Proximate determinants of ungulate distribution and abundance in Pilibhit Forest Division, Uttar Pradesh, India

Dissertation submitted to Saurashtra University, Rajkot
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the Master of Science Degree in Wildlife Science

Submitted by

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Under the supervision of

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CERTIFICATE

This is to certify that Mr. Ashish Bista has carried out an original piece of research in partial fulfilment of his M.Sc. (Wildlife Science) Degree of the Saurashtra University, Rajkot. The topic of his dissertation is "**Proximate determinants of ungulate distribution and abundance in Pilibhit Forest Division, Uttar Pradesh, India** ". We attest that the dissertation was carried out under our supervision from December 2010 to June 2011, and that this work has not been submitted for any other degree of any university/institution.

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I am grateful to my parents who supported me throughout my life and encouraged me to pursue this course at W.I.I. My this life may fall short to thank and serve you.

Dedicated to

All Frontline Staff

&

Conservationists

Summary

This study was conducted in Pilibhit Forest Division, Uttar Pradesh from December 2010-April 2011 to quantify the current status of ungulates, as a measure of tiger conservation efforts. The study focused on understanding the distribution and population size of ungulates in Pilibhit, and assessed the contribution of these species in tiger's diet. The study also looked into species-habitat association, at the level of proportion of habitat availability and grassland over space. Sampling framework followed Stratified Random Design, with spatially balanced approach. Estimates of distribution and population density were obtained following Single Season Occupancy Model and Distance sampling method.

A total of 41 grids (5.20 sq km each) were sampled following the above framework. These grids were sampled based on 41 line transects ranging from 1 to 3 km long, which accounted for 288 km sampling efforts, including 3-5 temporal replicates for each transects. This study was carried out in four ranges (Mahof, Mala, Barahi & Haripur) of Pilibhit Forest Division with spatial coverage of *ca.* 420 sq km. Occupancy pattern of ungulates were in the order of chital (100%), hogdeer (17%), wild pig (93%), nilgai (81%), swamp deer (11%) and sambar (3%). Global density estimate of ungulates for Pilibhit Forest Division was 40.5 animals/sq km. The most abundant ungulate was chital (22.4/sq km), followed by nilgai (12/sq km) and hog deer (7.2/sq km). It was found that there were higher densities in edge habitats and that there was a particular association for grassland, signifying the importance grassland patches in the ungulate densities in terai habitats. Scat analysis (n= 24) revealed that hogdeer and wildpig, though occur in low densities, appeared to be the preferred prey, while chital contributed in tigers diet substantially in proportion to availability in the area. With given prey availability, forests of Pilibhit has the potential to support tiger population of 8.1 animal/100 sq km.

The study highlights the significance of managed forests in terms of supporting considerable population of ungulates relevant for tiger conservation efforts. The study also supports the previous claim that grasslands support higher abundance of ungulate prey, and that in the absence of large sized prey, tiger switches to medium sized prey. The available information generated for the first time in Pilibhit Forest Division at large spatial scale provides a useful baseline for managers.

1.0 Introduction

1.1 **Background**

This study was formulated in the context of tiger conservation and looked into the ecological significance of grasslands in supporting ungulate population in one of terai habitats (Pilibhit forest) in India.

Terai is a fragile habitat which supports immense wildlife value due to existing grassland patches (Wikramanayake *et al.* 1998). Such potential habitats still exist outside Protected Area in many parts of terai with occupancy of tiger and its prey. However, these habitats are threatened both from human activities such as habitat fragmentation, collection of NTFPs, poaching, as well as management practices guided with very poor or no focus on wildlife in it. Because of paucity of information on distribution and abundance of tiger and its prey in non Protected Areas, wildlife value has remained compromised to great extent in such forests.

Estimation of population size using robust method is therefore critical to set management priorities in both conserving such potential habitat/animals and developing management strategies. In this context, this study was designed to generate reliable information on distribution and population size of ungulates using robust methods and to understand the importance of grassland in supporting ungulate population in terai. This study also makes an attempt to understand the contribution of ungulates in food habits of tiger.

1.2 Literature Review

1.2.1 Distribution, abundance and conservation of ungulates

Animal distribution and abundance are important aspects in understanding ecological patterns and processes (Williams et al 2001; Krebs 2009) which are driven by natural and human induced factors. Understanding such aspects becomes even more important when animal survival is at stake and management interventions have risen up. Many studies have shown that there is decline in range distribution and population size of tiger, on account of habitat degradation, prey depletion and poaching (Rabinowitz 1993; Kenney *et al.* 1995; Karanth & Stith 1999; Ramakrishnan, Coss & Pelkey 1999; Sunquist, Karanth & Sunquist 1999; Chapron *et al.* 2008). Evidently, small tiger populations can survive in areas where disturbances are minimal, and wild ungulate prey are available (Karanth & Stith 1999; Harihar, Pandav & Goyal 2009). Studies undertaken for understanding the ecology of tiger indicate that the availability and distribution of prey influences its resilience and behaviour. When prey are abundant, tigers continue to survive in fragmented and human dominated landscapes (Smith, Ahern & McDougal 1998; Sunquist, Karanth & Sunquist 1999). Several studies have demonstrated the positive correlation between tiger and prey densities (Sunquist & Sunquist 1989; Karanth & Sunquist 1995; Karanth & Stith 1999). Studies have also revealed that medium to large sized ungulates such as chital and sambar form the bulk of tiger diets (55% - 65% in India) (Karanth & Sunquist 1995; Sankar & Johnsingh 2002). Reliable estimates of prey abundance are, therefore, essential to develop an understanding of tiger ecology and to formulate effective conservation strategies.

1.2.2 Ecological driver of ungulate abundance

Role of ungulates to determine the population size of carnivores is widely studied and is considered to be one of the major factors for survival of predators. Ruminant population is determined by availability of forage (Jarman 1974) and low intensity of disturbance; which indeed reflects the habitat quality. There is difference in body size, morphology and digestibility of forage among ruminants, which sets selection of various habitats among ungulate species. Small bodied ungulates require nutritious forage as compared to medium and large bodied ungulates, because of high metabolism rate and usually remain in low abundance to supplement forage requirements.

Animals are abundant in some areas as compared to others. Since environmental conditions vary over space, there is variation in animal abundance (Brown 1984). Species which has narrow niche requirements will not attain high abundance. Most ruminants usually occupy less disturbed areas and prefer grasses to forbs/browse for forage.

Hogdeer is a grassland specialist, showing strong preference for grassland (Odden, Wegge & Storaas 2005) to meet forage requirements and to escape from predation. Hence availability of grassland patches over space and time will determine the distribution and abundance of this species. Chital abundance is also associated with grassland availability; and shows selection for upland grassland (Kumar *et al.* 2002). However, there is sexual segregation in usage of different habitat type by chital. Apparently, adult males live in forested areas while adult female are more associated with grassland (Moe & Wegge 1997). Wildpig, being a prolific breeder, mostly are present in low abundance utilising various habitat types, from interior of forest to peripheral areas along agricultural fields. Nilgai, are associated with open habitat along agriculture fields. They are either not reported in grassland of terai habitat (Seidensticker 1976), wherever reported they occur in low density 0.1/sq km (Wegge & Storaas 2009) in riverine forests of terai habitat. Therefore, for survival of species such as chital and hogdeer which are the principal prey species for tigers, major habitat correlate could be availability of grassland patches for forage and cover.

Monotonous climax vegetation fails to support high abundance of ungulates because of reduced productivity as compared to early successional stage of grassland and riverine forest. Riverine forests and grasslands in terai are important habitats which support high abundance of ungulates and thus survival of tiger is ensured which is ecologically adapted to survive in such habitat (Wikramanayake *et al.* 1998). These habitats have become rare outside the Protected Areas (Shrestha 2004). The presence of early successional stage (grassland and riverine forest) ensures the survival of species which require such habitat characteristics (Eisenberg & Seidensticker 1976).

Recent study conducted in Terai Conservation Area (TCA) by Mathur *et al.* (2011) indicates that grasslands in terai are areas with high biodiversity value. Study in Chitwan National Park shows that grassland associated species such as chital used different vegetation types as grasslands, riverine forest & sal forest (Seidensticker 1976). Likewise studies as Kumar *et al.* (2002) & Marthur *et al.* (2011) conducted in TCA reveals chital used grassland and closed canopy sal forest more prominently than other vegetation. But, Shrestha (2004) showed that grasslands and riverine forest supported higher abundance of ungulates as compared to Sal forest in Nepal terai part. It is clear that grasslands are important for supporting biodiversity value and usage of grass associated ungulates, but importance of grasslands in supporting abundance of ungulates is still not clear using robust method. One study which looked at similar aspects indicated that riverine forest supported higher absolute density than as compared to sal forest (Wegge & Storaas 2009)). With such dichotomous results (i.e. grasslands supporting biodiversity value but few studies to show importance of grasslands) shown from several studies, understanding the role of grassland patches for determining the distribution and abundance of ungulates is critical for ensuring the survival of both tiger and its prey.

1.2.3 Ungulate contribution to tiger food habit

Tiger prefers large bodied wild ungulates that constitute 75% of biomass in its food (Sunquist 1981, StØen & Wegge 1996, Biswas & Sankar 2002). Availability of large to medium sized ungulates therefore determines the survival of tiger. However, when large bodied ungulates are rare, there could be a shift in predation on medium sized ungulates. Removal of medium sized ungulates in such habitat with low large prey leads to non-selective predation (Karanth & Sunquist 1995). When large bodied ungulates are scarce, there is selection of prey among medium sized ungulates based on proportion of availability (StØen & Wegge 1996). However, this selection of prey was not in proportion to availability in Pench National Park (Biswas & Sankar 2002). With such contrary findings, it is important to understand the contribution of individual species in the diet of tiger in places such as Pilibhit FD where large bodied ungulates are scarce.

1.3 Rationale of the study

Tiger populations across their range face immense threat due to loss of natural prey, isolation of their habitat and poaching. Small, isolated populations are likely to suffer from stochastic events leading to inbreeding (Caughley 1994) and therefore, ensuring the habitat connectivity with simple and rapid monitoring tool for detecting changes would ensure the survival of tigers (Linkie *et al.* 2006; Jhala, Qureshi & Gopal 2011). Potential of forests outside Protected Area to serve as biological corridor and population cores has been flagged by few studies (Johnsingh *et al.* 2004; Shrestha 2004). Such forests not only serve the purpose of connectivity at landscape level, but also supports substantial population of tiger and prey (Wikramanayake *et al.* 1998; Johnsingh *et al.* 2004; Shrestha 2004). However most of such forest are soley managed for maximising the timber yield with limited emphasis on wildlife value and such forest may function as sink for wild animal when management focuses on production (Pulliam & Danielson 1991; Woodroffe & Ginsberg 1998) and conflict with local people increases (Ahearn *et al.* 2001).

