindrica, Erianthus ravennae* and *Vetiveria zizynoides*, silk cotton (*Bombax ceiba*) trees, and associated tall-grass flood plain habitats dominated by saccharum spontaneum to be productive habitats for a number of wild ungulates. In contrast, the quantity and quality of forage plant species for grazing ungulates are much lower in sal forests than in other (grassland, riparian and successional) habitats. Dinerstein (1980) concludes that these factors, coupled with the lack of plant species diversity in the sal forest understorey and the relatively low production of green grass in this habitat and the lack of available surface water (during the non-monsoon months) “account for the low carrying capacity of the sal forest for large terrestrial herbivores”.

4.7.3 The Katerniaghat Seed Farm

The seed farm area of Katerniaghat with its high ungulate densities and anthropogenic disturbances offers an interesting case study to understand the relevance of savanna habitats for sustaining populations of prey and tigers. The Katerniaghat seed farm in its current state is a 32 sq km area of grasslands, fallow-lands and cane forests comprised of two adjacent areas, Girijapuri and Baughlia. The area was formerly managed as an agricultural seed production facility for over three decades by the State Farms Corporation of India. However, following prolonged litigation the area was legally handed over to the Uttar Pradesh Forest Department in 2012. During the period of our study, large portions of the seed farm were fallow with some remnant plantations of Jatropha, mango, lichee and other species. The area lies surrounded by human settlements and cattle camps (gaurhis) and experiences considerable human pressures. A very large population of cattle (~16,854) grazes within the seed farm everyday. Despite the presence of cattle, the area supports high densities of wild ungulates (35/sq km) and consequently tigers. Managing the seed farm so it can continue to support high densities of ungulates may be crucial to sustaining tiger populations in Katerniaghat. The areas attractiveness to wild ungulates can be attributed to the mosaic of tall and short grasslands and riparian forests. Unfortunately, the area faces imminent threats such as the spread of noxious weeds and over-grazing by cattle. It is important that management actions in the seed farm be directed towards creating safe habitats for wildlife and heterogenous woodland-grassland habitats.

4.7.4 Managing Grasslands for wild ungulates : recommendations from previous studies

Management of ungulate populations depends primarily on an understanding of ungulate habitat relationships and a thorough knowledge of how management practices impact habitat quality and productivity. In DTR, current habitat management measures include cool season burning to promote new grass growth. However, to maintain the productivity of grasslands over longer time spans, previous studies have shown that burning and other management prescriptions needed to be strategically planned (e.g., cutting followed by burning) and the time of year in which these actions take place may be critical to the observed outcome. An experimental study in the Nepal Terai (Moe and Wegge, 1997) investigated the effects of various grassland management options and concluded that:

a. a combination of cutting and burning may result in the greatest overall increase in nutritional quality of forage plant species;
b. concentrations of N, P and Na were considerably higher than on unmanaged (untreated) grasslands;
c. although burned plots regenerated four times as many sprouts as the cut plots, the burned plots had higher levels of silica which negatively affects forage plant palatability;
d. cut plots attracted chital when no burned plots were available;
e. few deer were found on the plots that were not cut nor burned.

Hog deer feed on regenerating grass after fires in late February. Kakraha, Dudhwa National Park.

Wild pigs are widely distributed, but are infrequently encountered on transects.

Peet *et al*., (1999) conducted an experimental study on the effects of burning and cutting on *Imperata cylindrica* grasslands in the Royal Bardia National Park. They concluded that grassland patches not subjected to burning or cutting (management) for periods up to two years would not be substantially altered in plant species composition. To manage grasslands for ungulates, Peet *et al*. suggest that cutting and burning be rotated so that *Imperata cylindrica* dominated grasslands are subjected to these treatments every 2-3 years. This management practice will help maintain cover for a number of disturbance sensitive species including endangered hispid hares. Pete *et al*. (1997) also note that the moderate levels of removal of grasses by local communities for thatch and other purposes appears not to have deleterious impacts on tall-grass systems, and that such removal may actually help maintain these grasslands (see also Lehmkuhl *et al*., 1988). Kumar *et al* (2002) carried out an experimental study of the effects of cutting, burning and harrowing on the composition of the Madriya grasslands in Sathiyana Range of DNP. They noted that DNP's grasslands were of two major types - upland grasslands composed of *Imperata cylindrica*, *Desmostachya bipinnata* and *Vetiveria zizanoides,* and lowland grasslands dominated by *Sclerostachya fusca, Saccharum narenga* and *Saccharum spontaineum*. Further, they noted that this grassland composition was maintained even after 'treatment' in their experiment, though there was some evidence of *Deshmostachya bipinnata* appearing in areas where it was previously unrecorded and where the grassland had been harrowed and burned. These authors report that *D. bipinnata* is a less valuable forage species for wild ungulates than *I. cylindrica*, which it replaced in plots that were repeatedly burned and harrowed. Multiple years of burning and harrowing also reduced above ground biomass for *S. fusca* and *S. narenga*. In general, their recommendations are that:

a. grasslands be managed actively by cutting burning (in the cool season) to maintain habitat heterogeniety;
b. cutting and burning early in the cool season help create grazing areas and palatable grass for ungulates in the summer;
c. harrowing and burning may lead to a reduction in above-ground biomass and the replacement of the palatable *I. cylindrica* by the relatively unpalatable *D. bipinnata* and that harrowing be avoided or carried out infrequently;
d. cutting and burning should spare some grass patches to create habitat for grassland birds and other fauna; and

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A reintroduced population of rhinos inhabits the Rhino enclosure in the Kakraha area. Rhinos from Shuklaphanta WLS in Nepal are occasionally encountered in Kishanpur and Pilibhit, whereas some rhinos from the Bardia population reside in the Trans-Girwa area of Katerniaghat WLS.

e. that staggered burning of grassland patches may help maintain a mosaic of grazing lawns that would be beneficial for grazing ungulates, particularly in the summer months (see also Lehmkuhl,1989). They also recorded increased plant species diversity and heterogeneity in treated plots than untreated plots, with the appearance of a number of shrub and herb species in the former.

4.7.5 Competition with Livestock

Studies in arid deciduous and tropical forests in India have documented marked increases in populations of wild ungulates following reductions in livestock grazing (Khan *et al.*, 1996, Madhusudan, 2004). Dinerstein (1979c) suggested that wild and domestic ungulates in Bardia National Park in the Terai may be competing for the same fodder species, particularly during the summer months. Dhungel and O'Hara (1991) pointed to the important role of mega herbivores in maintaining short grasslands, but were uncertain whether these species serve as facilitators or competitors when in large numbers. Henshaw (1994) reported that overgrazing by cattle and goats in the eastern portions of Shuklaphanta Wildlife Sanctuary degraded the habitat and grasslands, and that these parts of the park were less attractive to wild ungulates. The Chilla Range of Rajaji National Park which has seen significant increases in chital density following the removal of buffaloes from the Park (Harihar *et al.*, 2009) further corroborates these findings.

4.7.6 Other Threats to Habitat

The habitats of large mammals in forests of the CTL are also affected by the spread of noxious or unpalatable weeds (most notably *Tiliacora acuminata*, a climber that is widely pervasive in the understorey of closed-canopy forests in DNP). We had few observations of wild ungulates, including chital, in forests dominated by *T. acuminata*. We believe this plant species contributes little to the diets of ungulates and also lowers overall habitat suitablity. The plant grows in dense, tangled mats that may hinder animal movement. Kumar *et al.*, (2002) and Midha and Mathur (2008) propose that changes in river hydrology are a significant threat to grassland and swampland habitats. This occurs as a result of altered flow regimes and siltation patterns, and because changes in river course may erode away key wildlife habitats (e.g., areas around Jhadi tal, an important swamp deer congregation site in Kishanpur WLS). Kumar *et al.*, (2002) also note that several sizable

Timber harvest in SKFD

patches of forest land, particularly in riparian areas of North Kheri Forest Division along the Sharada river have been encroached by farmers for crop production.

4.7.7 Poaching

Across the tiger's range, poaching is often a significant contributor to the decline in the density of wild ungulate prey populations (Steinmetz *et al* 2010, Linkie *et al* 2003). The Dudhwa National Park management plan (De 2011) also recognizes ungulate poaching to be a major issue - with many arrests being made each year. Traps and snares were encountered in the forest and reported to forest officials on many occasions over the two sampling years by our survey teams. Poaching pressure is thought to be especially intense along the northern borders of the Park, in part stemming from the demand for wild meat in Nepal (Paudel *et al.*, 2012). Damania *et al.*, (2003) noted that the size of human populations near tiger habitats is the single biggest threat to prey populations. In areas of high human density, prey are vulnerable to poaching for direct consumption. In addition, prey are vulnerable when they stray into farmlands to raid crops. Sustained high levels of poaching can push populations of certain species such as sambar beyond their ability to recover from small population size (Steinmetz *et al* 2010). Furthermore, tiger populations in areas that suffer high prey depletion are especially vulnerable to even minor increases in poaching pressures (Damania *et al* 2003).

Bhabbar habitat in Suhelwa WLS. The Churia hill of Nepal form the back-drop.

AN ASSESMENT OF THE STATUS OF TIGER AND THEIR PREY IN SUHELWA WILDLIFE SANCTUARY

5.1 INTRODUCTION

The area presently recognized as Suhelwa WLS (~635 km^2) in Balrampur and Shravasti districts of Uttar Pradesh was famed as the hunting grounds of the erstwhile princely states of Balrampur and Tulsipur. Over the years this lone representative region of the Bhabar ecosystem in UP, has experienced considerable habitat degradation and a significant decline in its tiger populations.

In the context of the Terai Arc Landscape in India, Suhelwa together with the forest fragments of Shravasthi, constitutes Tiger Habitat Block 7 (THB7) and lies disconnected from other such habitat blocks to its east (THB5&6-Pilibhit-Kishanpur-Dudhwa-Katerniaghat) and to its west (THB8 and 9-Sohagibarwa and Valmiki) (Johnsingh *et al.*, 2004). Although isolated from other tiger habitats in the Indian Terai, this region assumes significance owing to extensive connectivity with forests in Nepal. The 100 km long northern boundary of the sanctuary lies along the Indo-Nepal border and along its westernmost tip (West Suhelwa Range) it is connected to the newly declared Banke National Park in Nepal. The connection is effected through a ~3.5 km stretch of Nepalese Community Forests constituting the Suiya and Mahadevpuri Forest Blocks. Thus when viewed together with tiger habitats in Nepal, Suhelwa forms part of a ~1000 km^2 contiguous tiger habitat extending to Bardia NP. With Nepal's initiatives to revive wildlife corridors such as the Khata corridor through Community Forestry Programs proving successful (Wikramanayake *et al* 2010), the vision to secure a contiguous tiger habitat in the Central Terai and its eventual success is contingent on securing the future of sites such as Suhelwa in India.

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View of Khairman reservoir. The haphazard release of water by the irrigation department had left much of this reservoir dry at the time of the survey in November.

5.1.1 Previous Studies

Prior to this survey, information on the status of large mammals in the area was collated by three separate studies. (1) The earliest of these was by Johnsingh *et al*. (2004) who surveyed the entire Terai Arc Landscape to assess the status of tigers and other mammals. In Suhelwa, their foot surveys totaling 60 kilometers in length, comprised of numerous short transects along forest trails and river courses (raus) and animal signs encountered on these were recorded. This study reported that tiger signs were infrequently encountered in Suhelwa, and that the sanctuary as a whole suffered from very high anthropogenic pressures such as illegal logging, fuelwood collection and hunting. Their surveys also reported that leopards and hyenas appeared to be widely distributed across Suhelwa. (2) Jhala *et al* (2008) conducted a beat-wise occupancy surveys for signs of tigers, co-predators and prey across all tiger landscape complexes in India. In Suhelwa, their study found tiger occupancy within a 490km^2 area, and based on a calibrated index relating occupancy to abundance, Jhala *et al* (2008) estimated that this sanctuary supports 3-5 tigers. Their study also reported the presence of wild dogs in Suhlewa. (3) A similar survey, repeated two years later reported tiger occupancy in 441km^2 of Suhelwa (~ 80 % of the park) and concluded that the sanctuary supported a stable tiger population of 3-5 individuals (Jhala *et al*, 2011). It is pertinent to note here that this reported figure of the population size of tigers in Suhelwa is an index of abundance and not an estimated parameter from mark-recapture models that are known to be reliable estimators of population size. For this reason, Jhala *et al* (2010) explicitly state that the region's tiger population may be lower than they report based on their calibrated index.

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Reservoir in East-Suhelwa range. This perennial water source tends to be disturbed by the presence of cattle and humans in large numbers. Expansive patches of invasive *Lantana camara* grow to the waters edge.

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Bhabar terrain along the northern boundary of Suhelwa. The Churia hills visible in the background lie in Nepal

The occupancy surveys undertaken in the Suhelwa WLS in November 2012 are a part of a wider landscape-level assessment of large mammal occurrence-and-abundance in the Central TAL. For Suhelwa, the survey results presented in this status report are the percent-frequency of encounter for large mammals in the area, consistent with the work of Johnsingh *et al* (2004). This allows coarse comparisons of the status of large predators and prey in the sanctuary over a ten year period that separates the current surveys (2012), from those of Johnsingh and his colleagues (2002-03). In addition to describing the current status of tigers, this chapter lists factors that may be adversely affecting wildlife populations. Finally, this study summarizes some key management recommendations based on our preliminary findings. These data have been incorporated into landscape-scale site occupancy models. These models seek to establish key determinants of tiger occupancy by using covariates pertaining to habitat, anthropogenic disturbance and management. Site occupancy models explicitly account for the imperfect detection of animal signs (Hines *et al*., 2010, Harihar and Pandav 2012).

