HABITAT SUITABILITY EVALUATION FOR LEOPARD (*Panthera pardus*) USING REMOTE SENSING AND GIS IN AND AROUND CHITWAN NATIONAL PARK, NEPAL

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CERTIFICATE

This is to certify that the thesis of **Mr. Tej B. Thapa** entitled **"Habitat Suitability Evaluation for Leopard (*Panthera pardus*) using Remote Sensing and GIS in and around Chitwan National Park, Nepal"** is an original and independent research work submitted to the Saurashtra University, Rajkot (Gujarat), for the award of the degree of **Doctor of Philosophy in Wildlife Science**.

Mr. Thapa has carried out this research work under our guidance and supervision. The work presented in this thesis has not been submitted for any degree of any other University or Institution and it fulfils all the requirements for Ph. D. degree.

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SUMMARY

The leopard *Panthera pardus* is one of the large felid of Asia and Africa that is threatened by habitat loss and direct conflicts with humans. Owing to low population densities and cryptic habits leopard has remained little studied. This study evaluated landscape characteristics; determined distribution and relative abundance of leopards, analyzed diets of leopards and assess the extent, nature of human leopard conflicts and examined habitat use and preference in and around the Chitwan National Park and Buffer Zone (CNPBZ), Nepal. Methodologies used to accomplish these objectives included remote sensing, geographic information system (GIS), ecological field work (line transect sampling for prey, camera trapping for leopard and scat collection), social surveys and lab work for diet determination using micro-histological technique.

Supervised maximum likelihood classification of ALOS image delineated 16 land cover types: 4 types of Sal forest associations (*Shorea robusta*) (lowland Sal, mixed Sal, degraded Sal and hill Sal), 3 types of Riverain forest associations (*Trewia-Bambax, Acacia- Dalbergia*, and mixed riverine), 2 types of short grassland associations (flood plain grassland and short grassland), 3 types of tall grassland associations (swampy tall grass, tall grass and wooded tall grass), 2 types wetlands (rivers and lakes), exposed surface and the cultivated lands. Most extensive land cover category in the park was Sal forests (73%) followed by grasslands (12%), riverine forests (7%), exposed surface (5%) and water body (3%). Level of accuracy of supervised classification was high (84.53%). Landscape was heterogeneous with 6994 fine patches of different sizes and configurations. Patches characterized by density of 1.43 km^{-2}, mean patch size of 64.6 ha, low value (0.33%) of conectance, high value (98%) of aggregation index (AI) and even interspersion (IJI = 76%) in the landscape.

Prey populations were sampled from the elephant back through 34 four line transects (ranging from 2 to 6 km) in three different blocks representing climax Sal dominated forest (12 transects), area of previous settlements (10 transects) and buffer zone (12 transects) in the northern part of CNPBZ. Prey survey was done 4 times in each transect for each of summer and winter season for two years from 2007 to 2009. Overall estimated density using program DISTANCE ranged from 84.3 to 123.9 km^{-2} in different blocks. Estimated densities of chital (*Axis axis*) ranged from 59.3 to 117.7 km^{-2}, wild pig (*Sus scrofa*) from 3.5 to 16.1 km^{-2}, hog deer (*Axis porcinus*) 11.3 to 13.0 km^{-2}, Sambar (*Rusa unicolor*) 5.4 to 12.7 km^{-2}, barking deer (*Munticus muntjac*) from 3.6 to 5.5 km^{-2} provided a biomass of 6966 kg km^{-2}. Ungulate density and

biomass in the study area was found to be high compared to those from other areas in the Terai and even south Asia. The density of ungulate prey species was reported to increase by 309% since 1982, probably due to effective management and removal of livestock and human pressures.

Abundance and density information forms the baseline for conservation planning. Camera-trap surveys were carried out during winter 2008/09 and 2010. A total of 27 different individuals were captured (15 male, 10 female and 2 two of unknown sex) during a survey I (256 camera stations, 3840 trap nights) and 37 different individuals were trapped (20 females, 16 males, and 1 of unknown sex) during the survey II (310 sampling stations, 4650 trap nights). Leopard density estimated during survey I and II was 4.24 and 3.11 100 km^{-2} respectively using half MMDM method, 4.06 and 3.48 100 km^{-2} for the full MMDM under M_h model and 3.12 and 3.45 100 km^{-2} SECR method. The spatially explicit approach accounts for animal movements on and off the trapping grid in a formal way and is therefore preferable over the non-spatial approach.

Since predator ecology is largely governed by their prey, understanding a predator's foraging ecology can contribute to its conservation. Micro-histological scat analysis (n= 263) revealed that leopard consumed 15 different prey taxa (10 wild and 5 domestic) predominantly medium sized ungulates in Chitwan. Leopard diet constitutes of wild ungulates (78%), domestic animals (12%), birds and rodents (6%) and primates (4%). At the species level, chital comprised 45.8% of the relative frequency of occurrence. Biomass contribution of wild ungulates, domestic prey and small sized wild prey were found to be approximately 84%, 13% and 3% respectively. Chital contributed about 52% of biomass in prey rich habitat, while in prey poor habitat its contribution was 14.3% of total diet. In prey poor habitat livestock, primates, birds and rodents contributed 50.8% of leopard diet against 11.7% in the CNP. Multinomial likelihood ratio test confirmed non- random predation by leopard ($\chi 2 = 20.66$, DF = 4, $P< 0.001$). Selectivity estimates using group density revealed that the leopard consumed chital in greater proportion than availability, and hog deer, barking deer and wild pig were taken less than expected and consumption of sambar was in proportion to its availability.

Using livestock damage data and household questionnaire survey (n=180), I investigated the extent, patterns and financial loss of livestock kills by leopards and compared with that of tigers and local perceptions towards the conservation of large cats. Leopards and tigers were accounted for killing of approximately 57 and 54

animals/year respectively. Leopard primarily preyed on small stock mostly on goats (92.17%), while tiger killed goats (57.67%) as well as cattle (25.12%) and buffalo (12.56%). A significant association was found between prey size and predator types (χ^2 = 91.97, P < 0.001, df = 1). Livestock depredation by both cats showed seasonal, monthly and geographic variations. Reported loss amounted to US $ 13,727 per year, of which 36% accounted by leopards and 64% by tigers. Majority of local people expressed positive perceptions towards leopard (67%) and tiger (68%) due to the importance of these felids in the natural ecosystem, tourism and religion/culture. Though majority of respondents were not satisfied with current compensation system because of slow process and inadequate, still 47% accepted a slight increase in the population of large cats. In order to reduce depredation, livestock particularly goat should be kept in improved pens. Strengthening of buffer zone management program would be an important step forward for human- large cat coexistence.

Using camera trap data and landscape variables derived from remote sensing and GIS, I evaluated habitat use and effect of landscape and anthropogenic factors on habitat utilization of leopards in the CNPBZ using availability and use approach. A total of 178 independent photographic events were obtained from 566 trap locations. Leopards used habitat disproportionately to their availability (χ^2 = 12.65, df = 6, P = 0.04) in Chitwan. Leopard utilized more often grassland and Sal forest habitats than expected, while riverine forest and riverbed complex were used less than availability. Leopards negatively associated with the distance to forest edge and jungle roads, while the topographic variables and distance to water did not significantly influence habitat use. Leopard activity was found to be slightly higher during the night time (52%). Activity patterns showed, males were more nocturnal (62%) and females were more diurnal (61%), while both sexes were crepuscular more active between 16.00-22.00 hours. Leopard was found to be a generalist in habitat use but not a super generalist as presumed.

This study provided much needed baseline information on habitat characteristics of CNPBZ, abundance of leopard and prey population, feeding ecology and prey selection by leopard, leopard- human conflicts and habitat use of leopards. While sampling occasions were short, this study had the largest number of camera traps and trap efforts in south Asia. The baseline data generated by this study will be a good starting point to conceive a population monitoring program, ecological research and more dedicated management programs in future.

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Chapter 1
INTRODUCTION

1.1 GENERAL INTRODUCTION

The distribution and population abundance of large carnivores is shaped by three extrinsic factors (i) habitat and landscape features, (ii) the distribution and availability of resource (*e.g*. prey), and (iii) human attitudes and activities; as well as the intrinsic adaptive capacity of the species concern (Zimmermann, 2004). Habitat loss, fragmentation, depletion in prey populations, poaching and persecution are well documented threats for carnivore species (Nowell and Jackson, 1996; Inskipp and Zimmerman, 2009). The large carnivores are more vulnerable to decline due to their large home range and dietary requirements. As a result, their geographic ranges have reduced; populations have decrease in size and have become more isolated. Basically, removal of threats and successive habitat and prey restoration can lead to a population recovery through growth and immigration, if the connectivity to adjoining populations is facilitated and the dispersal rate sufficient (Zimmermann, 2004, Gurung *et al.,* 2008; Harihar *et al*., 2009a).

The large carnivores' predatory behaviour and the frequent damage to livestock have always caused conflicts with humans (Nowell and Jackson, 1996; Inskip and Zimmerman, 2009). The conflicts can be the most serious cause of carnivore mortality in human dominated landscapes (Arthreya *et al*., 2004; Goyal *et al*., 2007) and even along the reserve borders (Gurung *et al*., 2008; Blame *et al.,* 2010). Livestock depredation is the greatest source of conflict with humans and a major underlying cause for the disappearance of large cats from considerable areas of their former range (*e.g*. tiger *Panthera tigris* from most parts of China, Nowell and Jackson, 1996).

Conservation of large carnivores is a global priority due to numerous socio-cultural values and the critical roles they play in maintaining ecosystems (*e.g.*, Wikramanayake *et al.,* 1998; Merrill *et al.,* 1999; Mladenoff *et al.,* 1999). Effective management of carnivore populations is dependent on our understanding of the distribution, abundance and response of species to various available resources. Habitat quality, prey availability and prevailing disturbances have long been recognized as the primary influences in determining carnivore use and abundance in a given area, with habitat selection models as the primary tool for identifying those relationships. Conservationists believe that the management of large carnivore requires integrative ecosystem management at broad spatial scales (*e.g.*, Wikramanayake *et al.,* 1998; Mladenoff *et al.,* 1999; Carroll *et al.,* 2001) that leads to conservation of all the attributes of ecosystem (Steneck, 2005); therefore carnivores in general are a good taxon for the development of a predictive model of conservation (Cardillo *et al*., 2004).

In order to develop effective conservation strategies, biologists and managers need to understand and evaluate various resources that are available and the threats which confront populations, to predict the potential distribution and explore ways to reach it (Zimmermann, 2004). The Remote Sensing and Geographic Information System (GIS) combined with habitat modeling have proved to be an important tool to assess large scale habitat requirement for a given species. The habitat model gives information about the spatial extent, arrangement and fragmentation of habitat (Zimmermann, 2004). This is a necessary prelude to estimate the potential population size (Mladenoff and Sickley, 1998). Though considerable research and conservation effort has been directed towards the large and widely recognized cat species, leopards have received comparatively little attention.

1.2 ROLE OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

Spatial tools of remote sensing and GIS provide practical and quickest means for inventory and evaluation of natural resources. These techniques are useful to generate many vital information needed for conservation planning by deriving spatial and ecologically relevant predictor variables such as land covers (Roy *et al*., 1986; Hansen *et al.*, 2001; Shrestha, 2004; Gutierrez *et al*., 2005; Edwards *et al*., 2006; Thompson *et al*., 2006; Davis *et al*., 2007; Collingwood, 2008; McDermid *et al.*, 2005, Midha, 2008; Paliwal, 2008; Wang *et al*. 2010), canopy closure (Hyde, 2005), leaf area index (LAI; Chen and Black, 1992; Qi *et al.*, 2000; Li *et al.*, 2008). The classified thematic maps are the key inputs for most studies on landscape pattern analysis (Turner, 1990; Shao and Wu, 2008; Wang *et al*., 2009; Midha and Mathur, 2010; Munsi *et al*., 2010).

The GIS offers an important tool to develop spatially referenced estimates of key environmental resources on a landscape (Best, 1984) which are the keys to predict animal distribution. The growing accessibility of remotely sensed data and GIS tools has encouraged the extensive application of such an approach to a wide variety of management problems.

1.3 LEOPARDS

1.3.1 Distribution

The leopard (*Panthera pardus*) is a most widespread wild representative of the family Felidae (Nowell and Jackson 1996). The leopard's range spanned most of sub-Saharan Africa, as remnant populations in North Africa, Arabian Peninsula and Sinai/Judean Desert, south-western and eastern Turkey, and through Southwest Asia and the Caucasus into the Himalayan foothills, India, China and the Russian Far East, as well as on the islands of Java and Sri Lanka (Seidensticker and Lumpkin 1991; Nowell and Jackson, 1996; Sunquist and Sunquist, 2002; Henschel *et al.*, 2008) (Figure 1.1).

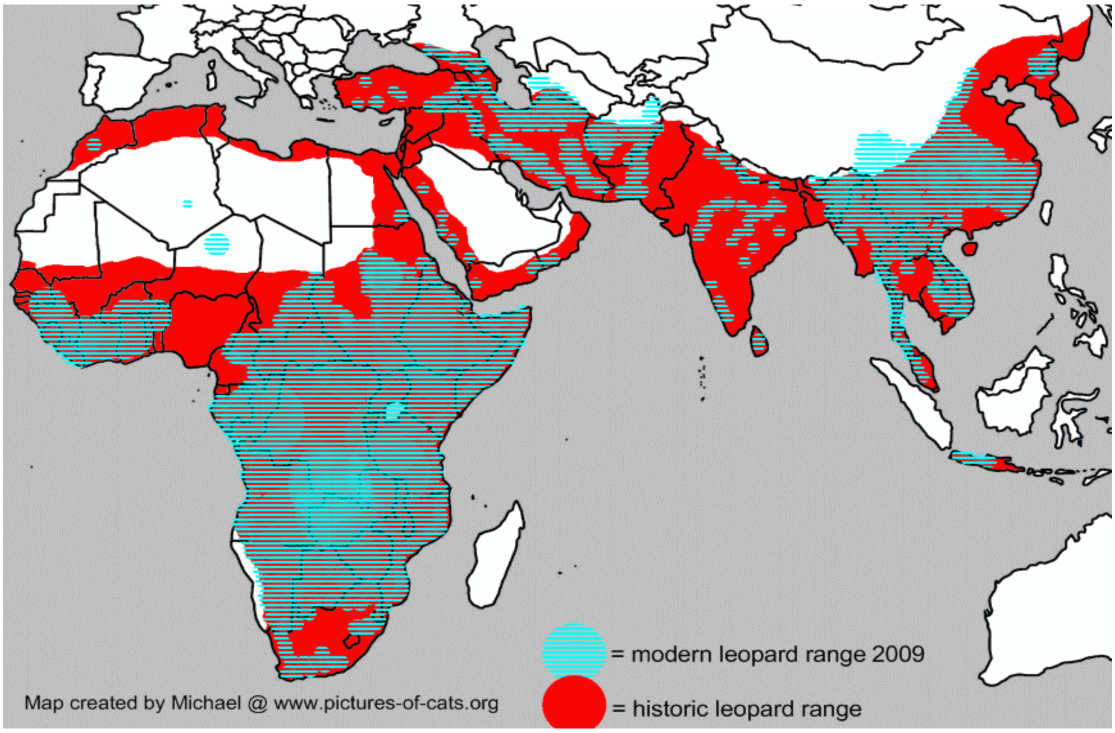


Figure 1.1 Global range of leopard distribution (Map source: http://www.pictures-of-cats.org/Leopard-Habitat.html)

1.3.2 Population Status

Leopards are typically deemed to warrant low conservation priority because of their widespread distribution and ecological flexibility, however, global population status is still uncertain (Nowell and Jackson, 1996; Henschel *et al*., 2008) because of difficulty in monitoring on account of their cryptic nature, large home range and low population densities (Rabinowitz, 1989; Bailey, 1993; Nowell and Jackson, 1996). Traditional pugmark survey method used to monitor abundance of large cats (Panwar, 1979; Riordan, 1998) has been found to lack statistical rigor (Karanth, 1987; 1988; 1995). Radio telemetry has been used to study these felids, but their nocturnal habits, low density, and wide- ranging behaviour makes application of this technique difficult (Karanth, 1995).

Camera-trap surveys in combination with standard capture-recapture population models provides useful alternative method for non-invasive monitoring of large numbers of individuals and statistically rigorous density estimates (Karanth, 1995; Karanth and Nichols, 1998). Density estimates of leopards in different areas across the range vary from ~1 to 30.9 individuals 100 km^{-2} with no obvious relationship with broad habitat type (Kostyria *et al*., 2003; Khorozyan, 2003; Chauhan *et al.*, 2005; Spalton *et al*., 2006; Ngoprasert *et al*., 2007; Edgaonkar, 2008; Henschel, 2008; Sankar *et al*., 2008; Simacharoen and Dungchantrasiri, 2008; Harihar *et al*., 2009b; Wang and Macdonald, 2009a; Chapman and Blame, 2010), but the site-specific factors such as levels of prey availability, fine-scale habitat variables, presence of co-predators and human disturbance might have influence the density. The effecting sampling area used to estimate leopard density ranged from 42.4 to 226.44 km^2 with limited number of trap locations (see review Chapter 5). Small effective sampling area is probably related to inflated density estimates (Dillon and Kelly, 2007; Maffei and Noss, 2008; Foster, 2008).

1.3.3 Diets and Prey Availability

The leopard's wide geographic distribution is often referred to as its wide habitat tolerance and versatility as a generalist predator (Nowell and Jackson, 1996). Bailey (1993) noted a minimum of 92 prey species used by leopards in sub-Saharan Africa, and known prey ranges in size from arthropods (Fey, 1964) to an adult male Sambar or Gaur (Sedeinsticker, 1976a, Karanth and Sunquist, 2000). Despite such an enormous prey size range, leopard diet is generally dominated by medium sized wild ungulates (<50 kg body weight) (Schaller, 1967; Essenberg and Lockart, 1972; Seidensticker, 1976a; Johnsingh, 1983; Rabinowitz, 1989; Seidensticker *et al.,* 1990; Johnsingh, 1992; Bailey, 1993; Karanth and Sunquist, 1995; Edgaonkar, 2008; Wang and Macdonald, 2009). Recent analysis of 33 studies on leopard feeding ecology revealed that leopards preferentially prey upon species within a weight range of 10–40 kg (Hayward *et al*., 2006a). Low densities of medium sized ungulate prey force leopard to switch to more abundant sub optimal prey such as rodents (Ramakrishnan *et al*., 1999; Sankar and Johnsingh, 2002) and/or secondary prey (livestock and dogs) (Seidensticker *et al*., 1990; Edgaonkar and Chellam, 2002; Goyal *et al*., 2007; Chauhan, 2008; Shah *et al*., 2009).

Distribution and abundance of carnivore species depends on the availability of different sized ungulate prey species (Karanth and Nichols, 1998; Carbone and Gittleman, 2002). However, information on the abundance of ungulate prey species is sparse in Nepal Terai (Seidentiscker, 1976; Dinerstein, 1980; Tamang, 1982; Malla, 2009; Wegge *et al*., 2009).

1.3.4 Spacing and Habitat Utilization

The leopard is solitary and aside from mating, interactions between individuals appear to be infrequent (Jenny, 1996). Like other solitary carnivores, the female leopards expected to space themselves according to resource availability, while the male spacing is based on both receptive female and availability of food resources. Reported home range of leopard varies from 6 km^2 (Seidensticker *et al*., 1990) to over 2000 km^2 (Bothma *et al*., 1997), however generally male territories ranged between 30 and 78 km^2, whereas 15– 16 km^2 are common for females (Nowell and Jackson, 1996).

In Bardia National Park, Nepal, annual home ranges of male leopard have been found at about 48 km^2 with an overlap of only 7%; while female ranges at 17 km^2; female home territories were seen to decrease to just 5.2 to 6.6 km^2 when she had young cubs (Odden and Wegge, 2005).

Information on the habitat use of leopard has been derived from the home range study using telemetry with small sample size (see review, Marker and Dickman, 2005;

Odden and Wegge, 2005). The broad habitat utilization of leopard are not unanimous and shown a tendency of utilization on the variety of forest and grassland habitats (Marker and Dickman, 2005). Recently, Simcharoen *et al*. (2008) reported that the mixed deciduous and dry ever green forest types, flat slope and areas close to stream channels are important landscape features for leopard habitat selection in Thailand. Similarly, Ngoprasert *et al*., (2007) found leopard habitat use positively increased with distance from the human disturbances. Seidensticket (1976a) reported that habitat use of leopard was influence by the presence of tiger in that area. Information on the habitat utilization of leopard, influence of landscape/habitat features and human activities on spatial distribution of this species is meager.

1.3.5 Leopards, Human and Livestock

Human-leopard conflicts most commonly involve killing of livestock, occasionally involve attacks on humans and leopard persecution (Mizutani, 1995; Nowell and Jackson 1996; Negi, 1996; Edgaonkar and Chellam, 1998; Mukherjee and Mishra, 2001; Goyal *et al*., 2007; Kissui, 2008; Tamang and Baral, 2008; Chauhan, 2008; Dar *et al*. 2009; Inskipp and Zimmerman, 2009). Therefore, effective conflict management strategy is essential for conservation of leopards. Any attempts to mitigate human–leopard conflict (Arthreya, 2006; Arthreya and Belsare, 2007) and improve the conservation of the culprit species should be based on an explicit understanding of the conflict patterns (Dar *et al*., 2009) and perceptions.

1.3.6 Major Threats

Like other large carnivores leopards are declining throughout their range due to habitat conversion, prey depletion, intense persecution and poaching for trade (Nowell and Jackson, 1996; Ray *et al.* 2005; Breitenmoser *et al.,* 2006, Breitenmoser *et al.,* 2007). Main threat of leopards in African rainforest is probably competition with human hunters for prey (Henschel, 2008). Nonetheless, leopard is somewhat tolerant of habitat conversion, and may persist close to large human populations provided they have suitable cover and prey (Hunter *et al*. in press). Still, leopards are found throughout most of their range; however, their populations have dramatically reduced over the last hundred years (Nowell and Jackson, 1996; Nowak, 1999; Uphrkyna, 2001; Henschel *et al*., 2008). A rapidly increasing threat to leopards is the poisoning of carcasses targeting carnivores, either as a means of predator control or incidentally (Henschel *et al*., 2008) and poaching for international trade (Breitenmoser *et al*., 2006; 2007).

1.3.7 Conservation and Management

The Wild Cat Status Survey (IUCN/SSC Cat Specialist Group) has categorized leopard as one of the Near Threatened felids (Henschel *et al.*, 2008). The leopard is placed in Appendix I in the Convention on International Trade in Endangered Species (CITES), and is protected under national legislation throughout most of their range (Nowell and Jackson, 1996). In Nepal leopard is protected under the National Park and Wildlife Conservation (NPWC) Act 1973. However, leopard has not been included in the Schedule I (the list of protected species) of the NPWC Act and there is no specific management strategy for its conservation outside the PAs, where they are surviving in considerable conflicts with people.

1.4 STATEMENT OF THE RESEARCH

Before the large-scale conversion of forests and the expansion of agricultural areas as a result of rapid growth of human population, the leopard was distributed throughout the Terai and Hills of Nepal, but now it is surviving as highly fragmented and disjunct populations (Shah *et al*., 2004). Although some research on leopard diets, activity, spacing and home range, and interaction with tiger have been done in Chitwan (Seidensticker, 1976a; 1977; Sunquist, 1983; MacDougal, 1988; Seidensticker *et al.*, 1990) and Bardia (Eliassen, 2003; Odden and Wegge 2005, Odden *et al*., 2010). However, leopard has not received any specific management attention in Nepal due to lack of reliable population data.

In recent years leopard-human conflicts are increasing in many parts of the country due to habitat restoration through community forestry programmes and plantations (Shah *et al.* 2004). Small patches of restored forests can provide temporary hiding place for leopard but such patches cannot support sufficient prey species, consequently leading to increased level of conflicts with humans. In areas around CNP, successful habitat restoration measures through effective management of buffer zone and corridors have provided additional habitats for wild animal species (Gurung, 2008). At the same time the area is subject to many natural interactions, succession and anthropogenic disturbances, which are creating habitat heterogeneity. Furthermore, increase in tiger population in the CNP has displaced the leopard to the peripheral areas, resulting in increased levels of conflicts with people (MacDougal, 1988). Thus, the knowledge on the ecological requirements, available resources and response of leopard to various landscape and anthropogenic factors are needed to plan long term conservation strategy for this species.

1.5 SCOPE AND AIM OF THE STUDY

Effective conservation of leopard requires a detailed understanding of factors that govern the species' spatial distribution and habitat use. Information that describe resource availability (habitat quality and prey abundance), constraints (conflicts with humans) and distribution and abundance of leopards are important requisites to devise the conservation strategy for the species. The objective of this study is to evaluate leopard habitat in and around Chitwan National Park using remote sensing, GIS and field data. The specific objectives are to:

(i) evaluate landscape characteristics in order to determine habitat quality,

(ii) determine distribution and relative abundance of leopard across habitat and disturbance gradients;

(iii) analyze diets of the leopards across the habitats;

(iv) assess the extent and nature of leopard - human conflict and suggest mitigatory strategies, and

(v) examine habitat use and preference of leopard

1.6 ORGANIZATION OF THE THESIS

The thesis is organized into nine chapters. This thesis consists of introduction (Chapter 1), description of study area (Chapter 2), six research chapters (Chapter 3- 8) and conclusions (Chapter 9). Each of these research chapters (3- 8) includes a brief introduction based on literature review followed by methodology, results and discussion. Chapter one provides general introduction and describes the background of the study, the role of remote sensing and GIS and ecological aspects of leopards.

Chapter 2 deals with the study area, its physical, biological environment and socioeconomic aspects of Chitwan National Park and Buffer zone. Chapter 3 evaluates the land cover and landscape spatial patterns of CNPBZ. Chapter 4 provides the density and biomass estimates of major prey species in the northern part of Chitwan National Park (CNP) and buffer zone (BZ). Chapter 5 provides population and density estimates of leopard using camera trap survey and analysis of data by both non-spatial capture- recapture and Bayesian spatially-explicit capture-recapture models. Chapter 6 describes food habits and prey selection of leopard by comparing prey frequency of composition between summer and winter season, and between prey rich and prey poor habitats. Chapter 7 evaluates human-leopard conflicts and compares the problems of leopard with that of tiger in the buffer zone of CNP. Chapter 8 deals with the use of various habitat types by leopard and also evaluates the effect of landscape and anthropogenic factors on habitat use. Chapter 9 presents the overall conclusion of the thesis. It also highlights the important findings, synthesis and management implications of the research.