This study intends to highlight the conservation significance of Pilibhit FD for supporting ungulate populations, one of the important determinants for tiger survival. This aspect needs to be highlighted in Pilibhit because it serves as suitable tiger habitat with estimated density of tiger 5 individual/100 sq km (unpublished data, WWF-India). In the larger Terai Arc Landscape context, the forests of Pilibhit provide functional connectivity between important tiger source populations such as Kishanpur WLS, Dudhwa NP (India) and Sukhlaphata WLR (Nepal). As focus has been to manage tiger population as one metapopulation at landscape level (Wikramanayake *et al.* 2011), the role of Pilibhit forest could be important. It is also important to realise the fact that wildlife values of Pilibhit FD is also facing immense anthropogenic pressure both because it is managed primarily for timber production, and because a large number of people from surrounding areas are dependent on the forest for fuel wood, fodder and other forest produce. Therefore, assessing the status of wild ungulates and understanding the significance of grassland is important in this forest for ensuring survival of tiger in both local and landscape context.

1.4 Objectives

To estimate distribution and abundance of ungulates in Pilibhit Forest Division, Uttar Pradesh.

Research Questions:

(a) What is the proportion of area occupied by different ungulate species in the Pilibhit Forest Division?

(b) What is the absolute density of ungulate species in Pilibhit FD?

To determine the spatial pattern in ungulate abundance with respect to coarse scale habitat characteristics.

Research Questions:

(a) Does the spatial pattern of abundance relate to habitat mosaic provided by wood land and grassland structure?

(b) Does grassland support higher abundance of ungulates?

To determine the contribution of ungulates in food habit of tigers.

Research Question:

(a) What is the composition of ungulate prey in tiger's diet and, is there any prey selection?

2.0 The Study Area

2.1. Location

The study was conducted in Pilibhit Forest Division, Uttar Pradesh, a part of Terai Arc Landscape. The study area covered *ca*. 420 sq km of four ranges of Pilibhit Forest Division, namely Mahof, Mala, Barahi & Haripur (Figure 1). The forests of Pilibhit has been proposed as a Tiger Reserve, that extends over ca 700 sq km with five ranges namely, Mahof, Mala, Barahi, Haripur and Deoria (Figure 1). In North, Mahof Range of Pilibhit FD shares its boundary with Surai Range of Terai East Forest Division, Uttarakhand, and extends to Deoria Range in south. Haripur and Barahi Range shares their boundary with North Kheri Forest Division, South Kheri Forest Division and Shahjahanpur Forest Divison. Deoria Range and part of Mala range forms an isolated block of forest from the main Pilibhit forest complex.

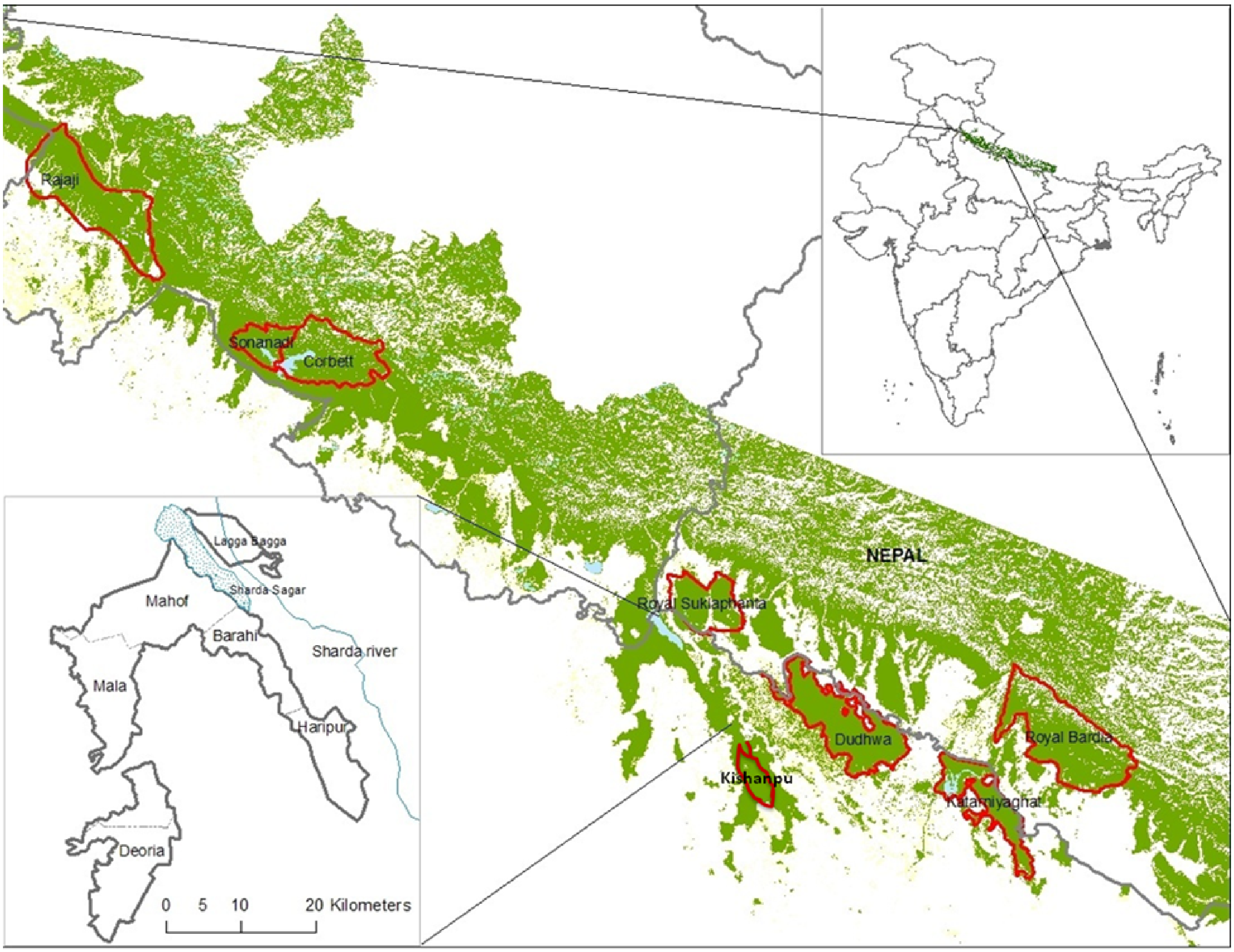

Figure 1: Map showing study area, Pilibhit Forest Division, Uttar Pradesh, India

2.1.1 Terai in general

The terai is an alluvial plain situated between Himalayan foothills and Gangetic plains. Terai extends from West Bengal in East and to Punjab in the west including parts of India and Nepal. Because water table is high and perennial rivers flow, numerous swamps and marshes characterise Terai with fertile alluvial soil. These swamps and marshes provided habitat preferred by many generalist as well as specialist species, including both mammals and avifauna.

This situation of land with high productivity and diverse wildlife value remained as a dilemma for administrators and conservationists. Because in such situations administrators looked terai as land with opportunities for exploitation of natural resources; while conservationist looked it as paradise for wilderness. Terai provided suitable habitat for animals with swamps and marshes and less influenced by human population, strictly regulated by malarial infection (Strahorn 2009). However, for the purpose of exploitation outside settlers were encouraged to settle down in terai land. Furthermore, after independence Government also settled refugees from East Pakistan and Pakistan in terai and encouraged them to reclaim the marshes and swamps and hunt to make land habitable. With malarial eradication programmes, policy such as a bounty for each dead tiger and no provision of complete ban on hunting of tigers and animals caused devastating loss of wildlife from terai habitat. The indication for decline of tiger and prey population is indicated from stories of Jim Corbett, where he mentions about tigers becoming maneater and, livestock uplifters and the reason may be associated to low prey availability, apart from tigers inability to hunt with old age. Therefore, terai is a landscape which has undergone transformation for fighting against malaria and creation of hostile environment for developmental activities by converting marshes and swamps, which once used to be prime wildlife habitat.

2.2 Topography

The terrain is flat in most part of Pilibhit Forest Division. There is a slight general slope in Chuka dhaya. Chuka dhaya is a rugged bank which runs from North to East part of the forest where ground drops down to Chuka River. There are numerous water bodies and channels in forests of Pilibhit FD. One such important water system is Mala river, which forms swampy areas on each side of it. This river runs through the centre of forest across Mahof range and Mala range. This river is of considerable importance for supporting wildlife value of Pilibhit and also provides cover and water for tigers, especially during hot summer. Apart from Mala river, another water system is Sarda Canal, that starts from Banbasa in Uttarakhand and runs through the forest of Pilibhit. There are no cemented banks in these canals.The canal has controlled the natural drainage of the soil and soil has retained moisture because of natural seepage (Nautiyal 1942).

2.3 Climate

Two extreme of temperatures prevail; winter (cold) and summer (hot) periods. Winter lasts for almost four month from November to February. There is heavy frost, dew fall and mist with some rains in December and January. The summer begins from March and lasts till monsoon arrives in June. The weather is hot during this period, with intense westerly wind. Monsoon arrives by mid June and prolongs till November. The water logging condition provides breeding ground for mosquitoes and prevalence of malarial fever.

2.4 Vegetation

As per the Working Plan of the area (Nautiyal 1942), the forest here is primarily composed of chandars and sal dominated forest. Chandars are areas with grass with or without sal which run north to south in parallel to rivers. Sal chandars are savannah type with composition of different grass species such as *Themeda caudate, Saccharum munja, Saccharum spontaneum, Vetiveria zizanioides, Imperata cylindrica, Heteropogon contortus, Ischoemum angustifolium* and sal coppice which are killed every year by frost and fire. Similarly, other category of chandars is Grass chandars which is different from Sal chandars as it does not contain any sal shoots. Species composition for this grassland is similar to above however; these remains waterlogged during rains and are low-lying areas. The dominated canopy is that of Sal, which is managed for commercial yield. Sal forest consists of pure sal trees with few sal associates such as *Terminalia belerica, Lannea grandis, Stereospermum spp, Haldina cordifolia* and *Lagerstroemia parviflora.* Undergrowth shrub vegetation is composed of species such as *Clerodendron, Pogostemon* and others. Owing to fact that it is a reserved forest managed for the purpose of commercial utilisation of timber, the forest has been classified based on quality of timber (Nautiyal 1942; Gupta & Joshi 1971) as

(a) Good Sal forests bordering the Chuka river

(b) Good and medium Sal forest of Dhamella

(c) Open Sal forest of grassy savannahs

(d) Miscellaneous forest of Surai reserve

(e) Miscellaneous forest of low alluvium, and (f) Chandars

2.5 Fauna

Carnivore species from cat family found in Pilibhit are Tiger (*Panthera tigris*), Leopard (*Panthera pardus*). Similarly jackal, small Indian civet (*Viverricula indica*), common palm civet (*Paradoxurus hermaphroditus*), mongoose and sloth bear (*Melursus ursinus*) are other carnivores found in Pilibhit. Chital (*Axis axis*), hogdeer (*Axis porcinus*), nilgai (*Boselaphus tragocamelus*), wildpig (*Sus scrofa*), barking deer (*Muntiacus muntjak*), sambar (*Rusa unicolor*), swampdeer (*Cervus duvauceli*), and chowsingha (*Tetracerus quadricornis*) are the ungulates found in Pilibhit. Small populations of sambar and swamp deer are also found along the chukka bank and Dhamella kuwa in Mahof range. Probably, swamp deer migrates from nearby areas of Kishanpur and Laggabagga. Few individuals of Asian Elephant (*Elephas maximus*) and one-horned rhino (*Rhinoceros unicornis*) occasionally visit the area near Laggabagga and Haripur.