5.1.2 Geography

Suhelwa sanctuary is a narrow strip (3 - 7 kilometers wide) of Bhabar-Terai forest flanked by the Nepal border on three sides. The south-western boundary of the park is close to Shravasthi Forest Division(27°52'20.34"N, 81°55'33.17"E) in India while the south-eastern boundary lies close to the town of Pachperwa (27°33'33.76"N, 82°44'35.14"E). Lying immediately south of the Churia hills in Nepal, the area primarily comprises of rugged mountains, and boulder strewn river beds especially along the northern boundary. Towards the southern boundary the Bhabar terrain gives way to flat Terai like floodplains. The area is drained by 8-10 major seasonal rivers many of which drain into artificial reservoirs built along the southern boundary of the park. The unique geophysical attributes of the area, its plantation history, and numerous drainages and reservoirs have given rise to a mosaic of varied forest types such as pure sal, teak, broad leaf moist deciduous, semi-evergreen and

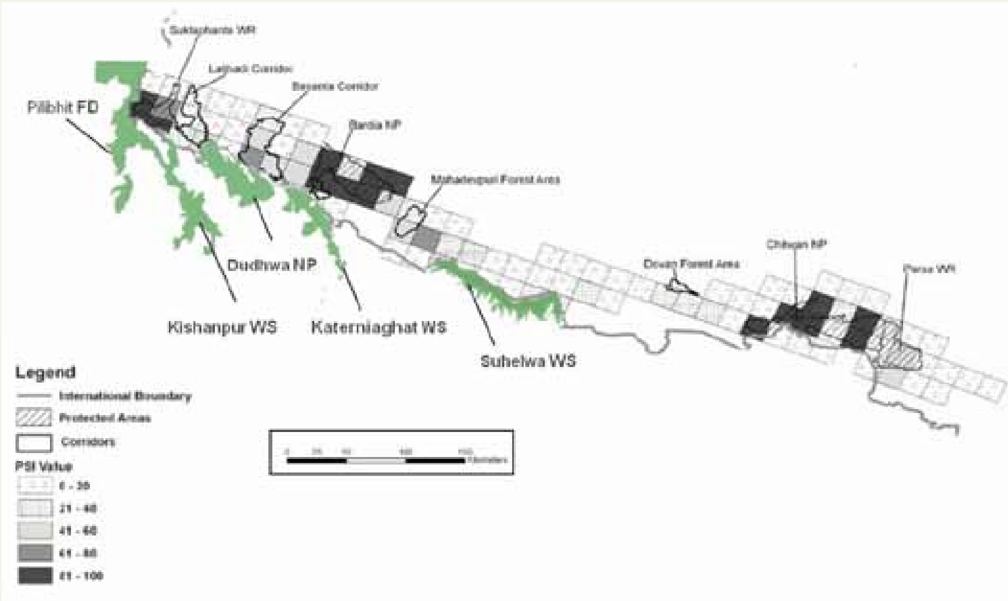

Figure 5.1
This map shows tiger occupancy values for grids within the Nepal portion of the TAL. In green are the protected areas within the study area. The Mahadevpuri forest area connecting Suhelwa to Banke shows moderate to high tiger occupancy indicating possible tiger movement between these areas. To the east of Suhelwa, Chitwan NP and Valmiki TR lie disconnected from the remaining patches in the TAL. With restoration of the Dovan and Lamahi corridors in Nepal, Suhelwa has the potential to connect Chitwan and Valmiki with Bardia NP and Katerniaghat WS. The Nepal occupancy map is adapted from Barber-Meyer *et al* (2012).

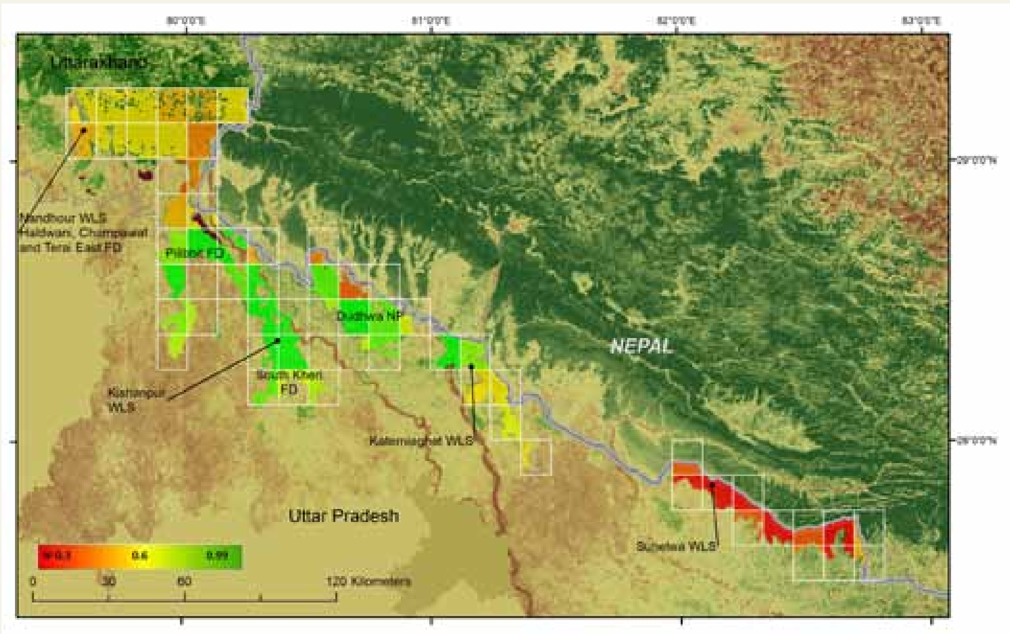

Figure 5.2
Map generated from a site occupancy model (Hines *et al.*, 2010) based on tiger signs recorded on trail surveys in the CTL. This map has been generated from preliminary analysis for data collected from sixty 166km^2 cells. Occupancy has been modeled as a function of relevant environmental covariates, similar to Harihar *et al.*, 2012.

small patches of grasslands fringing the reservoirs. The boundaries of the park are dotted by numerous villages which depend heavily on the forests for fuelwood, fodder and other NTFP. Many Nepalese villages are situated along the northern border. Their reliance on Indian markets necessitates frequent travel to towns on the Indian side. Consequently the forest is bisected by numerous foot- trails running in a north-south direction. Besides these trails, the SSB maintains a few roads within the forests leading to their posts located at regular intervals all along the border.

5.2 SIGN SURVEYS FOR LARGE MAMMALS

Methods and Rationale: The survey design adopted in Suhelwa is similar to the occupancy survey designs employed in the Western TAL (Harihar and Pandav 2012) and Nepal (Barber-Meyer *et al.*, 2012). To assess tiger occupancy at the landscape-scale, forests of the TAL region of Uttar Pradesh and Uttarakhand were gridded on a map such that each cell measured 166 km^2, a scale which accommodates the home range of adult male tigers (Harihar *et al.*,2012). Twelve such grids overlapped the geographical boundary of Suhelwa (figure 5.2. Within these grids sign surveys were carried out, along trails and river beds, employing spatial sub-sampling, wherein data was collected along 552 segments, each of which was 250 mtrs long (Karanth *et al* 2011). Observers recorded direct and indirect evidences of mammal species presence (spoors, scrapes, scat, and direct sightings) within 250 m segments (Johnsingh *et al.*, 2004) along all the survey trails. Evidences of anthropogenic disturbances such as signs of lopping, livestock presence and fuelwood collection were also recorded within each segment. Survey effort within each grid was scaled such that; for a grid with 100% habitat, the survey effort was 40 kilometers, and the effort was reduced in grids with less % habitat. Survey results are reported as the percent-frequency of encounters of large mammal signs, i.e. the percentage of 250 m segments within a surveyed grid on which signs were detected.

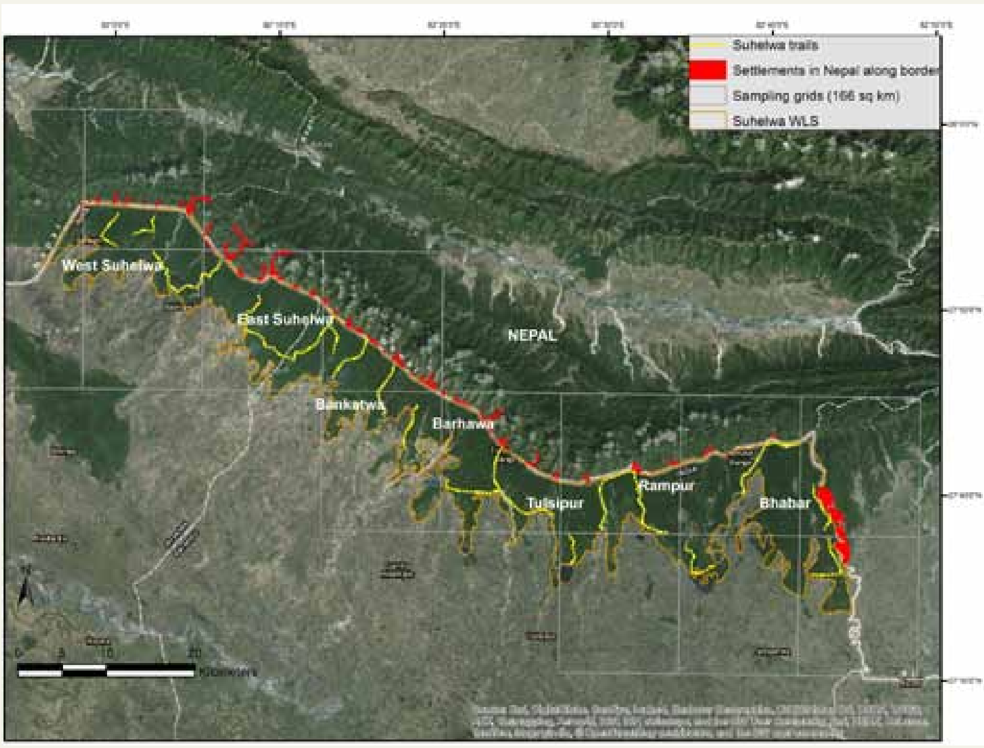

Figure 5.3
A satellite image showing the topography and boundary Suhelwa WLS, sampling grids (cell size is 166 km^2) the locationsof forest villages in Nepal along Suhelwa's northern boundary, and survey trails. The villages in Nepal demarcated in red have no significant road connectivity with other areas in Nepal and the inhabitants of these settlements rely on Suhelwa WLS for forest resources and also frequently travel through the sanctuary to markets in Uttar Pradesh.

Team conducting sign survey on the only maintained forest road in Suhelwa.

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5.3 PRESENT STATUS OF LARGE MAMMALS

Results for sign surveys in Suhelwa from the 2012 effort are summarized in Table 1 as the percent-encounter rate of animal signs encountered in Suhelwa. The encounter rates seem to suggest that the status of large mammals in the park is critical. However, it must be noted that these are counts of animal signs, unadjusted for (imperfect) detection probabilitiy. Table 5.1 lists frequency of encounter, (number of segments with signs/ total number of segments sampled), of large mammal signs in Suhelwa and other Bhabar habitats in the TAL. Values for Haldwani FD, Rajaji NP, Ramnagar FD, Suhelwa WS (2004) are from Jonhsingh *et al.* (2004). Values for Haldwani FD (2012) are from Mann *et al.* (2012). The following are the notable findings from our sign-surveys in Suhelwa.

1. Tiger sign encounter-frequency was lower in the current surveys (2012), than reported by Johnsingh *et al* (2004) - when 5.4 percent of the overall surveyed segments had tiger signs. In the present survey a single tiger sign was detected in the form of an old scat in the Jamdhara-nala, Bankatwa range, even though the overall survey effort was nearly 2 times higher in 2012. These results indicate that Suhelwa currently appears to have the lowest tiger densities among the protected Bhabar sites in the TAL such as Rajaji National Park, Ramnagar Forest Division, and Haldwani Forest Division. Moreover, the sign encounter rate for tigers in 2012 is considerably lower than that reported by Johnsingh *et al* (2004) suggesting that tiger populations in Suhelwa may have declined over the past decade.

Site	No of transects	Distance Surveyed	Tiger	Leopard	Sambar	Chital	Nilgai	Wild pig	Hyena
Haldwani FD (2012)	11	284	9.7(3.2)	33.4(5.3)	35.8(7.4)	22.6(5.6)	20.7(5.9)	14.7(2.04)	-
Haldwani FD(2004)	18	73.9	8.3 (12.7)	15.5(14.1)	54(37.6)	34.8(32.1)	8.4 (15.7)	18.6 (20.9)	-
Rajaji NP	16	67.3	12.9 (17.6)	33.4(21.8)	90.6(10.5)	88.3 (19.8)	4.5(11.5)	42(29.8)	-
Ramnagar FD	16	63.4	20.7(18.0)	9.1(10.4)	80.5(22.1)	58.8(36.5)	19.4 (28.5)	36 (30.7)	-
Suhelwa (2004)	13	64.7	5.4 (7.2)	8.2(7.8)	34.3(26.4)	48.3(29.5)	30(29.4)	61.3(29.4)	-
Suhelwa(2012-13)	12	138	0.36 (0.15)	12.8 (2.4)	12.31 (5.7)	53.9 (7.5)	32.9 (4.9)	43.1 (6.6)	28.26 (7.6)

Table 5.1
% Frequency of encounter of large mammal signs(SE) in Suhelwa and other Bhabar habitats in the TAL.

2. Sloth bear signs were sparse in Suhelwa with signs being detected in only 7 out of the 361 surveyed segments. These signs were encountered in Bankatwa, Tulsipur and Rampur ranges. Although sloth bears are common in Bhabar habitats, the factors responsible for their abundance patterns are poorly understood. For example in Haldwani forest division, which primarily comprises of Bhabar habitat and has high levels of anthropogenic disturbance, sloth bear encounter frequencies were 9.2% (2.7) (Mann *et al* 2013). The species was not recorded in Suhelwa by Johnsingh *et al* during their 2004 survey.

3. Leopard and Hyena signs were distributed across the sanctuary. While leopard encounter frequencies in Suhelwa are comparable with other Bhabar sites in the TAL, they are considerably lower than low tiger density sites such as Haldwani Forest Division (Table 5.1). In Bhabar areas, leopard populations have been shown to respond positively to declines in tiger numbers (Harihar *et al.*, 2012).

4. In Suhelwa, striped hyena signs were encountered in 28 % of the surveyed cells possibly making them the most widely distributed predator/scavenger in the area. The endangered species has so far been reported from only two other sites in the TAL: in Rajaji National Park they occur at densities of 5.67/100 km^2 (Harihar *et al* 2010), and in Haldwani forest division where the species has been reported to occur, seemingly in low densities (Mann *et al* 2012). The high encounter frequency for the species suggests that Suhelwa probably harbors a significant, albeit small, hyena population within the TAL.