Chapter 2
STUDY AREA

2.1 LOCATION

This study was carried out in the Chitwan National Park (CNP) and its buffer zone (BZ), located in the *Dun* valley and Siwalik hills in the South- Central lowland of Nepal (Figure 2.1). The Chitwan National Park was gazetted in 1973 and designated as UNESCO’s World Heritage Site in 1984 on account of its outstanding universal values. The park covers an area of 932 km^2 between 27^0 16' 56’’ to 27^0 42'14’’ N and 83^0 50’ 23’’ to 84^0 46’ 25’’ E, while the buffer zone (27^0 16’ 56’’ N to 27^0 42’ 13’’ N and 83^0 50’ 44'' E to 84^0 44’ 58'' E) extends 750 km^2 area. But latest GPS survey of the park boundary and GIS digitization based on 1992 topo maps shows the park and buffer zone covers 1182 km^2 and 766 km^2 of area respectively (DNPWC, 2000). CNP spans across portions of four districts namely, Chitwan, Nawalparasi, Parsa and Makawanpur. The park encompasses a wide diversity of habitats and species within the elevation range between 110 and 850 msl.

CNP is connected through a natural linkage of Barandabhar Corridor Forest to the lesser Himalayan Mahabharat Mountains to the north, and is contiguous with the Parsa Wildlife Reserve in the east and the Valmiki Tiger Reserve in India to the South. The Narayani River and Daunne hill marks the western boundary of the park, the Rapti River marks the northern boundary and Someshor hill, Rapti River and Jungle road marks the southern boundary.

2.2 GEOLOGY AND SOILS

The Chitwan is a *Dun* valley in the inner Terai between Lesser Himalayan Mahabharat Mountain range and Lower Himalayan foothills- the Churia (Siwalik) range. Geological structures of Chitwan *dun* and Siwalik has been described by Stocklin and Bhattarai (1982), DMG (1984) and Tamrakar (2004).

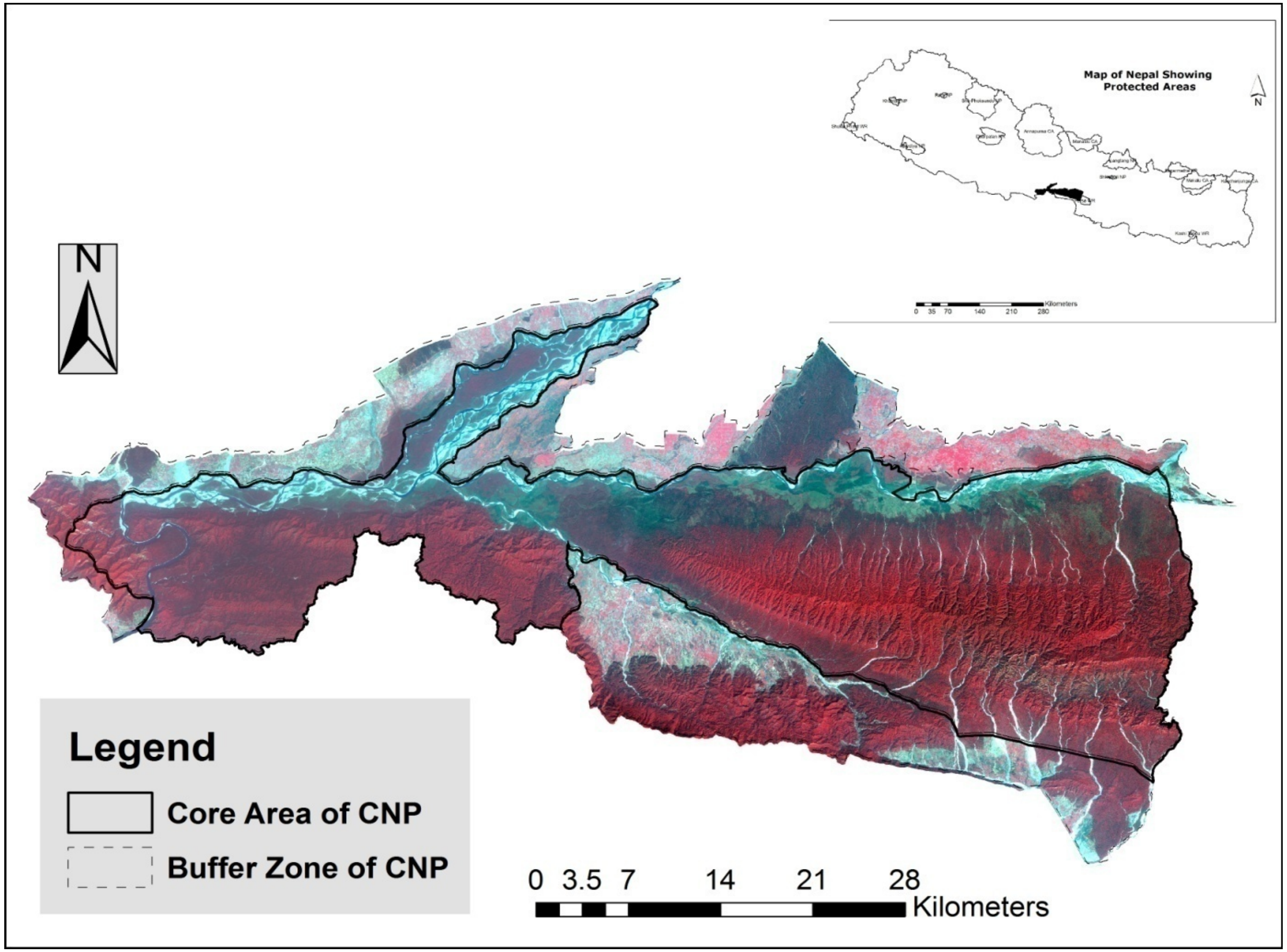


Figure 2.1 Map showing the Chitwan National Park and Buffer Zone, Nepal.

The Park is characterized by the flood plains of the Rapti, Riyu and Narayani Rivers, and Siwalik hills. The flood plain consists of a series of ascending alluvial terraces laid down by the rivers and subsequently raised by Himalayan uplift (Berry *et al*., 1974). The terraces are composed of boulders, gravels, sand and mud set in a fine silt matrix (Laurie, 1978, Tamrakar *et al*., 2008). There is rough gradient from the higher-lying boulders and gravels to sand and silts, and then to low lying silt loams and silty clay loam (Berry *et al*., 1974).

Geologically, the lower ranges of the Siwalik hills are of mid- Miocene to early Pliocene fluvial origin consisting mainly of the poorly consolidated detritus of sandstones, conglomerates, quartzites, phyllites, and outwash deposits from the severely eroded Tertiary rocks of the mountains further north (Kimura, 1994). Main Frontal Thrust fault produces steep cliffs on south-facing slopes. The valleys composed of layers of boulders and gravels in a fine silty matrix graded roughly from the higher boulders and gravels to sands, silt loams and silty clay loams (Bolton, 1975).

The park soils are representatives of Chitwan dun valleys types (Gee, 1963). Most of the land inside park is loamy with fine sand. Hills soils are sandy loam and loamy rubble with stony surfaces less than 50cm from bed rock. Soil types found in the valley has been identified as sandstone, conglomerates, quartzites, shales, and micaceous sandstones during soil survey (HMG, 1968). Alluvial soils range from sand and coarse loams on new terraces to sandy and silty-clay loam on older terraces.

2.3 HYDROLOGY

The CNP is drained by Narayani, Rapti and Riyu Rivers and their tributaries (Figure 2.2). The Churia hills are of generally low permeability, and the high monsoon rainfall runs off in numerous ephemeral streams and in rivers, which swell to many times their dry season sizes (Laurie, 1978). Drainage on the flood plains is generally good but the streams and rivers are seasonal in the hill. During dry season, the flowing water is available only in some rivers in Churia range but the porous Bhabar remains waterless. The standing water is confined to small lakes those are found throughout the park, generally on old river- courses. During the monsoon, extensive areas of grasslands and forests become inundated, and may remain waterlogged for long periods. In lowland areas, the river and streams often change the courses during flood times.

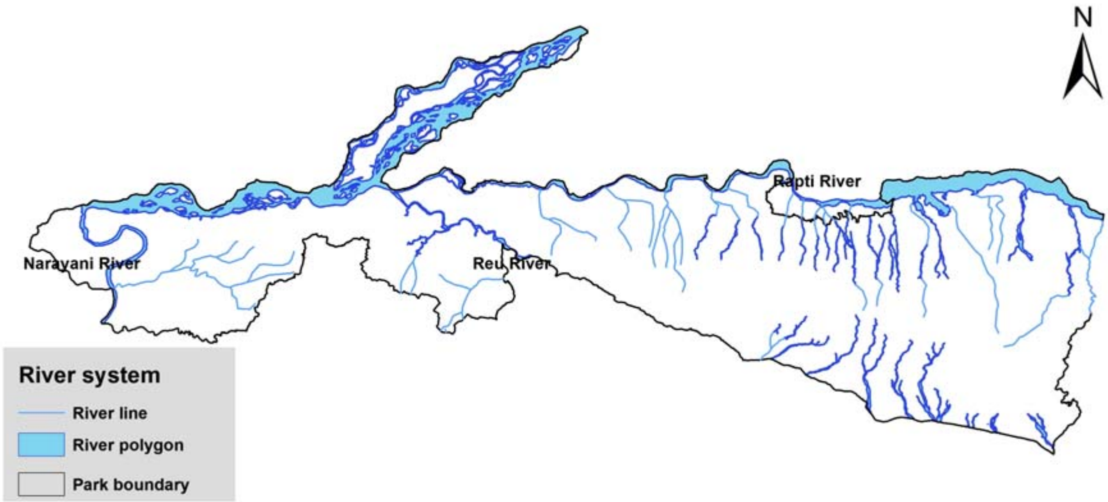


Figure 2.2 Map showing drainage system of the Chitwan National Park, Nepal.

2.4 CLIMATE

The Chitwan valley has a sub-tropical climate with three major seasons: summer (pre-monsoon), monsoon and winter (post monsoon) seasons. Summer season, extending from late February to mid June, is hot and dry period of the year. The monsoon season is hot and humid, and lasts from mid June to late September. Winter extends from late October to late February and is generally a cool season.

Rainfall is well distributed during southeast monsoons. Monsoon arrives in mid June and continues till late September. The mean annual rainfall over the period from 2004 to 2007 was 2437 mm, 77.5% of which occurred within four months of monsoon season (May- September) (Figure 2.2). From April onwards sporadic thunderstorms and hailstorms occur. There is continuous increase of rainfall from March to July which slightly decreases in August and peaks again in September, and then decreases till December (Figure 2.3). Winter months are relatively dry but a little rain occurs due to westerly wind.

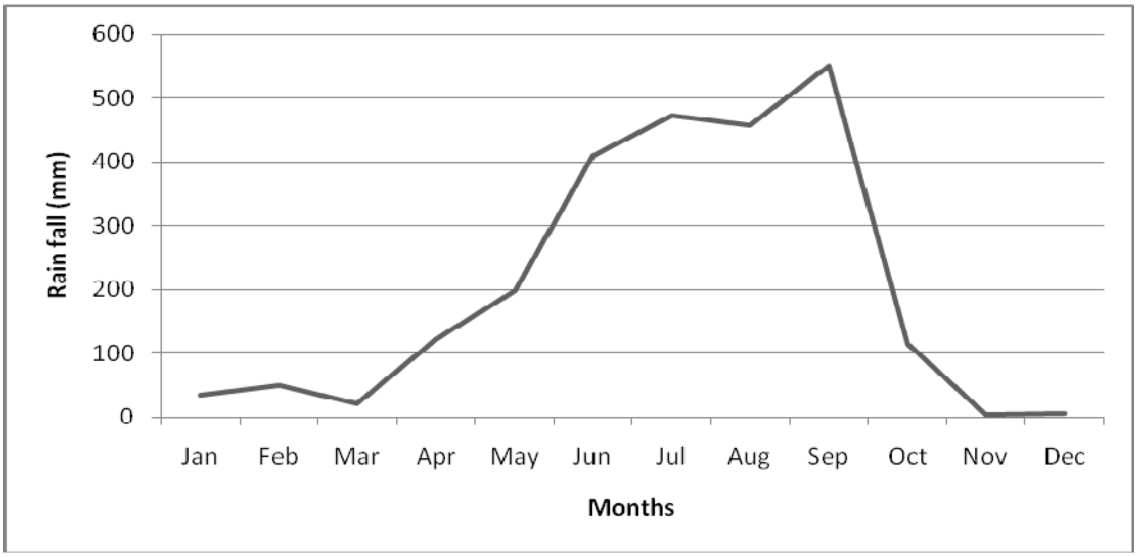


Figure 2.3: Variation in mean monthly rainfall from 2004- 2007 *(Source: DHM/GovN).*

The winter months (November to February) are colder and the nights and morning sare damp with heavy fog. January is the coldest month of year with mean minimum temperature recorded from 2004 to 2007 was 7.8^0 C. The temperature rises from January to May, stabilizes for four summer months and again decreases from September till January (Figure 2.4).

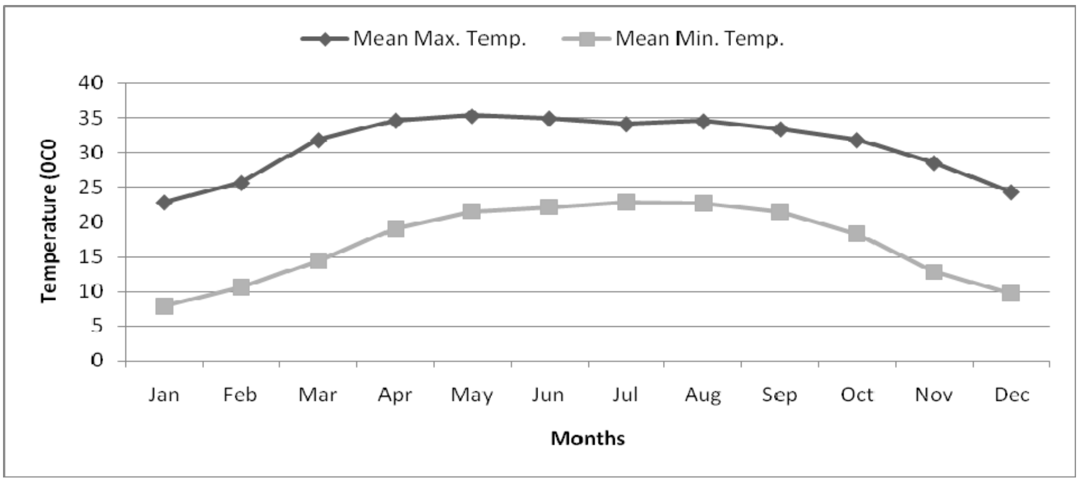


Figure 2.4: Variation in mean monthly temperature (^{0}C) from 2004- 2007 *(Source: DHM/GovN).*

Humidity is high all the year round except three dry months (April- June), with early morning readings of 100% relative humidity being recorded frequently at Bharatpur Meteorological station. Mean monthly relative humidity ranged between 89% in May and 98 % in December (Figure 2.5). Mornings during the winter months are characterized by heavy mists which persist for several hours after dawn, particularly in the river valleys. Cool and dry northerly winds from the greater Himalaya and the Trans Himalayan plateau reduces the daily temperatures. From February, winds from the west and south west rises temperatures and reduces relative humidity to minimum in May.

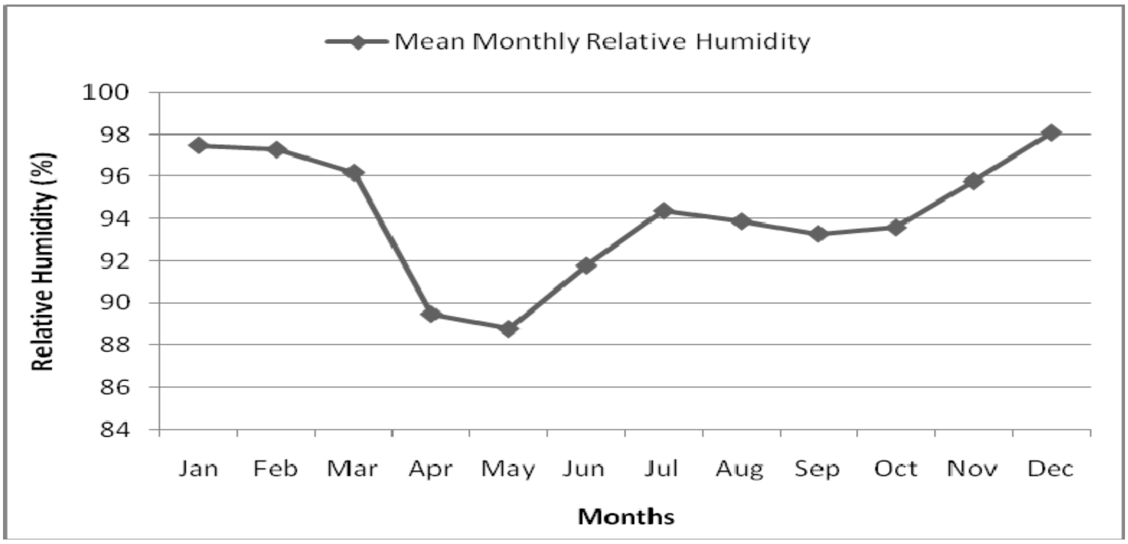


Figure 2.5: Variation of mean monthly Relative Humidity from 2004- 2007 *(Source: DHM/GovN)*

Local variations in climates have been reported within the Chitwan valley due to location relative to hills, the rivers, terrain and vegetation condition within short distances (Laurie, 1978).

2.5 VEGETATION

The general vegetation characteristics of the Chitwan National Park have been described by Bolton (1975), Laurie (1978) and Mishra (1982). Vegetation of CNP is subtropical type, with mosaics of early succesional flood plain communities in alluvial floodplain to climax Sal forest in relatively dry flat lands. About 70 percent of vegetation is predominantly Sal (*Shorea robusta*) forest, a moist deciduous vegetation type of the Tarai region (Stainton, 1972; Dobremez, 1976). The remaining vegetation types include grassland, riverine forest on the more moist areas (Laurie, 1978, Mishra, 1982b; Gurung, 1983) and Sal with Chir Pine, *Pinus roxburghii*, the latter occurring on the drier southern slopes of the Churia range.

Using satellite images, I classified land cover types of the CNPBZ into 16 types with four types of Sal forest associations (lowland Sal forest, mixed Sal forest, hill Sal forest and degraded Sal forest), three riverine forest associations (*Accacia/Dalbergia* association, *Trewia/Bombax* association, mixed riverine forest), three tall grassland associations (swampy tall grass, tall grass on *phantas* and tall grass within Sal forest), two short grassland associations (floodplain grassland and short grasslands), two types of wetlands (river and lakes), exposed surface and cultivated areas (Chapter 3). The cultivated area includes settlements that are found only in the buffer zone and there are no settlements inside the CNP.

The Sal forest is the ecologically characteristic climax vegetation of the Terai (Stainton, 1972; Dobremez, 1976). The Sal (*Shorea robusta*) is intermixed with *Terminalia tomentosa, T. bellerica, Dillenia pentagyna, Listea monopetala, Buchanania latifolia, Semecarpus anacardium* in Sal forest. Riverine forest is composed of *Dalbergia sissoo, Acacia catechu*, *Trewia nudiflora*, *Bombax ceiba*, *Butea monosperma, Careya arborea, Ehretia laevis, Ficus* spp.

Lehmkuhl (1994) has classified riverine grassland into eight different associations with ten phases. The floodplains are characterized by tall grass composed of *Saccharum spontanium, S. bengalensis, S. munja, Narenga porphyrocoma, Imperata cylindrica, Themeda villosa, Arundo domax, Phragmites karka*, etc. Important species of the short grasses include *Cynodon dactylon, Chrysopogon aciculatum, Erogrostis japonica, Clerodon viscosum, etc.*

Many lakes occur in the park and Barandabhar corridor forest in the buffer zone. A group of lakes has been designated as the "Beeshazar and Associated Lake Ramsar Site" in Barandabhar forest in the buffer zone. Several of oxbow type lakes are formed on old river beds which get flooded during monsoon, while in dry season they look like isolated lake (*tal*). Most of the lakes are found in riverine complex but Tamor Tal in Kasara and Beeshazar lake system are within the Sal forest. The vegetation around most of the lakes of riverine complexes is *Trewia/Bombax* forest association and *Arundo- Phragmitess* grassland association, where as the vegetations around the *tal* within Sal forest are the trees associated with Sal forest.

2.6 FAUNA

The CNP is rich in faunal diversity. Current checklists include 58 mammals, 539 birds, 56 herpeto and 124 fish species (Gurung, 1983; Edds, 1986; BPP, 1995; Shah and Tiwari, 2004; Baral and Upadhaya, 2006; Bhuju *et al.,* 2007). The prominent mammalian species of CNP are tiger (*Panthera tigris*), leopard (*Panthera pardus*), sloth bear (*Ursus ursinus*), gaur (*Bos gaurus*), greater one-horned rhinoceros (*Rhinoceros unicornis*), Asian elephant (*Elephas maximus*), Dolphin (*Platanista gangetica*). Ungulate prey species includes chital (*Axis axis*), hog deer (*Axis porcinus*), Sambar (*Rusa unicolor*), muntjac (*Muntiacus muntjak*) and wild pig (*Sus scrofa*).

CNP and BZ comprise two of Important Bird Areas (IBA) in Nepal (Baral and Inskipp, 2001). CNP supports 539 species of birds including 266 species of migratory species (Baral and Upadhaya, 2006, Bhuju *et al*., 2007). This is due to the Park's wide range of habitat types in a tropical lowland location where the distributions of eastern and western species overlap (Inskipp, 1989). Globally threatened species include greater adjutant (*Leptoptilos dubius*), lesser adjutant (*Leptoptilos javanicus*), Pallas's fish-eagle (*Haliaeetus leucoryphus*), greater spotted eagle (*Aquila clanga*) imperial eagle (*Aquila heliacal*), sarus crane (*Grus antigone*), bengal florican (*Houbaropsis bengalensis*), indian skimmer (*Rynchops albicollis*), white-throated bushchat (*Saxicola insignis*), jerdon's babbler (*Chrysomma altirostre*), slender-billed babbler (*Turdoides longirostris*) and bristled grass-warbler (*Chaetornis striatus*). Important reptile species found in good numbers in the park are Gharial (*Gavialis gangeticus*), marsh crocodile (*Crocodylus palustris*), golden monitor lizard (*Varanus flavescens*) and Asian rock python (*Python molurus*). Important fish species of the park are *Barilius* spp. *Tor putitora, T. tor, Puntius* spp., etc. (Edds, 1986).

2.7 DISTURBANCE FACTORS AFFECTING PARK ECOSYSTEMS

Natural and physical forces such as floods, fires, erosion, and human disturbance contribute to maintain a mosaic of grasslands, riverine forests and Sal forests in various stages of succession.

2.7.1 Flood

The riverine forests and grasslands along the floodplains remain water logged during monsoon season. The rivers and streams carry large loads of sediments during flood and hence frequently change the course. Monsoon floods and river dynamism are important natural forces responsible to maintain the grasslands and riverine forest communities.

2.7.2 Fire

Annual burning in Chitwan valley is an ancient human practice (Bolton, 1975; Laurie, 1978). The grassland and surface litter of Sal forest are burnt between January and April (Mishra, 1982a). Most fires are lit either by villagers or park staff (Laurie, 1978) to remove outer dry layers of tall elephant grass and to get new grasses. The people are using the canes of elephant grass for construction of walls and partitions in traditional houses. Early fires during January-February have little effect on shrub and grassland, but the late fires during March-April penetrate most part of the forests. Heavy fires reduce species diversity of grasses, shrubs and trees; however, the annual burning seems to maintain the grasslands from woody encroachments except *Bombax ceiba*, the only fire resistant tree (Troth, 1976).

2.7.3 Grass Cutting

Since 1978, local villagers have been permitted to enter the park each year to collect thatch grasses (Mishra, 1982a) and the grass cutting program (GCP) of the CNP is regarded as being very successful in gaining local people's acceptance of park. The GCP opens the park for short period (previously 14 days but now less than a week), where villagers may collect four essential products that are not available to them elsewhere, namely thatch grass (mainly *Saccharum spontaneum* and *Imperata cylindrica*) for roof, reeds (mainly tall grass species such as *Saccharum narenga*, *Themeda* spp., *Arundo* spp., *Typha elephantinam*, *Phragmites karka* and *Cyperus* spp.), rope bark (*Helicteres isora*) and rope grass (*Eulaliopsis binata*). Straeds and Helles (2006) estimated that the almost 50,000 tones of biomass were removed from the Park during ten days access of grass cutting in 1999; the total gross economic value of the GCP in 1999 was more than $1 million. Illegal fuel wood was the single most important product extracted from CNP and accounted for half of the total quantity and economic value of all resources collected (Straeds and Helles, 2000). Recently, Bhrikuti Paper Mill at Gaidakot is buying grasses harvested from the CNP. Long term impact of commercial exploitation of grasses on park ecology and socio-economy of local people is yet to be evaluated.

2.7.4 Tourism

Chitwan National Park is one of the most popular touristic destinations in Nepal. Tourism has concentrated in Suaraha area, where over 60 hotels operate and about 75% of the entry permits are issued from Sauraha. Visitors are taken to the core zone of the park on elephant, vehicles and on foot. Some adverse impacts of tourism on the biodiversity of the park are damage to the vegetation, disturbance to wildlife and pollution are visible (Aryal, 2005).

2.7.5. Other Human Disturbances

National Park and Nepal Army Protection force respectively employs 270 staff and about 800 army personnel, and about 700 staff from 7 concessionaire hotels dwells inside the park. In 2007, there were 55 and 68 domestic elephants respectively with the park and 7 concessionaire hotels. These elephants regularly grazed inside the park and several trees are regularly lopped to provide fodder. Besides, there are some illegal encroachments for grazing, thatch and fodder grass cutting, firewood collection, timber cutting, bamboo and vegetable collection and other non timber forest product (NTFP) collection. These illegal but fairly conspicuous encroachments into the park over the years have caused concern (Nepal and Weber, 1993; Kattel, 1995; Stræde and Helles, 2000; Dinerstein, 2003). Fishing activity is common in all rivers along the park border by local Bote who dependent on fish for their livelihood.

2.8 BUFFER ZONE AND ITS MANAGEMENT

A buffer zone (BZ) covering approximately 750 km^2 area was established around the CNP in 1996 (Sharma, 1998) to give protective layer to the National Park and to meet the resource needs of local people. Thirty five Village Development Committees (VDCs) and two municipalities are partly or almost wholly lie in the buffer zone. The BZ covers areas of national forest which are managed under community forestry, rivers, open land, streams and lakes, a plantation and private lands as well. Cultivated agricultural land (46%) is dominant land use category in the BZ followed by forest (43 %), shrub land, grassland and others (DNPWC, 2000) (Figure 2.6). The resources in the buffer zone in jointly managed by elected buffer zone management committee and park manager. In order to save the endangered wildlife and minimize conflicts, the buffer zone management committee has set some animal preventive infrastructure such as trenches, fences, watch towers and electric fences. 30-50 % of the park revenue is channeled for the buffer zone programme.