3.0 Sampling design and methods

Stratified random design was adopted based on sampling of regular sized grids, superimposed on processed IRS/WiFS satellite imagery available at Wildlife Institute of India (Johnsingh *et al.* 2004). The image provides 14 vegetation/land cover classes. Grid cells of 5.20 sq km area corresponding to ungulate home range were generated for the study area (ca. 420 sq km) using fishnet in ArcGIS. The area was stratified as (a) habitat (all forest and grassland types) and non-habitat (agriculture, barren land and built up areas), and (b) the proportion of forest and grassland in each cell. The sampling regime was to survey grids in proportion to available, so that equal amount of sampling effort could be accorded to the specific stratum. This ensured that grids were not sampled with bias, facilitated by the process of randomisation. Sampling the adjacent grids was avoided as far as possible, without compromising on the random selection of grids within each stratum. The general design adopted in this study, allowing for proportionate sampling represented by evenly distributed sampling units (in this case line transects) is referred to as 'spatially balanced design' (Stevens Jr & Olsen 2004).

First level of stratification was based on proportion of habitat available within grids, and the grids were pooled to represent four classes as (1) <25% of habitat, (2) 25-50% habitat, (3) 50-75% habitat and (4) >75% habitat. Since category with < 25% of habitat would not allow to lay adequate length of transect for sampling purpose, was not included in sampling framework. This level of stratification shows the level of exposure to non-habitat area, which are mainly land with agricultural fields. Similarly, for second level of stratification habitat was further classified based on proportion of grassland and forests within the grid. These are (1) forest cover with no grassland, (2) forest cover with trace grassland, (3) and forest cover with >11% grassland. Since grids with higher proportion of grassland were poorly represented in the area, all grids with >11% grassland were pooled together as one category.

A total of 41 grids were chosen in the entire study area (Table 1), and the basic sampling unit was line transect distributed in each of the chosen grids. The study was targeted in four of the Forest Ranges namely, Mahof, Mala, Barahi and Haripur, which together constitute the major portion (65%) of the Forest Division.

Table 1: Allotment of sampling effort at two stratum (*i.e.* proportion of habitat & grassland) for study design in Pilibhit Forest Division.

Strata	Category	Number of grids in each category	Selected grids for Distance sampling from each category	Sampled grids (%)	Transect length (km)
Proportion of Habitat	25-50%	30	9	30	15.4
	50-75%	26	10	38	22.2
	75-100%	78	22	28	49.2
Proportion of Grassland	No Grassland	46	11	24	24.7
	Trace Grassland	58	19	33	39.6
	>11% Grassland	39	11	28	20.7

3.1 Occupancy sampling for determining distribution pattern

Occupancy sampling involves binary response (presence/absence) of target species in a given spatial unit (i.e. grid cell) and the general model underlines 'Closure Assumption'. In order to eliminate the chances of false absence, sampling needed to be done in short interval of time with adequate number of repeats. MacKenzie *et al.* (2002) recommends minimum of two repeats when occupancy is >0.7 (over 70%) and detection probability is >0.3 (over 30%) for a single survey. This recommendation was followed with 2-3 temporal replicates in each grid cell spread over two weeks time period, considering that target ungulates are mostly generalist and chances of non-detection of animal presence was expected to be low. Of the 41 grids, 26 grids were chosen for occupancy sampling, and transects (n = 26) were sampled accordingly as described above. Presence signs as tracks, hoof marks, pellet, shed antler, and direct sightings were recorded during survey.

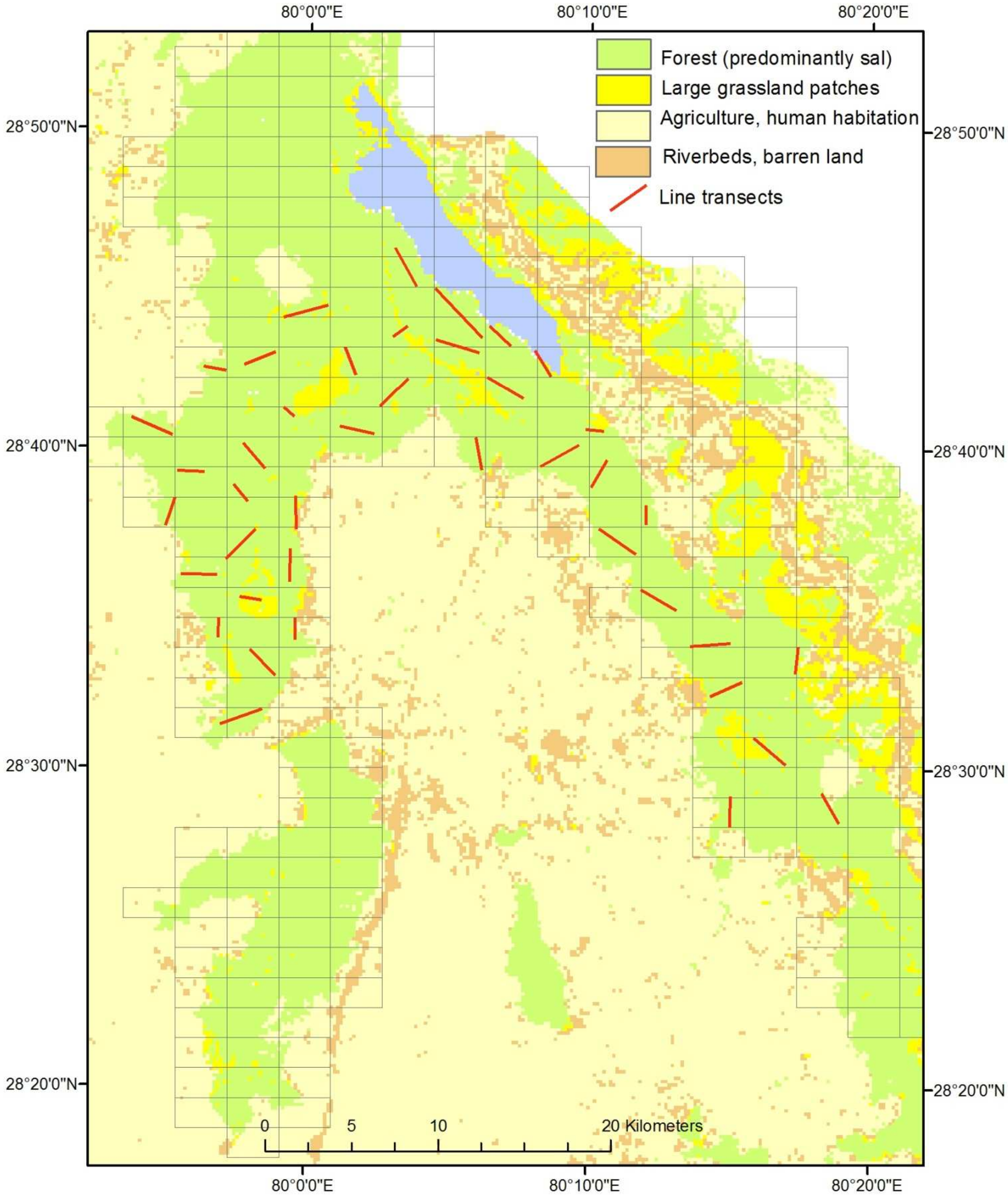

Figure 2: Map showing the design and transect locations in Pilibhit Forest Division.

3.2 Distance sampling for estimating ungulate densities

Distance sampling using open width line transect was adopted for estimating density of ungulates. A total of 41 spatial replicates of transects (1 to 3 km long) distributed in 41 grids were sampled, with 3-5 temporal replicates, amounting to 288 km efforts. Straight line transects were walked on foot by cutting and marking transects with color paint for the ease of walking transect so that more attention could be given in detecting animals rather than looking for paths. Though several trails/forest roads exist, walking line transect was preferred because estimates obtained from walking trails could be biased and unrepresentative to the habitat (Buckland 2001). Only two observers walked the transects in order to avoid unnecessary noise created while walking and hence ensuring better chances of animal sightings. When ungulates were sighted while walking transect, information was recorded on the species, cluster size, radial distance using laser Range finder and sighting bearing using Sunto compass. The population structure was also noted whenever sex and age was identifiable for each species.

3.3 Determining contribution of ungulates in tiger diet

Scats represent definite opportunity for understanding prey consumption pattern. Searches were made in systematic fashion along roads, trails and grassy stripes to collect tiger scat samples. Transect lines and roads/trails leading to transect were intensively searched for scats with minimum of three repetitions within a period of month. Since, 41 transect lines were laid all across Pilibhit FD, covering four (out of five) Ranges, better spatial coverage was ensured with minimum of 288 km search over period of 3-4 months. Additionally, some scats were also collected opportunistically and few came from areas which was a part of Pilibhit FD but not intensive study area.

A total of 24 scats were collected and were processed before observation under microscope for identification of prey item. These scats were soaked in water for 24 hours, washed with fresh running water and put in hot air oven for drying. Slides were prepared with at least 20 hair chosen randomly from different parts of sample as per the protocol by (Mukherjee, Goyal & Chellem 1994). These slides were viewed under microscope for identification of prey species in each scat samples.

3.4 Statistical Analysis

Occupancy Estimation: Detection history matrix was generated using field information on presence and absence in MS-Excel with 3 occasions (columns) and 26 sites (rows) and this was imported in program Presence 3.1. Single-season model was run to estimate the parameters: proportion of area occupied (ψ) and detection probability (p).

Density Estimation: Distance data was analysed in Distance Program ver. 6 using two approaches, (a) pooling data for all species for fitting global detection function curve and (b) fitting detection function at strata level. Density estimate involves fitting of detection probability curve computed as function of perpendicular distance to sightings of animal made (Buckland 2001; Thomas *et al.* 2002; Thomas *et al.* 2010). The model chosen were: Half-Normal function with Cosine adjustment, Half-Normal function with Hermite Polynomial adjustment, Uniform Cosine and Hazard rate function with Simple Polynomial adjustment (Thomas *et al.* 2010). The best fit model was selected based on lower AIC and high goodness-of-test value. Shape criterion and evasive movement was considered while analysing data. Narrow shoulder creates problem as it brings spikiness, so adjustment was made to fulfil shape criterion by setting appropriate distance interval using right truncation and cut points. Cut points were decided based on chi-square goodness of fit p value.

Distance sampling requires 60-80 cluster size for reliable estimation of density and this did not allow density estimation for species with low abundance such as sambar and swamp deer. For those species whose absolute density could not be obtained because of the sample size constraint, proportion of area occupied by species was used as indicator of abundance.

Composition on sex for overall chital and nilgai population pooled from all 41 transects were used for generation of 10000 bootstrap replicates using 95% bootstrap confidence interval calculation method. Average value obtained for each sex class for chital and nilgai with associated standard error is shown in Figure 11. For group size variation in habitat stratum, test of normality was performed using One-Sample Kolmogorov-Smirnov Test (chital $Z=2.775$, $p=0.000$; nilgai $Z= 1.352$, $p=0.052$ & hogdeer $Z=3.236$, $p=0.000$) in SPSS. After testing for normality, Kruskal-Wallis test was performed to see whether there is significant difference in group size between three habitats for chital. Similarly, One-way ANOVA was used to see if there is significant difference in group size for nilgai among habitat strata.