5. Signs of Asian wild dogs (Cuon alpinus) were also detected in Rampur range. The presence of this species in some parts of Suhelwa was also confirmed by local residents who accurately described the appearance and behavior of wild dogs to the research team. The species has become locally extinct from most sites in the TAL. Besides Suhelwa, the species is reported only from Valmiki Tiger Reserve and Chitwan National Park in Nepal. Unambiguous evidence for the presence of wild dogs in Suhelwa however requires clear documentation such as photographs.

6. Encounter frequency of large prey species such as Chital are low compared with those reported by Johnsingh *et al* (2004). Wild boar (Sus scrofa) and Nilgai (Boselaphus tragocalemus) were frequently encountered in Suhelwa and their encounter rates here are higher than those reported in other Bhabar tracts in India. Conversely, Sambar deer appear to be rare in Suhelwa, as is evidenced by low encounter frequencies.

Nepalese children herding goatsin Suhelwa WLS. The ground-cover in riparian habitats along *raus* (seasonal streams in the bhabar zone) is severely depleted by grazing.

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5.4 THREATS TO WILDLIFE

Evidence of livestock presence was recorded in 91 % of surveyed segments. This is because livestock presence was not restricted to segments along the park edges but was found uniformly distributed across the area. The situation was similar in 2004 when the encounter frequency for cattle signs was 91% and was the highest amongst all the other surveyed patches in the TAL (Johnsingh *et al.*, 2004). While cattle signs were common along the southern boundary, signs of goat herding were frequently encountered along the northern boundary. The narrow width of the park and the extensive northern and southern boundaries fringed by villages allow easy access of livestock and herders into the interior areas of the park. It is fair to say that there are few spaces within Suhelwa Sanctuary that can be considered to provide inviolate or even relatively undisturbed habitat for wildlife.

Within each 250m survey-trail segment we recorded presence of temporary or permanent water sources. In November, when the surveys were conducted, only 25% of the surveyed segments had water. These segments were restricted to areas fringing reservoirs, river beds close to the foothills, and the Terai areas downstream. Areas with water also experienced high intensity of human and livestock use. The reservoirs were being extensively used by cattle belonging to local Indian villagers, who also use these waters for irrigation purposes. On the northern fringes of the sanctuary, Nepalese villages make abundant use of the water resources. Water is a critical resource for sustaining wild populations. In Suhelwa water scarcity especially through the dry season (November to June) may be severely limiting the populations of both predators and prey. It is possible that the scarcity of water in Suhelwa may produce strong seasonal trends in habitat use by mammals, especially tigers who may find disturbance free water sources in the area during the monsoon months alone.

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Large pumps suction out water from meagre streams - to irrigate fields in the Sanctuary's periphery.

The quality of habitat is also adversely affected by the spread of of invasive weed species like *Lantana camara,* which grows in thick tangles often out-growing native flora with better forage value for wild ungulates. Invasive weeds can therefore lower the habitat's carrying capacity for wild prey and ultimately, for top predators including tigers.

Fuel wood extraction from the tiger habitat results in high levels of human intrusion in the forest interior and often involves the cutting of green branches and trees.

During the survey we also came upon sites with tell-tale signs of hunting such as an improvised grates over which poached game had been roasted. Traps, snares and other implements used by poachers have also been recovered from these forests in the past (RRDRO seminar report 2010, personal communication Niharika Singh).

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A village at the edge of the forest in Bankatwa Range of Suhelwa WLS. High densities of humans around the sanctuary translates into high pressure on forest resources.

5.5 DISCUSSION

Sign surveys, such as our surveys in Suhelwa, are a useful means of monitoring the occurrence of species such as tigers and their prey over large spatial areas and time (Karanth *et al.*, 2011). Moreover, data collected using a site-occupancy design can allow the monitoring of population trends and changes in species-occurrence using contemporary occupancy modeling approaches (Noon *et al.*, 2012).

These surveys in Suhelwa point to a decline in the region's tiger population over the last decade, and it appears that at the time of our surveys (October 2012), no resident tiger may have been present in the sites that were sampled. This does not rule out the possibility of the occurrence of one or more tiger in Suhelwa, but the severe paucity of tiger signs in Suhelwa leads us to conclude that tigers in Suhelwa may be visitors from neighboring forests of Dang and Banke in Nepal. The study of Barber-Meyer, *et al* reveals that tiger occupancy in Nepal forests proximate to Suhelwa is generally low (< 20%). The apparent decline of tigers in Suhelwa, an area that was historically an important tiger site, is a matter of serious concern.

While it is not possible to ascribe precise reasons for the apparent decline of tigers in Suhelwa WLS, the following may be contributing factors:

Population Decline in Nepal

Suhelwa is by itself a narrow, linear strip of forest and its value as tiger habitat is greatly enhanced by its largely uncompromised connectivity with Banke National Park in Nepal (approximately 500 km^2). The current decline may well be an artifact of rapid or progressive loss of tigers Nepal 9 (and in India). Notably, severe crashes such as the one observed here are often associated with poaching of tigers and their prey at unsustainable rates (Check 2006, Dinerstein *et al.*, 2007, Karanth *et al.*, 2004).

High Human Pressure on Forests

The sheer abundance of humans in the Suhelwa forests - in the form of grazers, fuel-wood collectors, NTFP collectors, defense personnel along the border and day-time wayfarers to and from Nepal - may have severely compromised the sanctity of tiger habitats. Given that the width of Suhelwa WLS is on an average about 4 km, such disturbance may have greater impact on wildlife than might be the case in forests with an insulated 'core'. Human movement in the park is primarily in a north-south direction along trails leading into Nepal and along many river channels and rivulets that flow south from the Churia hills.

Human dependance on Suhelwa's forests and demand for wildlife has been excerbated in recent years by the haphazard and rapid growth of human settlements in Nepal, adjacent to the Sanctuary's northern boundary. These settlements have poor road connectivity with markets and urban centers in Nepal, and most inhabitants regularly traverse through Suhelwa WLS. The growth of these settlements is worrying because Suhelwa is increasingly fragmented from the North lying Dang forests (in Nepal), and is hemmed in by human settlements in all directions.

Limited Water Availability and High Levels of Disturbance Along Stream Courses and Reservoirs

The effects of cattle and human presence in forests are probably most debilitating to wildlife along stream courses, ponds and reservoirs. The Bhabar tract of Suhewa can generally be categorized as being water-poor, and many of its stream courses (the raus) are bereft of water for much of the year. In other areas, the water drains into artificially constructed reservoirs along the Sanctuary's southern boundary. It is imperative that human and cattle pressure on these water sources be reduced in the day, and that patrolling efforts in such areas be improved, particularly at night.

Effectiveness of Protection Measures

At present, all forest *chowkies* are situated along or close to the sanctuary's southern boundary. A consequence of this is that the Northern boundary is not effectively manned by Forest Department staff. The few forest roads that exist are poorly maintained, and most sections of the forest are suitable for patrolling on foot alone. Our surveys indicate that large portions of the sanctuary may receive less-than-adequate patrolling effort and some areas may go un-monitored by forest department staff for relatively long periods. A number of SSB (border security) camps are located in the forest along the Indo-Nepal border, but these should not be considered as substitutes for Forest Department patrolling camps, given that the mandate of these two institutions is quite different. Greater collaboration between the Forest Department, SSB and security agencies in Nepal needs to be encouraged.

Investment in Sanctuary Infrastructure and Staff Training

Although Suhelwa has been gazetted as a Wildlife Sanctuary since 1988,it has received scant conservation attention from the government and little infrastructure has been developed to aid wildlife protection, improve wildlife habitats or build the capacity for forest department field staff for effectively patrolling the sanctuary or monitoring wildlife populations therein. There is an urgent need to post field level staff, especially forest guards, and over 30% of positions are currently vacant. This has led to a situation where Forest Guards have to protect very large beats, which cannot always be patrolled effectively.

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Nepalese villagers make their way to Indian markets along one of many SSB roads that connect the northern and southern boundaries of the park.

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Indian villagers wheeling cycles with fuelwood is a common sight in the park. The fuelwood is supplied to households, commercial eateries (*dhabas*) and brick kilns in the vicinity of the park.

Need for Greater Trans-Boundary Coordination

The proximity of Suhelwa to the Nepal border has serious implications for effective conservation in the area. The sanctuary provides for the needs of proximate rural communities from both villages in India and Nepal. The relatively unrestricted movement of livestock and of people from both, India and Nepal along multiple forest trails and stream courses in Suhelwa, may severely compromise wildlife habitats. This is further exacerbated by the hunting pressures, particularly from Nepal, to supply the demand for 'sukati' (wild smoked meat). Trans-boundary cooperation should be developed and enhanced through the following steps :

1. Initiation of joint patrolling efforts along the border.
2. Regularizing travel routes and hours, through the park into India, for Nepalese villagers settled along the park boundaries.
3. Curbing the sale of wild meat in Indian and Nepalese villages.
4. Initiating joint monitoring efforts to reliably ascertain the status of tigers in the Bake-Suhelwa landscape.
5. Recognition of the Banke-Dang (Nepal) and Suhelwa as a priority tiger recovery site and initiating measures to facilitate the recovery of tiger populations through enhanced protection, support to park management and strategic partnerships with local communities, and regulating conversion of forest land to settlements along the border in Nepal.
6. The proposed construction of border roads both, in India and Nepal can adversely affect the movement and survival of large mammals. Appropriate measures to mitigate road impacts are essential to maintain the integrity of habitats and secure small and vulnerable wildlife populations.

A tigress rests in the Sal forest understorey, Kishanpur WLS.

CONCLUSIONS AND RECOMMENDATIONS

Theoretical and empirical studies in ecology have predicted that tigers and other large mammals are highly vulnerable to extinction for a number of reasons. These include small litter sizes, the need for large home-range sizes (Cardillo *et al.*, 2003; Cardillo *et al.*, 2005), habitat fragmentation and loss of genetic heterozygosity in small populations (Pimm *et al.*, 1988; Davies *et al.*, 2005; Crooks *et al.*, 2011; Mondol *et al.*, 2013, Dinerstein 2007), and exposure to forest edges and densely-populated, human-dominated landscapes (Woodroffe and Ginsberg 1998, Woodroffe, 2000, Cardillo *et al.*, 2004). Even as small populations of tigers decline further, there is an increased realization of the prominent role of apex carnivores in ecosystems, and their conservation has been emphasized (Estes *et al.*, 2011; Ripple *et al.*, 2014).

In our study area, Dudhwa NP and other sites in the CTL, extrinsic threats to tigers are many and these are certainly accentuated on account of habitat fragmentation. The survival of small, remnant populations has probably been fostered by a combination of intrinsic factors such as the propensity of tigers to breed rapidly when adequate prey and cover are available (Karanth *et al.*, 2006), and by extrinsic factors such as the availability of adequate and relative inviolate cover in the form of tall grasslands, and by management and government policies and local cultures that have shaped peoples attitudes towards large carnivores (Woodroffe 2000). The influence of some of these factors on tigers and on prey species have been discussed previously in this report. These and other data will also be used to conduct more detailed analyses in the future, in order to develop a refined understanding of the ecology of tigers and ungulates across a human disturbance gradient.

The paragraphs that follow summarize the key findings presented in chapters 2, 3, 4 and 5 of this report and synthesize these findings in the context of key management and conservation themes at the landscape scale. The implications of study-findings are also discussed in the context of some key conservation issues that were presented in the introductory section. Finally, this report is concluded by identifying and listing, at a local scale, key conservation and management efforts that will aid in the recovery of tiger and prey populations in the

To sustain wildlife populations in the Terai, special attention needs to be paid to the conservation and protection of remnant patches of riparian habitat and flood-plain grasslands which support high densities of tigers, hog deer, elephants and other threatened species.

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Tigers occur in high densities around wetlands such as Jhadi tal, where the prey are abundant. A hear of swamp deer feeds in a recently burned grassland in Kishanpur WLS

CTL. This concluding section appears as a detailed table with specific recommendations for 26 forest Ranges that are nested in major PA's and Reserve Forests in the CTL. Specifically, this table identifies important attributes of the habitat and other factors that are likely to have an influence on the occurrence and abundance of tigers and prey species in each Range.

TIGER DENSITY AND DISTRIBUTION: ROLE OF PROTECTION, PREY AND HABITAT

Tiger populations in the individual Protected Areas of the CTL are small and some may face the risk of local extinction. While individual populations in DTR and Pilibhit are small, camera trap sampling studies also indicate a two-fold difference in the estimated density of tigers between these sites, even though they were sampled with similar density of camera traps. Estimated population sizes and densities of tigers in Kishanpur WLS (16 - 18, 4.92) and Pilibhit (23 - 28, 3.44) reside close to the median values of tiger densities reported from 30 sites across India by Jhala *et al.*, 2011, whereas the estimates for Dudhwa NP (14-22, 1.89 and Katerniagat (17 - 24, 2.22) lie below this median. While it is encouraging that some sites such as Kishanpur WLS support high tiger densities, the small populations sizes in some PA's are a cause for concern. The near-absence of tigers in some productive alluvial grasslands that are regarded as the most productive of habitats for tigers in the world (Sunquist 2010), and the population declines in a PA (Suhelwa WLS) point to the need for

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Although chital are probably the most abundant of the ungulate species in the CTL, they occur in higher densities in other areas of the Terai including Rajaji NP and Bardia NP. The fine-scale determinants of the distribution and abundance of ungulates merits greater attention in future studies.

heightened vigilance and proactive population recovery programs. It is also noteworthy that tiger populations in the CTL are significantly smaller than those reported in from some other sites in the Terai of India and Nepal, most notably Corbett Tiger Reserve and Chitwan National Park.