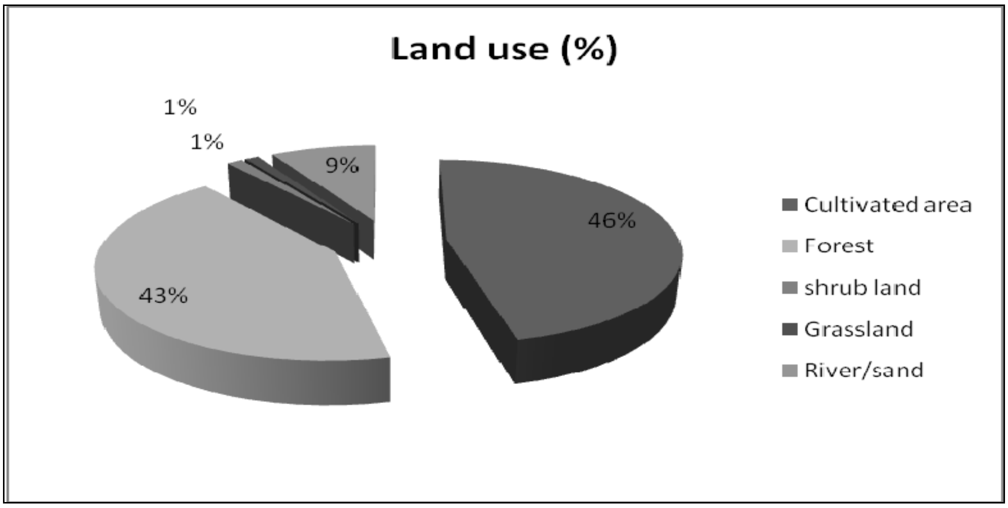


Figure 2.6 Land use in the Buffer Zone of the Chitwan National Park.

The buffer zone of CNP is inhabited by population of 223,260 from 36,193 households of various ethnicities; however Tharus are the main indigenous people (DNPWC, 2000). The agriculture is the dominant occupation among the people living in the buffer zone. As in most part of Terai, rice (*Oryza sativa*) is planted in June- July and harvested in November- December. However, in areas with permanent water source rice is grown twice in a year. Wheat (*Triticum avvenea*) and mustard (*Brassica* sp.) are most important winter crops.

Chapter 3

LAND COVER AND LANDSCAPE PATTERNS IN THE CHITWAN NATIONAL PARK AND BUFFER ZONE, NEPAL

3.1 INTRODUCTION

Knowledge on the land cover types and their spatial arrangement are necessary in order to understand the ecological processes as well as in planning and management of natural resources. Traditionally, land cover mapping relied mainly on the field based data, which are time, cost and labor intensive. However, remote sensing now provides an advance technology for gathering complete and accurate information on land cover for a large area within a relatively short time, and with low cost and man power.

Remote sensing technology is increasingly being used in the field of wildlife habitat analysis, mapping and monitoring. Many wildlife habitat monitoring studies have used physical characteristics of the environment such as land cover (Hansen *et al.*, 2001; Shrestha, 2004; Thapa and Lichtenenegger, 2004; Collingwood, 2008; McDermid *et al.*, 2008, Midha, 2008; Paliwal, 2008), canopy closure (Hyde, 2005), leaf area index (LAI; Chen and Black, 1992; Qi *et al.*, 2000; Li *et al.*, 2008). Remote sensing has also been recognized as an efficient technology for landscape scale habitat mapping (Osborne *et al.*, 2001; Kushwaha and Roy, 2002; McDermid, 2005; Hyde, 2005) and deriving predictor variable for distribution modeling, primarily by providing spatial and ecologically relevant predictor variables such as land cover or habitat classification over large geographical extents (Roy *et al.*,1986; Shrestha, 2004; Thapa, 2004; Gutierrez *et al*., 2005; Edwards *et al*., 2006; Thompson *et al*., 2006; Davis *et al*., 2007; Wang *et al*. 2010).

Landscape is composed of clusters of interacting elements (patches) (Forman and Godran, 1986). It often represents geographic areas along with its interaction with, and impacts from physical, ecological, geomorphic and anthropogenic processes (Naveh, 1987); hence the landscape is dynamic and unique in structure and function. The natural landscapes are rich in heterogeneity from a variety of factors such as biotic interactions, disturbances and ecological succession. Recently anthropogenic factor has been emerged as a more important determinant of landscape structure, pattern and dynamics. Both natural and anthropogenic factors are responsible for spatial heterogeneity in a landscape. Spatial heterogeneity is often measured with landscape metrics that refers to indices developed from categorical maps, and is focused on the characterization of the geometric and spatial properties of map patterns (McGarigal, 2002).

Landscape analysis is a process that quantifies landscape patterns and is commonly used for understanding its composition and configuration (Wang *at al*., 2009). The landscape patterns are quantified by number of metrics and such metrics have been used as surrogate to explain the species presence and abundance (McGarigal and McComb, 1995; Linke *et al*., 2005), habitat loss and fragmentation (Linke *et al*., 2005; Midha and Mathur, 2010; Munsi *et al*., 2010), habitat function and landscape pattern (Herzog and Lausch, 2001; Berland *et al*., 2008) and effects of ecotones and corridors on species movement (Bowers *et al*., 1996). Landscape metrics act as the quantitative link between spatial patterns of the landscape and ecological processes, such as animal movement and habitat selection (O'Neill *et al.*, 1988; Morris, 1987; Weins, 1986; Narumalani *et al*., 2004). Therefore, it is important to understand landscape patterns, dynamics and ecological process that influence patterns (Hargis *et al*., 1998). Spatial tools of remote sensing and Geographic Information System (GIS) have provided practical means for preparing classified thematic maps, which are the key inputs for most studies on landscape pattern analysis (Turner, 1990; Shao and Wu, 2008; Wang *et al*., 2009; Midha and Mathur, 2010; Munsi *et al*., 2010).

A few studies have attempted to classify vegetation types of Chitwan National Park (CNP), either focusing only on the rhinoceros habitats (Thapa, 2005; Kafle, 2005) or covering broad geographic area (Joshi, 2000; Shrestha, 2004; Panta *et al*. 2008) including CNP as part of their study area. All these study used medium resolution satellite images. I studied land cover and landscape patterns of the Chitwan National Park and Buffer Zone (CNPBZ) using high resolution satellite images. The CNP is one of the rich biodiversity areas in Terai (Bhuju *et. al*., 2007) and also most dynamic landscapes undergoing spatial and temporal changes due to natural and anthropogenic factors (Laurie, 1978; Mishra, 1982; Sharma, 1990; Nepal and Weber, 1993;

Lemhkulh, 1994; Strade and Helles, 2000; Dinerstein, 2003; Thapa, 2003; Strade and Treue, 2006). The ecological processes and human influences in terms of management interventions and disturbances create spatial heterogeneity. Therefore, landscape monitoring has been done to determine the effects of land use and management on landscape structures. The objectives of this study were to: i) classify land cover types in the park and buffer zone, and ii) determine landscape composition and spatial configuration. Accomplishing these objectives will allow for the creation of a more accurate and detailed land cover map covering arrays of habitats in the CNP and BZ. The increased thematic resolution (increased number of classes) of this map would also contribute to a more robust calculation of landscape metrics. A detailed land cover map and data covering entire CNPBZ is essential for research, planning and management of biodiversity.

3.2 METHODS

3.2.1 Data and Software Used

I used the ALOS (Advanced Land Observing Satellite) image from the Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) sensor. The spatial and spectral resolution of AVNIR-2 imagery provides high resolution image (spatial resolution 10 m, Swath Width: 70km) information of the Earth's surface which is appropriate for vegetation monitoring in heterogeneous landscape. Two scenes were used for mapping vegetation cover classification of CNPBZ. Both the scenes were cloud free and from February and March 2009. The data used were a level- 1B2 product which was geometrically (systematically) corrected. The ALOS (AVNIR) images contain four multispectral bands (0.52 – 0.86μm) corresponding to blue (B), green (G), red (R) and near infra-red (NIR). Topographic maps (1: 25,000) produced by the government of Nepal were also used as ancillary data sets.

Spatial analysis software the ERDAS IMAGINE 9.2 (Leica Geosystems GIS and Mapping LLC 1991- 2003) was used for image processing, and ArcGIS 9.3 (Environmental Systems Research Institute 1999- 2002) and ArcView 3.3 (ESRI 1999- 2002) for final map preparation. Using digital boundary of CNPBZ, both the images were clipped to extract the study area. FRAGSTATS 3.3 was used for landscape pattern analysis (McGarigal *et al*., 2002).

3.2.2 Land Cover Mapping

3.2.2.1 Image Pre - processing

To remove unwanted artifacts like additive effects due to atmospheric scattering, the first order radiometric corrections were applied using dark pixel subtraction technique (Lilesand and Kiefer, 1994). Both images were registered geometrically in ERDAS Imagine 9.2 using ground control points (GCPs) collected from topographic maps. Images were re-sampled by nearest neighborhood method using 20 GCPs for each image. Root Mean Square (RMS) error was lower than 0.5 pixels (5 m).

3.2.2.2 Ground Truthing

A field reconnaissance was done from February - June 2007 to have the clear idea on the vegetation types of CNPBZ. Later, intensive ground truthing was done during leopard sign survey (Chapter 5), prey survey (Chapter 4) and camera trapping (Chapter 5). The geographical coordinates of the homogenous cover types were recorded using a Global Positioning System (Garmin GPS MAP 60 CXS). From each location major species of vegetation was recorded. A total of 780 GPS points were collected from various parts of the park and BZ. Half of the GPS points were used for supervised classification and half for the accuracy assessment.

3.2.2.3 Classification Process

For land cover mapping, I established a land cover classification scheme which was based on the literature (Stainton, 1972, Laurie, 1978; Mishra, 1982; Lehmkuhl, 1994; Thapa, 2003; Shrestha, 2004; Champion and Seth, 2005). A total of 16 cover classes including 12 vegetation class (Table 3.1) were recognized.

A hybrid approach of classification by combining both unsupervised and supervised methods was followed to classify land cover types. At first, unsupervised classification was performed, using the nearest neighborhood algorithm to group pixels with similar spectral response into unique clusters. Unsupervised classification with ISODATA (Iterative Self-Organizing Data Analysis) algorithm examines similar pixels in an image and aggregates them into number of classes (Lilesand and Kiefer, 1994). Initially, each image was classified into 45 classes which were iterated 10 times with convergence threshold of 0.98. The homogenous clusters corresponding to a specific land cover types were assigned to appropriate class, using ancillary data, topographic maps, false color image and field knowledge, by swiping them on the top of the raw image. Latter these classes were merged into 16 different covers by recoding.

Later, cultivated lands and human settlement areas were masked out from each of the scenes to avoid misclassification due to spectral similarity of crops and grasslands. Then, the images were classified by a supervised classification technique using a maximum likelihood classifier (MLC), with appropriate signatures or training sets generated from half (390) of the ground control points collected during field survey, for corresponding land cover and vegetation classes. The MLC is widely accepted algorithm for image classification basically assigns land cover categories to pixels with similar spectral values (Jensen 1996). Finally, both the classified images were mosaicked to make a single continuous image.

Finally, the classified image was run through a standard majority filter (3x3) for smoothening so as to avoid errors of misclassification and to develop accurate indices for landscape structures.

3.2.2.4 Accuracy Assessment

Accuracy assessment is important to determine the quality of the information derived from remotely sensed data in classified maps (Conglaton, 1991; Fitzgerald and Lees, 1994; Jansses and Wel, 1994, Lellesand and Keifer, 1994; Jensen, 1996; Jensen, 2000; Stehman, 1997; Congalton and Green, 1999). Evaluation was done using both the standard error matrix and the Kappa Index of Agreement (KIA) for both overall and class specific results. The error matrix is a site-specific measure of the correspondence between the image classification result and the measured ground conditions, and is a standard first step for accuracy assessment (Foody, 2002). From the error matrix, user's, producer's and overall accuracies were obtained. User's accuracy indicates the reliability that a pixel classified on the map actually represents that class on the ground, whereas the producer's accuracy represents the probability of a reference pixel being correctly classified. Overall accuracy was determined by dividing the total number of correctly classified pixels by the total number of pixels in the error matrix (Congalton, 1991; Congalton and Green, 1999). Therefore, overall accuracy indicates accuracy of all classes, whereas user's and producer's accuracy measure the accuracy of individual classes. KIA is a discrete multivariate technique used to statistically evaluate the accuracy of the classification maps and error matrices, and measures both overall accuracy and of individual class accuracy (Collingwood, 2008).

The field reference data (556 points) on land cover types were used for the purpose of the accuracy assessment, with 50% (390 ground control points) of the total field data collected from each class saved for validation purposes and remaining data points were collected during camera trapping. The land cover information of these locations was compared to classified maps.

3.2.3 Landscape Patterns Analysis

The landscape pattern analysis helps to understand the spatial structure and health of landscape. Landscape analysis done was at three levels *viz* landscape, class and patch level (Table 3.1), because the variables concerning these three levels carry different kind of information. Landscape metrics were computed in the program FRAGSTATS ver. 3.3 (McGarigal *et al*., 2002) using land cover classified map as input. Program FRAGSTATS is a spatial pattern analysis program for categorical maps. The individual land cover type of different pixel was merged to form discrete patches using the eight-cell patch neighbor rule (McGarigal *et al*., 2002; Schindler *et al*., 2008). The metrics were chosen to try to limit redundancy in the physical characteristics being measured and to represent each of five main categories: (i) patch size and density, (ii) patch shape and edge, (iii) Isolation, proximity and connectedness, (iv) texture, and (iv) diversity (Table 3.1). For the computation of the landscape metrics, the land cover patches were delineated applying the eight neighbor rule.

Table 3.1 Landscape level (LL), class level (CL) and patch level (PL) metrics used in this study.

Acronym	Metric name	Level	Description	Unit
Group I. Patch size and density				
NP	Number of Patches	LL,CL, PL	Number of patches in a landscape	None
AREA_MN	Mean Patch Area	LL, CL	Mean size of the patch	Sq km
PD	Patch Density	LL, CL	Number of patches per unit area	No/1000ha
LPI	Largest Patch Index	LL, CL	Percentage of total area occupied by largest patch	%
PLAND	Percentage of Landscape	CL	Percentage of area occupied by certain land cover class	%
Group II. Shape and edge				
ED	Edge Density	CL	Total length of edge per unit area	none
MSI	Mean Shape Index	CL	A measure of overall patch shape complexity	none
Group III. Isolation, proximity and connectedness				
CONNECT	Connectance Index	LL	Percentage of patches which are joined , i e. inside a specified threshold	%
Group IV. Texture				
IJI	Interspersion and Juxtaposition	LL, CL	Measure of evenness of patch adjacencies, equals 100 for even and approaches 0 for uneven adjacencies	%
	Aggregation Index	LL	Percentage of neighbouring pixel, being the same land cover class, based on single-count method	%
Group V. Diversity				
SIDI	Simpson's Diversity Index	LL	Diversity measure, which equals 1 minus the sum of the squared proportional abundance of each patch type	none
SIEI	Simpson's Evenness Index	LL	Measures the distribution of area among the different patch classes	none

3.3 RESULTS

3.3.1 Land Cover Classes

A detailed (Figure 3.1) land cover map was developed using high resolution satellite images. Sixteen land cover types were identified and delineated. Land cover classification includes four types of Sal (*Shorea robusta*) forest associations (lowland Sal forest, mixed Sal forest, degraded Sal forest and hill Sal forest), three types of Riverain forest associations (*Trewia- Bambax, Acacia- Dalbergia*, and mixed riverine), two types of short grassland associations (flood plain grassland and short grassland), three types of tall grass associations (swampy tall grass, tall grass and wooded tall grass), two wetland types (river and lakes), exposed surface and cultivated lands including settlements (Table 3.2). The cultivated lands are found to be only in the buffer zone. From a detailed land cover map, a general map consisting of Sal forest, riverine forest, grassland, water body, exposed surface and cultivated area was prepared (Figure 3.3).

3.3.1.1 Sal Forest Association

(i) Lowland Sal Forest: The lowland forest occurs in moist and flat areas of the park and buffer zone. This forest association is mainly dominated by Sal tree. The almost pure stands of Sal forest are found between Jarneli and Sukibhar area. The Sal forest riches at the climax stage around Kasara area. The lowland Sal, *Shorea robusta* was associated with *Terminalia alata, Semecarpus anacardium, Syzygium cumini, Dillenia pentagyna, Ficus hispida, Cleistocalyx operculatus, Semecarpus anacardium, Xeromphis uliginosa, Litsea monopetala, Litsea monopetala, Legarus troemipardiflora*.

(ii) Mixed Sal Forest: Mixed Sal Forest occurred on the slightly elevated gentle slopes in Bhabar part of the park both southern and northern base of the Churia hills. The upper canopy composed of scattered *Shorea robusta* with *Terminalia alata*. Poor regeneration and high uprooting was common among the Sal at the Bhabar tract. Other important tree species associated are *Terminalia sp.*, *Adina cordifolia*, *Anogeissus latifolia*, Dilenia pentagyna, *Anogeissus latifolia, Lagerstroemia parviflora, Buchnania latifolia, Diospyros melanoxylon, Hymenodyction spp., Ficus sps, Cedrela toona Lannea coromandelica, Phylanthus emblica,* etc.

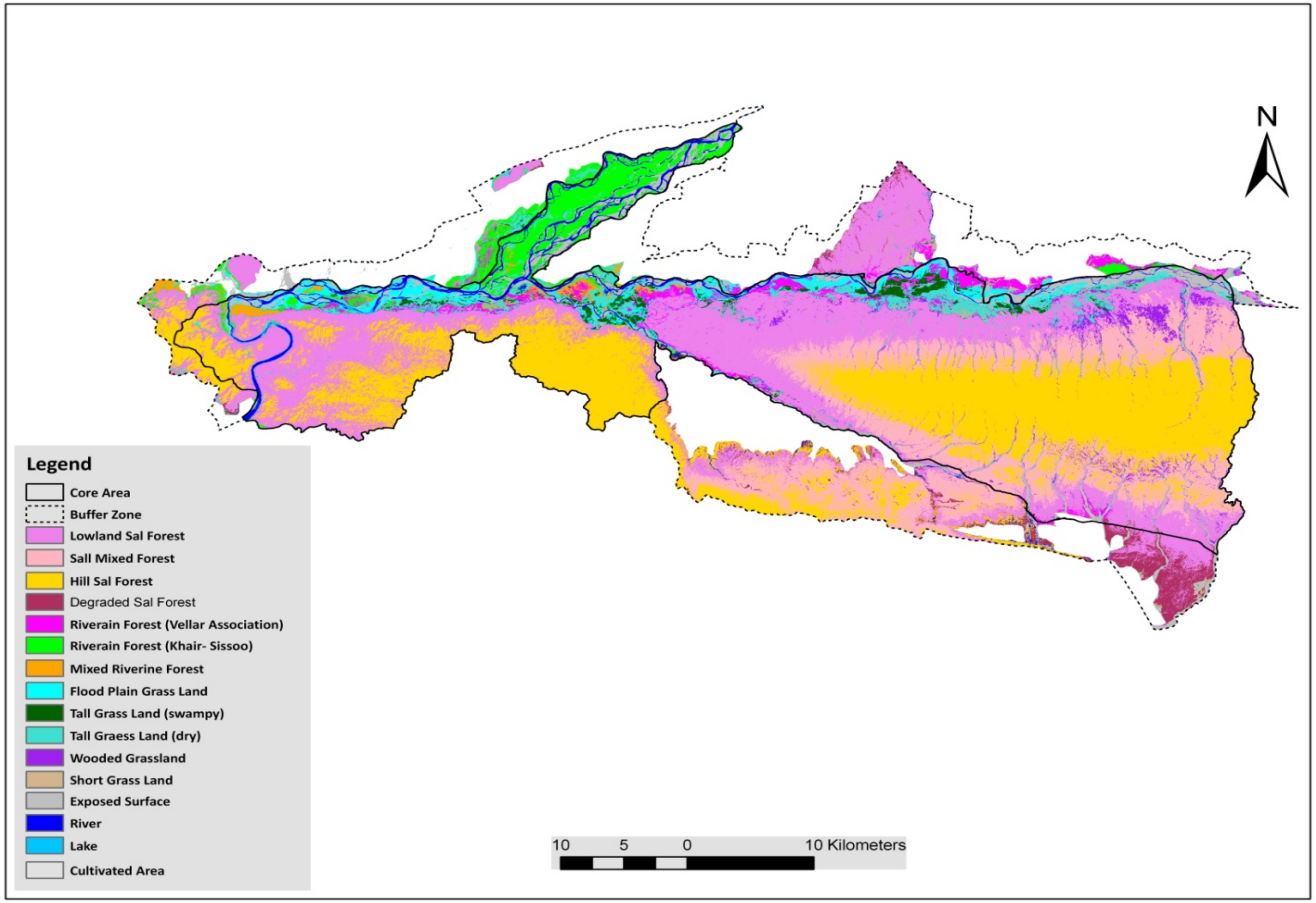


Figure 3.1 Detailed land cover classification in the Chitwan National Park and Buffer Zone, Nepal

Table 3.2 Estimated areas of land cover classes in Chitwan National Park and Buffer Zone, Nepal

SN	Land cover classes	Core Area		Buffer Zone	
		Area (km^2)	%	Area (km^2)	%
1	Low land Sal Forest	321.42	26.57	121.85	17.03
2	Mixed Sal Forest	187.37	15.49	70.01	9.79
3	Hill Sal Forest	372.58	30.80	49.70	6.95
4	Degraded Sal Forest	0.57	0.05	35.36	4.94
	Sub total	***881.95***	***72.90***	***276.92***	***38.70***
5	Riverine Forest (*Acacia-Dalbergia*)	55.95	4.62	19.70	2.75
6	Riverine Forest (*Trewia-Bambax*)	24.07	1.99	11.41	1.60
7	Riverine Mixed Forest	11.17	0.92	3.17	0.44
	Sub total	***91.18***	***7.54***	***34.28***	***4.79***
8	Floodplain Grassland	31.76	2.63	5.57	0.78
9	Short Grassland	10.13	0.84	6.77	0.95
	Sub total	***41.89***	***3.46***	***12.34***	***1.73***
10	Tall Grassland (Swampy)	17.62	1.46	0.35	0.05
11	Tall Grassland	52.88	4.37	7.77	1.09
12	Wooded Grassland	27.21	2.25	0.76	0.11
	Sub total	***97.71***	***8.08***	***8.87***	***1.24***
13	River	32.90	2.72	2.66	0.37
14	Lake	2.16	0.18	0.64	0.09
	Subtotal	***35.06***	***2.90***	***3.30***	***0.46***
15	Exposed surface	62.03	5.13	17.65	2.47
16	Cultivation	0.0	0.0	362.12	50.61
	Total	**1209.83**	**100.00**	**715.48**	**100.00**

(iii) Hill Sal Forest: The hill Sal forest was found in northern and southern slopes of Churia range and Someshor hills. Species composition of hill Sal Forest is much similar with mixed Sal forest at Bhabar region. The hill Sal was not taller like Sal Forest of lowland and Bhabar area. Major species associated with hill Sal were *Lagerstroemia parviflora, Adina cordifolia, Buchnania latifolia, Dilenia pentagyna, Bauhinia malabarica, Albizzia sp.,* etc. The hill Sal is usually superseded by *Pinus roxburghii* on drier southern slopes and also in the northern slopes in eastern part of the park. In the hill slopes, dry grasses occur with *Pinus roxburhgii*.

(iv) Degraded Sal Forest: Sal forest was found to be degraded forest around the villages in Thori, Madi and Barandabhar area. Species composition of these patches was similar to that of the lowland Sal forest. The degraded Sal forest is characterized by sparse distribution of trees with relatively low seedling and shrub and the ground cover mostly dominated by weeds such as *Lantana*.

3.3.1.2 Riverine Forest Association

(i) *Accacia- Dalbergia* Association: *Acacia catechu* and *Dalbergia sissoo* forest association was found on the recent sandy alluvial deposits along rivers (Narayani and Rapti). *Acacia- Dalbergia* association is pioneer species in succession. This type of forest was dominant features in the Narayani Island. *Acacia- Dalbergia* association forest are mixed with heavy growth of grasses and lianas. Annual flood and water logging are prominent features in this forest. *Acacia catechu* was found relatively in drier part.

(ii) *Trewia- Bambax* Association: *Trewia nudiflora* and *Bombax ceiba* forest was found mainly on Rapti flood plain representing latter stage of succession. The *Bambax - Trewia* association is a type of tropical deciduous riverine forest (Stainton 1972). Common tree species of this association were *Trewia nudiflora, Bambax ceiba, Listea monosperma, Mallotus philippinensis, Ehretia laevis, Premna obtusifolia, Albizia spp., Cassia fistula, Bischofia javanica, Meliousa glosidium, Smpolocos ramocysina, Artia elliptica, Premna barbeta, Artia elliptica, Butia monosperma, Bauhiniam malabarica, Litsea monopetala, Careya arborea, and Ehretia laevis.*

(iii) Mixed Riverine Forest: Small patches of mixed riverine forest occupied oldest and well drained upland sites. These forest patches appears to be advanced sucessional phase of *Trewia - Bambax* forest. Mixed riverine forest patches were relatively rich in tree diversity. Dominant over story species found in this forest type were *Dysoxylum sp*., *Persea sp*., *Trewia nudifiora*, *Mallotus philippinensis*, *Bombax ceiba*, *Syzigium cumuni*, *Ficus racemosa*. Mixed riverine forest occupied the oldest and stable river tracts.

3.3.1.3 Grassland Association

Five different grassland types including both short and tall grassland have been classified. The floodplain grassland and short grassland represent short grasses whereas swampy tall grassland, tall grassland and wooded grassland represented the tall grass.

(i) Floodplain Grassland: The floodplain grassland terminology here represents various grasses and herbs grow on exposed sandbanks of major rivers. Common species of this association are *Polygonum plebeium, Persicaria spp., Saccharum spontaneum*, and sedges like *Cyperus*, *Kyllinga* and *Mariscus spp*.

(ii) Short Grassland: Small sized short grass patches are found various places in the park usually along the edges of forest. Common species of this association are *Cynodon dactylon*, *Chrysopogon aciculatus, Setaria pallid - fusca, Paspalpalium spp.,* and *Digitaria setigera.*

(iii) Tall Grassland (Swampy): The swampy tall grassland represented by *Arundo - Phragmites* associations forms patches in swampy wetlands, along stream beds on the floodplain and around lakes.