Diet Analysis: Frequency of occurrence (%) i.e. number of scats with specific species over total number of scats in percentage and this was subsequently used to estimate the biomass consumed by predator following the Ackerman equation (Ackerman, Lindzey & Hemker 1984). This equation is represented as,

$$\mathbf{Y = 1.980 + 0.035\ X}$$

where Y = biomass (kg) of species in each scat, X = average weight of individual of each prey species, and 1.980 and 0.035 are standardised correction factors. Once the biomass consumption was determined for each scat, cumulative biomass consumption for specific prey species was obtained by multiplying the number of scats in which the species was found with the biomass value of individual scat.

Selection of prey was studied by comparing observed proportion of scat for each prey with expected proportion of scat for that prey in the area. Expected proportion of scat for each species was obtained from density of species and number of scat produced from one kill using equation given by (Karanth & Sunquist 1995):

$$\text{Expected proportion of scat containing prey in the area} = \{(di/dt)^{*}\lambda\}/\sum\{(di/dt)^{*}\lambda\}$$

where, di is the individual species density, dt is sum of density of all i species, λ= number of scat produced per kill which is computed as body weight (X) of animal divided by correction factor Y (Ackerman, Lindzey & Hemker 1984). Thus, obtained observed and expected proportion of scat containing each prey was compared for using Ivlevs' Index to understand the selectivity of prey by tigers:

$$\text{Ivlevs' Index} = U\text{-}A/\ U\text{+}A$$

where, U=Observed proportion of scat containing each prey, and A= Expected proportion of scat.

3.5 Organisation of dissertation

The thesis has been organized in the standard format used by previous WII M.Sc. dissertation projects. The content is presented in six sections; (1) Introduction, (2) Study Area, (3) Sampling Design and Methods, (4) Results, (5) Discussion and (6) Conclusion & Implications. All these information have been synthesised in Summary, given at the beginning of the dissertation. In the study area section, an overview of the location and description of the area is presented, including the broad character of terai habitats. The design & sampling framework for this study is dealt in details in chapter 3. Density estimate obtained based on distance sampling is presented in chapter 4, which also provides information on area occupied by ungulates as well as food habit of tiger in managed forest of Pilibhit Forest Division. Similarly, last two chapters (5 & 6) gives concluding remarks and highlights the important determinant of ungulates in Pilibhit. Citations are followed in the pattern of Journal of Applied Ecology.

4.0 Results

4.1 Occupancy pattern of ungulates

Single season model estimated high psi and p for all the major ungulate species (Table 2). Detection probability estimated for chital, hogdeer, nilgai and wildpig are 0.93, 0.51, 0.92 and 0.95 respectively, and these were accompanied by high detection probability. Due to low sample size, naive estimate was computed for sambar (0.03) and swamp deer (0.11).

Table 2: Occupancy statistics for ungulate species in Pilibhit Forest Division

Species	Naive estimate of ψ	Proportion of site occupied (psi)	Detection probability (p)	SE (p)	Model
Chital	**1.00**	**1.00(0.00)**	**0.93**	**0.03**	ψ(.) p(.)
Hogdeer	**0.15**	**0.17 (0.08)**	**0.51**	**0.17**	ψ(.) p(.)
Nilgai	**0.81**	**0.82 (0.07)**	**0.92**	**0.03**	ψ(.) p(.)
Wildpig	**0.93**	**0.93(0.05)**	**0.95**	**0.03**	ψ(.) p(.)
Sambar	**0.03**	**-**	**-**	**-**	-
Swamp deer	**0.11**	**-**	**-**	**-**	-

4.2 Global density estimates for ungulates

Field data from line transect were pooled for six ungulate species (chital, nilgai, hogdeer, wildpig, sambar and barking deer) to estimate overall ungulate density in Pilibhit FD, number of detection are shown in Table 3 below. However, first four ungulate species were abundant in the study area as indicated by encounter rate of species (Table 4) and potentially the most important prey for tigers because of their biomass and availability. With fitting global detection function (Figure 3) for these four ungulate species, the global density estimate was 40.5 individual/sq km, accompanied by low Coefficient of Variance (Table 4).

Table 3: Summary of ungulate detection in transects (n = 41) during study period.

Species	Number of clusters	Individuals	Total search effort (km)
Chital	184	713	288
Hogdeer	48	62	132
Nilgai	46	209	288
Wildpig	32	70	288
Sambar	1	3	288
Barking deer	2	2	288

4.3. Density estimates for individual species

Chital was found to be the most abundant ungulate species in Pilibhit Forest Division. The density estimate for chital was 22.4individual/ sq km with 14.7% CV (Table 4, Figure 4). Nilgai and hogdeer occurred with density estimate of 12/sq km and 7.2/sq km respectively (Table 4, Figure 5 & 6). Those transects which had grassland were pooled together for analysing hogdeer data. Since considerable grasslands were not available in these two ranges (Haripur and Barahi), species such as hogdeer, a grassland specialist could not be expected to occur in these forests and exclusion of transects in forest was expected to give reliable density estimate. However, hogdeer population is expected to be underestimated because all grassland patches were not possible to sample because of logistic constraint.

Table 4: Density of ungulates in Pilibhit Forest Division. *In each case, four detection functions were fitted to the data. Here the models (detection functions) with the lowest AIC in each set of models are reported with total effort of 288 km (except for Hogdeer 132 km)*

Species	n	ER (CV)	D (CV)	DS (CV)	GOF (df)	*p*	Model	ESW (CV)
Global	325	1.12 (7.5)	40.5 (10.6)	13.7 (9.3)	0.93 (9)	0.34	Half Normal Cosine	41 (5.5)
Chital	183	0.64 (10.4)	22.4 (14.7)	5.9 (13.2)	0.99 (9)	0.43	Hazard Poly	53.4 (8)
Nilgai	44	0.15 (18.8)	12 (47.2)	2.2 (44)	0.99 (5)	0.42	Hazard Poly	35.2 (39.8)
Hogdeer	47	0.36 (25.3)	7.2 (28.5)	5.9 (27.9)	0.69 (3)	0.50	Half Normal Hermite	30 (11.5)
Wildpig	29	0.10 (19.8)	5.4 (29.6)	2 (25.5)	0.84 (2)	0.56	Half Normal Cosine	24.6 (16.0)
Total abundance of overall ungulates *i.e.* chital, hogdeer, wildpig & nilgai in Pilibhit Forest Division (Mahof, Mala, Barahi & Haripur) was 17100 (10.6% CV)..								

ER(CV): Encounter rate with associated coefficient of variance; D(CV): density of individual/sq km with associated variance; DS(CV): density of groups/ sq km with associated coefficient of variance; GOF(df): Chi-square goodness-of-fit with degree of freedom; p: Detection probability; ESW (CV): effective strip width with associated coefficient of variance.

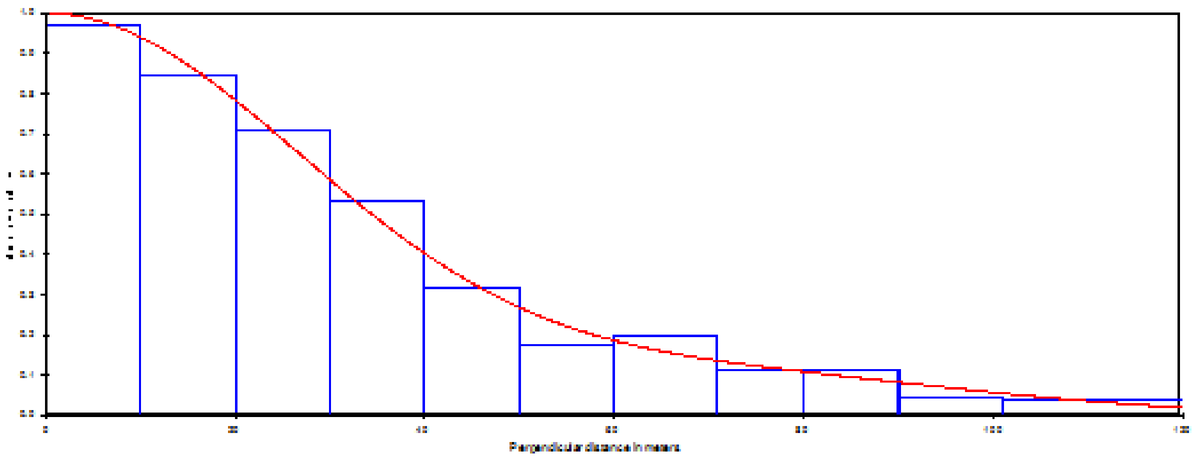

Figure 3: Detection function for global estimate including four ungulate species (Chital, Nilgai, Hogdeer and Wildpig), with chi-square goodness of fit (df) = 0.93 (9)

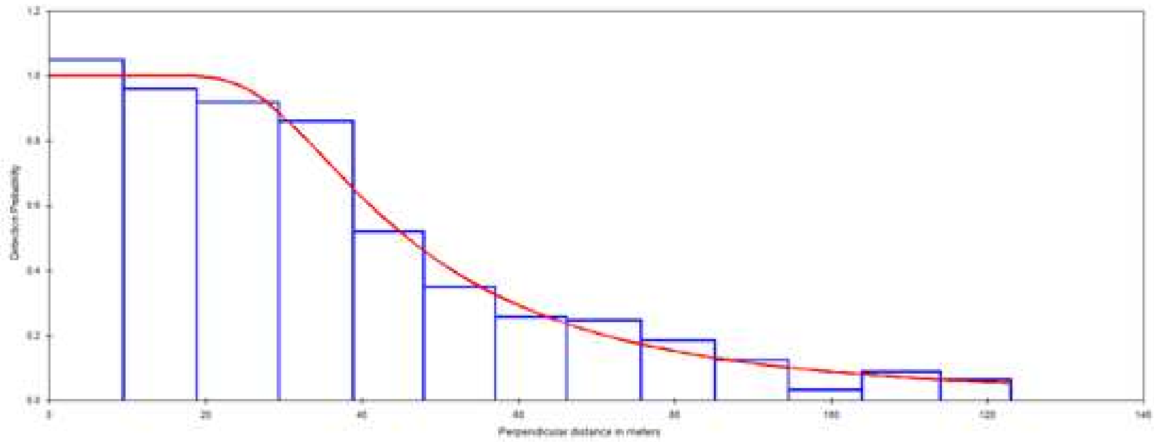

Figure 4: Estimated detection function for Chital, with chi-square goodness of fit (df) = 0.99(9)