The finding that tiger populations in the CTL are small, and occur at lower densities than other areas in the Terai Arc Landscape raises an interesting question: did tigers occur at much higher densities historically in the CTL (until the mid-1900's) than they do today? While there is only limited anectodal information on historic tiger numbers, it seems plausible that recent and on-going declines that are eroding away extant tiger populations may be indicative of longer-term trends in the region. Some evidence of recent declines comes from surveys conducted over the last decade. Even our estimates are not strictly comparable with those of Jhala' *et al.*, (2008, 2011), because of differences in the extent of camera-trap-arrays, we note that these previous surveys captured a sizably greater number of individuals in some sites, from a smaller area and with 5-fold less trapping efforts - than we did. Hunting pressures on tiger or prey populations may have played a role in structuring the populations we observe today. These pressures exist is documented both in Protected Area management plans (eg. De 2001), as well as in recent news reports (eg. Pioneer 2013). It is also noteworthy that some forest edges in DNP and Katerniaghat, particularly those along the international border, were found to be associated with lower densities of both tigers and their ungulate prey species.

Patterns of tiger distrbution and abundance observed in the present study indicate that local variations in the distribution and densities of tigers in the CTL are influenced by local variations in prey densities, by habitat (presence of water and grassland-woodland mosaic habitats), by habitat connectivity and by local scale variations in hunting pressure and other forms of anthropogenic disturbance on wildlife populations and habitats. With regard to prey-influence on local variations in tiger populations, there are two key observations. The first is that tigers occur in their higher local densities in areas where principal prey species congregate(notably the Maholi area of Belrayien Range, Kakraha Rhino rehabilitation area in DNP, Jhadi Tal in Kishanpur WLS and the Bagluia Seed Farm in Katerniaghat WLS). Several of these areas are buffer zone forests and also face high cattle grazing pressures, particularly in the day-time hours. The second observation is that wild ungulates with the exception of chital and wild pigs are very restricted in their distribution in the CTL, and sambar exist in extremely low densities. It is likely therefore that chital and wild pigs are the species that are predominantly perdated upon by tigers, except in some wetland and grassland habitats where swamp deer and hog deer populations persist.

By way of habitat preferences, there appears to be a strong association between grassland habitats and riparian tracts and high densities of tigers. This could be on three counts: firstly because such areas are also the preferred habitats of several cervid species including hog deer and swamp deer (Dinerstein 1980, Shrestha 2004). Second because these tracts usually provide better cover than sal forests, and lastly because tigers prefer to be in or around water, particularly in the warmer months. Interestingly, the existence of perennial water sources, (such as the grassland-fringed Suheli river that forms the southern boundary of DNP), provides suitable habitat and supports high prey densities. As a result, tigers are more concentrated in their use of these forest edge areas, than they are of more interior regions of the forest that are sal-dominated and have fewer grasslands and streams.

Finally, it is important to note that a site's ecological carrying capacity for tigers will be determined by the availibility of adequate numbers of prey, and high-quality habitat. Given adequate protection and low disturbance, the availibility of ungulate prey will be regulated by the environment: ie. the structure and composition of forest and grassland habitats, terrain and year-round water availibility. These factors will need to be thoroughly investigated and taken into account when managers seek to estimate the carrying capacity to establish realistic population recovery targets.

TIGER CAPTURE DYNAMICS AND POPULATION STRUCTURE

Sampling Protected Areas and Reserve Forests in their entirety (or nearly so) using camera trap blocks proved to be an effective way of surveying populations to make reliable inferences on population parameters. In the absence of reliable previous information on tiger-movement between sites, our study was also designed to maximize the probability of capturing individuals that may have moved between sites. High capture probabilities (0.95 - 1) suggest that nearly all individuals in the sampled populations are likely to have been exposed to camera traps.

Data from this study suggests that in DNP and Katerniaghat WLS, there are almost as many adult male tigers as there are females. An even sex ratio appears to be an anomalous scenario in the social biology of tigers, and is likely to retared the growth and recovery of small populations. It appears that there is a link between these unusual sex-ratios and habitat fragmentation. Sites that are not fragmented, or well connected with other tiger habitats through forested corridors are also associated with female-biased sex ratios that are considered to be the norm in tiger populations. Contrarily, sites with limited or no connectivity (eg. DNP) had a male biased sex ratio over the study period.

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Nilgai are widely distributed across the CTL, and a frequently seen along forest edges.

From camera trap data, the annual population 'turn-over' rates were estimated to be between 20 and 30 percent in the study sites. A disproportionately large numbers of tigers that we were not able to account for were transient-class or adult males. Over the study period, the mortality of two transient age male tigers and two adult males, most likely of human-induced causes such as poisoning. Given the fragmented nature of the landscape, and our observation that tigers frequently make forays into sugarcane plantations and other farmland areas, there is an urgent need to restore key wildlife corridors in order to facilitate dispersal and sustain tiger meta-populations in the landscape.

PREY DENSITY AND DISTRIBUTION

Encounter rates for ungulate prey were highly variable both, across and within sites sampled by this study in the CTL. A disproportionate number of detections on line transects came from grassland and riparian forest habitats, with fewer detections in closed-canopy sal forests. Chital and hog-deer both occurred commonly in grassland-forest edge habitats, whereas swamp-deer were restricted to wetland areas. Wild pigs were encountered in forest and short-grass habitats. Swamp deer frequently occurred in large congregations and line transect-sampling methods appear to be unsuitable to monitor swamp-deer populations. The abundance of prey therefore varies greatly with marked ‘hot-spots’ or areas of high abundance and large forest areas with low prey densities.

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The 'management' of grasslands by fire and cutting has been identified as an important measure to increase productivity in these habitats for ungulates. Previous studies have recommended that burning must be restricted to the cool season. Here forest department staff ignite fires in the forest-understory mid-March.

Estimated densities of ungulates (detections pooled across species) ranged between 10 and 26 in Dudhwa Tiger Reserve. These estimates are notably lower than estimates from Pilibhit Forest Division (Bista 2011). Nowhere in the CTL did this study record densities reported by Wegge *et al.*, (2009) for the Karnali River flood plain area of the Royal Bardia National Park or by Harihar *et al* (2009) in Rajaji National Park. As prey encounter rates were low in most areas of the CTL, we were unable to generate an adequate number of detections for any ungulate species to allow reliable species-specific estimates using Conventional Distance Analysis. For comparison, studies with similar or less sampling effort (eg. Harihar *et al.*, 2009, in Rajaji N.P.and Bagchi *et al.*, 2003 in Ranthambore National Park) had considerably more detections of ungulates from fewer transect lines, allowing species-specific estimation.

This study reiterates the findings of previous studies (eg Dinerstein 1980, Wegge *et al.*, 2009, Seidensticker *et al.*, 2010) that in the Terai-duar eco-region, ungulates achieve their highest biomass in the productive flood-plain grasslands and associated forests, but occur at much lower densities in climax sal forests. It has also been noted that while extensive patches of tall-grass and swamp habitat may sustain populations of some species such as swamp deer, most grazing ungulates are benefited by short-grass habitats. A case in point is the Bagluia Seed Farm area in Nishangara Range of Katerniaghat WLS. The Seed Farm area comprises primarily of fallow farmland, that is slowly being transformed into a grassland characterized by *Cyanadon dactylon* lawns and several associated species of grass. Even though such areas are disturbed and grazed by many thousand cattle in the day-time hours, they attract large numbers of wild ungulates and the Seed-Farm area (approximately 36 km^2) was used extensively by 3-6 tigers, including two territorial males. By contrast, the relatively undisturbed and homogenous sal-dominated forests of Dharmapur, Nishangara and Murtiah ranges are virtually devoid of ungulate prey and for the large part, bereft of tigers.

While habitat factors limit prey populations, ungulate densities are also low in several areas in the landscape because of poaching pressure on populations (De, 2001). To prevent such losses, there is an urgent need to systematically and regularly patrol on foot, areas in the forest interior, away from roads and trails. The manpower deficit in the forest department staff (forest guards in particular), because of a long-standing moratorium for new recruitment imposed by the state government, has resulted in a situation where several chowkis are under-staffed.

Finally, it is importamt that managers rely on the best available information, or initiate studies to inform habitat management strategies - that are not only beneficial to ungulate prey and other large mammals but also protect and promote biodiversity and sustain diverse taxa including arthropods, reptiles, amphibians, and birds.

A LESSON FROM SUHELWA: A SANCTUARY IS NO SAFE HAVEN

Recent sign surveys in Suhelwa WLS indicate that the sanctuary no longer supports a resident population of tigers, even though one or more individuals may sometimes make forays into this area. This is worrying because the area was historically known to be a productive area for tigers, because there is extensive habitat stretching into Nepal that Suhelwa is connected with and because these forests has been a managed as a Protected Areas for several decades. The Suhelwa forests by themselves are a narrow strip, lack any significant tracts of grasslands and are very disturbed. These findings from Suhelwa, highlight the plight of wildlife habitats that have been besieged by anthropogenic pressure, where management has been ineffective in protecting small and vulnerable wildlife populations.

The revival of tigers in Suhelwa may be aided by recovery in the adjoining Churia Hills of Nepal (the proximate forests of Dang in Nepal have been recognized as a Tx2 recovery site by WWF-India's Tigers-Alive Initiative (WWF-India 2013). Efforts to revive the tiger population will require a serious commitment to work with communities residing around Suhelwa WLS, to reduce their dependence on forests, and by creating energy solutions for local populations. More so, the presence of livestock such as cattle and goats, in large numbers has resulted in these forest being very disturbed, and the small patches of grass along stream courses are severely overgrazed. Pressure on Suhelwa's wildlife populations and habitats also stems from villages in Nepal along the sanctuary's North boundary, emphasizing the need for trans-boundary conservation.

The finding that tigers are extinct (or nearly so) in Suhelwa WLS also underscores the fact that often it is not sufficient to declare a forest patch as a Protected Area in order to conserve its wildlife and habitats. Suhelwa WLS lacks-even the most basic infrastructure that would allow effective administration and patrolling. Its few roads are ill maintained, there are few chowkis in the forest interior and the Forest Department is perennially understaffed. There is an urgent need for intervention to protect key habitats and important water-sources for wildlife, reduce human pressure in such zones, and to take cognizance of the fact that the sanctuary still supports small populations of hyenas, leopards and most likely, wild-dogs, which need to be protected.

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Tuskers spar on the road leading from Palia Kalan to Dhangadi, Nepal, through Dudhwa National Park. While new roads and other infrastructure projects are being planned, administrators and planners must recognize the need to maintain the sanctity of key wildlife habitats and wildlife corridors.

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A fragile balance: in some forests of the CTL tigers, leopards, elephants, bears and humans all eke out a precarious existence.

PROTECTED AREAS AND HUMAN-USE OF TIGER HABITATS

From two years of sampling, this study has revealed complex patterns in the density and abundance of tigers. Surprisingly, preliminary analysis indicate that there may be no simple relationships between the density and distribution of tigers and the levels of human use of forests. While certain Protected Areas such as Kishanpur WLS are associated with the highest tiger densities recorded in the CTL, others such as Dudhwa National Park were found to support very small tiger populations. Paradoxically, Pilibhit Forest Division, a narrow forest with intensive timber harvest operations continues to harbour one of the most significant tiger populations in the landscape. Tigers occur at their highest densities in the landscape in Kishanpur WLS, which is nestled between Pilibhit Reserve Forest and South Kheri Reserve Forest. Notably, our surveys in Suhelwa WLS points to a drastic decline in the tiger population in a site that was identified by, Billy Arjan Singh, as being a prominent and productive area for tiger hunts in the mid-1900's. The density of tigers in each site appears to be influenced primarily by the availability of ungulate prey, and also by habitat connectivity, the presence of water and grasslands, effectiveness of existing protection measures and by human presence in forests.

Even though some forest areas with considerably high levels of human presence, (e.g. Pilibhit and South Kheri FD), continue to support tiger populations, we believe that there is a threshold of disturbance beyond which tigers and their prey may well be affected by human presence in tiger habitats. This is illustrated by the fact that Kishanpur WLS, which is perhaps the best 'insulated' site in the landscape - on account of canals, rivers and buffer forests that help restrict the entry of village dwellers into the forest, and likely supports the highest density of breeding females within the CTL. However, it must be noted that there are several small village enclaves within Kishanpur WLS. At the other end of the disturbance-spectrum lies Suhelwa WLS. Its fragmented southern boundary is defined by multiple breaks in forest cover, where agricultural land has ingressed into the forests, and there are rapidly growing villages along its northern boundary. This has resulted in a situation where there are few areas in the sanctuary that are unlikely to be influenced by edge-effects.

Lastly, it is important to highlight on the numerous roads and railway lines that bisect the TAL's forests. Notable among these are the highway from Khutar to Palia that passes through the central region of Kishanpur WLS; tigers have suffered fatalities in road accidents on this highway, over the years. The highway from Palia to Chandan Chowki and Gauriphanta pass through the core zone of Dudhwa National Park; this road is relatively narrow, is consistently used in the day time, though night-time traffic is sparse. Finally a highway passes through the entire length of Katerniaghat WLS, cleaving it into a northern and southern half, and allows vehicle-borne travelers easy access to the forest interior. Similarly two roads with constant traffic flow pass through Mala range, and one through Haripur range and areas of Sampoornanagar range of NKFD. Extensive lengths of railway line also run through portions of Pilibhit, Kishanpur, Dudhwa and Katerniaghat and trains operate at high speeds (often 60 km/ph or faster) both during the day and at night. The impacts of these sources of disturbance on wildlife in forests, forests that are already narrow and fragmented have not been investigated in any detail. However data from other studies indicates that forest roads can severly affect the survival of wild tigers (Kerley *et al.*, 2002). There is therefore cause for great concern about the proposed construction of new paved roads near the India-Nepal border in both countries. These roads will pass through many hundred kilometers of forest habitat, and could severe connectivity in the fragile corridors, linking forests in India and Nepal.

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Agriculture in the Terai is becoming increasingly mechanized. The ample availability of ground water and fertile alluvial soil has resulted in this region's growing importance as a 'food bowl' for India. The winter wheat crop is harvested outside Kishanpur WLS.