(iv) Tall Grassland: This type of tall grassland found as patches in areas of the park from where villages were evacuated. The tall grasses are represented by *Saccharum- Narenga* associations. Species composition included *Imperata cylindrical.*

(v) Wooded Grassland: Patches of wooded grasslands are occurred mainly Bhabar where rivers and streams from Churia hills flooded during monsoon and area remain high moisture. Such patches are characteristic of *Shorea robusta*, *Dilenia* *pentagyna*, *Syzigium cumuni*. *Themeda villosa* which forms a tall grass cover in these patches between Sal forests.

3.3.1.4 Wetlands

This category included major rivers and interspersed natural lake. The Narayani, Rapti and Rew are major rivers in the study area. The important lakes included Lami tal, Tamor tal and Devi tal in the park and Beeshazar and associated lakes in the BZ.

3.3.1.5 Exposed Surface

The exposed surface included sand bank in river bed and riverine islands, and other eroded areas.

3.3.1.6 Cultivated Area

The settlements and cultivated areas are present only in the buffer zone. The common crops grown in these areas included paddy, wheat, maize and oil seeds.

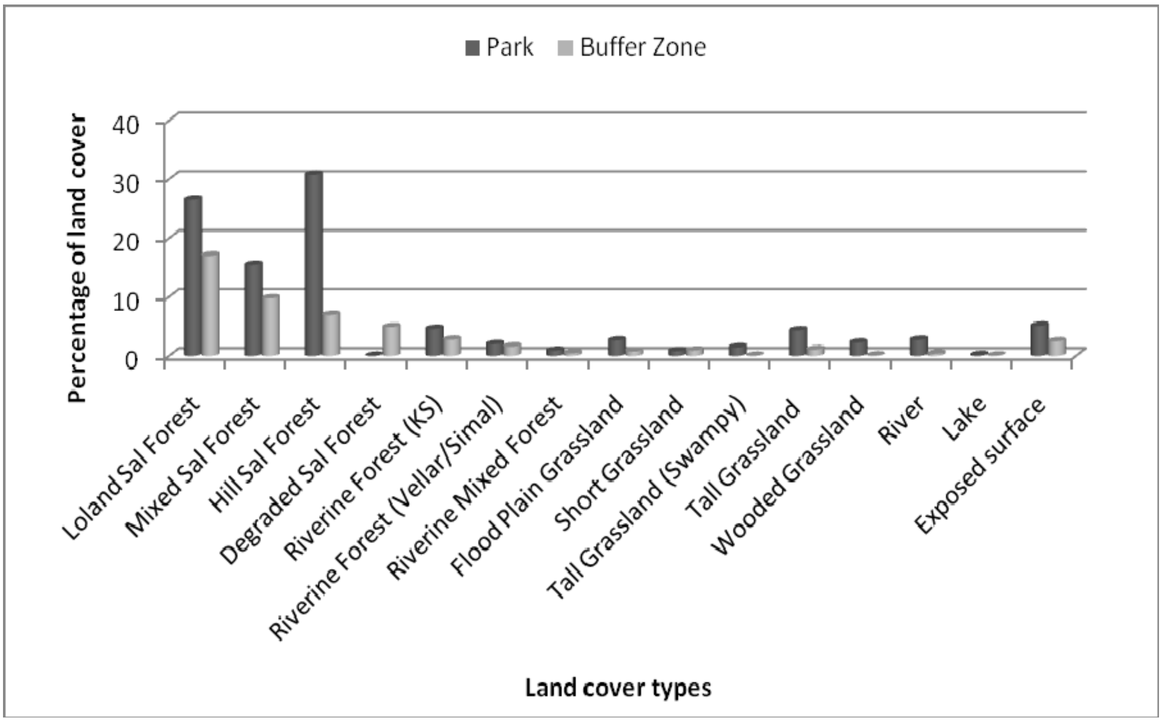


Figure 3.2 Land cover types in Chitwan National Park and Buffer Zone, Nepal.

3.3.2. Extent of Various Land Covers

Most extensive land cover category of the Chitwan National Park was Sal forest (72.90%), which was followed by grass land (11.53%), riverine forest (7.54%), exposed surface (5.12%) and water body (2.89%) (Table 3.2). Among the Sal forest types, 26.56%, 15.49% and 30.79% of the area occupied by the low land Sal, mixed Sal and hill Sal forest respectively. Three distinct types of riverine forest association such as *Acacia - Dalbergia* (4.62%), *Trwia- Bambax* (1.99%) and mixed riverine forest (0.92%) were identified. I categorized five different grassland associations viz floodplain grassland (2.63%), scrubby short grassland (0.84%), swampy tall grass (1.46%), tall grassland (4.37) and tall grass with sparse woody vegetation (2.25%). The different physical cover types included rivers (2.72%), lakes (0.18%) and exposed surface (5.13%).

Similarly, the most extensive land cover/land use type in the buffer zone was cultivated area (50.61%). Habitats in the buffer zone was classified as Sal forest (38.70%), riverine forest (4.79%), grasslands (2.97%), wetlands (0.46% excluding wetlands of the cultivated areas) and exposed surface (2.47%) (Table 3.2 and Figure 3.2).

3.3.3 Accuracy Assessment

The average overall accuracy for the supervised ML classification was 84.53% (Table 3.3). The average Kappa Index of Agreement (KIA) was also high (0.83). Both the producer's and user's accuracy were over 80% for cover classes except degraded Sal forest, riverine mixed forest and tall grasslands (Table 3.3).

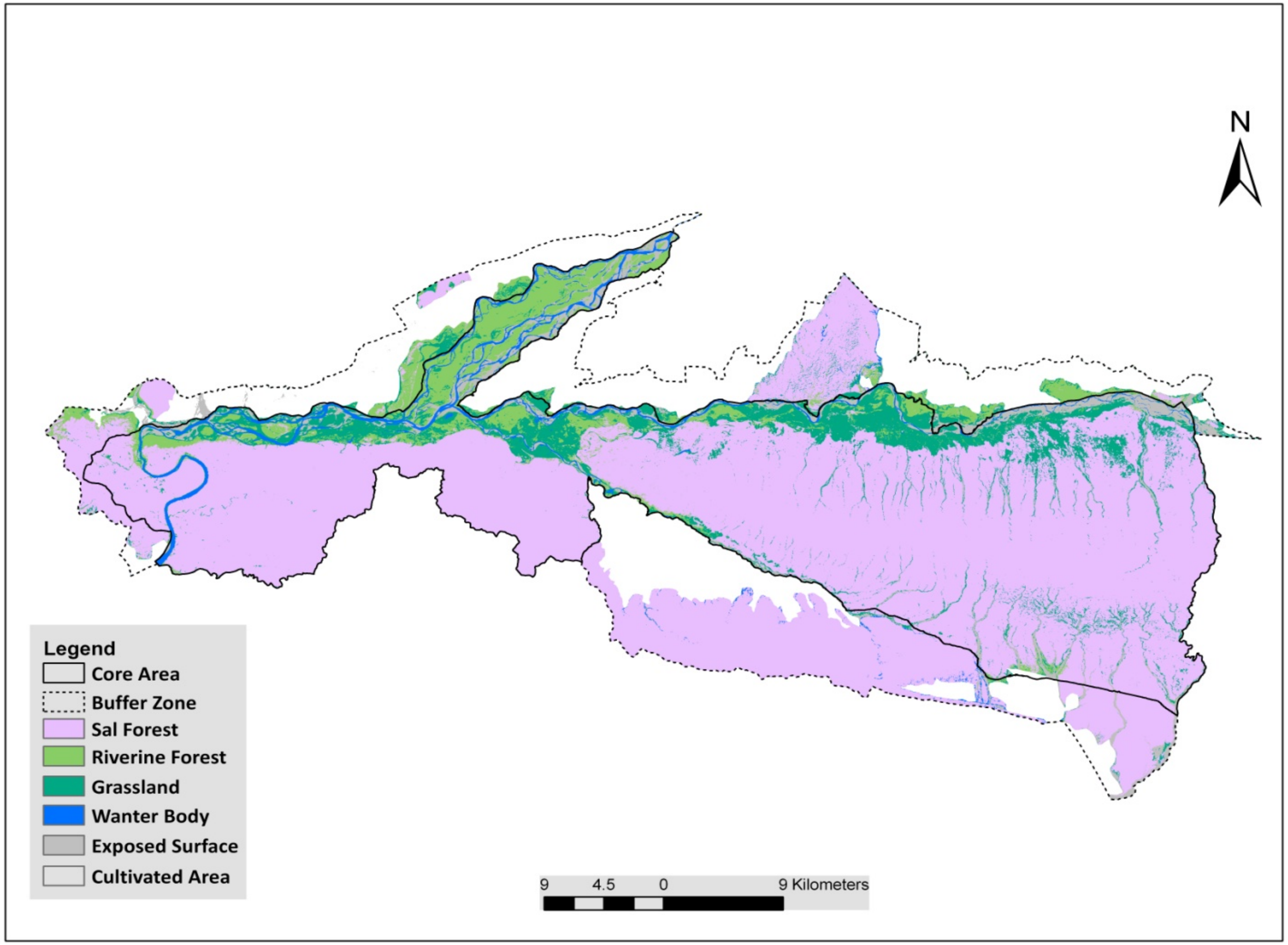


Figure 3.3 Generalized land cover types of Chitwan National Park and Buffer Zone, Nepal

Table. 3.3 Error matrixes of the land cover classification.

Columns: Reference Test Data																		
		LSF	MSF	HSF	DSF	AD	TB	RMF	FPG	SG	WS	TG	STG	RI	LA	ES	Sum	U. Acc (%)
Rows: Classified data	LSF	39	2	1	1	0	0	0	0	0	0	0	0	0	0	0	43	90.70
	MSF	2	36	2	1	0	0	0	0	0	0	0	0	0	0	0	41	87.80
	HSF	1	3	38	2	0	0	0	0	1	0	0	0	0	0	0	45	84.44
	DSF	3	2	1	26	0	0	2	0	1	0	0	0	0	0	0	35	74.29
	AD	0	0	0	0	24	1	1	0	0	1	1	0	0	0	0	28	85.71
	TB	0	0	0	0	2	28	2	0	0	1	0	1	0	0	0	34	82.35
	RMF	0	0	0	1	1	3	26	0	0	0	1	0	0	0	0	32	81.25
	FPG	0	0	0	0	1	0	1	23	0	0	1	2	0	0	0	28	82.14
	SG	1	0	0	2	0	1	0	1	25	0	1	0	0	0	1	32	78.13
	WG	0	0	0	0	1	1	3	1	0	42	2	0	0	0	0	50	84.00
	TG	1	0	1	0	0	0	1	2	0	1	36	2	0	0	0	44	81.82
	STG	0	0	0	1	1	1	0	0	0	0	2	30	0	0	0	35	85.71
	RI	0	0	0	0	0	0	0	0	0	0	0	1	35	2	0	38	92.11
	LA	0	0	0	0	0	0	0	0	0	1	0	0	2	20	0	23	86.96
	ES	0	0	0	3	0	0	1	0	2	0	0	0	0	0	42	48	87.50
	Sum	**47**	**43**	**43**	**37**	**30**	**35**	**37**	**27**	**29**	**46**	**44**	**36**	**37**	**22**	**43**	**556**	**90.70**
	P. Acc. (%)	82.97	83.72	88.37	70.27	80.00	80.00	70.27	85.19	86.21	91.30	81.82	83.33	94.59	90.91	97.67		
	Overall accuracy (%) 84.53																	
	Kappa index= 0.83																	

U . Acc. = User's accuracy, P. Accu. = Producer's accuracy, LSF= Lowland Sal forest, MSF= Mixed Sal forest, HSF= Hill Sal forest, DSF= Degraded Sal forest, AD= *Acacia/Dalbergia* forest, TB= *Trewia/Bambax* forest, RMF= Riverine mixed forest, FPG= Floodplain grassland, SG= Short grassland, WG= Wooded Grassland, TG= Tall grassland, STG= Swampy tall grassland, RI= River, LA= Lake, ES= Exposed surface.

3.3.4 Landscape Patterns

Natural landscape in CNPBZ has been characterized in relation to the major land cover classes. The landscape appears to be complicated at all three level of hierarchy viz landscape, class and patch.

3.3.4.1 Landscape Level Metrics

Landscape of CNPBZ was found to be heterogeneous in nature with 6994 fine patches of different size and configuration (Table 3.4). The patch density and mean patch size were 1.43 km^{-2} and 64.6 ha. The results of FRAGSTATS analysis revealed that the patches characterized by low value (0.33%) of conectance (CONNECT), high value (98.29%) of aggregation index (AI) and evenly interspersed (IJI= 75.73%) in the landscape. Both Simpson's Index of Diversity (0.55) and Evenness (0.58) indicated the moderate level patch diversity.

Table 3.4 Configurational landscape metrics calculated from ALOS Image of the Chitwan National Park and Buffer Zone.

Metrics	**Value**
Number of Patches (NP)	6994
Patch Density (PD)	1.43 km^{-2}
Largest Patch Index (LPI)	60.67 %
Patch Area (AREA_MN)	64.66 ha
Interspersion Juxtaposition Index (IJI)	75.73%
Aggregation Index (AI)	98.29%
Connectance Index (CONNECT- 300m)	0.33%
Simpson's Index of Diversity (SIDI)	0.55
Simpson's Evenness Index (SIEI)	0.58

3.3.4.2 Class Level Metrics

I computed metrics for 15 different classes using raster data as input in the program FRAGSTATS (Table 3.5). The percentage of landscape occupied by different classes (PLAND) varied from 0.19% by lake to the 28.321% by hill Sal forest (Table 3.5). The hill Sal forest was followed by low land Sal forest (27.25%) and mixed Sal forest (17.50%).

Amongst different land cover types (Table 3.5), the hill Sal forest occupied highest percentage of cover (28.32%), number of patches (8.37%), patch density (0.17 km^{-2}), largest patch index (4.59%) and highest aggregation index (97.24%). Except Sal forest (low land Sal, mixed Sal and Hill Sal) and *Accacia/Dalbergia* riverine forest, all forests and grassland types have PLAND below 6% and mean patch size below 15 ha.

Edge density in 15 different land cover classes was from 0.25 m/ha of lake to 4.66 m/ha of lowland Sal forest. Similarly, the values of mean shape index (MSI) for all cover classes were greater than 1.

The interspersion/juxtaposition index (IJI) value ranged from 45.50% (hill Sal forest) to 88.13% (tall grassland) indicating that the tall grasslands were highly interspersed and hill Sal forest were aggregated in a particular area (Table 3.5). Except, the hill Sal forest and Sal mixed forest, all other classes had IJI values higher than 60% indicating relatively well interspersion in the landscape.

Table 3.5 Class level metrics for landscape of Chitwan National Park and Buffer Zone

TYPE	PLAND (%)	NP	PD No/km^2	MPS ha	LPI %	ED m	MSI	IJI %
Lowland Sal forest	27.25	732	0.15	57.88	2.99	4.66	1.35	74.91
Sal Mixed forest	17.50	446	0.09	61.01	3.14	3.53	1.27	53.45
Hill Sal forest	28.32	837	0.17	52.61	4.59	4.26	1.36	45.50
Degraded Sal forest	2.01	244	0.05	12.86	0.28	0.66	1.34	64.91
Riverine forest (*Accacia/Dalbergia*)	5.37	556	0.11	15.07	0.64	1.65	1.27	78.82
Riverain forest (*Trewia/Bambax*)	2.55	519	0.11	7.64	0.10	1.20	1.29	88.13
Mixed riverain Forest	0.75	326	0.07	3.62	0.05	0.48	1.19	75.76
Tall grassland	3.58	558	0.11	9.97	0.22	1.75	1.36	88.54
Tall grassland (Swampy)	1.23	261	0.05	7.24	0.06	0.6	1.28	70.18
Wooded grassland	1.23	503	0.10	3.82	0.07	1.24	1.46	65.57
Floodplain grassland	2.26	359	0.07	9.74	0.10	0.92	1.29	75.11
Short grassland	0.60	535	0.11	1.71	0.01	0.63	1.21	78.34
River	2.42	258	0.05	14.61	0.43	1.61	1.60	64.55
Lake	0.19	233	0.05	1.28	0.01	0.25	1.20	77.99
Exposed surface	4.75	625	0.13	11.83	0.33	2.44	1.54	81.19

3.3.4.3 Patch Level Metrics

Patch level metrics were computed to characterize patches in class and landscape. The description of landscape and class metrics depend upon the individual patch characteristics in each class or landscape, hence the values of only the Patch area (AREA_HA) have been used to further description.

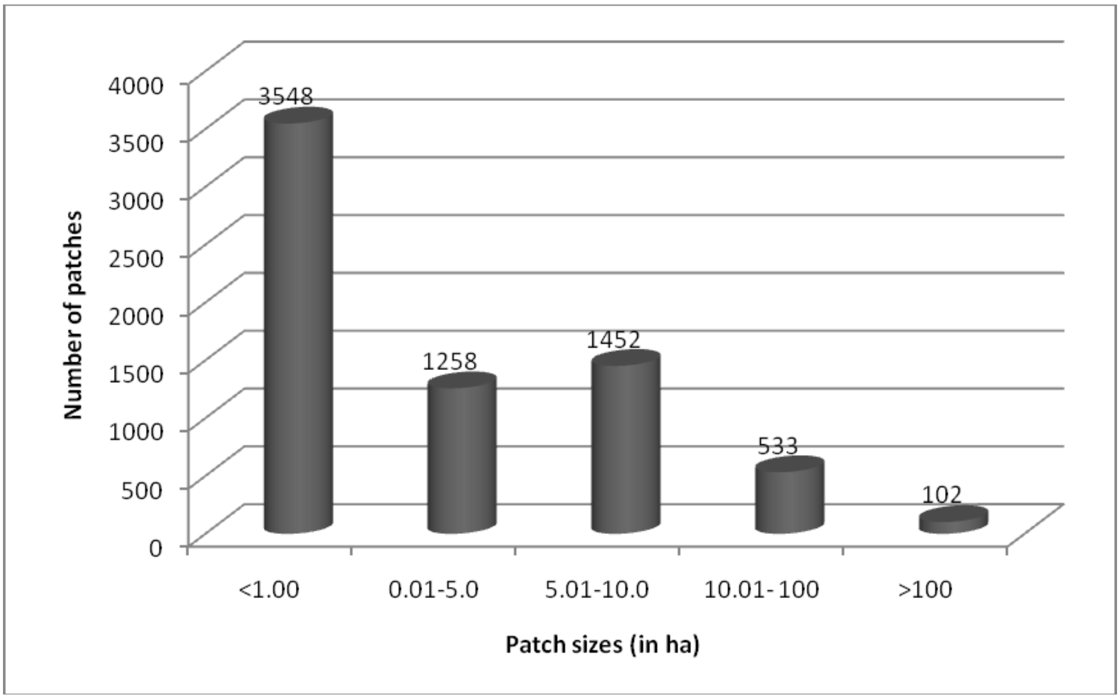
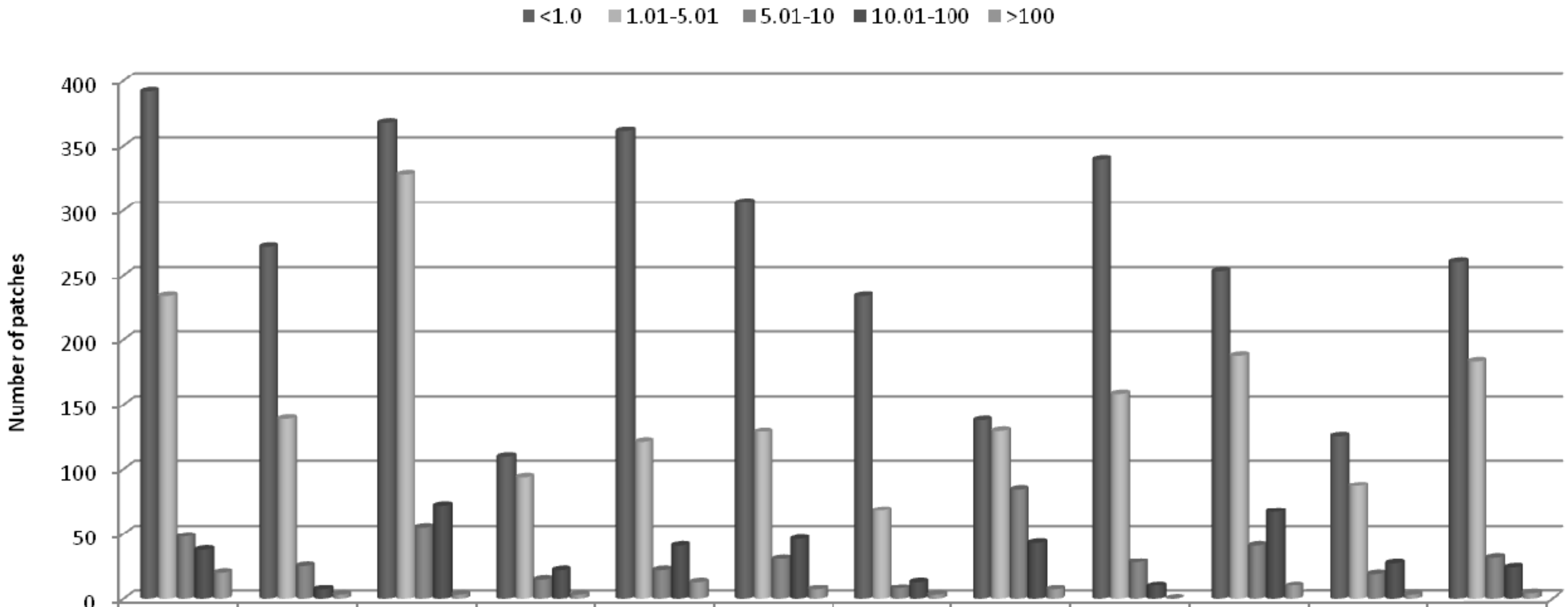


Figure 3.4 Distribution of patch size in landscape

A total of 6693 patches of 16 different land cover classes were delineated from the landscape (Figure 3.4 and 3.5). The analyses revealed that the size of 51.47% patches were less than 1 ha, 18.25% patch ranged between 1- 5 ha and only 102 patches had size larger than 100 ha (Figure 3.4).



	Lowland Sal	Mixed Sal	Hill Sal	Degraded Sal	Accacia/D albergia	Trewia/Ba mbax	Mixed Riverine	Floodplain Grassland	Short Grassland	Tall Grassland	Swampy tall grassland	Wooded grassland
<1.0	392	272	368	110	361	306	234	138	339	253	125	260
1.01-5.01	234	139	328	94	121	129	68	130	158	188	87	183
5.01-10	48	25	55	15	22	31	8	84	28	41	19	32
10.01-100	38	7	72	22	41	46	13	43	10	67	27	24
>100	20	3	3	3	13	7	3	7	0	10	3	4

Classes

Figure 3.5 Number of patch size (in ha) distribution among vegetation classes

3.4 DISCUSSION

3.4.1 Land Cover Classification

Spectral information available in the high resolution ALOS imagery and extensive field work enabled to delineate 16 land cover types and obtain cover estimates in various classes. The band combination of near infrared (band 4), red (band 3) and green (band 3) was useful in discriminating vegetation associations. The response of near infrared band to foliage content or leaf area index (LAI) was useful in differentiating vegetation association or even species (Taylor, 1993; Lillesand and Kiefer, 1994; Jensen, 1996). Many factors such as species composition, vegetation strata, crown closure, crown geometry, stand density, soil moisture, hill slope, aspects, hydrologic regime and sun angle affect the spectral signatures recorded and made the classification more challenging (Treitz *et al*., 1992; Price 1994; Fuller *et al*., 1997; Shrestha, 2004) even at high resolution imagery. Vegetation cover type with multi-layered structure is susceptible to problems of canopy overlap, often leading to confusion in interpretation (Nagendra, 2001). The dry grass cover with scattered pine and Sal trees on the southern slopes of Churia range had characters similar that of tall grass with scattered trees in Bhabar tract in the northern part of the park. Presence of multiple vegetation strata in a forest had a higher spectral reflectance due to higher LAI (Shrestha, 2004). In such situation, I focused on the compatibility of ground data collected and the spectral signatures of vegetation patterns in satellite images. As a result, the land cover classes were adequately classified and obtained cover estimates.

I classified vegetation into Sal forest association including low land Sal forest, mixed Sal forest, hill Sal forest and degraded Sal forest; riverine association comprising the *Accacia/Dalbergia* forest, *Trewia/Bambax* forest and mixed riverine forest and grassland association consisting of flood plain grassland, short grassland, swampy tall grassland, tall grassland and wooded grasslands. Present classification is compatible with the previous description on the vegetation pattern and succession in the lowlands of Nepal in Chitwan (Laurie, 1978; Mishra, 1982; Lemhkulh, 1994; Thapa, 2003) and Bardia (Dinerstein, 1979; Weschle, 1997; Jnawali, 1995; Sharma, 1999). The detailed classification (Figure 3.1 and Table 3.2) presented here could be useful for monitoring land cover dynamics, and also in research and management of wildlife species particularly associated with grasslands and riverine forest. The overall accuracy of the vegetation/land cover map worked out to be 84.53% and of Kappa Index of Agreement (KIA) was 83%.

Result of this study clearly reveals that the vegetation cover of CNPBZ is composed of mosaics of various types. Climate, topography, edaphic gradients, annual burning and seasonal flooding cycles are dominant features in shaping vegetation mosaics in the CNP, where as anthropogenic pressure is an equally important disturbance factor in the buffer zone forest. Influence of seasonal flooding on vegetation structure is prominent in the floodplain association that includes riverine forest and grasslands. Seasonal flooding brings rapid changes in vegetation patterns by removing forest cover, depositing silts, sands and gravels, thereby changing soil structure, soil erosion and inundating the area temporarily (Eckholm 1976; Reiger, 1976). Similarly annual burning is an important determinant in shaping vegetation dynamics in Sal associations and grasslands. Sparse distribution of *Shorea robusta* in a top canopy shows the inter-specific competition with other tree species, thus providing chances to germinate for other opportunistic species which occur in less abundance in mature forest (Ohsawa *et al*., 1986). Such situation was commonly observed in mixed Sal forest at Bhabar tract, where Sal was observed to be uprooted and outnumbered by species like *Adina cordifolia*, *Anogeissus latifolia*, *Dilenia pentagyna*, *Lagerstroemia parviflora*. The human influence was clearly reflected in the land cover classes as the degraded Sal forest lies close to human habitation and comprises sparse trees with relatively low sapling and ground cover and mostly dominated by unpalatable weeds (*e.g. Lantana*). The transition among the classes seemed to be governed by flood cycle, moisture condition, substrate type, annual fire as well as human influence.