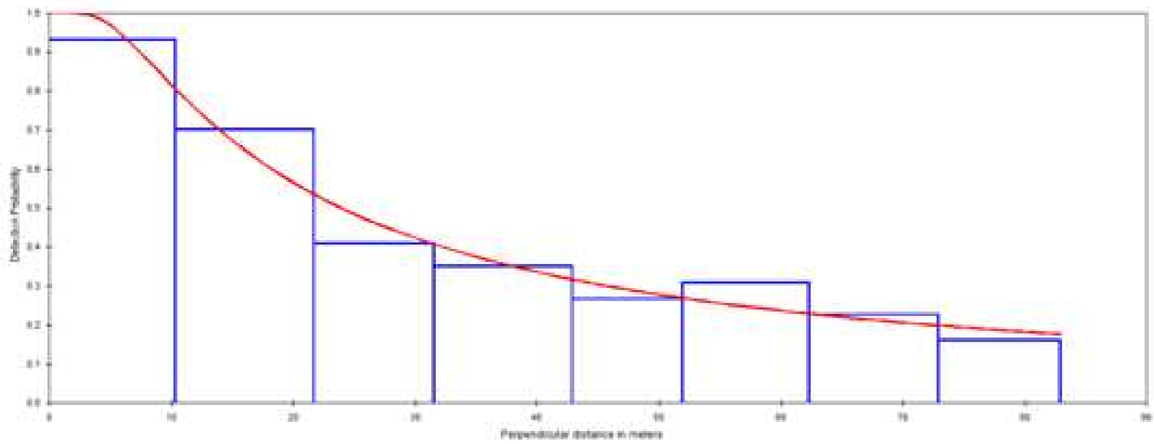

Figure 5: Estimated detection function for Nilgai, with chi-square goodness of fit (df) = 0.99 (5)

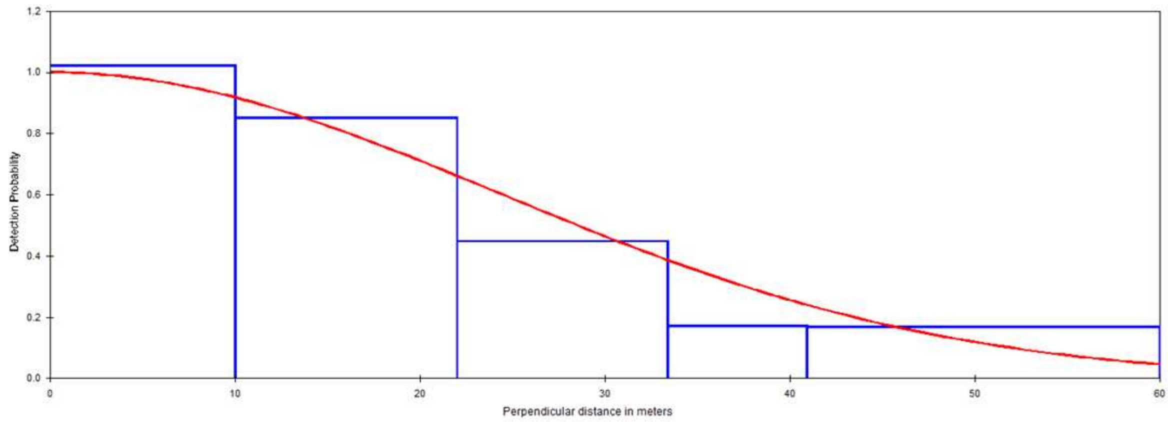

Figure 6: Detection function for Hogdeer, with chi-square goodness of fit (df) = 0.69 (3)

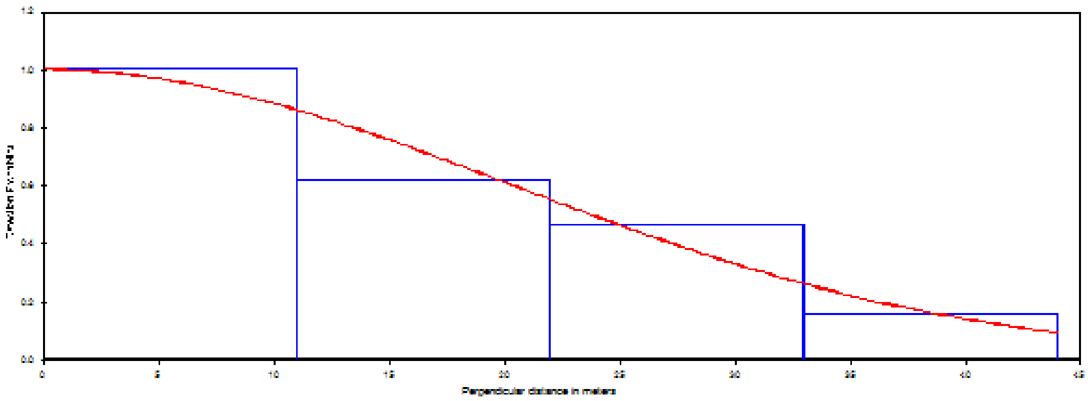

Figure 7: Estimated detection probability of Wild pig, with chi-square goodness of fit (df) = 0.84 (2)

4.4 Density estimates in habitat and non-habitat strata

We hypothesized a priori that density of ungulates would be higher in areas with high proportion of habitat (forest & grassland patches). However, habitat with more exposure to non-habitats (especially to agricultural fields) supported relatively higher density estimates than the other two strata (Table 5, Figure 8). The fact that the estimate in 25-50% stratum is associated with high variation and wide CI, it is likely that certain patches have inflated the estimate.

Table 5: Density of ungulate prey in different strata in Pilibhit Forest Division. *In each case four detection functions were fitted to the data. Here the models (detection functions) with the lowest AIC in each set of models are reported with total effort of 288 km.*

Strata	Categories	n	Effort (km)	D (CV)	DS (CV)	GOF (df)	p	ER(CV)	ESW (CV)
Habitat	**25-50**	54	48	70.7(21.9)	13.4(17)	1.0 (6)	0.4	1.0(15.7)	41 (6.6)
	50-75	74	69	33.5(16.7)	12.9(13.8)			1.0(12)	
	75-100	197	172	36.9(14.0)	13.7(12.4)			1.1(10.4)	
Grassland Proportion	**Forest with no grassland**	70	83.8	33.5(18.1)	9.8(13.0)	0.99 (8)	0.3	0.83(11.7)	42.2 (5.7)
	Forest with trace grassland	134	134.3	37.9(13.9)	11.8(11.5)			0.99(10)	
	>11% grassland	118	70.6	49.7(17.7)	19.7(15.7)			1.67(14.7)	

Table 6: Density of chital in different strata for proportion of grassland in Pilibhit Forest Division. *In each case four detection functions were fitted to the data. Here the models (detection functions) with the lowest AIC in each set of models are reported with total effort 288 km.*

Strata	**Categories**	n	Effort (km)	D (CV)	DS (CV)	GOF (df)	p	ER(CV)	ESW (CV)
Grassland Proportion	**Forest with no grassland**	29	83.8	9.7 (25.8)	3.2(20.8)	0.95 (8.0)	0.4	0.34(19.1)	53.7 (8.2)
	Forest with trace grassland	90	131.5	24.5 (18.1)	6.3(15.6)			0.68(13.2)	
	>11% grassland	64	70.6	35.7 (25)	8.4(21.8)			0.9(20.2)	

D(CV): Density of individual/sq km with associated variance; DS(CV): density of groups/ sq km with associated coefficient of variance; GOF: Chi-square goodness-of-fit; df: degree of freedom; p: Detection probability; ER(CV): Encounter rate with associated coefficient of variance; ESW (CV): effective strip width with associated coefficient of variance.

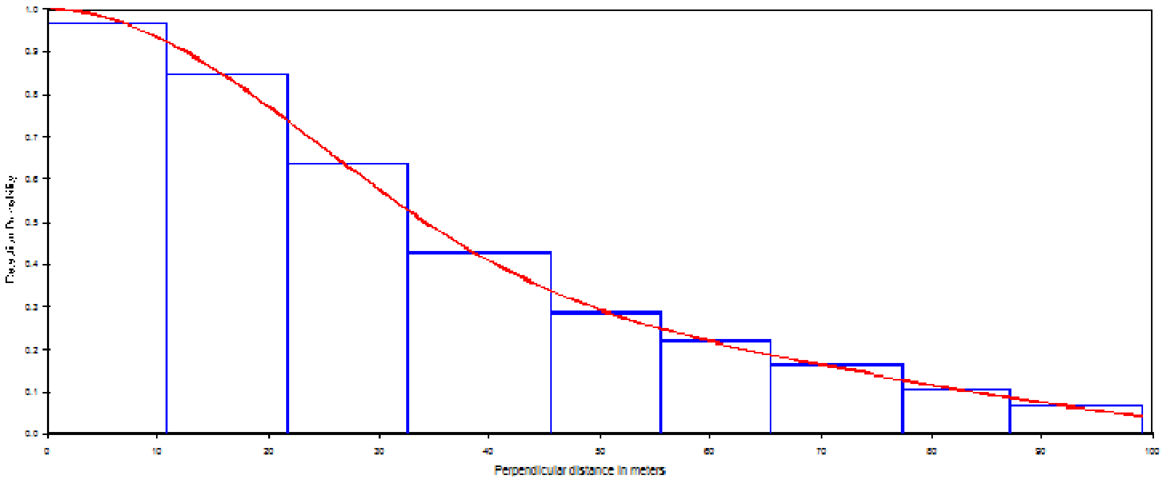

Figure 8: Detection function for global estimate (pooled for four species) in habitat and non-habitat stratum. Model selection: Half normal cosine & chi-square goodness of fit (df) =1 (6).

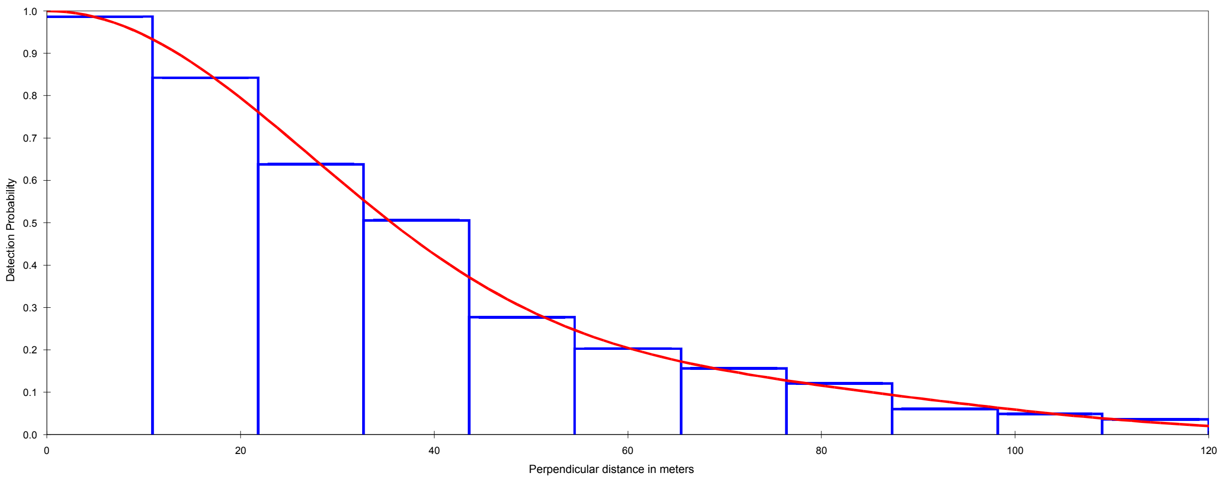

Figure 9: Detection function for global estimate (pooled for four species) in proportion of grassland stratum. Model selection: Half normal cosine & chi-square goodness of fit (df) =0.99 (8).