PARK-PEOPLE RELATIONSHIPS AND HUMAN-WILDLIFE CONFLICT

Bagga village in Surai range, Chaltua, Kishanpur, Kamp, Tanda, Dhakka and Maharajnagar in Kishanpur WLS, South Kheri FD and Haripiur range, Surma and numerous other Tharu Settlements and the Bisinapur-Rampurwa village cluster in Katerniaghat WLS are prominent human settlements in the forests of the CTL. A number of these settlements have been recognized as revenue land and are not in the jurisdiction of the forest department. Of all these settlements, conflict between local communities and the forest department has been particularly severe in the Tharu community belt in the Northern areas of DNP in recent years (with over 37 villages) bordering North Sonaripur, Dudhwa and Bankati Ranges. Protests and episodes of violent conflict have arisen at several of the forest chowkis in this area in recent years. Most conflicts appear to be over the extraction of forest resources such as grass and timber for home construction by local populations, and restrictions on the removal of such items imposed by the forest department. This has resulted in conflict between the public and government agencies and tensions have been further excerbated by a politicization of of these issues and and differences on interpretation and implementation of the FRA. Co-incidentally, most areas in the proximity of the Tharu villages in DNP are associated with lower densities of tiger and prey than we expected those habitats to support. There is a real need to delineate critical wildlife habitats, and establish mechanisms to regulate resource extraction by local communities and also redress conflict that arises over access and rights of forest resources, particularly in buffer zone forests that also sustain tigers.

A tigress with a young bull in Ramwapur block in Dudhwa National Park. Human tiger conflict is elevated in foret-edge zones which are intensively used by humans, cattle and sometimes by tigers as well.

Human wildlife conflict, involving tigers occurs on occasion in the CTL's forests and commonly involves cattle-lifting. In some areas of the landscape that are important cattle grazing sites (such as the banks of the Sharda River in Pilibhit and North Kheri Forest Divisions), recent cases of tiger-poisoning have been reported, highlighting the need for heightened vigilance and law-enforcement. Conflict has becomes a matter of grave concern particularly when there have been human injuries or fatalities. While such instances have occoured sporadically in recent years in this region, there are many records of tigers that have made forays into crop fields, and occasionally residing in sugarcane plantations for extended durations of time. This is often a cause of anxiety for human communities that are afflicted by a the presence of a tiger in their neighborhood. These cases have been particularly hard for the forest department and other government and conservation agencies to manage, especially when females are accompanied by cubs, making capture and relocation operations difficult. There is an urgent need to set up a mechanism to extend conservation efforts into farmlands. This is in order to protect tigers and ungulates in areas of habitation and cultivation, while also working with communities to ameliorate impacts of tigers and crop-raiding ungulates on human lives or livelihoods.

EFFECTS OF FRAGMENTATION AND RESTORING CONNECTIVITY

Connectivity between habitat patches appears to be an important determinant of tiger population sizes. Not surprisingly, the ~1300 km^2 contiguous patch of forest comprising of Pilibhit FD, South Kheri FD, Kishanpur WLS and Surai Range (Uttarakhand) is the single most productive area for tigers in the landscape and holds a population of around 50 adult tigers. This patch appears to be connected with Shuklaphatna Wildlife Reserve, and perhaps also with Nandhour WLS. Likewise, through communication with colleagues in Nepal, we have recorded the movement of tigers between Bardia NP (Nepal) and Katerniaghat WLS via the Khata corridor. DNP, on the other hand appears to be isolated and its corridors with forests in Nepal have been eroded by recent development and urbanization.

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The carcass of a tiger that may have succumbed to poisoning

It appears that the absence of well-defined forest corridors may influence not just the population size, but also the sex ratios. As has been observed in Chapter 3, sex ratios from camera trap data suggest that there are as many adult males in some populations as there are females. This appears to be an aberrant condition for the social-biology of wild tigers. By restoring connectivity between Dudhwa, Laljhari and Basanta in Nepal , and between the Garah-Lalpur Patch and the Mala Range in Pilibhit, and protecting these habitats, it is likely that tiger populations in these areas will 'recover' (see Chanchani *et al.*, 2014 for details on tigers in Pilibhit Forest Division). It is pertinent to note that the absence of corridors and breaks in connectivity between forests has resulted in a patchy distribution of mammals other than tigers - including bears, leopards, elephants, rhinos and swamp deer. Maps and details of important corridors in the CTL have been provided in Appendix 3.

Some recent assesments of the status of corridors and habitat connectivity in the TAL can be found in Wikramayake *et al.*, 2004., Jhala *et al.*, 2011 and Kanagaraj *et al.*, and 2014, Sinha and Talukdar 2014 and in a forthcoming joint report on the status and movement of tigers in the Trans-Boundary Terai Arc Landscape. The assesment of wildlife use by corridors and restoration of habitat connectivity are key objective of WWF-Indias Terai Arc Landscape Program, and continues to be an area of active research and conservation. A recent WWF-India document has noted that the proposed development of new roads along the international borders in Nepal and in India can disrupt corridors and has recommended measures to prevent the further fragmentation of wildlife habitats (WWF 2014).

Forest department staff on a patrol. Kishanpur Wildlife Sanctuary.

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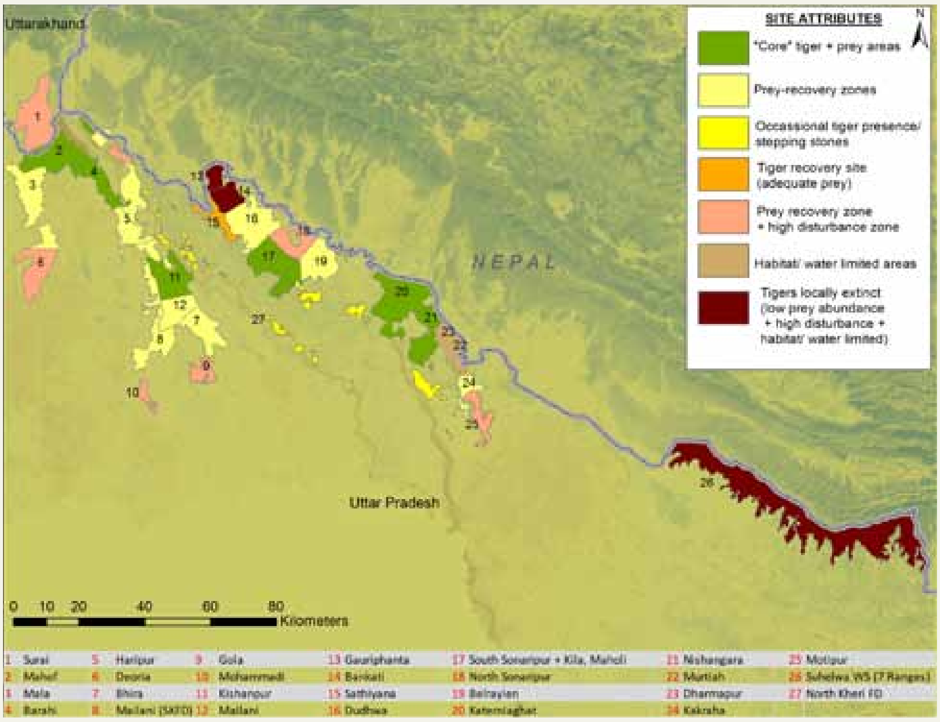
EFFECTIVE PROTECTION IN PROTECTED AREAS, RESERVE FORESTS AND FARMLANDS

There is an urgent need to update and invigorate protection mechanisms in all tiger occupied areas in the CTL. Specific measures in this direction include (a) ensuring that there are adequate numbers of motivated and trained forest guards and beat watchers who are suitably equipped for effective round-the-clock patrolling and monitoring. (b) Designing patrolling programs that ensure that forest department personnell regularly reach all areas of forests and grasslands, including sites distant from maintained roads and trails. This will require the construction of anti poaching camps in remote or vulnerable areas, an increased use of elephants in patrolling tall grass and swamp dominated areas accross the landscape and the presence of sufficiently large patrolling teams that can walk through dense vegetation in search of poachers, snares and traps. (c) There is an urgent need to develop mechanisms to effectively patrol forest-interior areas in the monsoons when many roads do not permit vehicle movement and several areas experience flooding. (d) Enhanced vigilance along the international border in association with the Sashastra Seema Bal (SSB) is essential to protect vulnerable wildlife populations. (e) Coordinated protection and intellegence operations with security agencies in India and Nepal may be effective in curbing of wildlife crimes and thereby will aid population recovery efforts.(f) Special attention needs to be paid to areas with high cattle grazing pressure (eg. North Kheri Forest Division, forests along the Sharda River, Mahof Range of PFD, Suheli River of DNP and the Seed Farm and Trans-Girwa areas of Katerniaghat), where tigers may commonly prey upon cattle and face an elevated risk of being poached or poisoned. (g) Reserve Forests in the landscape such as North and South Kheri Forest, Shahjehanpur and Terai East Forest Divisions are also important habitats for tigers and it is recommended that protection and patrolling efforts in these sites be prioritized to a similar level as the Tiger Reserves. (h) Speedy and effective legal prosecution of individuals convicted in wildlife crime cases. (i) Building synergies with forest dependant local communities to stem wildlife crime and enhance public support for conservation. This is emphasized in areas where communities have a known preference

Figure 6.1
Map of Ranges in the Central Terai Landscape illustrating areas that serve as (i) core tiger habitats (typically associated with breeding tigers), (ii) prey-limited areas where protection and restoration efforts need to focussed, (iii) areas that are infrequently used by tigers (iv) areas with superior habitat and adequate prey, but associated with sporadic use by tigers (v) areas with low prey densities and high disturbances, (vi) areas where tiger and prey are likely to be primarily limited by habitat constraints, and (vii) areas from which tigers and prey have been locally extirpated in the recent past. This map incorporates information presented in table 6.1 and also utilizes additional information on the distribution of water and human disturbance. Range-wise details have not been presented for Suhelwa WLS as this site was not sampled with camera traps or line transects.



for bush-meat. (j) Finally, because tigers and ungulates often venture into farmlands where they face a risk of being poached, protection efforts need to be extended into the agricultural matrix, with the involvement of local human communities. SMART patrolling programs that have recently been initiated in Pilibhit Forest Division are a step towards more efficacious patrolling and law enforcement.

RESTORING VIABLE TIGER POPULATIONS - A ROAD-MAP FOR CONSERVATION IN THE CTL.

With regard to the recovery potential of tiger population in the CTL, Dudhwa National Park and Suhelwa WLS are sites that currently most merit conservation interventions focused on increasing tiger and prey populations. In DNP, tigers and prey occur at very low densities and occupy habitats that encompass about one half of the total area of the National Park. Within DNP, several areas in Sathiyana, Dudhwa, North Sonaripur and Bankati Ranges, that are wetlands or grasslands and appear to be high-quality tiger habitat, were not used frequently by tigers at the time of our surveys. Suggested management measures to promote the recovery of tiger and prey populations in these areas include careful management of grasslands to maintain grazing areas with year-round forage availability for grazers, and intensified patrolling to check the hunting of animals along the Park's northern and western boundaries. Mobilization and involvement of forest-adjacent communities is important for the success of planned recovery-programs. Conservation efforts in the narrow and highly disturbed Suhelwa WLS are likely to be very challenging. Here, management will need to adopt a two-pronged conservation strategy that involves (i) engagement with local communities to reduce the presence of livestock and humans in key wildlife habitats (along some stream courses), and (ii) intensive patrolling in the Park's interior. The recovery of tiger populations in Suhelwa is dependent on the recovery of populations in the adjacent forests in the Churia hills of Nepal. These forests are considerably larger in their extent, and connected with Banke and Bardia National parks which support a sizably large tiger population.

The future of tigers in the Terai will depend to a great degree on the tolerance of local populations towards these predators that sometimes maim or kill cattle, and more occasionally humans. Effective human-wildlife mitigation measures including compensation schemes and effective action to support and address the grievances of affected individuals are essential to conserve large carnivores.

Whether or not small populations recover will depend to a large extent on the ecological and the social carrying capacity of the sites to support larger tiger populations than currently exist. The ecological carrying capacity pertains to the population size and distribution of prey, and the extent of suitable habitats that are available for tigers entering these populations to utilize. The social carrying capacity alludes to the attitudes of local populations towards wildlife, and their willingness to self-mobilize or work in conjunction with government and other agencies towards conservation goals. The social carrying capacity is influenced by many drivers including cultural associations with wildlife and forests, economic conditions, representation and participation in governance, political view-points and affiliations, geographic locations, rural-infrastructure and energy supply, and education. For conservation programs to be designed appropriately, and for progress towards their targeted outcomes - the ecological and social carrying capacities must be duly considered, and addressed through targeted conservation and sustainable-development actions. In this report, we have identified some key ecological factors that are likely to have influence on tiger populations, and we recommend that detailed studies be undertaken to explore the social-carrying capacity for tigers in the CTL. For examples of studies exploring aspects of community - conservation initiatives and dynamics in ecologically similar areas, readers are referred the works of Berkes 2007; Baral and Heinen 2007; Mehta and Heinen 2001 and Kellert *et al.*, 2000).

An important and unique feature of the CTL is its proximity to the international border with Nepal that also forms a boundary of Suhelwa WLS, Dudhwa NP and Katerniaghat WLS and a section of Pilibhit FD. The 'open' border between the two nations encourages peace, prosperity and the well being of the region's human populations. It also facilitates movement of wildlife through remnant corridors. However, the 'open' international border also creates some challenges in law enforcement, and has resulted in increased human presence and pressure win wildlife habitats in the CTL. It is essential that the two nations develop synergies for effective conservation. Steps in this direction may be in the form of joint-programs to monitor and protect wildlife populations, efforts to reduce forest encroachments and human pressure on wildlife habitats, the restoration of trans-boundary corridors. In addition, enhanced protection and increased awareness among government agencies and the public will promote the conservation of the unique and diverse flora and fauna of the Terai.

Table 6.1 summarizes key information for 25 ranges in three Reserve Forests and three Protected Areas in the CTL where tigers and prey populations were intensively sampled. This table also lists important conservation issues in each Range, and identifies areas where recovery efforts should be focused. Ranges in Suhelwa WLS, North Kheri and Shahjehanpur Forest Division were not sampled with camera traps and are not featured in this table. These sites need to be monitored intensively in the future. For the sites that we have listed in this table, the application of prescribed management and conservation actions will be a significant step towards sustaining and recovering tiger populations. Today, a majority of the Terai's fabled wetlands have been drained and the region has come to be one of South Asia's great food basins. Even so, tigers still define the regions' culture and occupy an apex position in its trophic web. Conserving tigers in this landscape has undoubtedly enabled the survival of many other species, large and small, that have shared the tiger's habitat for millenia. By conserving tigers, we will continue to protect and promote the integrity and diversity of fragile Terai ecosystems.