Among the land cover classes, Sal forest association was the most dominant class in CNPBZ. As CNP lies in *Dun* valley, Bhabar and lower Himalaya under sub tropical climate therefore Sal forest is dominant features (Stainton, 1972, Champion and Seth, 2005). The continuous tract of Sal forest was found to be broken along the streams flowing from the Churia hills both south and north, and along the course of main rivers (Narayani, Rapti and Reu), the riveine forest occupy.

3.4.2 Landscape Patterns

Landscape metrics were calculated to characterize the landscape patterns. Landscape metrics quantifies the configuration of and composition of landscape elements (class and patch) and thus, help in quantifying the relation of spatial characteristics of patches, classes of patches or entire landscape with the ecological processes (Narumalani *et al.,* 2004). There are well over 100 statistical measures of landscape structure at both the class- and landscape- levels (McGarigal *et al*., 2002). It is therefore useful to quantify the redundancy of landscape metrics to identify a suite of structure components that together account for the major independent dimensions of landscape structure exhibited in real landscapes (Cushman *et al*., 2008). I have selected 8 landscape, 6 class and single patch level metrics to quantify the landscape patterns of CNPBZ.

I have generated 8 independent gradients of landscape per land cover class, yielding a total of 1206 landscape structure gradients across all classes (Table 3.3). Three Sal forest types; the hill Sal forest (28.32%), lowland Sal forest (27.25%) and mixed Sal forest (17.50%) dominate the landscape by coverage (Table 3.3). Comparatively, smaller percentages of landscape (PLAND) occupies by the riverine forest association and grassland communities but were characterized by relatively higher number of patch in relation of PLAND, smaller value of largest patch index (LPI) and smaller mean patch size, indicating their patchy distribution in the landscape. All these cover types were well interspersed. Probably, soil types, local hydrologic regime, seasonal flooding and annual burning play vital role in creating heterogeneity in the landscape particularly in the grassland and riverine complexes.

The analysis of landscape metrics of the CNPBZ revealed its heterogeneous character with large number (6994) of patches, smaller mean patch size (1.43 km^2), but with moderate patch diversity (0.55) and evenness (0.58), and intermediate level of interspersion of forest types. The higher number of patches and smaller mean patch size in a landscape indicates its spatial heterogeneity at a finer resolution. The edge density of all covers types except Sal forest association was relatively low (Table 3.4). Higher value of edge density represents higher spatial heterogeneity and less compactness (Munsi *et al*., 2010). The result revealed that the mean shape index of cover classes in CNPBZ ranging between 1.2 and 1.57 (Table 3.4) was lower than the estimates from Dudhwa landscape, India (Midha and Mathur, 2010). Increasing value of shape index is indicator of irregular and complex shape which is more vulnerable to edge effect (Munsi *et al*., 2010).

Interspersion and juxtaposition index (IJI) measures the interspersion of different patches in the landscape. Low value of IJI represents clumped or disproportionate distribution of the patches whereas high IJI value represents patch types are uniformly adjacent to each other. The IJI values obtained in this study (Table 3.4) clearly indicated that the mixed Sal, hill Sal, degraded Sal and tall grassland with Sal were more clumped in distribution.

Chapter 4

DENSITY, BIOMASS AND POPULATION STRUCTURE OF MAJOR PREY SPECIES OF LARGE CATS IN THE NORTHERN PART OF THE CHITWAN NATIONAL PARK AND BUFFER ZONE, NEPAL

4.1 INTRODUCTION

Herbivore prey species, mainly wild ungulates, play a crucial role in the forest ecosystem as they regulate the ecosystem structure and function through energy transfer, nutrient cycling, seed dispersal; and maintaining soil structure and ensuring ecosystem developmental processes (McNaughton, 1979; Crawley, 1983; Kortlandt, 1984; Naimann, 1988). Wild ungulates are major parts of carnivore diets (Schaller, 1967; Seidensticker, 1976; Johnsingh, 1983; Karanth and Sunquist, 1995; Biswas and Sankar, 2002; Bagchi *et al.*, 2003; Edgaonkar, 2008; Wang and Macdonald, 2009), their distribution, abundance and population structures are affected due to anthropogenic activities, resulting in depletion of carnivore populations (*e.g.* tiger-Karanth and Stith, 1999). Large carnivore abundance is directly correlated with ungulate densities (Schaller, 1967; Seidensticker and McDougal, 1993; Karanth, 1995; Karnath and Sunquist, 1995; Karanth and Nichols, 1998; Miquelle *et al.*, 1999; Carbone and Gittleman, 2002; Karanth *et al.*, 2004a). Hence, maintaining prey populations is essential for ecosystem health and for maintenance of a viable carnivore population in an ecosystem.

Ecological knowledge on prey population, densities and biomass derived using valid methods are important pre-requisite for the population management of prey species as well as their predators (Karanth, 1995). However, relatively low densities, unique habitat requirements, crop raiding behavior, their consumption by local people and lack of scientifically valid studies makes their conservation difficult (Karanth and Sunquist, 1992).

Earlier attempts made in estimating population parameters of ungulate species in south Asian forest from Nepal (Seidentiscker, 1976; Dinerstein, 1980; Tamang, 1982), India (Schaller, 1967, Berwick, 1974; Johnsingh, 1983, Mathur, 1991) and Srilanka (Eisenberg and Lockhart, 1972) are important to gain knowledge on the ecology of ungulate species. However, these initial studies failed to address important questions relating to probabilities of detection and representative sampling (Karanth and Sunquist, 1992; Karanth and Stith, 1999). Karanth (1987a) emphasized the use of statistically and biologically valid methods in prey population estimation. Several important studies using DISTANCE sampling, a most valid method in population estimation, have been carried out in tropical forests of India (Karanth and Sunquist 1992, Varman and Sukumar, 1995; Khan *et al*., 1996; Karanth and Nichols, 1998; Biswas and Sankar, 2002; Jathanna *et al*., 2003). However, a very few estimates of prey population using DISTANCE sampling are available from Terai Arc Landscape (Harihar, 2005; Harihar *et al*., 2009; Malla, 2009; Wegge and Storas, 2009).

The abundance of prey species of large cats has been estimated in Chitwan by Seidensticker (1976) and Tamang (1982). Over the last three decades, there have been changes in habitat structure in the CNPBZ due to exclusion of cattle from the park and buffer zone forests, succession and invasion of woody species in grasslands and invasion of exotic alien species (*e.g*. *Michania micrantha*) in moist parts mainly on riverine forest, flood plain grassland and wetlands (Sapkota, 2007). These factors led to changes in habitat structure available for herbivores and consequent changes in abundance and habitat occupancy of different prey species are expected. Up till now, no systematic research has examined the abundance and structure of prey population in the CNPBZ. In this context, this study aimed to assess prey abundance and population structure from areas with different management history and disturbance gradients. Specifically, this study was designed to: (i) estimate the population density and biomass of major prey species of large cats, and (ii) compare estimated densities and biomass with the earlier reports from the same area (Tamang, 1982) so as to assess the influence of conservation on prey species.

4.2 METHODS

4.2.1 Site Selection

Three intensive sampling blocks were selected from northern parts of the Chitwan National Park (CNP) and buffer zone (BZ) to sample prey populations. These blocks were representative of climax Sal dominated forests (Kasara block), areas from where human habitation has been recently relocated (Padampur block) and areas in buffer zone (Barandabhar block), where some human disturbance (grass and fodder collection) still exists (Figure 4.1).

Block 1: The block 1 (hereafter Kasara block) is located in the center of the park around Kasara and is mainly characterized by dominant climax Sal forests. Wetlands and patches of grasslands are interspersed within the Sal forest, and smaller patches of riverine complex lies at the northern part of Kasara block. This area is intensively managed since the establishment of the park in 1973 and no resource extraction is allowed.

Block 2: The Block 2 (hereafter Padampur block) is comprises the old village site of Padampur Village Development Committee and its impact area around immediate periphery, and small part of this block lies in the Kumroj buffer zone community forests. Vegetation mainly consists of tall grasslands in the abandoned fields and regenerating Sal forest, river beds, wetlands and Riverine forest. Padampur village was inhabited by 11,208 famers who maintained about the same number of livestock (DNPWC, 2000). Villagers used to graze their livestock in the park and river bank as they have no grazing area around the village. After voluntary resettlement of the village (1997- 2003), Padampur area formed a good habitat for wildlife species. Effective management of this area has been initiated after complete relocation of villages in 2003. Removal of grasses from the Padampur area is allowed every year during winter season.

Block 3: Block 3 (hereafter Barandabhar block) is located in the Barandabhar Corridor Forest (BCF) in buffer zone of the CNP. The BCF extends from the northern boundary of Chitwan National Park as a strip to the foot hills of the Lesser Himalayan

Mahabharat range. BCF covers an area of about 70 km^2 and has average width of 8 km in the south but tapers towards the north with a width of about 1.7 km (Thapa 2003). Beeshazar and associated Lakes Ramsar site is an important habitat component of the BCF. The BCF was heavily degraded due to excessive resource extraction and grazing. Effective protection and management in BCF started in mid nineties through the introduction of buffer zone program around CNP. Regulated grass cutting is allowed only from community forests (300m area from the boundary of BCF) and livestock grazing was totally controlled, except in the south east corner (Khorsor entry point). Banning of livestock grazing and grass cutting regulation allowed the forest to regenerate with successive increase in the number of wildlife species. The habitat mosaic of Barandabhar block comprises the regenerating Sal forests, wetlands, short grasses and a small stretch of riverine forests (Thapa 2003).

4.2.2 Sampling Prey Population

Prey species was sampled from the elephant back (Tamang, 1982) through the line transects in three intensive sampling areas. The line transect method (Eberhardt, 1978; Anderson *et al.*, 1979; Burnham *et al.*, 1980; Lack *et al.*, 1994; Buckland *et al.*, 1993; Buckland *et al.*, 2001) have been used extensively for estimating animal densities in a variety of habitats in South Asia (Karanth and Sunquist, 1992; 1995; Varman and Sukumar, 1995; Khan *et al.*, 1996; Biswas and Sankar 2002; Bagchi *et al*. 2003; Jathanna *et al*. 2003; Edgaonkar, 2008; Harihar *et al*., 2009; Paliwal, 2009; Malla, 2009). We rode elephant along transects at a roughly uniform speed of 3 km/h and carefully detected the prey groups. Wegge and Storass (2009) reported that the density estimates from elephant back did not differ from block counting of ungulates, except in the case of barking deer and barasingha. A compass (Silva) and a GPS (Garmin GPS Map 60 CXS) were used to make sure that the walk was straight.

A total of 34 transects; 12 (2- 3 km), 10 (2- 5 km) and 12 (3- 6 km) were laid in Kasara, Padampur and Barandabhar blocks respectively (Figure 4.2). In BCF, I used existing permanent transects spaced 500 m apart, established and used by the Biodiversity Conservation Center (BCC) for regular monitoring of ungulates since 2003, whereas new transects were established in Kasara and Padampur. Before sampling, we minimally removed branches and lianas in the riverine complex to enable easy and quite elephant movement (Wegge and Storaas, 2009). Total length of transects were 27.5, 40 and 60 km in Kasara, Padampur and Barandabhar respectively. Prey species were surveyed four times in each season during summer (March- June) and winter (November- February) from 2007 to 2009. In 2007, only the Barandabhar block was surveyed. All three blocks were surveyed in 2008, and Kasara and Padampur blocks were surveyed in 2009 making two year data in each block. Total transect effort was 2040 km for all blocks. Prey species were surveyed in the morning between 6.00 to 10.30 AM. In each survey, total length, the number of clusters detected, cluster size, cluster composition, sighting distance (measured with a laser range finder- Bushnell Yardage Pro 400), sighting angle (measured with compass- Silva) and geographic coordinates (recorded with a GPS- Garmin GPS MAP 60 CXS) were recorded for each prey species encountered.

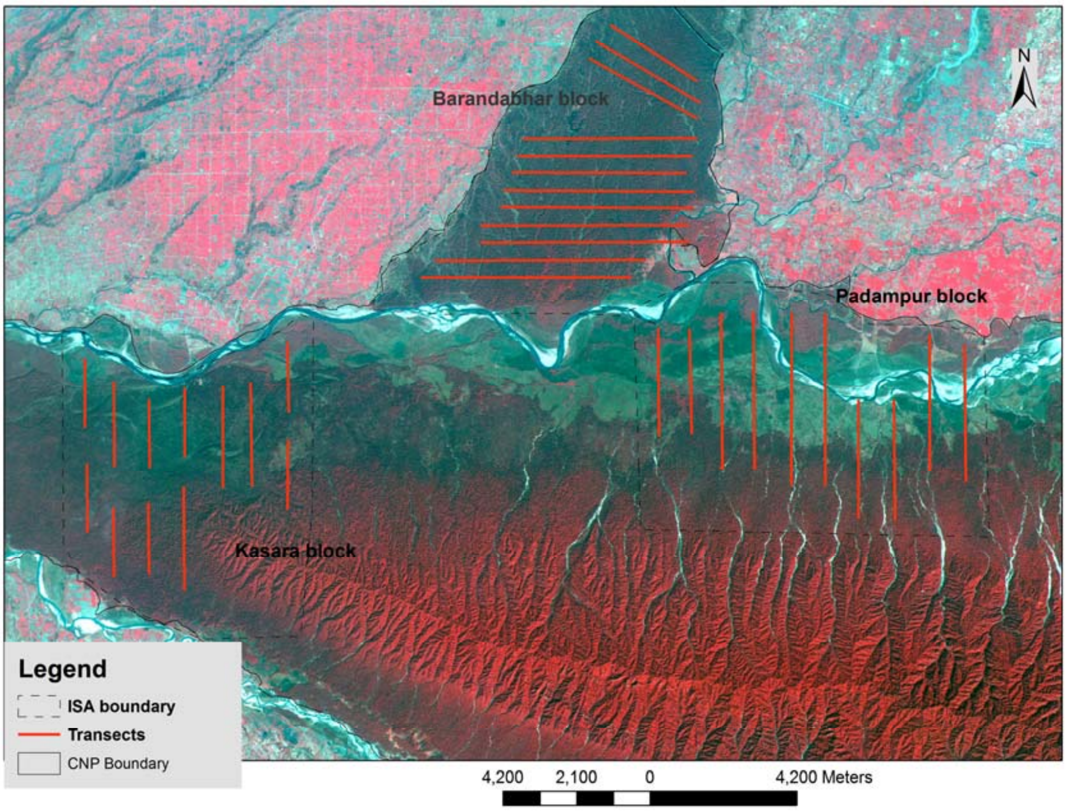


Figure 4.1 Map showing location of transects used for prey estimation in three selected intensive study sites.

The sighting distance and angles for species occurring in clusters were recorded from the center of the cluster. The sighting distance from the center of the group to the point of observation was visually estimated during 2007 survey. The visually estimated distance was checked regularly by pacing out of the distance. A laser range finder was used for distance measurement during the survey in 2008 and 2009.

4.2.3 Analysis

4.2.3.1 Density Estimates

Program DISTANCE 6.0 release 2 (Thomas *et al*., 2006) was used to estimate density of prey species. Prior to generating final results using program DISTANCE, an exploratory analyses of the distribution of the distances was done by data in small intervals and plotting the resulting histograms (Buckland *et al*., 2001) to detect for any evidence of evasive movement, 'rounding' and 'heaping' of data and to truncate outlier observations, if necessary, for improving model fitting (Jathanna *et al*., 2003; Edgaonkar, 2008; Wang, 2010). To maximize the number of sightings, a detection-probability function was estimated from pooled data on annual basis for ISAs for each species. An appropriate model (the best key function- with the appropriate adjustment term) was judged using Akiake's Information Criteria (AIC) values provided that the p-value for the chi-square goodness of fit for the model was greater than 0.05 (Burnham and Anderson, 2003). Parameters such as encounter rate (n/L), strip width (ESW), average probability of detection (p), cluster density (Ds), cluster size (Y) and prey density (D) were also estimated using program DISTANCE (Burnham *et al.*, 1980; Buckland *et al.*, 1993). Density estimates are presented on seasonal basis for species with sufficient encounter rate for each site and pooled annual estimates for all species for all sites. The one- way analysis of variance (ANOVA) (Zar, 2009) was used to compare in density between sampling sites for all species and season for species with detection allowed estimating seasonal density.

4.2.3.2 Effects of Transect Efforts on Density Estimates

Since the sampling efforts (length of transects covered) for three sampling blocks were different, so transect data were re- sampled to make similar efforts. The influence of transect efforts on density estimates were evaluated by keeping similar transect length in all the survey blocks. The efforts was made similar by excluding data from selected transects. In Barandabhar block, transects were originally laid 500 meter apart, so I removed data from 5 transects and kept 1 km distance between the remaining transects. Similarly, I dropped data from two randomly selected transects from Padampur block. The remaining length of transects in Barandabhar (34 km) and Padampur (31 km) was more closer to the length of transects in Kasara (27.5 km). Estimated density of resulting transects were compared for consistency with original estimates.

4.2.3.3 Biomass Estimate

The biomass (kg km^{-2}) of each prey species was calculated by multiplying the mean individual density (D) by its average estimated unit weight (Tamang, 1982; Wegge *et al*., 2009). Various estimates of body weight are available for south Asian major prey species (Schaller 1967; Eisenberg and Seidensticker, 1976; Tamang, 1982; Johnsingh, 1983; Karanth and Sunquist, 1992; Wegge *et al*., 2009). Biomass were estimated for three sampling sites based on mean ecological density (of summer and winter) and was derived from 2008 survey only.

4.2.3.4 Population Structure

Data on age and sex composition were recorded during regular sampling of the line transects. Individual animals were classified as adult male (AM), adult female (AF), sub adult male (SM), sub adult female (SF) and young (Y) on the basis of physical characteristics derived from literature (Schaller, 1967; Prater, 1971; Eisenberg and Lockhart, 1972; Mishra, 1982). The fawn (F) and Juvenile (J), as categorized by Mishra (1982), were included in the category of young (Y). Animals were categorized to sex and age classes using combinations of sexually dimorphic physical characteristics, such as morphological configuration, external genitalia, age-specific differences in body size, presence, shape and size of antlers and bone lumps; and association with parents. Data collected during 2008 was only used to analyze population structure.

4.3. RESULTS

4.3.1 Detection

Major prey species of big cats sighted during the 2040 km transect surveys between 2007- 2009 in the CNP and BZ were chital (*Axis axis*), barking deer (*Munticus muntjac*), hog deer (*Axis percinus*), sambar (*Rusa unicolor*), wild pig (*Sus scrofa*), gaur (*Bos gaurus*), Rhesus macaque ((*Macaca mulatta*), langur (*Semnopithecus hector*). Analysis showed high detection frequencies for ungulates, however, the detection frequencies of gaur, Rhesus macaque and langur were below the minimum of 40 detection (Table 4.1) required for analysis in the DISTANCE (Burnham *et al*., 1980; Buckland *et al*., 1993).

Chital, barking deer, sambar, wild pig and macaque were detected from all the blocks, while gaur, hog deer and langur were detected only from the Kasara and Padampur area (Table 4.1). The seasonal detections (number of observations) were sufficient (above 40) only for chital in all blocks, barking deer in Barandabhar site and hog deer at Padampur site, hence densities were estimated seasonally for these species only (Table 4.5). Year wise and block wise densities were estimated for all species (Table 4.2- 4.4).

4.4.2 Estimation of Densities of Prey Species

The seasonal and annual overall density (number of individuals km^{-2}) was highest for chital in all sites during both summer and winter followed by sambar and wild pig (Table 4.2- 4.5). Barandabhar block supports highest (123.9 ± 12.14) overall ungulate densities (animals km^{-2}) followed by Kasara (101.8 ± 12.93) and Padampur (84.3 ± 10.14) (Table 4.2- 4.5). Among the ungulates chital had significantly higher density in Barandabhar compared with Kasara and Padampur block. Barking deer had higher densities in Barandabhar but Kasara and Padampur sites had comparable densities, the sambar densities were higher in Kasara followed by Padampur and Barandabhar, and the densities of wild pigs are significantly higher in Padampur followed by Kasara and Barandabhar sites. The ANOVA result revealed that the densities between sampling sites was significantly different for chital ($F = 127.55$, $df = 2$, $P = 0.01$) and no statistical differences were found for the barking deer ($F = 4.10$, $df = 2$, $P = 0.139$), sambar ($F = 7.05$, $df = 2$, $P = 0.73$) and wild pig ($F = 2.50$, $df = 2$, $P = 0.23$).

Table 4.1. Seasonal variations detection (number of clusters) of prey species in Chitwan National Park andbuffer zone, Nepal (2007- 2009).

Year	**Season**	**Survey site**	**No of transects**	**Total length**	**Chital**	**Muntjack**	**Hog deer**	**Sambar**	**Wild pig**	**Gaur**	**Rhesus Macaque**	**Langur**
2007	**Winter**	BB	12	240	164	56	-	33	39	-	-	-
	Summer	BB	12	240	175	59	-	44	32	-	3	-
2008	**Winter**	BB	12	240	203	51	-	42	21	-	5	-
		Kas	12	110	55	30	6	40	30	-	-	2
		PP	10	160	52	29	70	32	28	-	2	-
	Summer	BB	12	240	207	56	-	32	35	-	7	-
		Kas	12	110	49	27	4	43	31	4	-	2
		PP	10	160	63	38	74	37	34	2	-	-
2009	**Winter**	Kas	12	110	42	32	8	40	29	6	-	2
		PP	10	160	50	26	58	38	28	1	4-	-
	Summer	Kas	12	110	51	28	8	43	36	6	-	1
		PP	10	160	56	38	63	39	29	2	1	-
	Total			2040	1167	470	291	463	372	21	22	7

N B, BB: Barandabhar, Kas: Kasara and PP- Padampur

Table 4.2. Density estimates of ungulate prey species in Barandabhar Corridor Forest in the Buffer Zone of Chitwan National Park, Nepal (2007-2008).

Survey Year	Species	Model	f (o)	p-hat	ESW	n	Cluster	Ds (SE)	CV (%) Ds	D (SE)	CV (%) D	95 % CI
2007	Barking deer	Half- normal key	0.36	0.45	27.12	103	1.37 (0.58)	3.95 (0.46)	11.86	5.5 (0.68)	12.45	4.28- 7.03
	Chital	Half- normal cosine	0.29	0.33	33.91	337	10.61 (0.62)	10.35 (0.92)	8.9	110.7 (12.48)	11.28	88.62- 138.25
	Sambar	Half- normal key	0.41	0.30	24.55	70	1.77 (0.10)	2.96 (0.79)	26.94	5.3 (1.46)	27.61	3.09- 9.08
	Wild pig	Hazard rate key	0.30	0.53	32.27	52	2.09 (0.22)	1.67 (0.29)	17.79	3.1 (0.63)	20.22	2.09- 4.65
	All	Half-normal cosine	0.33	0.33	30.09	598	6.94 (0.40)	20.70 (1.53)	7.41	121.7 (11.43)	9.4	101.08- 146.54
2008	Barking deer	Uniform cosine	0.34	0.4	28.59	112	1.43 (0.73)	4.07 (0.56)	13.97	5.4 (0.78)	14.52	4.04- 7.21
	Chital	Half - normal cosine	0.31	0.34	31.48	397	8.84 (0.48)	13.13 (1.15)	8.79	117.7 (12.84)	10.91	94.89- 145.92
	Sambar	Unifom cosine	0.37	0.41	26.35	73	2.04 (0.14)	2.88 (0.39)	13.78	5.9 (0.92)	15.53	4.37- 8.08
	Wild pig	Half- normal key	0.38	0.42	25.73	68	3.01 90.30)	2.75 (0.45)	16.59	9.1 (1.81)	19.81	6.19- 13.51
	All	Hazard rate /hermit polynomial	0.31	0.31	31.42	647	6.39 (0.33)	21.45 (1.75)	8.19	123.9 (12.14)	9.8	102.23- 150.27

(Here f(0) = Probability Density Function at zero; p-hat = detection probability; ESW = Effective strip width; n= number of observations; Cluster = average cluster size; D_s = group density; D = individual density; CV% (Ds) and CV% (D) = coefficient of variation on estimate of Ds and D respectively and the 95% Confidence Interval (95% CI) on the estimates of individual density D; SE = standard error).

Table 4.3. Density estimates for ungulate prey species in Kasara block, Chitwan National Park, Nepal (2008- 2009).

Survey Year	Species	Model	f(o)	p- hat	ESW	n	Cluster	Ds (SE)	CV (%) Ds	D (SE)	CV (%) D	95 % CI
2008	Barking deer	Uniform cosine	0.16	0.55	59.15	57	1.52 (0.9)	2.19 (0.34)	15.65	3.2 (0.54)	16.71	2.31- 4.51
	Chital	Uniform cosine	0.20	0.55	49.78	120	11.56 (1.14)	6.08 (0.91)	15.1	83.9 (15.92)	18.98	57.59- 122.27
	Sambar	Half- normal cosine	0.35	0.34	27.95	61	3.13 (0.30)	3.35 (0.65)	19.63	12.7 (2.85)	22.5	8.18- 19.73
	Wild pig	Half- normal key	0.21	0.51	46.37	60	3.13 (0.31)	2.94 (0.50)	17.19	11.9 (2.43)	20.45	7.95- 17.77
	All prey	Half- normal cosine	0.40	0.27	24.73	306	6.08 (o.50)	19.95 (2.09)	10.5	101.8 (12.93)	12.7	79.26- 130.83
2009	Barking deer	Half- normal key	0.22	0.50	45.26	52	1.75v(0.17)	2.92 (0.53)	18.41	4.7 (0.95)	20.16	3.17- 7.05
	Chital	Hazard rate key	29.0	0.34	33.43	92	13.34 (1.27)	6.09 (1.01)	16.68	80.1 (15.74)	19.65	54.52- 117.83
	Sambar	Half- normal cosine	27.0	40.0	36.11	62	2.00 (0.12)	5.28 (0.87)	16.54	9.1 (1.60)	17.68	6.41- 12.87
	Wild pig	Hazard rate key	0.33	0.33	29.87	65	2.27 (0.18)	5.23 (1.68)	32.19	13.3 (4.44)	33.3	7.01- 25.43
	All prey	Hazard rate key /hermit polynomial	0.36	0.30	27.55	256	9.15 (0.66)	11.73 (3.03)	25.84	100.4 (27.55)	27.43	59.13- 170.58

(Here f(0) = Probability Density Function at zero; p-hat = detection probability; ESW = Effective strip width; n= number of observations; Cluster = average cluster size; D_s = group density; D = individual density; CV% (Ds) and CV% (D) = coefficient of variation on estimate of Ds and D respectively and the 95% Confidence Interval (95% CI) on the estimates of individual density D; SE = standard error).