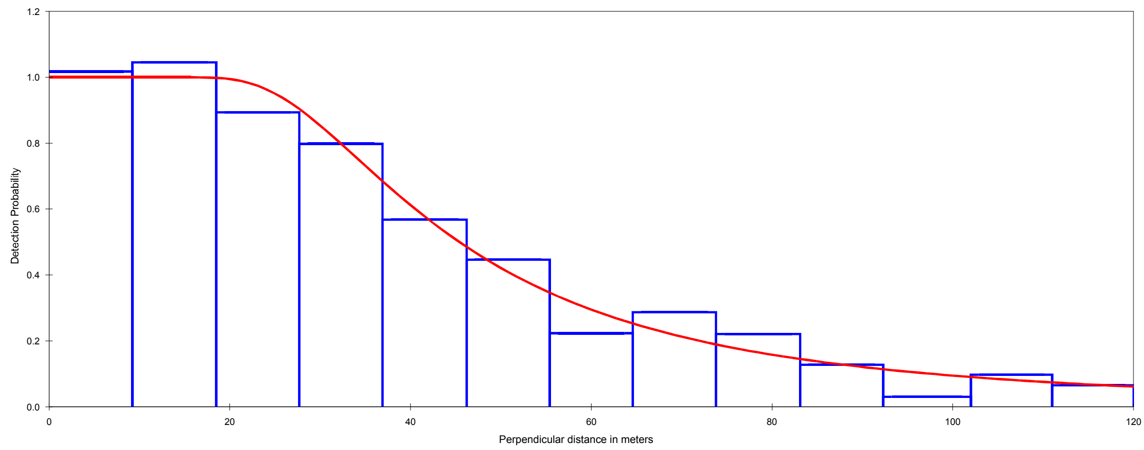

Figure 10: Detection function for chital in proportion of grassland stratum. Model selection: Half normal cosine & chi-square goodness of fit (df) = 0.95(8).

4.5 Density estimates in grassland proportion strata

There is difference in density estimate for strata with & without grassland patches for four ungulate species. Stratum with some proportion of grassland showed relatively higher abundance of ungulates (Table 5). Global estimate for forest with no grassland supported lower abundance (33.5 /sq km) with 18.1% CV as compared to forest with trace grassland and >10% grassland, 37.9 /sq km and 49.7/sq km respectively with 13.9% & 17.7% CV (Table 5, Figure 9). Chital showed distinct difference in density estimate for strata with and without proportion of grassland and increasing proportion of grassland supported higher densities of chital (Table 6, Figure 10)

4.6 Population composition

Chital and nilgai population shows bias towards female. Percent occurrence of female chital and nilgai was found to be 57.7% and 63.4% respectively, which is much higher than male (28.4% and 16.2% of occurrence respectively). Similarly, adult-female and fawn ratio was found to be 1:0.2 for chital population, and 1:0.4 for nilgai population. Difference in group size was found not to be significant for chital and hogdeer among three habitat strata (chi-square=2.473, df=2, p=0.29 & chi-square=1.521, df=2, p=0.467 respectively). However, there was a significant difference in group size for nilgai among three strata (F=3.970, p=0.026).

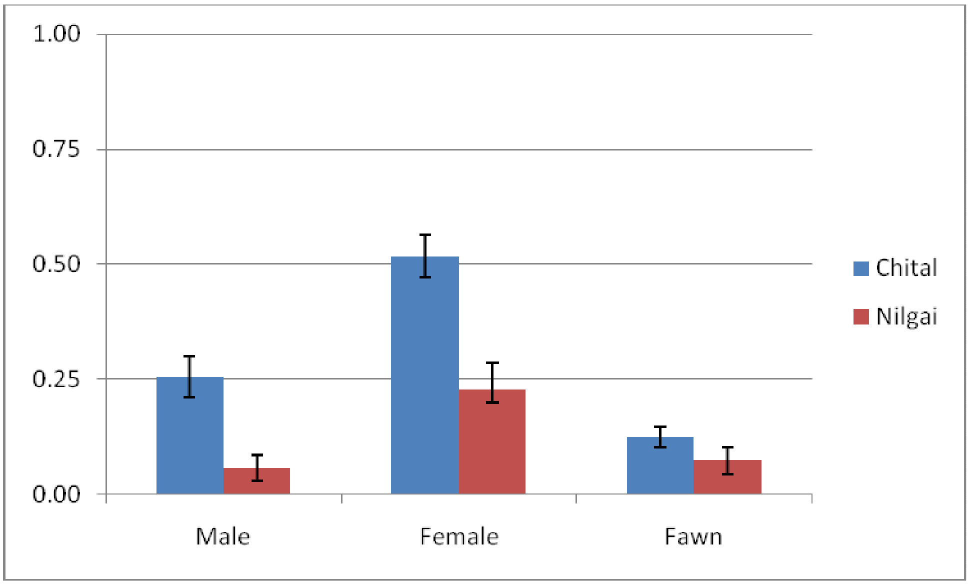

Figure 11 : Sex composition of chital and nilgai with associated standard error from 95% bootstrap confidence interval calculation for Pilibhit Forest Division

4.7 Ungulate contribution in tiger diet

Tiger diet was primarily constituted by four species, nilgai, chital, hogdeer and wild pig. Of the total prey consumed, three species namely chital, hogdeer and wildpig formed the bulk of tiger food habit with 80.7% occurrence. Langur and rodents also formed a part in tiger's diet (9.7% occurrence). Biomass contribution was highest from chital (40 %), followed by nilgai, wildpig and hogdeer (Table 7). Total biomass available for chital, hogdeer, wild pig and nilgai was 3,690 kg/km^2 in Pilibhit Forest Division, out of which 115 kg was consumed in the tiger diet during the sampling period.

Table 7: Contribution of prey species in tiger diet in Pilibhit Forest Division (scat sample n =24).

Species	Prey item in Scat	Frequency of Occurrence (%)	Occurrence (%)	Body weight (X kg)	Correction factor (Y kg)	Biomass Consumption Kg(%)
Chital	12	50.0	38.7	53	3.84	46.02(40.0)
Hogdeer	6	25.0	19.4	27	2.93	17.55(15.3)
Wildpig	7	29.2	22.6	38	3.31	23.17(20.2)
Nilgai	3	12.5	9.7	169	7.90	23.68(20.6)
Langur	2	8.3	6.5	8	2.26	4.52(3.9)
Rodent	1	4.1	3.2	-	-	-

Ivlves' Index showed that predation occurs disproportionately to availability, indicating selective predation of ungulates prey (Table 8, Figure 12). Consumption of hogdeer and wildpig was more than the availability, whereas nilgai consumption was less than availability. However, chital was consumed almost in proportion to availability.

Table 8: Selectivity Index of ungulate prey in Pilibhit Forest Division.

Species	**Scat/kill**	**Density**	**Available Biomass (kg/sq km)**	**Observed proportion of scat (U)**	**Expected proportion of scat (A)**	**Ivlevs' index U-A/U+A**
Chital	13.82	22.11	1171.83	0.5	0.43	0.46
Hogdeer	9.23	7.24	195.48	0.25	0.09	0.08
Wildpig	11.48	7.37	280.23	0.29	0.12	0.42
Nilgai	21.41	12.09	2043.21	0.13	0.36	-0.49

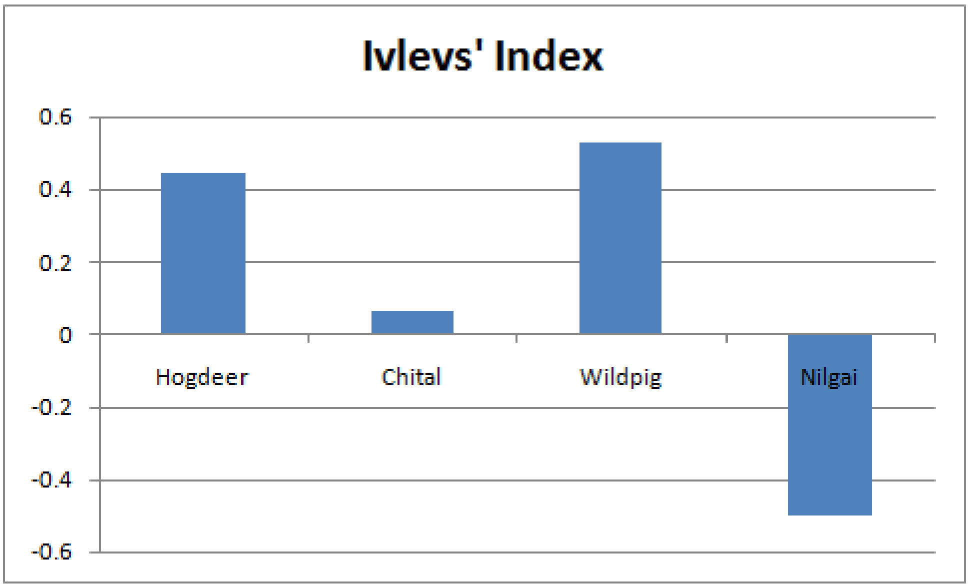

Figure 12: Ivlevs' index showing selectivity of ungulates by tiger in Pilibhit Forest Division.

5.0 Discussion

5.1 Distribution and population size of ungulates

The distribution pattern, determined as a function of proportion of area occupied by the species in a given sampling unit, revealed that the ungulates occur widely in Pilibhit FD and occupy most parts of the forest. Of these ungulates, chital and wildpig were well represented across the area, while nilgai showed affinity to edge habitats and was rarely seen in grassland patches. Hogdeer occurred in grassland patches of Mahof and Mala Range. Almost 58% of sightings of hogdeer in transect were in grassland patches, and the remaining 42% of sightings were in forest-grass mosaic. Apart from these species, sambar was recorded on one transect and swamp deer was recorded along Chuka reservoir on three transects. There is paucity in information available on occurrence of ungulates from this forest. This study has generated scientific information on ungulate occurrence & abundance using robust and reliable method in Pilibhit Forest Division. Prior to this, Johnsingh *et al.* (2004) was the only scientific work that assessed ungulate prey availability in Pilibhit. However, this study was rapid in nature and had relied upon indices over scientifically robust estimators that require intensive sampling procedures. Nevertheless, these two studies clearly demonstrate high proportion of area being occupied by ungulates in Pilibhit, which is noteworthy for the area which has been under intensive forestry operation for several years, and usually such forests are ignored from the conservation point of view.

Though occurrence of most ungulates was high however direct sightings of animals were low. During the study period, 63% of observations of chital on line transect walk was made when animal was seen flushing with or without alarm call. This indicates that though animals are present, but may remain undetected because of three reasons: a) flushing behaviour of animal at high flight distance without any alarm call; b) openness of forest though provided better visibility might induce fear on animal so they might be maintaining larger flushing distance; and c) animal seems to avoid using trails/forest road more often.

In density estimation, effective strip was usually large, and this could be attributed to vegetation characteristics containing openness and therefore, high visibility. As mentioned elsewhere, the Pilibhit Forest Division is managed entirely for commercial utilisation of timber (Nautiyal 1942; Gupta & Joshi 1971). Clearing/cutting of shrubs and herbs is routine activities in this forest, which provided observer with better visibility. As compared to other species, there was a high variance in density estimate of nilgai. The patchy distribution of nilgai along edges would have contributed to such high variance.