Table 6.1 Range-wise assesment of tiger habitats, threats and conservation opportunities for in the CTL.

Range	Site	Area (km²)	Extent of forest edge in km	predicted density of tigers/100 km²	SD (tiger density)	average prey encounter rates	SD prey er	Grassland area (km²)
Surai	Terai East (Uttarakhand State)	173.70	61.33	3.10	0.01	2.72	0.96	12.97
Mahof	Pilibhit	144.52	22.92	7.05	0.02	3.92	1.00	22.31
Mala	Pilibhit	156.50	82.25	7.39	0.01	3.37	0.91	19.93
Barahi	Pilibhit	92.84	59.20	2.52	0.14	3.75	0.75	9.08
Haripur	Pilibhit	110.20	56.28	4.71	0.01	3.16	0.90	40.50
Deoria	Pilibhit	112.55	77.37	1.15	0.00		na	14.20
Bhira	SKFD	127.29	77.00	5.02	0.01	2.79	1.52	11.15

Major conservation & management issues	Unique habitat features	Conservation opportunities
Presence of Bagga Village within forest. Regular use of forest roads by traffic. High grazing pressure and many Gujjar settlements. Proximity to Nepal border and Khatima and Tanakpur which are wildlife-trade hubs. Small grassland areas. Selectively logged forest. Connectivity with Nandhour via Kilpura-Khata corridor is tenuous.	Extensive canals, presence of the Sharada-Sagar reservoir.	'Restore' the Kilpura-Khatima Corridor to connect Nandhour with Pilibhit. Increase management synergy with the Pilibhit Forest Division. Reduce disturbance in key habitats along water sources. Strategic patrolling and increased vigilance to deter poaching. Restore Kilpura-Khatmia corridor.
Proximity to Bagga village, presence of a highway, Grazing pressure from Bagga village and Gujjars in Surai Range. High pressure from villages along southern boundary. Puranpur - Khatima highway bisects important tiger habitat has un-regulated both during the day and night traffic. High tourism pressure in Chuka may be detrimental for wildlife.	Extensive grassland areas, presence of the Mala River, Chuka reservoir and perennially flowing canals. Presence of swamp-deer. Recent report of a poached tigress (2013).	Several breeding females have home ranges. Added protection will help sustain the population. Need for effective management of grasslands, and year-round foot patrolling in sensitive areas.
Presence of 3 highways and a railway line. Lalpur and Garah ranges are disconnected by a highway and farmland.	Presence of the Mala river, canals and small grasslands.	Strengthen protection, and establish anti-poaching camps particularly in the Mathana and Garah-lalpur blocks, and along Mala river.
Presence of heavily-used roads, forest is very narrow. Immense cattle-grazing pressure in Lagga-Bagga and Simra.	Perennial water flow in canals. Lagga Bagga is a portion of Shiklaphanta WLS and is a wildlife-rich area.	Increased patrolling and curbing grazing pressure in the Simra area can help secure the Pilibhit-Shuklaphanta corridor.
Extensive sal plantations that are not productive for large mammals. Grassland areas along the Chuka and Sharada Rivers are heavily grazed and disturbed.	The most extensive riparian and grassland areas in PFD are in the eastern areas of Haripur range. This Range connects PFD with Shuklaphanta, SKFD and Kishanpur WLS.	Improved protection along the Sharada River may benefit hog deer and tigers, and strengthen an important corridor with Nepal.
Discontinuous from the rest of Pilibhit. Heavily disturbed by constant human movement, a road, and cattle grazing. Presence of 'crowd-pulling' Ashrams in forest interior	The Khannot river and several perennial streams and canals guarantee year-round availability of fresh water.	Restoring connectivity (creation of the Lalpur-Garah corridor) may allow tigers to establish territories in Deoria range. Protect habitats along water sources and reduce day-time disturbance.
Forests are narrow, and there are several villages and public roads within. Logged forest.	Presence of the Ull River, sharada River and many plantations with grassy under-story provide good wildlife habitat.	Need to enhance protection efforts along the Sharada, and reduce disturbance in some key wildlife habitats.

Range	Site	Area (km²)	Extent of forest edge in km	predicted density of tigers/100 km²	SD (tiger density)	average prey encounter rates	SD prey er	Grassland area (km²)
Mailani (SKFD)	SKFD	86.08	64.00	3.96	0.01	4.58	1.10	2.14
Gola	SKFD	42.50	41.00	1.94	0.07	3.25	0.25	3.61
Mohammadi	SKFD	22.75	37.04	0.56	0.00		na	0.31
Kishanpur	Kishanpur WLS	117.95	17.75	8.34	0.03	5.40	1.91	23.99
Mailani	Kishanpur-WLS	79.07	5.20	3.38	0.02	2.85	0.48	12.47
Gauriphanta	DNP	37.91	36.50	0.00	0.00	0.34	0.08	1.03
Bankati	DNP	63.80	6.50	0.00	0.00	0.17	0.16	7.24
Sathiyana	DNP	57.00	48.00	0.01	0.00	0.99	0.44	18.77

Major conservation & management issues	Unique habitat features	Conservation opportunities
Narrow forests, heavily used by humans. Presence of a highway between Mauhrena and Bharigama beats. A tiger cub was caught in an ungulate-snare in 2013, highlighting hunting presure. Logged forest.	Presence of the Kheri Canal, and Ull and Katna rivers.	Riverine tracts attarct tigers and must be secured. Studies need to be conducted to determine how forettery operations influence the occurrence and abundance of wildlife.
Bottle-neck in connectivity between Bhira and Gola Ranges.	Presence of extensive wetlands and streams.	Unexpectedly high tiger use for a area that appears to be 'marginal'. Key habitats along water bodies need to be protected.
Small, disturbed and fragmented forest, witnesses occassional tiger use.	Presence of perennial water source may attract tigers.	Monitor movement of tigers through farmlands from Mailani range to Mohammadi. Enhance protection.
Presence of a highway, railway line and 2 villages within the sanctuary.	Extensive grasslands, wetlands, the Ull and Sharda Rivers and the Kheri Canal. Buffered from forest-exterior villages by other forests and water bodies.	Protect key habitats to support breeding tiers. Manage tourism better. Emphasis on grassland management. Enhance protection and monitoring along the Sharda river, using elephants.
Prey densities and tiger use of this area were surprisingly low. Presence of Madah ashram in the forest attracts many vehicle and pilgrims.	Presence of the Ull River and associated grasslands	Strengthen protection, manage grasslands along Ull River. Reduce human disturbance in Madah ashram.
Presence of a highway, and long shared border with settlements in Nepal. The Laljhari corridor has been 'encroached' by settlements.	High quality sal forests and some riparian tracts.	Co-ordinate with agencies in Nepal to restore the Laljhari corridor. Reduce human pressure both from populations in Nepal and India.
Proximity to many Tharu settlements (forest enclaves). Water is relatively scarce in the summer. Presence of a highway.	Several large grasslands (phantas), and presence of perennial water (*nalas*).	Manage grasslands and enhance protection to recover tiger and prey populations. Engage with communities to reduce conflict
Proximity to Nepal border, high hunting pressure in Neora and nagrol Nala areas. Protection efforts are inadequate in grasslands and riparian forests of Belghat and Ambargarh blocks. Very limited tiger presence in past 3 years suggests that this area merits urgent management attention.	Extensive grasslands, the Suheli River and several nalas. Some of the finest riparian habitat in the Indian Terai. Presence of swamp deer, hog-deer and elephants.	Protect key habitats to support breeding tiers. May require the creation of anti-poaching camps in the remote forest interior and the use of elephants to patrol grassland habitats. Effective grassland management is also an important objective. High recovery potential for tigers.

Range	Site	Area (km^2)	Extent of forest edge in km	predicted density of tigers/100 km^2	SD (tiger density)	average prey encounter rates	SD prey er	Grassland area (km^2)
Dudhwa	DNP	157.45	77.00	0.64	0.00	0.79	0.64	30.00
South Sonaripur	DNP	108.00	20.00	4.51	0.03	3.60	2.14	34.30
North Sonaripur	DNP	95.41	68.20	3.14	0.02	0.81	0.34	7.95
Belrayien	DNP	165.20	59.20	1.96	0.02	0.96	0.59	30.21
Katerniaghat	Katerniaghat	181.00	90.00	4.63	0.01	2.12	1.63	48.00

Major conservation & management issues	Unique habitat features	Conservation opportunities
Surma, a Tharu settlement in the core zone and proximity to several other 'hostile' villages along northern and southern boundary make management challenging. Roads and railway line in the interior. This large range of Dudhwa National Park witnesses far lower use by tigers that might be expected.	Several phantas, and seasonal wetlands, and riparian habitat along the Suheli river. Extensive patches of 'old-growth' sal forests.	Protect key habitats to support breeding tiers, manage grasslands for prey. Priority recovery Range for tigers and prey.
Human pressure is low in most areas which are insulated from the forest periphery, except Gulra block. High tourism pressure. Trains ply at high speeds through this wildlife-rich area. Human wildlife conflict (cattle lifting) commonly reported in Gulra range.	Large grassland and riparian habitat tracts. Complex habitat mosaics, wetlands and the Suheli River. Fenced enclosure for Rhinos may provide protection to other ungulates as well.	Protect key habitats to support breeding tiers, manage grasslands for ungulate prey, and other wildlife (eg. Bengal florican). Effective tourism management. Enhanced protection along India-Nepal border. Implement cattle compensation scheme.
Proximity to many forest-interior Tharu settlements. Hunting pressure on wild ungulates. Shares boundary with settlements in Nepal. A large section of this forest along the Mohana river is narrow and faces extremely high human pressure. Many camera thefts indicate that protection needs to be enhanced.	Small but significant grasslands along the Jaura nala. Mohana river marks the Northern Boundary.	Enhanced protection. Solicit community engagement to strengthen conservation. Restore habitats and reduce disturbance along Mohana river.
Long forest-edge. The Basanta corridor (in Nepal) is connected with Belapersua block, near the Mohana River. High cattle grazing pressure along southern boundary, and frequent cattle lifting by tigers. Recurring camera losses in Mauhrena and Bhairampur blocks. Some productive wetland habitats (eg Bhadi tal) do not support high prey and tiger densities as was expected.	Large wetlands, and tracts of productive Riparian habitat along the Suheli River, and in wetlands like Bhadi and Chaurela tal.	Protect key habitats to support breeding tiers. Initiate efforts to revive the Basanta corridor in association with Nepal. Elephants use Bhadi and other wetlands.
Long border with settlements in India and Nepal. Presence of Bhartapur village (Trans-Girwa beat) and Bicchia village in 'prime' tiger habitats. A number of roads and a railway line pass through this Range. The Girajapuri seed farm attracts both wild and domestic ungulates, but is highly disturbed and over-grazed by cattle.	Presence of the Girwa river and reservoir has created rich wetland habitats.	Strengthen protection, manage grasslands. Reduce dependance of local communities on forest resources. Regular joint monitoring and patrolling along Indo-Nepal border. Need for increased vigilance along the southern end of the Khata corridor. Restore habitats in the seed farm.

Range	Site	Area (km^2)	Extent of forest edge in km	predicted density of tigers/100 km^2	SD (tiger density)	average prey encounter rates	SD prey er	Grassland area (km^2)
Nishangara	Katerniaghat	109.87	57.50	1.51	0.01	2.07	2.15	32.50
Murtiah	Katerniaghat	45.26	29.50	0.12	0.00	0.17	0.13	0.84
Dharmapur	Katerniaghat	48.92	22.00	0.00	0.00	0.47	0.86	0.35
Kakraha	Katerniaghat	41.36	52.00	0.01	0.00	0.10	0.02	1.16
Motipur	Katerniaghat	57.31	60.00	0.96	0.01	na		0.53

Major conservation & management issues	Unique habitat features	Conservation opportunities
The Bagluia seed-farm area is over-grazed by cows and buffaloes. Presence of a road and railway line.	The seed-farm area is used by many wild-ungulates and tigers (despite day-time grazing). A large canal serves as an important water source.	Restore wildlife habitat in the seed farm, and reduce cattle grazing pressure. Enhanced protection along the international border, and water sources.
The forests are dominated by dense-tree-growth. Few grasslands or water sources. Long border with settlements in Nepal. Presence of a road and railway line.	Dense sal and *Terminalia* forest, with few understorey openings.	Protect key habitats. Enhanced protection along the international border.
The forests are dominated by dense-tree-growth. Few grasslands or water sources. Long border with settlements in Nepal. Presence of a road and railway line.		Protect key habitats. Enhanced protection along international border.
The forest is narrow and highly disturbed.	A canal serves as a water-source and attracts many ungulates.	Increase protection , reduce disturbance levels.
The forest is narrow, degraded and highly disturbed.	A small river serves as a perennial water source. Cane and other scrub forests allowed the existence of a tigress with cubs in 2013.	Increase protection efforts, reduce disturbance.