Table 4.4. Density estimates for ungulate prey species in Padampur block, Chitwan National Park, Nepal (2008- 2009).

Survey Year	**Species**	**Model**	**f (o)**	**p- hat**	**ESW**	**n**	**Cluster**	**Ds (SE)**	**CV (%) Ds**	**D (SE)**	**CV (%) D**	**95 % CI**
2008	Barking deer	Uniform cosine	0.25	0.49	39.7	65	1.36 (0.74)	2.55 (0.47)	18.64	3.6 (0.69)	19.27	2.45- 5.24
	Chital	Uniform cosine	0.22	0.50	45.0	112	11.46 (0.96)	3.88 (0.38)	9.88	59.3 (9.19)	9.19	43.65- 80.53
	Hog Deer	Half- normal key	0.27	0.45	36.2	144	2.20 (0.12)	6.37 (0.82)	12.95	13.0 (1.83)	14.04	9.84- 17.28
	Sambar	Uniform cosine	0.21	0.52	47.36	68	2.07 (0.12)	2.24 (0.38)	17.1	5.4 (0.98)	18.3	3.73- 7.82
	Wild pig	Half- normal key	0.31	0.63	31.65	54	4.07 (0.61)	1.91 (0.34)	17.95	10.3 (2.37)	22.95	6.60- 16.20
	All prey	Half- normal key	0.24	0.44	40.24	458	4.84 (9.33)	17.78 (1.88)	10.58	84.3 (10.14)	12.04	66.16- 107.42
2009	Barking deer	Uniform cosine	0.31	0.48	31.72	61	1.32 (0.69)	3.00 (0.53)	17.67	3.9 (0.72)	18.28	2.77- 5.72
	Chital	Half- normal key	0.22	0.44	44.79	104	13.26 (1.09)	3.41 (0.46)	13.65	61.7 (10.53)	17.68	44.06- 86.40
	Hog deer	Half- normal key	0.32	0.43	31.19	118	2.09 (0.12)	5.909 (0.63)	10.83	11.3 (1.38)	12.26	8.85- 14.40
	Sambar	Half- normal key	0.24	0.45	41.04	76	2.19 (0.13)	2.89 (0.50)	17.58	6.5 (1.23)	18.82	4.48- 9.52
	Wild pig	Half- normal cosine	0.54	0.36	18.25	51	2.90 (0.47)	4.36 (0.87)	19.96	16.5 (3.97)	24.02	10.33- 26.46
	All prey	Half- normal cosine	0.31	0.40	32.23	430	5.08 (0.38)	20.84 (2.11)	10.15	88.1 (10.49)	11.91	69.58- 111.63

Here f(0) = Probability Density Function at zero; p-hat = detection probability; ESW = Effective strip width; n= number of observations; Cluster = average cluster size; D_s = group density; D = individual density; CV% (Ds) and CV% (D) = coefficient of variation on estimate of Ds and D respectively and the 95% Confidence Interval (95% CI) on the estimates of individual density D; SE = standard error).

Table 4.5 Seasonal density (± SE) estimates of chital, barking deer and hog deer in Chitwan National Park and buffer zone, Nepal (2007-2009).

Year	Season	Barandabhar		Kasara	Padampur	
		Chital	**Barking deer**	**Chital**	**Chital**	**Hog deer**
2007	Winter	102.3 ± 15.40	5.8 ± 1.00	-	-	-
	Summer	120.2 ± 18.49	5.2 ± 0.9	-	-	-
2008	Winter	115.5 ± 16.72	5.5 ± 1.18	84.5 ± 21.58	54.4 ± 12.92	11.9 ± 2.56
	Summer	122.2 ± 17.89	4.9 ± 1.00	86.7 ± 24.58	66.5 ± 13.84	14.3 ± 2.38
2009	Winter	-	-	77.7 ± 21.37	52.8 ± 12.84	10.4 ± 1.74
	Winter	-	-	84.9 ± 20.29	74.2 ± 16.15	13.1 ± 2.21

Density estimates of chital and hog deer reveals higher values in all sites during summer than winter, but reverse trends exhibited in barking deer (Table 4.5). The estimated density of chital in all blocks (Barandabhar, F_{12} = 3.56, P> 0.05, Kasara, F_{12} = 1.78, P> 0.05, Padampur, F_{12} = 18.30, P> 0.05), Barking deer (Barandabhar, F_{12} = 10.53, P> 0.05) and Hog deer (Padampur, F_{12} = 7.18, P>0.05) between winter and summer season did not show any significant difference. Overall and chital density estimates were higher in second survey year in Barandabhar (117.7±12.84) and Padampur block (59.3±9.19) then first survey year (110.7±12.48 in Barandabhar and 61.7±10.53 in Padampur) but was reversed in Kasara block (83.9±15.92 in 2008 and 80.1±15.74 in 2009) (Table 4.2- 4.4).

4.4.3 Effects of Transect Efforts on Density

Removal of transects results into the length of 34 and 31 km in Barandabhar and Padampur blocks respectively. The removal of some transects from analysis results into the reduction of detections of all species and slight change in density estimates (Tables 4.2, 4.4 and 4.6). For example, estimated overall density (123.9 km^{-2}) and chital density (117.7 km^{-2}) before removal was very close to overall density (125.5 km^{-2}) and chital density (118.9 km^{-2}) estimates after removal of few transects. In all the cases density estimates were associated with slightly higher standard error and coefficient of variation.

4.4.4 Biomass Estimate

Biomass was reported for three sampling sites estimated from the mean ecological density derived only from 2008 prey survey (Table 4.7). Biomass of wild ungulate species was highest in Barandabhar site compared to the Kasara and Padampur sites. Chital biomass was the highest with 79%, 59% and 61% contribution to overall ungulate biomass in Barandabhra, Kasara and Padampur. Biomass of chital was followed by sambar, wild pig and barking deer in Barandabhar and Kasara but in Padampur block chital is followed by sambar, wild pig, hog deer and barking deer.

Table 4.6. Re-sampled density estimates of ungulate prey species in Barandabhar and Padampur blocks (2007- 2009).

Block	**Year**	**Species**	**Ds (SE)**	**CV (%) Ds**	**D (SE)**	**CV (%) D**	**95 % CI**
BCF	2007	Barking deer	4.04 (0.76)	19	5.2 (1.01)	19.51	3.48- 7.70
		Chital	10.59 (1.06)	10.03	112.1 (15.63)	13.96	85.13- 147.53
		Sambar	2.63 (0.49)	18.83	5.6 (1.18)	21.08	3.70- 8.54
		Wild pig	3.03 (0.64)	20.07	6.9 (1.59)	23.31	4.31- 10.89
		All	20.84 (1.60)	7.7	122.3 (13.34)	10.91	98.61- 151.67
	2008	Barking deer	4.06 (0.66)	16.31	5.74 (0.97)	17.02	4.07- 8.08
		Chital	10.99 (1.32)	12.05	118.9 (17.78)	14.95	88.22- 160.49
		All prey	18.77 (2.36)	12.6	125.5 (18.30)	14.58	93.49- 68.59
PP	2008	Barking deer	2.42 (0.45)	18.64	3.3 (0.64)	19.45	2.25- 4.92
		Chital	3.88 (0.36)	9.3	61.9 (10.13)	16.36	44.88-85.49
		Hog Deer	6.57 (0.97)	14.88	12.9 (2.05)	15.93	9.35- 17.82
		Sambar	2.65 (0.49)	18.67	6.1 (1.126)	19.99	4.19- 9.50
		Wild pig	2.55 (0.45)	17.71	13.1 (2.92)	22.38	6.60- 16.20
		All prey	17.92 (2.40)	13.43	85.1 (12.63)	14.84	62.92-115.15
	2009	Barking deer	3.07 (0.54)	17.75	3.9 (0.71)	18.43	2.69- 5.61
		Chital	3.90 (0.62)	16.11	64.6 (12.96)	20.08	43.43-96.02
		Hog Deer	6.12 (0.74)	12.16	11.5 (1.59)	13.80	8.77- 15.20
		Sambar	2.71 (0.61)	16.46	8.9 (1.62)	18.09	6.20- 12.94
		Wild pig	4.82 (0.91)	19.91	16.9 (4.00)	23.62	10.65- 26.92
		All prey	23.18 (2.41)	10.42	96.2 (11.96)	12.43	75.1- 123.21

(Here D_s = group density; D = individual density; CV% = coefficient of variation on estimate, 95% CI= 95% Confidence Interval on the estimates, SE = standard error; BB: Baradabhar block and PP: Padampu block).

Table 4.7 Biomass of major prey species in the Chitwan National Park and buffer zone, Nepal (2008).

Species	Unit weight* (kg)	Biomass (kg km-2)			
		BCF	Kasara	Padampur	Mean
Chital	54	6354.18	4531.14	3201.66	4695.66
Barking deer	17	91.8	54.91	60.86	69.19
Sambar	198	1176.12	2514.6	1069.2	1586.64
Hog deer	33	-	-	430.32	143.44
Wild pig	45	411.75	535.05	465.3	470.7
Total	--	8033.85	7635.7	5227.34	6965.63

N B *Source: Tamang (1982)

Hog deer are mainly confined in the Rapti flood plain and old village site of Padampur and contribute 8.23% of biomass in the Padampur block. Chital contributed 67% of the mean standing ungulate prey biomass in Chitwan. Chital, sambar and wild pig were widespread and contributed over 95% of the total prey biomass (Figure 3.2).

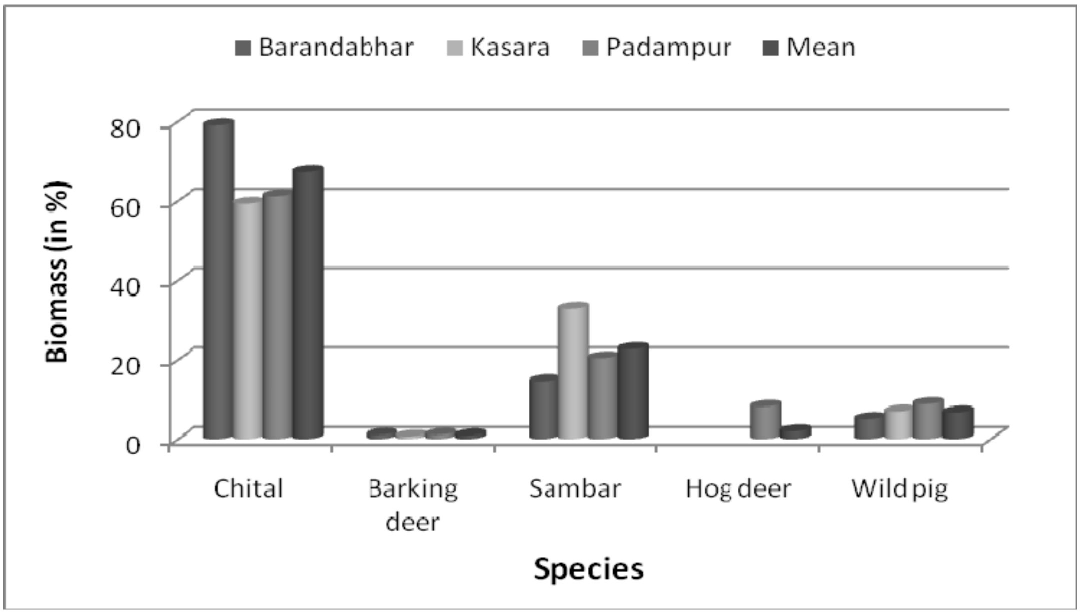


Figure 4.2 Proportions of the standing biomass of different prey species in Chitwan National Park and buffer zone, Nepal.

4.4.4 Population Dynamics

Comparison of mean of the density estimates of 2008 survey of three blocks with the estimates of Tamang (1982) revealed that the overall prey density increased 309%, chital 518%, sambar 297% and wild pig 361% during 26 years period, while the densities of hog deer and barking deer declined (Table 4.8, Figure 4.3).

Table 4.8. Comparison of density (number km^{-2}) and biomass (kg km^{-2}) estimates prey species in Chitwan in 1982 and in 2008.

Species	1982*		2008	
	Density	Biomass	Density	Biomass
Chital	16.8	907	86.9	4695.66
Sambar	2.7	535	8.0	1586.64
Wild pig	2.9	131	10.5	470.7
Hog deer	7.9	261	4.3	143.44
Barking deer	6.6	112	4.1	69.19
Total	36.9	1946	113.8	6965.63

N B* Source: Tamang (1982)

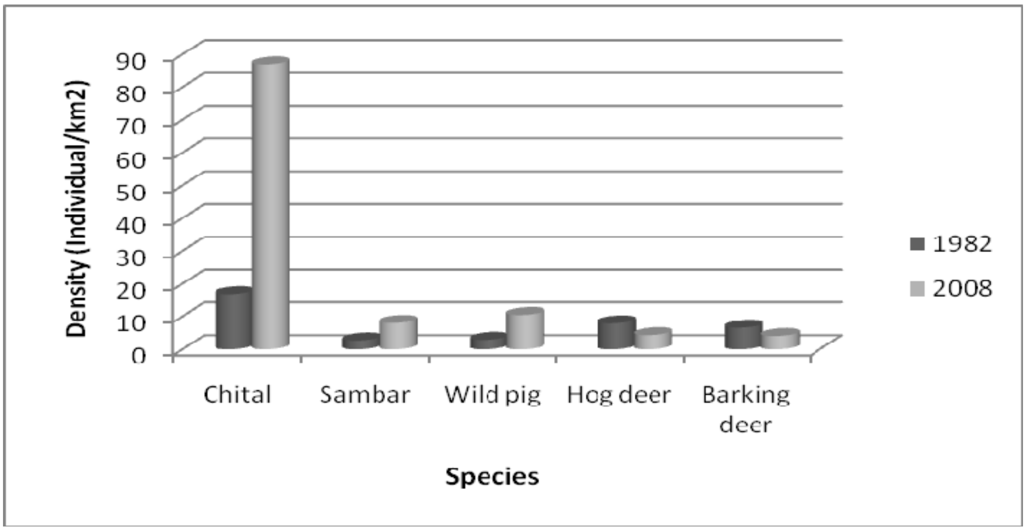


Figure 4.3 Ungulate densities in Chitwan National Park and buffer zone, Nepal in 1982 and 2008.

During the period between 1982 and 2008, there was significant change in the biomass contribution of various ungulate prey species to the total prey biomass in CNP and BZ (Figure 4.4). Contribution of chital biomass to overall prey biomass was increased from 47% of 1982 to 67% in 2008. Contributions of wild pig unchanged but sambar, hog deer and barking deer decreased.

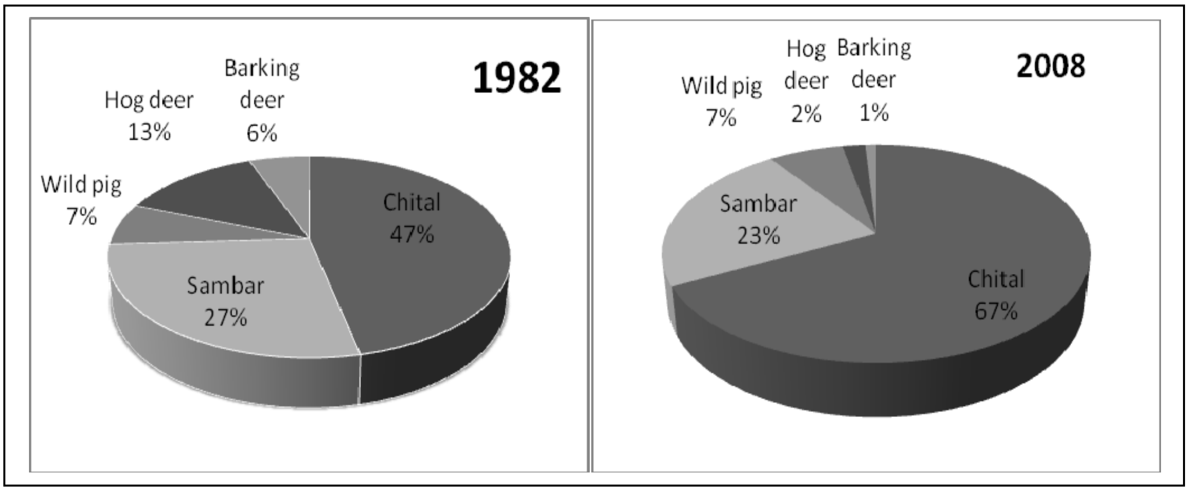


Figure 4.4. Species wise biomass contribution (%) to overall ungulates prey biomass in 1982 and 2008 in Chitwan National Park and buffer zone.

4.4.5 Population Structure

A total of 8102 individuals of major prey species (chital, sambar, barking deer and wild pig) belonging to 1501 clusters recorded during 2008 survey were used to classify into age- sex category (Table 4.9). For all ungulate species over 90% of observed individuals were classified into age- sex. Number of individual recorded and mean group size estimates of all prey species was higher during summer season than that of winter. Among the prey species chital formed the largest group and barking deer formed the smallest group. Average group size of chital, barking deer, sambar, hog deer and wild pig during winter season were 9.26, 1.42, 2.08, 2.19 and 2.63 respectively.

Table 4.9. Seasonal group size and population structure of prey species in Chitwan National Park and buffer zone, Nepal (2008)

Season	Species	N	MSG	Proportion of individual in category					
				AM	AF	SM	SF	Y	Unidentified
Winter	Barking deer	158	1.42	37.34	38.60	3.80	4.43	8.23	7.6
	Chital	2936	9.26	26.4	36.91	5.80	9.35	13.92	7.62
	Sambar	238	2.08	21.01	42.86	5.89	8.4	13.4	8.4
	Hog deer	167	2.19	23.35	43.11	5.99	9.58	11.4	6.59
	Wild pig	240	2.63	22.09	38.34	4.58	10.0	14.2	10.83
Summer	Barking deer	243	1.37	41.32	39.52	4.2	4.6	5.39	4.99
	Chital	3398	10.23	27.01	35.87	6.23	10.5	14.09	6.3
	Sambar	243	2.23	21.48	44.21	4.56	9.5	12.4	7.85
	Hog deer	178	2.28	22.58	43.01	5.91	6.99	12.37	9.14
	Wild pig	301	3.14	22.6	38.87	3.98	6.98	20.26	7.31

Proportions of pre- reproductive age group (sub adult and young) recorded during winter and summer season contributed 16.46% and 13.19% of total population of barking deer, 29.07% and 30. 82% of chital, 27.69% and 26.46% of sambar, 26.92% and 26.42% of hog deer and 28.78% and 31.22% of wild pig. Proportions of young in a population were similar for all species between summer and winter seasons except wild pig, in which 20.26% recorded individuals were young during summer in contrast to 14.2% of winter (Table 4.9). Young to female ratio (number of young/100 adult female) was lowest in barking deer (13.6 in summer and 21.32 in winters) and highest in Chital (38.66 in winter and 37.20 in summers) among the deer.

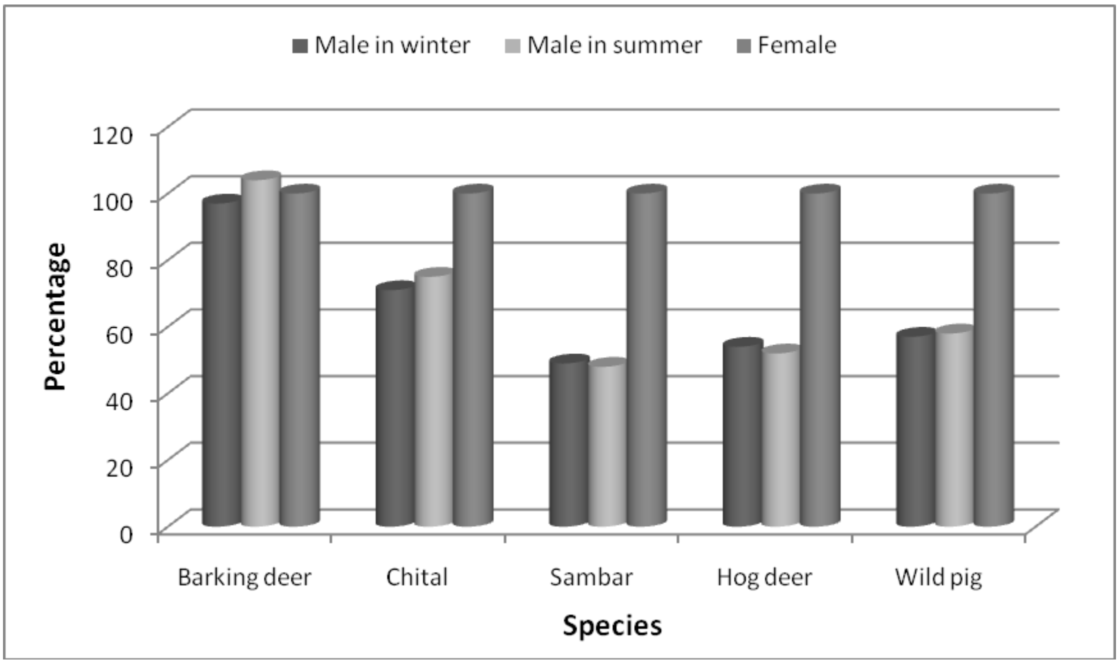


Figure 4.5. Sex ratio (number of males per 100 female) of ungulate prey species in Chitwan National Park and buffer zone, Nepal.

The adult sex ratios of the chital, sambar, hog deer and wild pig was female biased and in barking deer it was closed to 1 on 1 (Figure 4.5). Estimated adult sex ratios both in winter and summer season was biased towards female by 71 and 75: 100 for chital, 49 and 48: 100 for sambar, 54 and 52: 100 for hog deer and 57 and 58: 100 for wild pig. The proportions of sub adult females were higher than the sub adult male in all species (Table 4.9).

4.5. DISCUSSION

4.5.1 Detections

The results clearly revealed a high abundance of ungulate prey species in Chitwan among the protected areas of Terai (Table 4.10). The detections of all major prey species of big cats were more than the minimum 40 observations recommended by Burnham *et al.* (1980) for reliable density estimates using DISTANCE program except for gaur, macaque and langur. Chital, sambar, barking deer, wild pigs and macaque were widely distributed throughout the study area, but hog deer was associated with riverine complex and gaur with Churia Range. The high observation of ungulates in Chitwan was correlated with high density. In general, observed number of groups and individuals were higher during summer season than winter indicating that the summer season was more appropriate for prey species survey in Terai. Relatively higher observation of prey species during summer season probability related to the increased visibility during summer season survey.

4.5.2 Density

The overall density estimates derived from this study (Table 4.2- 4.4) shows that sites of this study supports a high density of ungulates (123.9 km^{-2} in Barandabhar, 101.8 km^{-2} in Kasara and 84.3 km^{-2} in Padampur in 2008). Individual species density estimates revealed that the chital was most abundant prey species in all sampling sites followed by wild pig (9.15 km^{-2}) in BCF, sambar in Kasara (12.70 km^{-2}) and hog deer in Padampur (13.04 km^{-2}). This estimation showed that the Central (Kasara) and Northern (Padampur) part of CNP and northern part of BZ (Barandabhar) are among the areas that supports higher prey density in Terai (Seidensticker, 1976; Dinerstein, 1980; Tamang, 1982; Harihar *et al*., 2005; Malla, 2009; Karki *et al*., 2009; Wegge and Storas, 2009; Table 4.10) and even in South Asia (Khan *et at.*, 1996; Karanth and Nichols, 1998; Biswas and Sankar, 2002). This estimate does not imply uniform and high level of prey density throughout CNP and BZ. My impression was that the Churia range, south east and south western part of the park supports low density of prey species. Past reports of ungulate densities from Terai ranged from 26 km^{-2} in CNP (Sedensticker 1976) to 281.8 km^{-2} in a small stretch of riverine complex of Bardia National Park (Wegge and Storas 2009, Table 4.10). Densities between sampling sites is significantly different for Chital ($F = 127.55$, $df= 2$, $P = 0.01$) only.

Chital contributed more than 90% to the overall density estimates in Barandabhar, 80% in Kasara and 70% in Padampur (Table 4.2- 4.4). Low density of Chital in comparison to other blocks was compensated by hog deer in the tall grassland of Padampur old village site, where the proportion of combined density of chital and hog deer was about 80%. Similar high proportion of chital to overall density estimates were also reported from Bardia (Wegge and Storas, 2009; Malla, 2009), Gir (Khan *et al*., 1996), Pench (Biswas and Sankar, 2002), and Kahna (Karanth and Nichols, 1998). Chital prefers habitat mosaics consisting of forest cover intermingled with patches of short grass, wetlands (Mishra, 1982) and edges and openings created by natural ecological process or human intervention. Habitat in Barandabhar comprises mosaics of regenerating Sal forest mixed understory interspersed with open wooded bush, short grassland and wetlands (Thapa, 2003). Kasara block is manly occupied by Sal dominated mature forest but this area also consists of undulating slopes, hills, flood plains, wetlands, tall and short grass, and in some places sparse trees with grasses and forbs as ground vegetation. Habitat mosaics of Barandabhar and Kasara provide year round food, cover and water for wildlife species. Chital prefer secondary Sal forest, riverine forest, and grassland with good understory of grasses, forbs and tender shoots (Dinerstein, 1987; Bhatta and Rawat, 1995; Wegge *et al*. 2000). Thapa (2003) reported natural fragmentation and human disturbances had little impacts on the distribution of chital. Relatively low chital density in Padampur area in comparison with other sites can be attributed partly to the relatively high proportion of tall grassland which were avoided by gregarious chital and partly to the heavy infestation of *Michaenia micrantha* the Invasive Alien Plant Species (IAPS) which create unsuitable foraging ground for many ungulate specie. *Michaenia micrantha* rapidly colonizes riverain complexes, moist areas in the short grasslands and open areas within the patches of tall grass (Sapkota, 2007). In addition, the abandoned agricultural field of Padampur area is under the process of ecosystem development and stabilization, and successive colonization of prey and predators after the relocation of last village in 2003. In future more stable population of predator, prey as well as other species could be expected.

Higher density of sambar in Kasara (13.04 km^{-2}) site than in Barandabhar (5.3 km^{-2}) and Padampur (5.4 km^{-2}) indicates it's linking with undulating topography of Churia and mature forest (Kasara); avoidance of human disturbances (Barandabhar) and tall grass lands (Padampur). Estimated densities of sambar in Terai and Churai ranged from 2.4 km^{-2} in Bardia (Karki *et al*., 2009) to 24.3 km^{-2} in Chilla Rajaji (Harihar, 2005, Table 4.10). Sambar generally avoids disturbed and open secondary forest (Schaller, 1967; Wegge, 1976, Dinerstein, 1987). Thapa (2003) observed that sambar was mainly confined to the central part of Sal forest with *Shorea- Terminalia* understory in Barandabhar and was negatively correlated with fragmentation and human disturbances.