Variance in density estimate for hogdeer was also high, but this variance is contributed from encounter rate component. Since hogdeers are grassland specialist and shows high preference to grassland patches (Dhungel & O'Gara 1991), hogdeer distribution was patchy. Therefore variance estimation in density estimate needed to be corrected for Poisson distribution with over-dispersion to derive reliable variance for encounter rate (Jathanna, Karanth & Johnsingh 2003) to address patchy distribution of animal. Owing to non-random distribution of hogdeer, the variance was corrected using over-dispersion factor b equal to 3 as recommended by Buckland (2001).

Compared to other studies carried out in Terai, density estimates of Pilibhit FD was found to be low. Chital density of Bardia NP was estimated to be ca 190.8 animals/sq km in 1998 (Wegge *et al.* 2009) in the flood plain areas. This study was conducted in small area with block count method. Another study also shows similar density estimate of chital in Barida NP as 267 individuals/ sq km in riverine habitat (Wegge & Storaas 2009). On the same line, 49.9/sq km density for chital was estimated in Chilla range during 2007 (Harihar, Pandav & Goyal 2009). Density estimate of chital in Pilibhit when compared to these studies is substantially low. However, this difference in density estimate could be because of variation in habitat characteristics and protection given in the area. There is no riverine habitat in the main complex of Pilibhit FD. It is important to recognize that riverine habitat has actually supported high abundance of ungulates in Bardia, apart from grasslands (Wegge *et al*. 2009; Wegge & Storaas 2009). Wegge *et al.* (2009) showed that ungulate population of Bardia NP increased four times since 1976 to 1998, chiefly because of increase in chital and hogdeer population as better protection was ensured after establishment of Bardia National Park. Apart from these abovementioned factors, forestry practices operative in Pilibhit can also have adverse impact on ungulate population. Study conducted for understanding impact of selective logging on ungulate population has indicated negative influence of logging (Heydon & Bulloh 1997) and in areas with logging, removal of fruit bearing tree induces limited resources for animal (Davies *et al.* 2001).

Similarly, hogdeer density was estimated to be 77 / sq km in floodplain of Bardia National Park (Odden, Wegge & Storaas 2005) which is higher than density estimates (i.e. 7/ sq km) in Pilibhit. This drastic difference in density estimate is likely to be because of three reasons: a) difference in sampling method used in these studies, density estimate was obtained using drive count method in Barida National Park whereas this study estimated density using standard distance sampling methods; b) difference in habitat types; Bardia NP supports floodplains which are regulated by natural floods, unlike Pilibhit where small grassland patches exist without any flooding and c) similar habitat in terai is surveyed on elephant back, but because of field constraint transects were walked on foot and hence grassland was not sampled adequately in this study.

Nilgai density (12/ sq km) in Pilibhit is higher as compared to other parts of terai. Lack of published data on density estimate of nilgai from Chitwan NP is perhaps indication to low occupancy in Chitwan (Seidensticker 1976). Similarly, low density of Nilgai was recorded in Bardia too (Wegge *et al.* 2009; Wegge & Storaas 2009). Such high population of Nilgai could be because of high perimeter to area ratio in Pilibhit FD.

5.2 Importance of habitat area and grassland in ungulate densities

As provided in the result section, the ungulate densities responded differently to three levels of stratification on habitat, although the difference was not statistically significant. However, a general pattern of the estimates indicated that edge habitats to have higher densities. As the forests in such grids are relatively more exposed to agricultural field then other two habitat strata, such grids provide opportunities to animal for easy entrance to fields for crop raiding. The sharp boundaries that exists between forest and agricultural field has facilitated crop raiding further. Interestingly, the high variations associated with these estimates reflect that use of edge habitat relates to either suitable forage availability or use of the adjoining agriculture crops, but these are restricted in some patches. A clear understanding of the spatio-temporal dynamics of such habitat usage would have direct management implications and help to mitigate human-wildlife conflicts in the form of crop damage.

Nilgai sightings in transect walk was higher in edge grids, while chital and wildpig did not show any apparent choice for edge or interior grids. One possible explanation for this is nilgai prefers open and scrub type vegetation for refuge during day time adjacent to agricultural crop. The undergrowth vegetation is composed primarily of shrubs which are less palatable such as *Clerodendron, Mallatous philippinensis, Ehretia laevis, Miliusa velutina, Semecarpus anacardium, Eupatorium,* and *Holarrahaena antidysenterica*. The availability of nutritious forage in adjoining field crops provides opportunities for animal to suffice their nutritional requirements. Study conducted in Bardia shows that almost 47% of lentils and 24% of wheat were lost because of crop raiding adjacent to Park boundary, and half of the loss was contributed by chital and wildpig (Studsrød & Wegge 1995). The emerging results from this study signify the importance of edge areas in terms of management interventions such as patrolling and conservation oriented activities as animals are found to occur in such areas.

The present study corroborates the earlier findings of Shrestha (2004) that grassland supports higher abundance of ungulates, although the difference was not well pronounced for all four ungulate species (i.e. chital, hogdeer, nilgai & wildpig) pooled together. However, there was a distinct pattern in density estimate for chital (one of grass associated ungulate species) across three categories for stratum proportion of grassland and density for chital increased with increasing proportion of grasslands.

Shrestha (2004) found riverine and grassland habitat supported higher relative abundance of ungulates as compared to sal forest which is different from habitat characteristics available in Pilibhit. Since grasslands were embedded within Sal forest, hogdeer were also recorded in such sal forests (48% of sightings of hogdeer were made in Sal forest which possessed small grassland patches embedded within it). Another independent study conducted in Bardia National Park, Nepal showed hogdeer abundance to be lower in sal forest, with highest hogdeer and chital abundance in tall grassland and riverine habitat respectively (Wegge & Storaas 2009).

Especially, for hogdeer which is grassland specialist, conservation of these grasslands is very critical to ensure survival of this species which already suffers from narrow declining distribution range. The strong preference to tall grassland (Odden, Wegge & Storaas 2005), not changing habitat use even when grassland are disturbed with burning and cutting, makes this species vulnerable and therefore conservation and maintenance of grassland patches is mandatory. Mahof Range followed by Mala Range has higher proportion of grassland as compared to other ranges and hence this Range has high potential to support hogdeer population including other ungulate species associated with grass for habitat use.

5.3 Contribution of ungulates in tiger food habits

Occurrence percent suggest that medium sized cervids formed the highest proportion (80.6%) in tiger diet as compared to large bodied antelope (9.68%). In Pilibhit FD, medium sized ungulates contributed 75.4% of biomass to tiger diet. It shows high dependence of tigers on medium sized ungulates for the purpose of procuring food. Chital was one of the most abundant ungulate and also formed major components in tiger food habit in the study area. Chital was selected in proportion to availability. The reason is that chital is the most abundant ungulate species, widely distributed in various parts of forest and grassland habitats in Pilibhit FD, and that it presents with wide range of group size ranging from 1 to 19 individuals (average group size being 3.9). This provides higher chance for chital to be predated most often because of its distribution as well as group size patterns. However, because of open nature of forest providing better vigilance and their crop raiding behaviour, chital might have evolved certain escape strategies from predators.

Although the sample size was low, there was a clear preference towards hogdeer and wildpig in tiger's diet. Spatio-temporal overlap of use of grassland patches by tigers and hogdeer for its daily requirement make tiger-hogdeer relationship stronger. It is likely that similar relationship exist between tiger and wild pig, since both are nocturnal when predation activity is higher. Nilgai consumption was in disproportionate to availability with no selection shown. Nilgai, one of large bodied ungulate formed 20% of biomass in tiger's food habit. Though density of nilgai was comparable to that of hogdeer, there was difference in contribution made by these two species in tiger diet. The difference in habitat use over space and time might have influenced such consumption pattern. Nilgai encounter rate suggests they use edge areas more often as compared to interior forest and grassland patches which provide escaping opportunity from predators.

Previous studies have shown that in the absence of high abundance of large bodied ungulates, predation occurs without any selection to maximise number of prey in diet. This study showed that when there is low abundance of large bodied ungulates, tigers could switch over to medium sized ungulates and show selective predation.

5.4 Prediction about tiger abundance

With available ungulate density for four species which form the major prey for tiger (as suggested from tiger food habit), tiger abundance was estimated using equation given by

Karanth *et al*. (2004). Pilibhit Forest Division has potential to support a tiger population of 8.1/100 sq km as obtained with prediction of estimated density estimate of ungulates (i.e. 40/sq km). Johnsingh *et al.* (2004) also concluded that chital, hogdeer and wildpig are major prey for tiger in terai. Among ungulates, chital is the most abundant, contributing to tiger diet in proportion to availability, while hogdeer and wildpig are harvested disproportionately by tiger. Hence maintaining population of these ungulates would be crucial for tiger conservation in this forest and quality of which is determined by the proportion of grassland patches in Pilibhit Forest Division. High level of human disturbance would have depressed the ungulate population to a great extent, indication of which is expressed as estimated human-cattle density 31.8/sq km (66.8%CV) in the forest of Pilibhit. Other than these, current practice of logging, assisted natural regeneration and fire burning practices would also have significant impacts on ungulate population which needs to be investigated exclusively.

Presently, tiger population in Pilibhit Forest Division is estimated to be 5 tigers /100 sq km (unpublished data, WWF-India). Although it is comparable with other low density areas, it is lower than the estimated potential of 8.1 tigers / 100 sq km for this area. Johnsingh *et al* (2004) mentions that Mahof and Mala range with tall grassland habitat have potential to support 10-15 breeding tigers. Similarly, when priority has become to safeguard the surviving tiger population, at beat level (Jhala, Gopal & Qureshi 2008) to landscape level (Wikramanayake *et al.* 2011) the importance of such forest could not be sacrificed. Present tiger population might have been depressed because of factors related to habitat availability and varying level of disturbances in forest which affect ungulate population. In order to ensure tiger conservation in this forest, maintaining ungulate population with prioritising the significance of grassland patches and focusing in peripheral areas of forest is important, meanwhile disturbances induced in the form of human activities including forestry operations require careful analysis and actions. Whilst setting up conservation oriented activities with reliable scientific information is paramount to tiger-prey survival (Seidensticker, Gratwicke & Shrestha 2010), such information generated is crucial.

6.0 Conclusion and Implications

Pilibhit Forest Division, though a managed forest with intense forestry operations, supports moderate to high level of distribution and abundance of ungulates, which in turn reflects quality of habitat for tiger population. There are, however, variations in the pattern among the species. In the context of wild ungulate occupancy along the forest edges adjoining agriculture field, it is imperative for the management to focus on these areas for protection measures and to address conflict related issues. Although this pattern indicates habitat selection by certain species, it may also indicate limitation in attractive forage within the forested habitats. A closer investigation on the forage distribution in terms of quantity and quality would further strengthen the understanding of ungulate status in this area. It was clear that grasslands influence the ungulate densities, and chital density increased with increasing proportion of grassland; however it would be worth investigating the spatial pattern of grasslands. It is likely that while the grassland offers the quality habitat for forage, the forest-grassland mosaic may be the optimal habitat for the ungulates. In this context, the managed forests with regulated forestry practices providing for grassland mosaics cannot be negated in the conservation point of view. If this is further supported with habitat quality information, it may open up new dimension in the way managed forests are considered in the conservation of wildlife. Pilibhit Forest Division with four ranges (Mahof, Mala, Barahi & Haripur) has potential to support tiger population 8.1/ 100 sq km, however, tiger population seems to be compromised at 5/ 100 sq km at present for reasons associated to habitat characteristics and anthropogenic pressure. This study clearly shows that peripheral areas of forests and grasslands are crucial for supporting ungulate abundance, which is determinant for tiger survival. The fact that Pilibhit Forest Division has already been proposed for declaring it as a Tiger Reserve, which calls for inviolate spaces, the findings of the result has implication for further development in decision making and management interventions.