Sharing the findings from a camera trap study with residents of a forest-edge village.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APPENDIX 1
PROFILES OF TIGERS CAPTURED IN DUDHWA TIGER RESERVE IN 2013

(left flank) *(right flank)*

DNP 1

DNP 2

DNP 3

	(left flank)	*(right flank)*
DNP 5		
DNP 6		
DNP 8		
DNP 9		

(left flank) *(right flank)*

DNP 10

DNP 11

DNP 13

DNP 15

	(left flank)	*(right flank)*
DNP 16		
DNP 17		
DNP 18		

JUVENILES AND CUBS

(left flank) *(right flank)*

Banke cub 1

Banke cub 2

Gulra cub 1

(left flank) *(right flank)*

Gulra cub 2

Gulra cub 3

APPENDIX 1
PROFILES OF TIGERS CAPTURED IN KATERNIAGHAT IN 2013

(left flank) *(right flank)*

KGT 1

KGT 2

KGT 4

(left flank) *(right flank)*

KGT 5

KGT 7

KGT 8

KGT 10

(left flank) *(right flank)*

KGT 11

KGT 12

KGT 13

KGT 15

(left flank) *(right flank)*

KGT 17

KGT 19

KGT 20

KGT 21

(left flank) *(right flank)*

KGT 25

JUVENILES AND CUBS

Kakraha juvenile 1

Kakraha juvenile 1

Kakraha juvenile 2

KGT 19 Motipur female with 2 cubs

APPENDIX 1
PROFILES OF TIGERS CAPTURED IN KISHANPUR IN 2013

(left flank) *(right flank)*

KIS 1

KIS 2

KIS 3

(left flank) *(right flank)*

KIS 4

KIS 5

KIS 6

KIS 7

(left flank) *(right flank)*

KIS 9


KIS 10


KIS 11


KIS 12


(left flank) *(right flank)*

KIS 13

KIS 14

KIS 21

KIS 22

(left flank) *(right flank)*

KIS 23

JUVENILES AND CUBS

(left flank) *(right flank)*

Cub of KIS 7

Cub of KIS 7

Cubs of KIS 7

Cub of KIS9

Cub of KIS9

Cub of KIS9

KIS 5 with cubs

KIS 7 with cubs

APPENDIX 1
PROFILES OF TIGERS CAPTURED IN SKFD IN 2013

(left flank) *(right flank)*

SK 1

SK 3

SK 4

(left flank) *(right flank)*

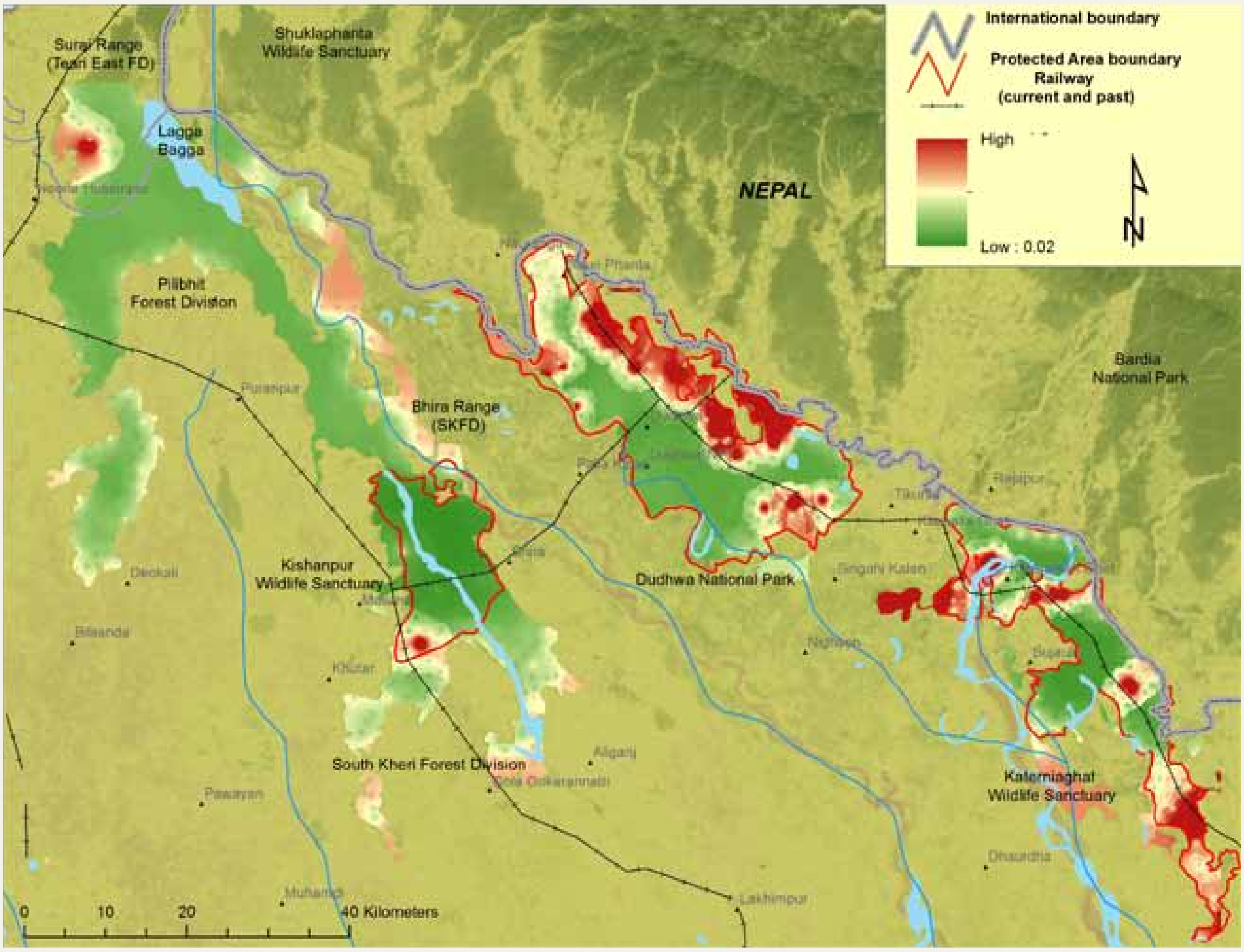
SK 5

SK 7

SK 8

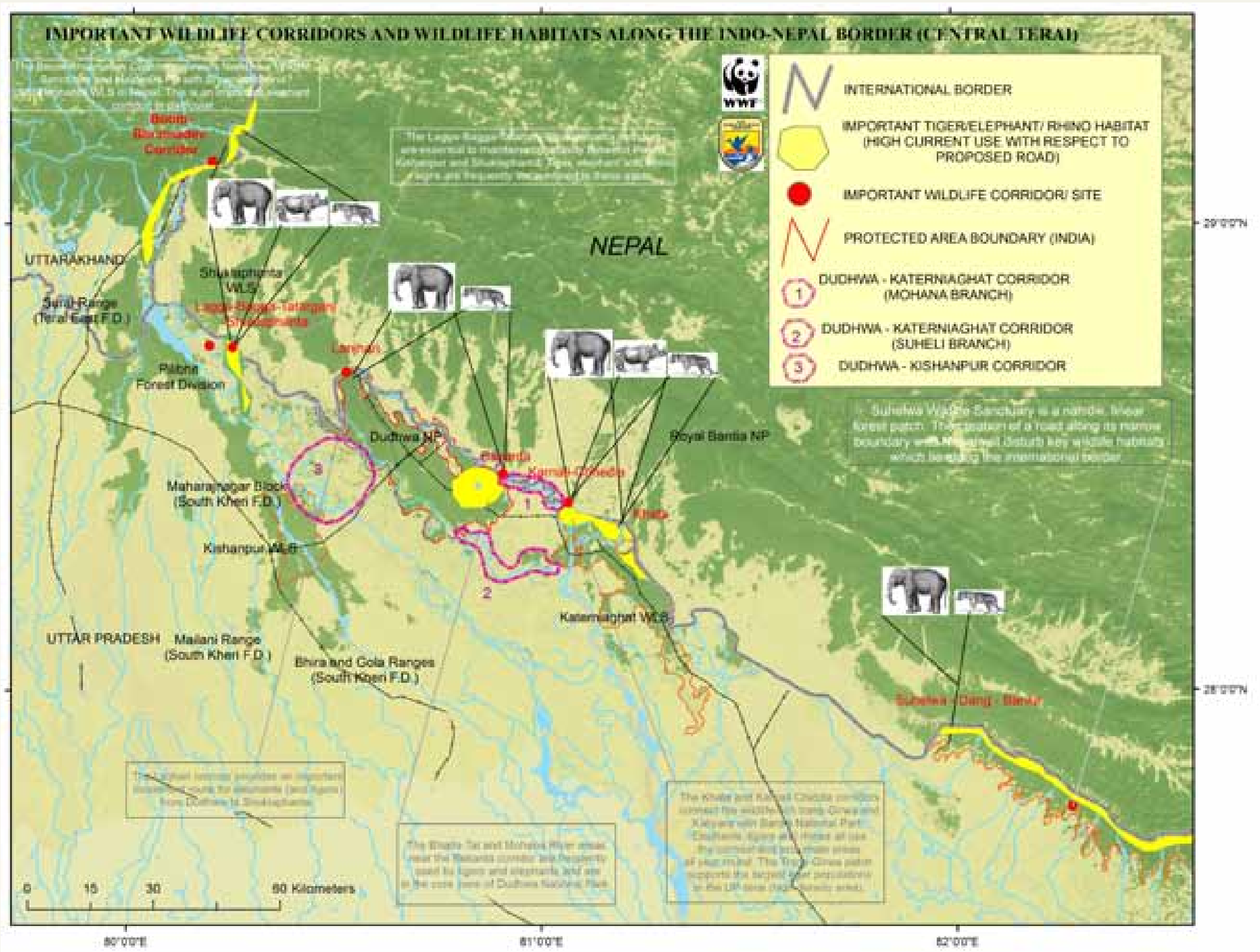
Bharigamma cub

APPENDIX 2
"THREAT MAP" FOR DUDHWA TR AND PILIBHIT FD



This map was created by interpolating camera trap locations, based on the duration for which they were functional in the field. Cameras that were deployed for longer period (and remained intact) were assigned a low threat score, whereas cameras that were stolen or vandalized were associated with a high threat score (high theft zones are in shades of red in this map). Statistical and mapping operations were carried out in program R and Arc GIS.

APPENDIX 3
MAP OF IMPORTANT CORRIDORS IN THE CENTRAL TERAI LANDSCAPE



APPENDIX 4
TIGER CONSERVATION IN NORTH AND SOUTH KHERI FOREST DIVISIONS

South Kheri Forest Division (area ~ 280 km^2) shares boundaries with Kishanpur WLS, Pilibhit FD and Shahjehanpur FD. This forest division is comprised of four ranges Bhira, Mailani, Gola and Mohammadi. The Sharda river flows along the eastern boundary of Maharajnagar block of Bhira Range. The Ull River flows through the southern portion of Bhira and Gola ranges, while the Katna river flows through a portion of Mailani range. The Kheri branch of the Sharada canal (which originates in Pilibhit Forest Division) flows through the western portions of Mailani Range. The vegetation in SKFD is dominated by sal forests (with associates such as Termanalia alata, and Mallotus philippensis). Portions of the forest are under extensive eucalyptus and teak plantations.   Like Pilibhit FD, SKFD is associated with managed timber extraction, particularly dead and diseased sal trees.

Camera trap data yielded evidence for the presence of 10 tigers in South Kheri Forest Division. Five of these were also camera trapped either in Kishanpur WLS or Pilibhit Forest Division, and were therefore not unique to South Kheri FD. Of the other five, 1 female held a territory in Bhira range, 2 females in Mailani range and one female and one male in Gola Range. All these animals were distributed along perennial water sources. Maharajnagar block and the northern portions of Gola Range which is characterized by marshy-habitats appear to be 'superior' tiger habitats in SKFD. We encountered chital, wild pigs and nilgai on line transects in SKFD, and no large groups or congregations were encountered. Some portions of SKFD, including Maharajnagar and Palnapur blocks experience high levels of cattle grazing.

These results indicate that South Kheri Forest Division does not have inferior wildlife value in comparison to the better known wildlife areas (Kishanpur WLS and Pilibhit FD). We recommend that even if SKFD continues to be managed as a worked forest with sanction timber extraction, due attention needs to be paid to the conservation of the regions large mammals and other wild fauna.

North Kheri Forest Division is an unusual Reserve Forest. This forest division is made up of numerous small forest patches strung out along the Northern bank of the Sharda River, and along the Mohana river. Other small patches of NKFD lie in the agricultural belt between Dudhwa National Park and Katerniaghat WLS (Figure 4A). The forest patches of NKFD (area ~ 165 km2)range between 0.2 and 30 km2 in area and are characterized by riparian vegetation dominated by species such as *Acacia catechu*, *Bombax ceiba*, *Zizyphus species*, *Dalbergia sissoo* and tracts of *Saccharum spontanum* and other grasses. Several areas of North Kheri Forest Division have been encroached by sugar-cane cultivators, and the boundaries of some forest patches along the Sharda river are 'remoulded' each year, by flooding events (Midha and Mathur 2014) Although most patches of the North Kheri Forests are disconnected with other forest areas, several patches have been associated with the intermittent occurrence of tigers. In particular, we documented tiger presence based on indirect evidence (signs) or through opportunistic camera trapping in four forest patches namely Tatarganj, Paraspur-Lagdhan, Majgai and Manjhra. We also encountered tiger pug-marks along the Mohana River, on the India-Nepal border.