Barking deer was widely distributed throughout the study area. It has higher density in Barandabhar than the climax Sal dominated forest of Kasara and grassland of Padampur sites. Comparison of barking deer density estimates across the Terai (Table 4.10), indicted that the ranged from 0.5 km^{-2} in flat area of Rajaji NP (Singh *et al*., 2005) to 6.6 km^{-2} in Chitwan NP (1982). Thapa (2003) reported that the barking deer preferred secondary and mature forest including Sal forest with mixed understory, Sal forest with *Shorea- Terminalia* understory and riverine forest; and is less sensitive to human disturbances.

Hog deer was adequately detected from Tall grassland of Padampur and inadequate sightings from the Rapti bank in Kasara site. Density estimate of hog deer from Padampur area (13.04 km^{-2}) was higher in comparison to estimates of Terai except that estimated from Suklaphanta Wild Life Reserve (SWR) (Table 4.10). Low density of hog deer in Kasara and Barandabhar blocks can be explained by less availability of flood plain tall grass habitat preferable for hog deer in these sites.

Wild pig was widely distributed in all the study sites and density estimate from all sites are higher than that reported from other parts of Terai (Table 4.10). Sedensticker (1976) reported high summer season density of wild pig (11.5 km^{-2}) from Chitwan. Wild pig density from Barandabhar (9.15 km^{-2}), Kasara (11.89 km^{-2}) and Padampur (10.34 km^{-2}) blocks of Chitwan are close to the estimates from moist deciduous forest of Nagarhole (10.1 km^{-2}, Karantha and Sunquist, 1992) and Ranthambhor (11.4 km^{-2}, Bagchi *et al.*, 2003) and lower than reported from Sariska (17.5/km^{2}, Avinandan, 2003). Wild pig density in Barandabhar might have been over estimated because they frequent open marshy areas where visibility was higher. Such open marshy habitats are characteristic of Barandabhar block.

The estimated densities of chital in all sites and hog deer in Padampur were slightly higher in summer season than winter (Table 4.6), but these differences are not statistically significant. High level of detection and density during summer season could be the result of high visibility in summer after burning the forest.

Table 4.10. Estimates of wild ungulate species density, total density and biomass from different studies across the Terai Arc Landscape compared with the estimates from the Chitwan National Park and Buffer Zone (2008).

Location	Density (number km^{-2})								Biomass Kg km^{-2}
	Chital	Sambar	Barking deer	Hog deer	Wild pig	Nilgai	Swamp deer	Total	
Chitwan NP[1]	17.3	3			5.8	-	-	26	2933
Chitwan NP[2]	16.8	3	6.6	7.9	2.9	-	-	37.4	2589
Chitwan NP[3] (2009)	43.9	8	3.7	5.1	4.2	-	-	62.6	-
Bardia (1977)[4]	29.7	-	-	-	4.2	5	-	40.1	2842
Bardia (Riverine complex)[5]	267	-	1.5	6.8	1.5	0.1	4.9	282	-
Bardia (1998)[6]	190	-	2.6	3.2	4.2	0.1	0.2	-	-
Bardia (Babai)[7]	25.5	4	2.45	-	1.19	-	-	28.8	1892
Bardia (Karnali)[7]	85.3		3.08	4.96	3.07	-	-	91.5	4825
Bardia NP[4]	55.4	2	1.3		4	-	-	67.8	-
Sukla WR[4]	54.1	-	-	16.3	-	-	22	86.2	-
Rajaji (Flat)[8]	19.7	6	0.5	-	5.41	-	-	31.4	-
Rajaji (Hill)[8]	18.6	24	3.91	-	3.69	9.5	-	59.9	-
Rajaji (Chilla)[9]	56.2	24	-	-	6.6	4.3	-	90.1	6879
Chitwan BZ (BCF)[10]	118	6	5.4	-	9.2	-	-	124	8034
Chitwan (Kasara)[10]	83.9	13	3.2	-	11.9	-	-	102	7636
Chitwan (Padampur)[10]	59.3	5	3.6	13.04	10.3	-	-	84.3	5227

Source: 1= Sedensticker 1976; 2= Tamang 1982; 3= Karki *et al*. (2009); 4= Denerstein 1979; 5= Wegge and Storas (2009); 6= Wegge *et al*. (2009); 7= Malla (2009); 8= Singh et al. (2005), 9= Harihar (2005); 10= present study in Chitwan National Park and Buffer Zone.

4.5.3 Effects of Transect Efforts on Density

Although, I observed little change on the overall and chital density estimates of removal of some transects from analysis. However, the re-sampling of the of the field survey data for Barandabhar and Padampur blocks showed that number of observation and consequent precision in estimates of abundance decrease with decreasing sample sizes, as expected. Higher transect efforts would be desirable for higher precision and accuracy.

4.5.4 Biomass

The individual species densities were used to determine the pattern of prey biomass in each sampling sites (Table 4.2- 4.5). Like numerical density, biomass was also higher in Barandabhar block (8033.85 kg km^{-2}) than Kasara (7635.7 kg km^{-2}) and Padampur (5227.34 kg km^{-2}). These estimates are among the highest in Terai Landscape (Table 4.10). Biomass reports from Terai ranged from 2842 kg km^{-2} in Bardia (Dinerstein, 1980) to 6879 kg km^{-2} in Chilla range of Rajaji Park, India (Harihar, 2005). In all sampling sites, chital and sambar contribute about 80% to total biomass of major prey species. Thus, this study also confirmed a general pattern that a relatively few ungulate species contribute the bulk of prey biomass in Terai (Seidensticker, 1976; Dinerstein, 1980; Tamang, 1982; Harihar, 2005; Malla, 2009) and elsewhere in South Asia (Karanth and Sunquist, 1992; Khan, 1997).

4.5.5 Population Dynamics

The density of wild ungulate prey species increases by 309% in Chitwan during 26 years from 36.9/km^{-2} in 1982 (Tamang, 1982) to 113.84 animas/km^{-2} in 2008. The change is due to the remarkable increase of chital, sambar and wild pig, but barking deer slightly declined. If we compare hog deer density only for Padampur block (among the present study sites, only the Padampur block consist of the potential habitat- the flood tall grass), the hog deer was increased nearly 164%. The increase in prey species was probably due to release of livestock and human pressure. Wegge and Storas (2009) documented increase of ungulate population particularly chital, the mixed feeder and hog deer, true grazers in Bardia NP over 22 years due to effective management and removal of livestock grazing. Unlike Bardia, density of sambar and wild pig was also increased in Chitwan. Wegge and Storas (2009) concentrated their study in riverain complex which may not be more appropriate habitat for Sambar. Similar population recoveries following removal of livestock pressure have been documented from Gir (Khan *et al.*, 1996), Bandipur (Madhusudan, 2004) and Rajaji (Harihar *et al*., 2009). Large felids such as tigers and leopards have been reported to respond to the prey biomass and densities (Carbone and Gittleman, 2002, Karanth *et al*., 2004a). High prey densities may be responsible for high density of tiger (8.08 /00 km^2, Karki *et al*., 2009) and moderate density of leopard (4.34/100km^2, Chapter 5 of this thesis). Chitwan is one of the few areas across the entire range of tiger that supports a population of over 100 individuals.

4.5.6 Population Structure

The sex ratios of both sub adult and adult ungulate prey species, except adult barking deer, were in favor of female. Similar disproportionate sex ratio for these species has also been documented in other studies in Chitwan (Tamang, 1982; Mishra, 1982) and elsewhere (Schaller, 1967; Johnsingh, 1983; Karanth and Sunquist, 1992; Biswas and Sankar, 2002; Bagchi *et al*., 2008). Female biased sex ratio in ungulate prey is often interpreted in terms of sexual selection (Clutton-Brock *et al*., 1982), preferential male selection for killing by predator (Tamang, 1982; Johnsingh, 1983) and injuries due to intra specific aggregation, and solitary habits of males and lack of alertness during rut, and dispersal make them more vulnerable to predation by large felids and canids (Karanth and Sunquist, 1992). In addition, as density increases the adult sex ratio in ungulate populations typically favors females (Festa *et al.*, 2003). Young to female ratio in Chitwan was lower in chital and sambar than the estimates from Nagarhole (Karanth and Sunquist, 1992), Pench (Biswas and Sankar, 2002) and Ranthambhor (Bagchi *et al*., 2008), India.

In conclusion, the northern part of the Chitwan National Park and buffer zone supports a high density and biomass of native ungulate prey species compared to other protected areas in Terai. Chital and sambar contributed bulk of biomass like elsewhere in south Asia. Substantial increase in densities of chital, sambar and wild pig have been observed in this study compared to previous studies. The increase has been mainly due to removal of livestock and human pressures and intensive habitat management. The sex ratios of all prey species, except barking deer, were in favor of females indicating male biased predation by carnivores. If conservation efforts are to maintain a viable predator population, then prey density must be maintained high. Habitat management could help to maintain high population of ungulates. This will support support a relatively large population of predators in Chitwan.

Chapter 5

ESTIMATION OF LEOPARD (*PANTHERA PARDUS*) POPULATION AND DENSITY IN AND AROUND CHITWAN NATIONAL PARK, NEPAL

5.1 INTRODUCTION

The leopard (*Panthera pardus*) is a widespread large cat, with a range that includes much of the Asia, Africa, Middle East and South Eastern Europe (Nowel and Jackson, 1996; Sunquist and Sunquist, 2002). As a result of their wide occurrences, leopards are often considered as lower conservation priority among the large cat species and it is currently categorized as “Near Threatened” on the IUCN Red List (Henschel *et al.,* 2008). However, loss of habitat, poaching for illegal trade, declining prey populations and persecution in retaliation has created a discontinuous patchwork of leopard populations throughout its range (Bailey, 1993, Nowell and Jackson, 1996; Uphyrkina *et al*., 2001; Nowell, 2007). Because of heavy poaching and persecution, leopard is listed on the Appendix I of the Convention of International Trade of Endangered Species of Flora and Fauna (CITES).

Reliable information on the abundance of the leopard is scarce (Kostyria *et al.*, 2003; Chauhan *et al*., 2005; Edgaonkar, 2008; Henschel, 2008; Simacharoen and Dungchantrasiri, 2008; Harihar *et al*., 2009) and their conservation status is often assumed on the basis that they are widespread and can survive in the human dominated landscapes, but the presence of leopards in an area does not necessarily mean that a viable population occurs. Like many other large felids, leopards are difficult to monitor because of their cryptic nature, large home range sizes, and low population densities (Bailey, 1993; Rabinowitz, 1989; Nowell and Jackson, 1996). Traditional pugmark surveys and scat analyses have been used to study leopards and tigers (Panwar, 1979; Riordan, 1998), but there are many limitations to these methods (Karanth, 1987b; 1988; 1995). Although these techniques have provided some insight into felid ecology, diet, behavior and some index of relative abundance, they have not been successful in estimating population size or density. More recently, radio telemetry has been used to study these felids, but their nocturnal habits, low density, and wide-ranging behavior make application of this technique difficult, expensive and time intensive (Karanth, 1995; 1999). Despite these problems, data collected using this method has provided density and home range estimates for leopards (Rabinowitz, 1989; Seidensticker, 1976; Simcharoen and Dungchantrasiri, 2008).

Recently, camera-trapping methods have been developed and implemented to study elusive felids (Karanth, 1995; Karanth and Nichols, 1998; Nichols and Karanth, 2002). For animals possessing unique coat patterns, infrared cameras capture them using photography and a capture-recapture history is established for each individual (Karanth, 1995; Karanth and Nichols, 1998). By positioning the cameras in a specific arrangement, density is determined through mark-recapture frame work (Karanth, 1995; Karanth and Nichols, 1998). The camera trapping technique was used to estimate the density of tigers *Panthera tigris* (Karanth, 1995; Karanth and Nichols, 1998; Carbone *et al*., 2001; Karanth *et al*., 2004b; Wegge *et al*., 2004; Jhala et al., 2008), leopard *Panther pardus* (Kostyria *et al*., 2003; Chauhan *et al.,* 2005; Spalton *et al*. 2006; Edgaonkar, 2008; Henschel, 2008; Simacharoen and Dungchantrasiri, 2008; Harihar *et al*., 2009; Wang and Macdonald, 2009a), jaguars *Panthera onca* (Maffei *et al*., 2004; Noss *et al*., 2003; Wallace *et al*., 2003; Silver *et al*., 2004), Puma (Kelly *et al*., 2008; Paviolo *et al*., 2009) and Ocelot *Leopardus pardalis* (Trolle and Kery, 2003; 2005; Dillon, 2005; Maffei and Noss, 2008; Kolowski and Alonso, 2010).

To date only few studies have estimated leopard abundance using camera traps (Chauhan *et al*., 2005; Edgaonkar, 2008; Harihar *et al*., 2009; Wang and Macdonald, 2009a). Where estimates have been made, they were usually limited to a small effective sample area (42.4- 226.44 km^2) with limited number of camera trap locations (10- 56) except Bhutanese study (Wang and Macdonald, 2009a). To achieve conservation objectives that adequately protect leopard populations, conservation planners need accurate estimates of distribution and densities across a variety of habitats, and disturbances gradients.

In Nepal, leopards are threatened with habitat loss and fragmentation, prey depletion, persecution in retaliation and poaching (Shah *et al*., 2004), and the natural habitat outside the protected areas are not sufficiently large enough to support a viable population of leopard. Leopards are displaced by tiger even in protected areas (MacDugal, 1988; Odden *et al*., 2010; Harihar *et al*. 2011). Although leopards are living in the human dominated landscape but the potential source population is in the protected areas where they are surviving with their superior competitor tiger.

The aim of this chapter was to estimate population size and density of leopard in Chitwan National Park and Buffer zone using camera trapping as method in Mark-Recapture framework.

5.2 METHODS

5.2.1 Study Site

This research was conducted in Chitwan National Park and Barandabhar Corridor Forest at the Buffer Zone (see Chapter 2; Figure 5.1).

5.2.2 Preliminary Survey

Prior to field sampling, potential camera trap locations were identified from the topographic maps and satellite images in a Geographic Information System (GIS) domain. A preliminary survey was carried out by walking trails, jungle roads and stream beds to verify/identify trap sites using potential trap locations from the map uploaded in the Global Positioning System (GPS) as reference point. The potential camera trap site must function as a natural funnel such that if the target species is nearby it will naturally choose to walk through the point as there are no alternative routes in the immediate area (Harmsen, 2006). Geographic coordinates of all the potential locations collected during preliminary survey were then plotted in GIS domain along with associated details. The final camera point selection was based on concentration of signs of target species and their prey, jungle roads or trails or narrow stream beds, where movement is basically constrained by some barrier, distance from the closest trap sites, altitude and habitat types, ensuring that sample effort covered all types of habitats.

5.2.3 Camera Trapping

Camera traps were used for estimating leopard population and density following the method developed for estimating tiger abundance (Karanth, 1995; Karanth and Nichols, 1998; 2002; Karanth *et al*., 2001). This method has been extensively used for density estimates of other cryptic felid species that possess individually unique coat (spot or stripe) patterns such as leopard (Henschel and Ray, 2003; Kostyria *et al*., 2003; Khorozyan, 2003; Chauhan *et al*., 2005; Spalton *et al*., 2006; Simcharoen and Duangchantasiri, 2008; Khorozyan *et al*., 2008; Edgaonkar, 2008; Ghoddoustii *et al.*, 2008), snow leopard (Spearing, 2003; Jackson *et al*., 2006; McCarthy *et al*., 2008), Janguar (Wallace *et al.*, 2003; Maffei *et al.*, 2004; Silver *et al*., 2004; Soisalo and Cavalcanti, 2006; Harmsen, 2006; Foster, 2007), Ocelot (Trolle and Kery, 2003; Dillon, 2005), etc.

Camera trap data was collected during two successive winters (November 2008- March 2009 and January- March 2010) in all the available habitat types in the CNP and BZ. Due to logistic constraints, the survey during winter 2008/09 (hereafter survey I) covered only flat and accessible areas of the CNP and Barandabhar Corridor Forest (BCF) in the buffer zone but survey during winter 2010 (hereafter survey II) covered whole of the CNP and BCF (Figure 5.1). Camera trapping was done in phase wise manner due to less availability of camera number. Two separate digital remote camera models (Moultrie and Stealth Cam) were used in this study. Moultrie (Moultrie GS D40, MOULTRIE) and Stealth cam (STEALTH I540IR, Stealth cam, Grand Prairie, TX, USA) are passive infrared cameras which function independently and measure motion and temperature in a targeted area via a heat and motion sensor. When an animal passes in front of the camera, motion and temperature changes are detected by the sensor and the camera is triggered to take a photograph.

Following the theoretical assumption of capture- recapture model that all the individuals in the population have a non-zero capture probability and therefore camera traps should be spaced to ensure that no individual's home range lies between cameras (Karanth and Nichols, 1998; Wang and Macdonal, 2009a). Smallest estimated home range size of female leopard in CNP was 7 km^2 (Seidenstiker *et al.,* 1990); that estimation was from the area with high prey abundance and tiger occupancy was low at that time. The trap stations were, spaced 1.0 km to 2.5 km apart, close enough to each other such that a 7 km^2 circle around a trap station would overlap with the 7 km^2 circle of its nearest stations. The 7 km^2 circle equates to a maximum distance between neighboring trap stations of ~ 2991 m apart. Hence, in this survey design, the capture probability of every leopard within the study area was more than zero.

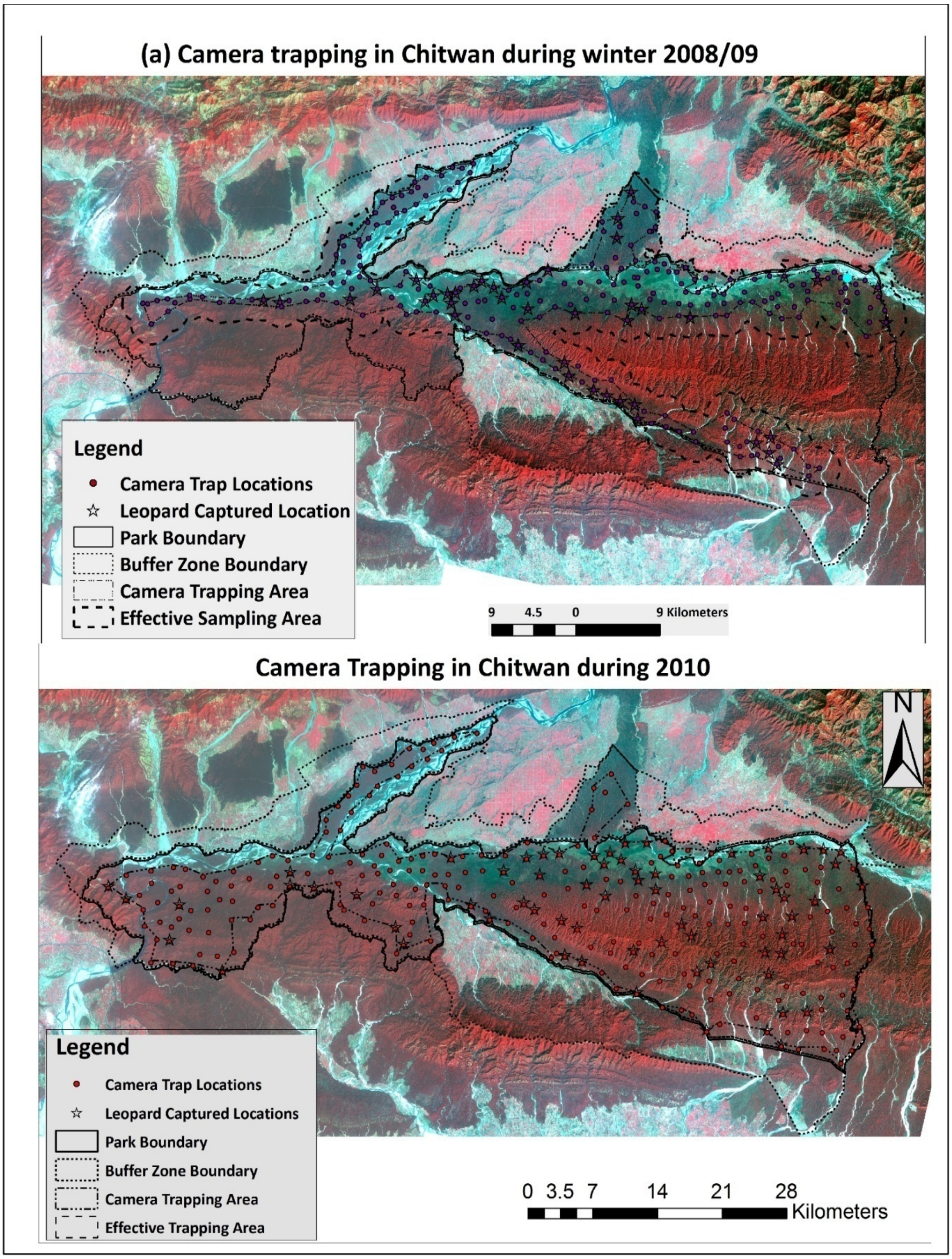


Figure 5.1. Camera traps locations, leopard capture locations and effective sample area in Chitwan during November 2008 to March 2009 (a) and January 2010 to March 2010 (b).

Camera trapping stations were set up along existing trails, jungle roads, stream beds, ridge tops, animal trails, etc. To photograph both sides of the animal for positive identification, each station contained paired cameras, one on either side of the trail at a distance of 3.5 to 5.0 m from the center of the trail. The use of double camera at a station reduces the risk of loss of trap- nights through camera failure.

Cameras were mostly fixed on trees or mounted on wooden posts and maintained a height of 40- 45 cm. Once mounted, all cameras were tested in the field to ensure that a target would be detected and photographed as it passed by the camera station. The cameras were programmed to run continuously for 24 hours, when activated takes three snaps with interval of 5 seconds and 1 minute time delay before next activation. Cameras were monitored every 1- 3 days to check performance and battery status, and to document the presence of animal tracks.

5.2.4 Analysis

5.2.4.1 Individual Recognition of Leopards

Every photographed leopard was identified by comparing the shape, size and topography of rosettes (Figure 5.2). The rosette patterns in the leopard coats are unique to individuals and distinguishable (Miththapala *et al*., 1989; Henschel and Ray, 2003). The overall pattern of leopard coat generally looks similar on both flanks of same individual but each side is unique and different from other side. Thus, pattern comparison was done on a single flank, i.e. left flank photographs were compared with other left flank photographs and right flank photographs were compared with other right flank photographs. Photographs that were difficult to identify due to distorted coat patterns or underexposed, were matched after some image processing to enhance contrast and brightness. Photos that could not be identified were discarded from the analysis.

All identified leopards were sexed from external genitalia (males), presence of cubs (females) and general appearance (much larger body size, plump muzzle, wider chest and front limbs in males) (Khorozyan *et al*., 2008).

a)

b)

c)

Figure 5.2. Identification of individual leopards based on their characteristic pattern of rosettes. (a) and (b) show the same adult male, whereas (c) indicates a second male.

5.2.3.2 Population and Density Estimates

I analyzed abundance and density of leopards from the camera trap data using two approaches; (i) none-spatial capture-recapture model (conventional approach)- adding buffer width of ½ of the mean maximum distance moved (½ MMDM) and mean maximum distance moved (MMDM) around camera trap array (Wilson and Anderson, 1985a, b; Karanth and Nichols, 1998; Trolle and Kery, 2003) and (ii) spatially explicit capture- recapture (SERC) model- explicitly using the information on capture histories in combination with spatial locations of captures under a unified Bayesian modeling framework (Royle *et al*., 2009).

Non-spatial Capture-Recapture Model (Conventional Approach)

Leopard abundance was estimated under mark- recapture framework using the Program CAPTURE (Rexstad and Burnham, 1991). The mark- recapture analysis is used to estimate abundance from camera trap data using closed or open population models. Closed population models allow accurate estimation of population size with confidence intervals (Harmsen, 2006).

All identified leopard was given ID unique to each individual. A capture history, which consists of a string of 0s and 1s, indicating if an animal was or was not photographed on each trapping occasion, was created for each leopard using each day as sampling occasion. The capture histories of all leopards were combined, called *X*-matrix (Otis *et al*., 1978) and analyzed with Program CAPTURE2 (Hines, 1994) to estimate leopard abundance. Two separate capture histories corresponding each for either flank were prepared and data set with greater number of individuals were used for analysis.

Within program CAPTURE, there are estimates of population parameters under various assumptions of the sources of variation in capture probabilities: null (M_o), time variation (M_t), behavior variation (trap-response) (M_b), and heterogeneity variation (M_h). The null model (M_o) corresponds to the case which assumes that the capture probability across all individuals is the same. The time variability model (M_t) assumes for the probability of capture to change over time, whereas behavior variability model (M_b) assumes the probability of capture to change after its first capture (trap-happy or trap shy) and heterogeneity variation (M_h) assumes that each individual has its unique capture probability, and this differs from that of all other individuals. There are also combinations of all three models of variability; M_{bh}, M_{th}, M_{tb} and M_{tbh}. Goodness-of-fit tests and test of models was calculated using program CAPTURE2. A model selection procedure which rank the variety of models according to appropriateness using a discriminate function criterion was used (Otis *et al*., 1978; White *et. el*., 1982; Rexstad and Burnham, 1991). Model M_o, the simplest model, is sensitive to violations of the assumption of similar individual capture probabilities, so when this model was selected, the parameters computed using the next best model have also been presented. Both geographic and demographic closures were assumed and the program CAPTURE statistically tested these assumptions.

The density (D) is defined as N/A where N is the estimated population of leopard determined by program CAPTURE and A is effective sampling area (ESA). The effective sample area encompasses the camera trapping area bounded by a polygon with a buffer strip around it that takes into account those individuals whose home ranges may include areas that are only partially contained within the camera trapping area. There are various methods to estimate buffer width such as half MMDM (e.g. Karanth and Nihcols, 1998), MDM (e.g. Trolle and Kery, 2003; Cuellar *et al*., 2006), absolute MDM (e.g. Kawanishi and Sunquist, 2004), and home range radius (e.g. Wallace *et al*., 2003, Sharma *et al*., 2010). Karanth and Nichols (1998) used a buffer whose width was based upon half of the mean maximum distance moved (HMMDM) among multiple captures of individuals. This method has been followed by many researchers. Another approach of estimating effective sampling area is to add a circle of radius *W* around each trap location and then calculate the area bounded by the merged perimeter (Maffei *et al*., 2004; Silver, 2004; Dillon, 2005; Foster, 2007). This approach is useful to check whether there are any 'holes' between traps where individuals could have zero probability of capture (Maffei *et al*., 2005). A few studies did not calculate an effective sampling area for density estimation instead they used the area bounded by a minimum convex polygon of the outer traps, or the boundary of a park or reserve (e.g. Carbone *et al*., 2001; Cullen *et al*., 2005; Heilburn *et al*., 2006).