Tiger scat analysis revealed that chital contributes to bulk of its diet, in line with the distribution pattern and abundance of chital in Pilibhit FD. It is clear that in the absence of large prey, tiger would continue to survive on medium to small prey species, and would reach moderate densities. Such switch over of prey selection is not uncommon, but the findings highlights the selection for a species that is widely distributed, presenting better encounter opportunities for tiger, which is a wide ranging species. This was also highlighted by

Johnsingh *et al*. (2004). Interestingly tiger showed selection for hog deer and wild pig which are not in high densities, perhaps owing to spatio-temporal overlaps by tiger in their habitats. Notwithstanding, the large sample size would perhaps substantiate the observations. It could be surmised that the prevailing situation in Pilibhit Forest Division is comparable with some of the protected areas in the country, and deserve to receive adequate scientific and management interventions, in order to support wildlife conservation represented by tiger at local and landscape scales.

References

Ackerman, B.B., Lindzey, F.G. & Hemker, T.P. (1984) Cougar Food Habits in Southern Utah. *The Journal of Wildlife Management,* **48,** 147-155.

Ahearn, S.C., Smith, J.L.D., Joshi, A.R. & Ding, J. (2001) TIGMOD: an individual-based spatially explicit model for simulating tiger/human interaction in multiple use forests. *Ecological Modelling,* **140,** 81-97.

Biswas, S. & Sankar, K. (2002) Prey abundance and food habit of tigers (*Panthera tigris tigris*) in Pench National Park, Madhya Pradesh, India. *Journal of Zoology,* **256,** 411-420.

Brown, J.H. (1984) On the Relationship between Abundance and Distribution of Species. *The American Naturalist,* **124,** 255-279.

Buckland, S.T. (2001) *Introduction to distance sampling: estimating abundance of biological populations*. Oxford University Press, USA.

Caughley, G. (1994) Directions in Conservation Biology. *Journal of Animal Ecology,* **63,** 215-244.

Chapron, G., Miquelle, D.G., Lambert, A., Goodrich, J.M., Legendre, S. & Clobert, J. (2008) The impact on tigers of poaching versus prey depletion. *Journal of Applied Ecology,* **45,** 1667-1674.

Davies, G., Heydon, H., Leader-Williams, N., MacKinnon, J. & Newing, H. (2001) The effects of logging on tropical forest ungulates.

DeFries, R., Hansen, A., Newton, A.C. & Hansen, M.C. (2005) Increasing Isolation of Protected Areas in Tropical Forests over the past Twenty Years. *Ecological Applications,* **15,** 19-26.

Dhungel, S.K. & O'Gara, B.W. (1991) Ecology of the Hog Deer in Royal Chitwan National Park, Nepal. *Wildlife Monographs***,** 3-40.

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

Gupta, A. C. & Joshi, D.P.(1971) Working Plan for the Pilibhit Forest Division.

Harihar, A., Pandav, B. & Goyal, S.P. (2009) Responses of tiger (Panthera tigris) and their prey to removal of anthropogenic influences in Rajaji National Park, India. *European Journal of Wildlife Research,* **55,** 97-105.

Heydon, M. & Bulloh, P. (1997) Mousedeer densities in a tropical rainforest: the impact of selective logging. *Journal of Applied Ecology,* **34,** 484-496.

Jarman, P.J. (1974) The social organisation of antelope in relation to their ecology. *Behaviour,* **48,** 215-267.

Jathanna, D., Karanth, K.U. & Johnsingh, A. (2003) Estimation of large herbivore densities in the tropical forests of southern India using distance sampling. *Journal of Zoology,* **261,** 285-290.

Jhala, Y.V., Gopal, R. & Qureshi, Q.(2008) *Status of Tigers, Co-Predators and Prey in India.* National Tiger Conservation Authority and Wildlife Institute of India, Dehradun. TR 08/001 pp. 164.

Jhala, Y., Qureshi, Q. & Gopal, R. (2011) Can the abundance of tigers be assessed from their signs? *Journal of Applied Ecology*, **48**, 14-24

Johnsingh, A., Ramesh, K., Qureshi, Q., David, A., Goyal, S., Rawat, G., Rajapandian, K. & Prasad, S. (2004) Conservation status of tiger and associated species in the Terai Arc Landscape, India. RR-04/001, Wildlife Institute of India, Dehradun, Pp. viii+ 110.

Karanth, K.U., Nichols, J.D., Kumar, N.S., Link, W.A. & Hines, J.E.(2004) Tigers and their prey: predicting carnivore densities from prey abundance. *Proceedings of Natural Academy of Science,* **101**, 4854-4858.

Karanth, K.U. & Stith, B.M. (1999) Prey depletion as a critical determinant of tiger population viability. *Riding the tiger: tiger conservation in human-dominated landscapes***,** 100-113.

Karanth, K.U. & Sunquist, M.E. (1995) Prey Selection by Tiger, Leopard and Dhole in Tropical Forests. *Journal of Animal Ecology,* **64,** 439-450.

Kenney, J.S., Smith, J.L.D., Starfield, A.M. & McDougal, C.W. (1995) The long term effects of tiger poaching on population viability. *Conservation Biology,* **9,** 1127-1133.

Krebs, C.J. (2009) Ecology: The Experimental Analysis of Distribution and Abundance. Pearson Education, Chollerstrasse.

Kumar, H., P.K. Mathur, J.F. Lehmkuhl, D.V. S. Khati, R.D. & Longwah, W. (2002) Management of Forests in India for Biological Diversity and Forests Productivity, A New Perspective - Volume VI: Terai Conservation Area (TCA). pp. 158. WII-USDA Forest Service Collaborative Project Report, Wildlife Institute of India, Dehra Dun.

Linkie, M., Chapron, G., Martyr, D.J., Holden, J. & Leader Williams, N. (2006) Assessing the viability of tiger subpopulations in a fragmented landscape. *Journal of Applied Ecology,* **43,** 576-586.

Mathur, P.K., Kumar, H., Lehmkhul, J.F., Tripathi, A., Sawarkar, V.B & De, R.(2011) Mammal indicator species for protected areas and managed forests in a landscape conservation area of northern india. *Biodiversity and Conservation*, **20**, 1-17

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Andrew Royle, J. & Langtimm, C.A. (2002) Estimating site occupancy rates when detection probabilities are less than one. *Ecology,* **83,** 2248-2255.

Moe, S.R. & Wegge, P. (1997) The Effects of Cutting and Burning on Grass Quality and Axis Deer (Axis axis) Use of Grassland in Lowland Nepal. *Journal of Tropical Ecology,* **13,** 279-292.

Mukherjee, S., Goyal, S. & Chellem, R. (1994) Standardisation of scat analysis techniques for leopard (Panthera pardus) in Gir National Park, Western India. *Mammalia,* **58,** 139-144.

Nautiyal, S.N.(1942) Working Plan for the Pilibhit Forest Division.

Odden, M., Wegge, P. & Storaas, T. (2005) Hog deer Axis porcinus need threatened tallgrass floodplains: a study of habitat selection in lowland Nepal. *Animal Conservation,* **8,** 99-104.

Pulliam, H.R. & Danielson, B.J. (1991) Sources, sinks, and habitat selection: a landscape perspective on population dynamics. *The American Naturalist,* **137,** 50-66.

Rabinowitz, A. (1993) Estimating the Indochinese tiger Panthera tigris carbetti population in Thailand. *Biological Conservation,* **65,** 213-217.

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

Sankar, K. & Johnsingh, A. (2002) Food habits of tiger (Panthera tigris) and leopard (Panthera pardus) in Sariska Tiger Reserve, Rajasthan, India, as shown by scat analysis. *Mammalia,* **66,** 285-289.

Seidensticker, J. (1976) Ungulate populations in Chitawan Valley, Nepal. *Biological Conservation,* **10,** 183-210.

Seidensticker, J., Gratwicke, B. & Shrestha, M. (2010) How many wild tigers are there? An estimate for 2008.

Shrestha, M.K. (2004) Relative ungulate abundance in a fragmented landscape: Implications for tiger conservation. University of Minnesota.

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

Stevens Jr, D.L. & Olsen, A.R. (2004) Spatially balanced sampling of natural resources. *Journal of the American Statistical Association,* **99,** 262-278.

Støen, O. & Wegge, P. (1996) Prey selection and prey removal by tiger (Panthera tigris) during the dry season in lowland Nepal. *Mammalia,* **60,** 363-373.

Strahorn, E.A. (2009) An environmental history of Postcolonial North India. Peter Lang, New York).

Studsrød, J.E. & Wegge, P. (1995) Park-People Relationships: The Case of Damage Caused by Park Animals Around the Royal Bardia National Park, Nepal. *Environmental Conservation,* **22,** 133-142.

Sunquist, M.E. (1981) *The social organization of tigers (Panthera tigris) in Royal Chitawan National Park, Nepal*. Smithsonian Institution Press Washington, DC.

Sunquist, M., Karanth, K.U. & Sunquist, F. (1999) Ecology, behaviour and resilience of the tiger and its conservation needs. *Riding the tiger: tiger conservation in human dominated landscapes***,** 5-18.

Sunquist, M.E. & Sunquist, F. (1989) Ecological constraints on predation by large felids. *Carnivore behavior, ecology, and evolution,* **1,** 283-301.

Thomas, L., Buckland, S.T., Burnham, K.P., Anderson, D.R., Laake, J.L., Borchers, D.L. & Strindberg, S. (2002) Distance sampling.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A. & Burnham, K.P. (2010) Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology,* **47,** 5-14.

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

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

Wikramanayake, E., Dinerstein, E., Seidensticker, J., Lumpkin, S., Pandav, B., Shrestha, M., Mishra, H., Ballou, J., Johnsingh, A. & Chestin, I. (2011) A landscape based conservation strategy to double the wild tiger population. *Conservation Letters*.

Wikramanayake, E.D., Dinerstein, E., Robinson, J.G., Karanth, U., Rabinowitz, A., Olson, D., Mathew, T., Hedao, P., Conner, M., Hemley, G. & Bolze, D. (1998) An Ecology-Based Method for Defining Priorities for Large Mammal Conservation: The Tiger as Case Study. *Conservation Biology,* **12,** 865-878.

Williams, B.K.,Nichols, J.D. & Conroy,M.J. (2001) Analysis and Management of Animal Populations. Academic Press, San Diego.

Woodroffe, R. & Ginsberg, J.R. (1998) Edge effects and the extinction of populations inside protected areas. *Science,* **280,** 2126.