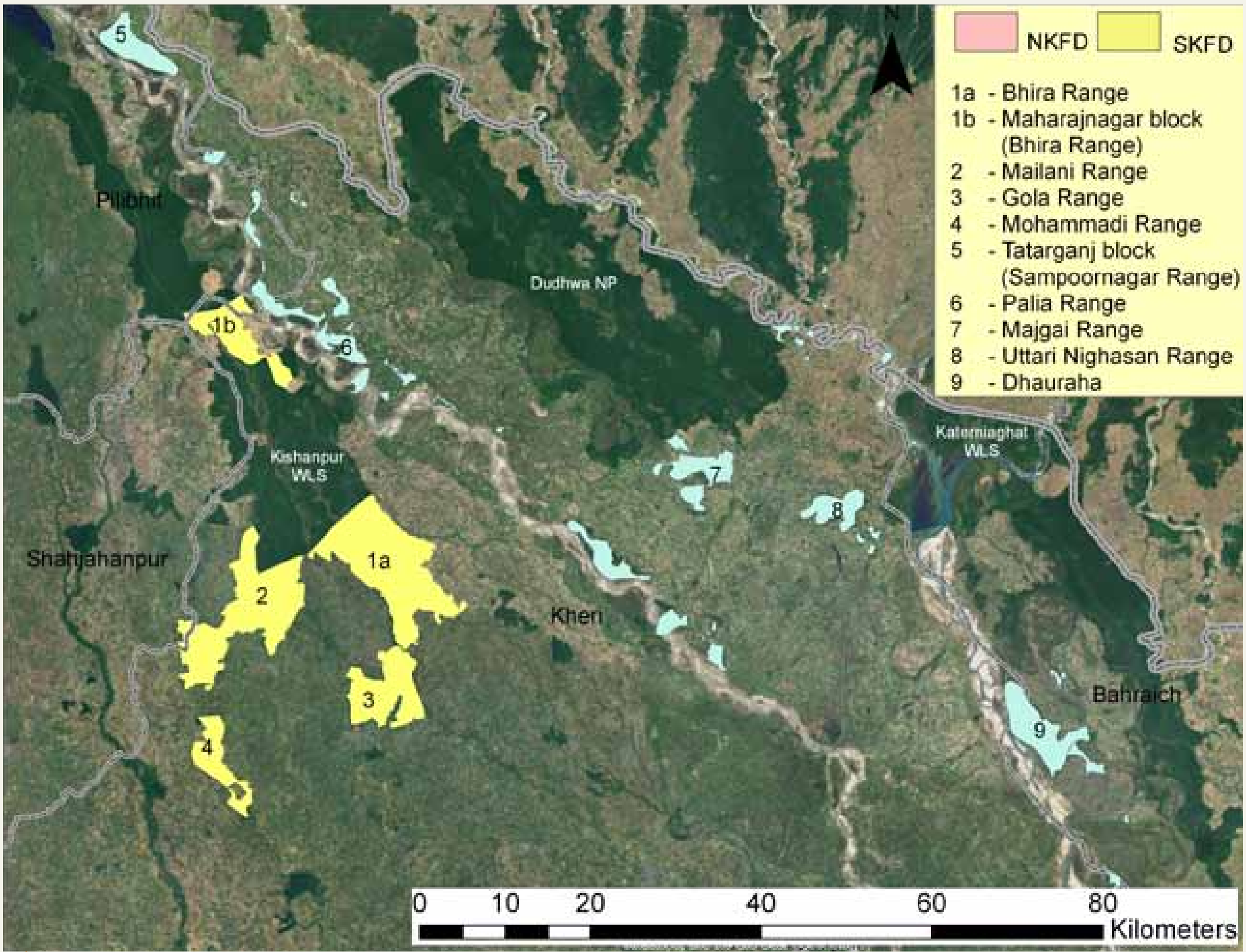


Figure 4A
Ranges and forest patches of South and North Kheri Forest Division. Note: Some patches of NKFD may have been omitted from this map.

The appearance of tigers in some of these forest patches on occasion, and regular use of other patches (e.g. Tatarganj and Paraspur-Lagdhan) poses some interesting questions about the distribution and movement of tigers. More so, such occurrences are a reminder that conservation efforts need to be extended to forests beyond Protected Areas. Particularly, we believe that there is an urgent need for higher levels of enforcement and patrolling in the Tatarganj and Paraspur patches. The former site serves as an important corridor that links the Kishanpur-Pilibhit forest complex to Shuklaphanta WLS in Nepal. The later is close to Kishanpur WLs, and we photo-documented the presence of a female with two young cubs in the forests and cane plantations of Paraspur in 2013. To protect dispersing tigers, it is also very important that the Majgai and Manjhra forests along the Suheli river (between DNP and Katerniaghat WLS) be protected, as also the north-lying remnant forest and grassland areas along the Mohana river. The Mohana river, is thought to serve as a corridor for the movement of rhinos, elephants and possibly also for tigers (Sinha 2003).

The forests of NKFD are primarily distributed along the Sharda river and are suitable habitats for tigers and several prey species even though they are disturbed and disconnected from larger forest tracts. Tigers are commonly present in NKFD's forest patches, even though they may not be resident in these small patches. It is important that NKFD's forests be thoroughly surveyed in the near future and that monitoring be carried out for for tigers other wildlife on a regular basis. The need for enhanced conservation and protection measures in these frorests, which may serve as corridors or 'stepping stones' for dispersing tigers is emphasized.

APPENDIX 5
TESTING FOR CLOSURE

Site and year	Occasions	Stanley and Burnham			Otis et al	
		Chi square stat.	Df	p value	z-value	p-value
DNP 2012	60	138	36	0.00	-5.5	0.00
DNP 2013	60	6894	58	0.00	-6.8	0.00
Katerniaghat 2012	54	63	40	0.01	-6.4	0.00
Katerniaghat 2013	59	4605	52	0.00	-5.2	0.00
Kishanpur 2012	47	7818	45	0.00	-1.22	0.11
Kishanpur 2013	47	5505	45	0.00	-1.88	0.03
Pilibhit 2013	59	124	32	0.00	-6.35	0.00

Table 5A 1
Site and year specific results for the Otis *et al* (1978) and Stanley and Burnham(1999) tests for population closure.

For the tiger populations sampled by camera traps, we assumed demographic closure for the sampling period (≤ 60 days) —that is, gains (birth and immigration) and losses (death and emigration) minimally affect population size during the study period. We also took necessary steps in data analysis to ensure geographic closure. Given that a large enough state space S is defined in conjunction with SECR models, the likelihood of violation of geographic closure is greatly reduced (Royle *et al.*, 2009). We used a 15 - 20 kilometer buffer around the trap array to describe S. We tested for closure using (a) the Otis *et al.*, 1978 test which assumes heterogeneity in recapture probabilities (b) the Stanley and Burnham 1999 test for closure which assumes variation in recapture probabilities over time and (c) the Pradel test, which allowed us to estimate the sampling area population growth rate λ over the trapping period (Boulanger and McLellan, 2001, Gerber *et al.*, 2012). Closure tests were carried out in program Close Test, Version 3 (Stanley and Burnham 1999), and in program MARK. The complete data-sets (spanning the entire length of camera trapping at each site, up to a maximum of ~ 60 days) were used in closure tests. This is different from the compressed block data sets that have been used for closed population estimation.

Table 5A 2
Site and year specific results for the Pradel test for population closure. The parameter λ, or population growth rate parameter, is centered at 1, when a population is stable (shows no growth or decline) over the period of interest.

Site	Λ	SE λ	CI λ
Dudhwa 2012	0.99	0.01	0.97 - 1.01
Dudhwa 2013	1.00	0.01	0.99 - 1.02
Kishanpur 2012	1.00	0.01	0.98 - 1.01
Kishanpur 2013	1.00	0.01	0.99 - 1.01
Katerniaghat 2012	0.98	0.01	0.96 - 1.00
Katerniaghat 2013	1.01	0.01	1.00 - 1.02
Pilibhit 2013	1.00	0.01	0.99 - 1.03
Pilibhit complex 2013	0.99	0.01	0.97 - 1.00

Methods and results :Closure tests

We believe the assumption of demographic closure for the sampled populations is justified because (a) A mark-recapture analysis was restricted to individuals are likely to have been > 2 years in age (adults); the entry of new individuals into the population (births), during the trapping period would not therefore lead to closure violation, (b) by maintaining a trap spacing of 1.4 to 2 km we minimized the chances of failing to capture females with young cubs who are known to have restricted movements, (c) the death of an adult member of the sampled populations during the trapping period would violate closure, we did not record any known events of tiger deaths within the camera-trap periods that we deemed 'closed' (maximum 60 days. Our results (from SECR models) suggest that the 15 kilometer buffer of habitat areas around the camera trap arrays used in our analysis more than adequately included the activity-centers of animals exposed to camera traps in all sites (see sections 2.2.5 and 3.3.4). This suggests that the populations were likely to have been geographically closed.

When our data for tiger populations from the central TAL landscape were analyzed using the tests of Otis *et al*. (1978) and Stanley and Burnham (1999), the assumption of geographic closure was not met. Z scores and associated p values from the Otis *et al* (1978) test and chi square and p values from the Stanley and Burnham (1999) tests for each of the sites over 2012 and 2013 are provided in tables 2.3 and 2.4. Low p values indicate the lack of population closure.

Use for the Pradel model to test for closure provided little evidence for permanent closure violations. The estimates of λ and associated standard errors are all centered around a value of 1.00 (table 2.4). These results are interpreted in more detail in the discussion.

Discussion : Closure Tests

The populations we sampled were likely to be geographically closed. This conclusion is based on the following: (a) SECR estimates are relatively stable when the ESA is rescaled to incorporate a range of values from the 1/2 MMDM to a distance of 20 kilometers; (b) for Dudhwa NP and the Pilibhit-Surai-Kishanpur-South Kheri forest complex, we sampled 'tiger habitats' in their entirety, and believe it is appropriate to assume that animals photo-captured had their home range centers within these areas. This is true for Katerniaghat as well, except that this sanctuary is connected with Bardia National Park (Nepal) via the Khata corridor. Our large buffers (15 - 20 km) for density analysis extended deep into this corridor and described the state-space adequately. Although the Surai forests are connected with the Kilpura Range of Haldwani Forest Division, functional connectivity through the existing forest-corridor may be severely compromised and tigers may rarely use these areas (Meraj Anwar, WWF-India, pers. comm.); (c) the capture accumulation curves (chapter 3) reveal that even when a 'rotating-block' design was employed to sample a site with camera-traps, the capture-accumulation curves for new individuals in camera-traps typically reached an asymptote in 12 - 20 days, which suggests that there were relatively few new entrants into our study populations; and, (d) Pradel model analysis (Table 2.4) provided evidence for the lack of tigers permanently immigrating into, or emigrating from, the sampled areas. Analysis by Harihar *et al* (2009) for tiger capture-recapture data clearly indicate that as the trap-area increases (to ~ 50 km^2), estimates of site-fidelity approach 1, whereas immigration rates drop towards 0. Trap-areas in all sites in our study were > 200 km^2.

The results of some commonly used tests for population closure suggest we may have violated this assumption. However, given that capture probabilities in the sampled populations were primarily affected by individual heterogeneity it was unlikely our data would met the assumptions of Stanley and Burnham's (1999) test which assumes time variation in the data. Our test results, (the data did not meet closure assumption), are probably an artifact of violation of assumptions related to detection rather than to population closure (Gerber *et al*., 2011).

APPENDIX 6
A BRIEF REVIEW OF SPATIAL CAPTURE-RECAPTURE MODELS AND DENSITY ESTIMATION METHODS

The development of spatially explicit capture recapture (SECR) models - which we have used for the analysis of capture-recapture data - was motivated by the lack of a method that adequately utilized spatial information for closed capture-recapture models, for data from trap arrays (Borchers and Efford 2008, Efford *et al*. 2009, Royle and Dorozio 2008). These methods are now widely applied in conjunction with camera trap data for marked populations (O'Connor and Karanth, 2010, Royle at al., 2013). Until the development of SECR modes, when estimates of (density) were of interest, existing analytical methods relied on the use of half mean maximum distance moved (MMDM) estimator to define the effective trapping area over which the sampled population was assumed to be distributed. While this estimator was evaluated to be relatively unbiased simulation studies (Wilson and Anderson, 1985), a limitation is that the buffer distance and effective trapping area delineated by these methods is ad-hoc and not explicitly linked to animal species biology. Specifically, describing the trapped area using MMDM approaches is thought to not adequately describe the movement of animals on and off the sampling grid. A likely consequence of this is non-closure, thereby making the estimates of N less reliable (Royle and Gardner., 2011) and there is a tendency for density estimates to be being biased high (Obbard *et al*., 2010, Noss *et al*., 2012, Ivan *et al*., 2013). Biased estimates of density can result in flawed conservation and management decisions/ actions that may imperil populations of rare or threatened species.

The recently developed genre of SECR models provide more robust methods to analyze capture-recapture data. By incorporating spatial information for trap sites, in addition to individual encounter histories, SECR models account for unequal capture probabilities for individuals depending on whether their home range centers lie centrally or peripherally within the sample unit. Moreover, SECR approaches specifically address issues such as trap spacing, and accommodate trap designs wherein traps are rotated in blocks (the design adopted by us). SECR models have the assumption at the activity centers s remain fixed over the duration of the study. In addition, spatial capture recapture models require (i) activity centers to be randomly distributed, (ii) encounter probability (animal detection) to be a function of distance from an individual's home range centre, and (iii) independence of encounters. (Royle *et al*., 2013). The effectively sampled area in the spatial capture recapture framework is viewed as being influenced by the overall sampling effort (number of sample stations and occasions over which they are active). In addition, the effective sample area is also a function of the movement process of the species being sampled (scaled by the parameter σ) (Royle and Dorozio, 2008, Borchers and Efford, 2008).

The underlying principle for SECR models derives from point process models, wherein the point process is typically modeled as a binomial process (conditional on N), or a Poisson process (not conditional on N). Individual animals are assigned spatial attributes in the form of latent unobserved activity centers, S, such that for a population of N centers, si, individuals are distributed in some manner over the study area (Royle and Gardner 2009). The activity centers are distributed over an area S, which typically contains the trap array and some buffer around it. Observations from camera traps are in the form

A peacock displays to a covey of peahens in the Sathiyana grasslands of Dudhwa National Park.

yijk for individual i = 1,2…I, in trap j = 1,2…J and occasion k = 1,2…K). The probability of individuals of being captured in a trap j is modeled as a function of distance of activity centre from the trap location, and another estimated parameter. Appending conventional capture-recapture models with point process models thus provides an elegant way to analyze data derived from trap arrays or genetic samples. Royle and Young (2008), and Royle *et al*., (2009 a,b) have developed Bayesian hierarchical models that incorporate both capture-recapture and point process models by explicitly describing both the distributions of individuals animals in space (ecological process), and encounters of individuals in space (imperfect observations of that process). Hierarchical Bayesian models with random effects provide a means of estimating two unknown parameters concurrently (si, or the home range centers, and N the number of individuals). Density D is estimated by estimating the density of activity centers si within S. The analysis of these models utilizes Monte Carlo simulations from the posterior distribution. This distribution is the product of the distribution of random effects and the conditional likelihood (Royle and Gardner 2011). Likelihood frameworks for the analysis of SECR data have been developed by Efford *et al*., (2008 & 2009). These models can be viewed as being similar to individual covariate models in conventional capture-recapture models. Given that these models comprise of several random effects (locations of individual animal activity centers), the analytical framework utilizes the integrated likelihood.

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STATUS AND CONSERVATION OF TIGERS AND THEIR PREY IN THE UTTAR PRADESH TERAI

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