Such approach can be acceptable if it is known that the members of the population do not leave the park boundaries; but when individuals do move beyond the trapping grid will overestimate the true density.

In this study, the maximum distances of all leopard trapped in multiple locations were averaged to determined the MMDM. Half of this MMDM value and full MMDM values were used as buffer around each camera stations in Arc GIS. The ESA was estimated by merging area of all of the circular buffers around each camera location (Maffei *et al*., 2004; Silver 2004; Dillon, 2005; Foster, 2007). Any portion of the ESA that lay outside the natural habitat such as human habitation was subtracted using a GIS package (Karantha and Nichols, 1998; Silver, 2004; Dillon 2005). Estimating ESA using merged circular buffers around each trap location is assumed to be more useful approach in study areas with irregular boundary and having dense human settlements immediately around the park. The standard error (SE[D]) was computed as the square root of the variance of D(Var[D]) (Karanth and Nichols, 2002).

Bayesian Spatially-Explicit Capture-Recapture Models

The density of leopard was also estimated using SPACAP package version 1.0. The SPACECAP package directly estimates animal density by explicitly using the information on capture histories in combination with spatial locations of captures under a unified Bayesian modeling framework (Singh *et al*. 2020). The Bayesian SECR model is a hierarchical model comprising two components (i) a point process model describing the distribution of individuals in space and (ii) capture process model describing the observation of individuals in traps, offers advantage on dealing with problems posed by individual heterogeneity in capture probabilities and non-asymptotic inferences (Royle *et al*. 2009). Details of models and analyses by this approach for camera trapping data is available in Royle *et al*. (2009) and methods have been described by Singh *et al*. (2010).

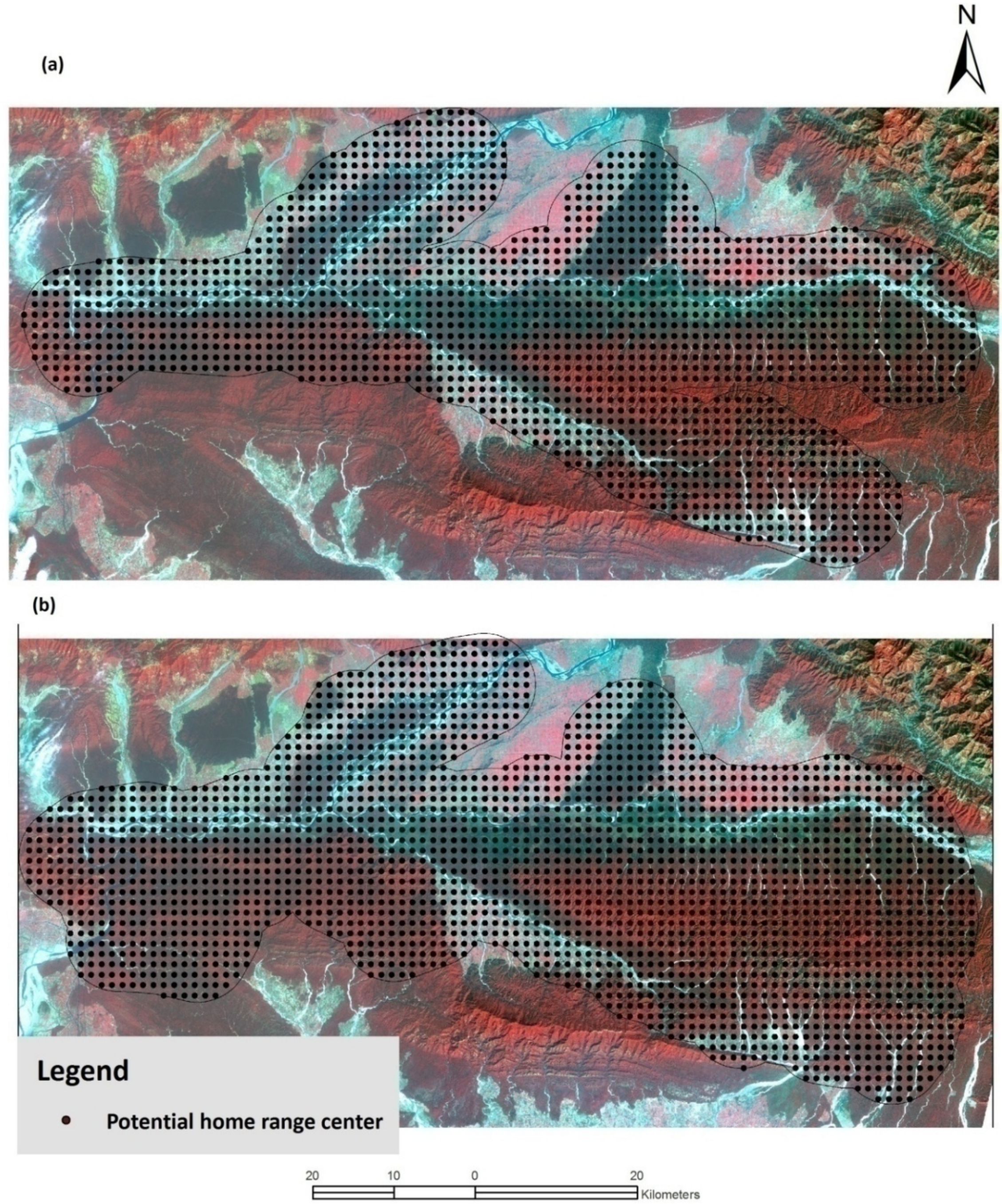


Figure 5.3. Chitwan National Park camera trapping area showing potential activity (potential home range center) within camera array and 5 km buffer area around.

Following Singh *et al*. (2010), I prepared three types of input files to analyze data in the SPACECAP package: (i) Animal Capture Detail File, (ii) Trap Deployment Details File and (iii) State- space Details File. These files are saved in ASCII comma separated format (.csv), because SPACECAP can only read these types of input files. The animal capture details file consist of location ID (unique identification number given to each location), the animal ID (unique identification number of captured leopard) and the sampling occasion number (unique occasion number given to each sampling day starting from1). The trap deployment file consists of trap location ID and spatial location of trap IDs in X and Y- coordinates (in Universal Transverse Mercator UTM projection system) along with information on the occasions when each camera trap location was operational during the survey. The trap deployment data were organized in a two dimensional matrix of camera trap locations and sampling occasions in a binary, 1s and 0s, indicating a particular camera trap station was or was not operational on a particular sampling occasion. The potential home range center (or activity center) file represented by a large number of equally spaced points in the form of a very fine mesh in the surveyed area containing the camera trap array with an extended buffer surrounding it, known as “state- space” of the underlying point process (Singh *et al*. 2010). These points represents all possible potential activity centers (or home range centers) of all the individuals in a population being surveyed. I generated mesh of points (potential home range center) using Arc GIS in camera array and 5 km and 10 km buffer (Figure 5.3). The potential home range center file consist of X and Y coordinates of all the potential activity centers in the UTM Projection System, and habitat suitability indicator indicating with 1s or 0s representing the potential activity centers lies within suitable habitat or not. This analysis has been run in SPACECAL v 1.0 under program R environment.

The SPACECAP package uses the Markov-Chain Monte Carlo (MCMC) simulation algorithm written in Program R to estimate the parameters of the Spatially - Explicit Capture Recapture Models (Royle *et al*., 2009). For MCMC simulation, I selected 50000 iterations, 1000 burn in values (number of initial values to discard during the MCMC analysis) and 1 as thinning. Only iteration numbers defined by the thinning rate are stored during the analysis (Singh *et al*., 2010).

5.3 RESULTS

5.3.1 Capture Success and Sampling Efforts

Two separate camera trapping surveys were conducted in Chitwan and separate estimates are reported for each survey. A total of 256 and 310 camera trap stations were set up during survey I and survey II respectively at altitude between 87 msl to 609 msl. Total sampling efforts of survey I (2008/09) and survey II (2010) were 3840 and 4650 trap nights respectively (Table 5.1).

Table 5.1. Camera-trapping efforts (in trap nights) in camera trapping in Chitwan National Park and buffer zone, Nepal

Survey	**Duration**	**Number of camera trap stations**	**No. of occasion**	**Total efforts (trap nights)**
Survey I	20/11/2008- 25/03/09	256	15	3840
Survey II	20/01- 21/03/2010	310	15	4650

*Trap nights with functional camera.

A total of 179 leopard photos (105 left flanks and 74 right flanks) were obtained from 77 capture events at 43 trapping stations during survey I and 197 leopard photos (103 left flank and 94 right flank) were collected from 98 capture events at 67 trapping stations during survey II. Photo capture success was not good as expected because only 36% and 39% of the capture events yielded leopard pictures of both flanks during survey I and survey II respectively. Leopard photos were captured from all the available habitats between 125 msl to 609 msl. Of the total photos, 165 (including 92 left flanks and 73 right flanks) and 192 (including 99 left flanks and 93 right flanks) were quality photos from survey I and survey II respectively (Table 5.2). Using photos of left flank only, I identified 27 leopard for first survey data and 37 for second survey, while right flank yielded 24 and 34 individual leopards (Table 5.2).

Table 5.2. Capture events and number useful photos of leopard in Chitwan

Survey	Leopard capture events	No of locations where leopard was photographed	Number photo taken			No of photo used for identification			No of individual identified	
			Total	LF	RF	Total	LF	RF	LF	RF
Survey I	77	43	179	105	74	165	92	73	27	24
Survey II	98	67	197	103	94	192	99	93	37	34

Among the sampled animals, the frequency of capture ranged from 1 to 8 times (Figure 5.4). Males were captured up to 8 times while the females were captured up to 4 times.

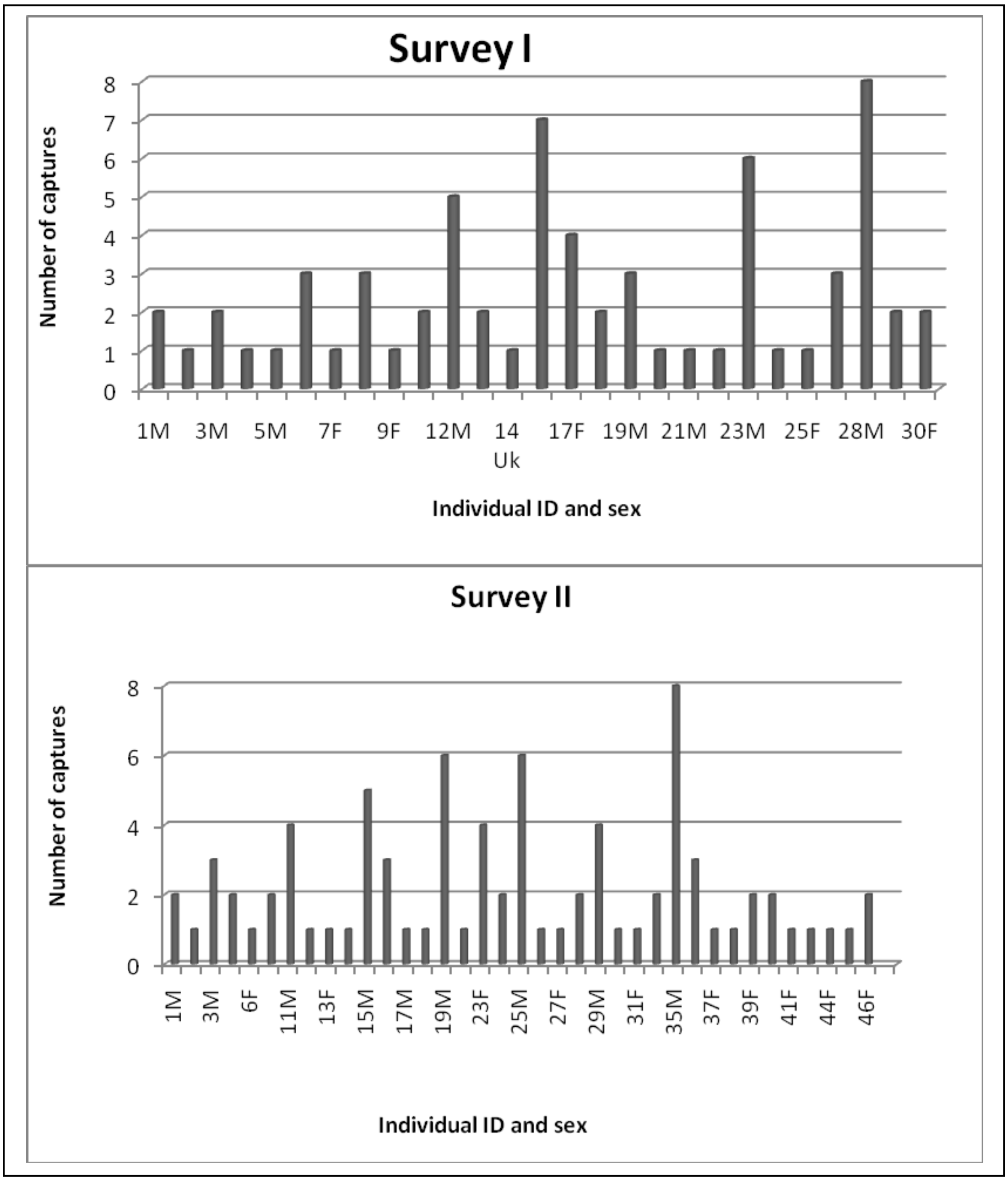


Figure 5.4. Capture frequencies of individual leopard (M- male and F- Female)

The sex ratio in the first survey skewed toward male but in second survey it was balanced (Table 5.3). Only 2 and 1 individuals could not be sexed during survey I and II respectively.

Table 5.3. Sex ratio of leopard camera trapped in Chitwan National Park and buffer zone, Nepal.

Survey	Male	Female	Unknown	Sex ratio (No of male per females)
Survey I	15	10	2	1.5
Survey II	16	20	1	0.8

During both the camera trapping survey in Chitwan an asymptote in the cumulative number of individuals identified was not reached till the fifteenth sampling occasion (Figure 5.5) indicating further sampling would have yield new individuals.

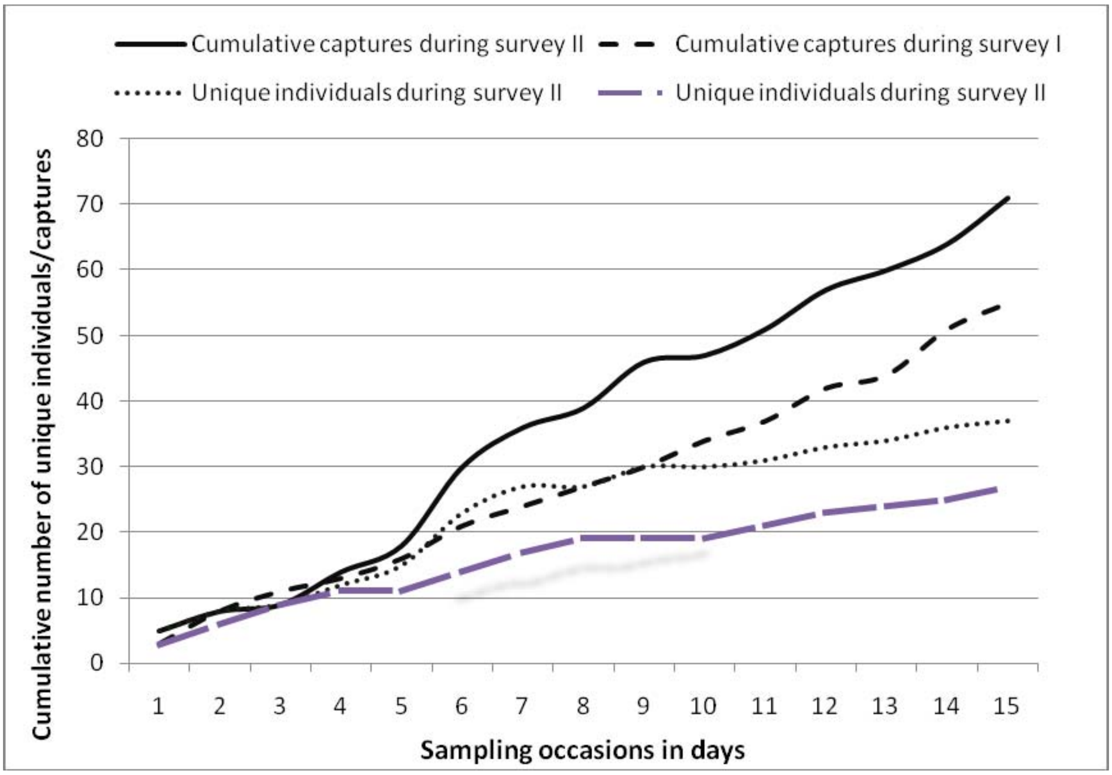


Figure 5.5. Rate of captures and cumulative number unique leopard camera trapped with increase of sampling occasions in Chitwan during 2008/09 and 2010 surveys.

5.3.2 Tests for Population Closure and Model Selection

Closure tests in program CAPTURE (Otis *et al.*, 1978; Rexstad and Burnham, 1991) indicated that the sampled populations of both the surveys met the assumptions of closure (Z = 0.403, P = 0.656, survey I and Z = -0.607, P = 0.271, survey II) (Table 5.4).

Table 5.4. Results of test for population closure (z = test statistic, P = significance level) and testing assumptions used by CAPTURE to select the best fit model for analyzing leopard data in Chitwan National Park and buffer zone, Nepal.

Survey	**Model selection criterion**				**M_h Goodness of fit**			**Closure test**	
	M_o	**M_h**	**M_b**	**M_t**	**χ^2**	**df**	**p**	**z**	**P**
Survey I	1	0.82	0.45	0.0	7.87	14	0.89	0.40	0.65
Survey II	1	0.92	0.0	0.38	25.21	14	0.03	0.61	0.27

M_o = Null model, M_h = Heterogeneity effects model; M_b = Behavior effects model; M_t = Time effects model.

The model M_o scored the highest in the overall model selection test followed by the model M_h in Program CAPTURE for both year's data (Table 5.5). There was no variation in heterogeneity, time and behavior in capture probabilities for leopard data from both the survey. Although model M_o is the best fitted model for both surveys, population size estimator of model M_o is known to be sensitive to violations of the underlying model assumption of homogeneous capture probabilities (Otis *et al.*, 1978). Because of the robustness of the estimator under model M_h (Burnham and Overton, 1979; Karantha and Nichols, 1998), the population estimates computed under both M_o and M_h model are presented and used further analysis. The M_h jackknife estimator was used for population estimation under M_h model.

Table 5.5. CAPTURE Program results for the model selection ranking for leopards in Chitwan National Park and buffer zone, Nepal.

Survey	M_o vs M_h			M_o vs M_b			M_o vs M_t			M_h Goodness of fit		
	χ^2	df	P	χ^2	df	P	χ^2	df	P	χ^2	df	p
Survey I	1.80	2	0.41	1.05	1	0.30	6.98	14	0.89	7.87	14	0.89
Survey II	4.29	2	0.12	0.04	1	0.84	28.6	14	0.01	25.21	14	0.03

M_o = Null model, M_h = Heterogeneity effects model; M_b = Behavior effects model; M_t = Time effects model.

Estimated average capture probabilities (p- hat) under Mo (0.104 and 0.116) are higher than that of M_h jackknife (0.083 and 0.099). The overall probabilities that a leopard was captured at least once over the sampling period (M_{t+1}/n) were higher under M_o model than that of M_h (Table 5.6).

Table 5.6. Estimation of population of leopard in Chitwan National Park and buffer zone, Nepal (2008/09 and 2010) using only left flank photos.

Survey	**Null model (M_o)**				**Heterogeneity model (M_h)**			
	p- hat	M (t+1)/N	N ± SE	95% CI	p- hat	M (t+1)/N	N ± SE	95% CI
Survey I	0.116	0.87	31± 3.03	29- 41	0.099	0.72	37± 5.49	31- 54
Survey II	0.104	0.82	45± 4.24	41- 58	0.083	0.64	57± 9.43	46- 84

5.3.3 Leopard Population and Density

Using left flank photos, the estimated population size of leopards were 31±3.03 and 45±4.24 under M_o estimator for survey I and survey II respectively and 37±5.49 and 57±9.43 under M_h estimator (Table 5.6). A total of 16 and 19 leopards were trapped two or more times respectively during Survey I and Survey II. The estimated MCP polygon for survey I and survey II of camera trap were respectively 463.98 km^2 and 969.56 km$^{2.}$ The mean distances moved by leopards were 4.31 km and 4.38 km, yielding a buffer width of 2.15 km and 2.19 km for ½ MMDM and 4.31 km and 4.38 km for full MMDM (Table 5.7). The estimated effective sample area was 851.6 km^2 and 1403.35 km^2 using buffer widths estimated by ½ MMDM and full MMDM (Table 5.7) respectively.

Table 5.7 Estimation of population densities of leopard in Chitwan National Park and buffer zone, Nepal

Methods	**Survey**	**CT Area (km^2)**	**Buffer Width (in meter)**	**Effective Sampled Area (km^2)**	**Density Estimation (leopards/100km^2)**	
					M_o	**M_h**
HMMDM	Survey I	463.98	2157.73	851.60	3.64±1.23	4.34±1.46
	Survey II	969.56	2190.07	1403.35	3.20±1.44	4.06±1.83
FMMDM	Survey I	463.98	4315.46	1189.35	2.60±0.88	3.11±1.44
	Survey II	969.56	4380.14	1636.43	2.74±0.7	3.48±0.89

I present four different estimates of leopard density for each of two different surveys using buffer width of ½ MMDM and full MMDM, and population estimates of both M_o and M_h model. Estimated density (±SE) of leopard in Chitwan per 100 km^2 by buffering the camera trap MCP with (1) ½ MMDM using population estimates of M_o was 3.64 (±1.23) and 3.20 (±1.44) and M_h was 4.34 (±1.46) and 4.06 (±1.83) respectively for survey I and II; and (2) full MMDM using population estimates of M_o was 2.60 (±0.88) and 2.74 (±0.7) and M_h was 3.11 (±1.44) and 3.48 (±0.89) for respective surveys of 2008/09 and 2010 (Table 5.7).

The density estimates from SPACECAP package for survey I and survey II were 3.12 leopards 100 km^{-2} and 3.44 leopards 100 km^{-2} respectively (Table 5.8). These estimates are close to the density estimates by conventional method with buffer strip of full MMDM (Table 5.7). The population estimates (Nsuper) was 41.11 and 63.35 respectively of survey I and Survey II.

Table 5.8. Summaries of model parameters for the leopard camera trapping survey data of 2008/09 and 2010

Survey	Parameters	Mean	SD	95% posterior interval
Survey I	Sigma	1.26	0.26	0.81- 1.77
	lam0	0.01	0.01	0.01- 0.01
	Beta	-3.62	6.94	-14.27- 8.23
	Psi	0.18	0.03	0.12- 0.24
	Nsuper	41.11	4.81	32- 50
	Density	3.12	0.36	2.51- 3.87
Survey II	Sigma	0.62	0.12	0.41- 0.87
	lam0	0.01	0.01	0.006- 0.01
	Beta	1.42	0.39	0.62- 2.14
	Psi	0.27	0.05	0.18-.0.34
	Nsuper	63.35	9.04	46- 80
	Density	3.45	0.49	2.50- 4.35

Sigma - encounter probability, lambda- detection probability at trap location that considered as home range, Beta- the regression coefficient that measures the behavioral response, Psi- data augmentation parameter, Nsuper- Population size, and Density- animals 100 km^{-2}.

5.4 DISCUSSION

5.4.1 Sampling Efforts and Capture Success

I have attempted to analyze photographic capture-recapture data for estimating abundance of leopard in Chitwan for two successive winters. This study provides the first statistically valid model- based leopard density estimates from Terai and Churia environment of Nepal. In terms of sampling efforts, which involve double cameras in each of uniformly distributed 256 and 310 trap locations, 3840 and 4650 trap nights (Table 5.1) and large effective sampling area, this study represents one of the largest ever attempted. Studies estimating leopard abundance in south and south east Asian region had involved a total of 10- 81 camera trap locations in the selected intensive study sites of a park (Chauhan *et al*., 2005; Edgaonkar, 2008; Simchroen and Dungchantrasiri, 2008; Harihar *et al*., 2009; Wang and Macdonald, 2009a; Table 5.8).

Smaller survey areas are reported to be associated with estimation of inflated density (Cuellar *et al*., 2006; Harmsen, 2006; Jackson *et al*., 2006; Dillon and Kelly, 2007; Maffei and Noss, 2008).

Failure of one side camera was evident in several cases in this study; only 36% and 39% of the capture events yielded leopard pictures of both flanks during survey I and survey II respectively. The probability of capture (M_{t+1}/n) of a leopard were higher in survey I (0.87 under M_o and 0.72 under M_h) than that of survey II (0.82 under M_o and 0.64 under M_h), but both values were comparable to other studies (0.69 to 1.0, *e. g*. Edgaonkar, 2008). Both males and females were photographed but the percentage of total capture of males (61.73%) was higher than female (38.27%) indicating existence of heterogeneity in capture probabilities with respect to sex. Edgaonkar (2008) also reported consistently higher rates of male photos than female. An asymptote in the cumulative number of unique individuals captured was not reached till the fifteenth sampling occasion for both the surveys in Chitwan indicating inadequacy of sampling and further sampling could yield new individuals. Reported asymptote from other studies ranged from 9th sampling occasion in Jigme Singye Wangchuck National Park (JSWNP), Bhutan (Wang and Macdonald, 2009a) to 6 weeks in Satpura Tiger Reserve, India (Edgaonkar, 2008). But Edgaonkar (2008) was unable to report an asymptote till the end of his sampling period (33 days) in Sariska Tiger Reserve, India. Trap avoidance behaviour in leopard was clearly evident in our study even in photographs. There were few incidences that leopard avoided to pass between cameras instead it passed other side of camera. The lower recapture rate female leopard than male also indicates females were avoiding trap after first capture (Figure 5.3). Trap shyness in tiger is reported as a major concern in fixing cameras at a point for longer duration (Wegge *et al*., 2004; Sharma *et al.*, 2010).

The estimated value of sex ratio was 1.5 male per female in survey I and 0.8 males per female in survey II. Even if we suppose that all the unsexed individuals were female, because females are difficult to sex than male, the sex ratio in survey I was unequal. However, the females could have been underestimated because females have smaller territories and move less than the males, and therefore have lesser opportunities to be captured. Edgaonkar (2008) reported female biased sex ratio (1.7 female per male with the range of 0.6 to 2.7 female per male) for leopard in Satpura

Tiger Researve and Sariska Tiger Reserve, India. Higher capture frequency of males was reported from Huai Kha Lhaeng Wildlife Sanctuary, Thailand by Ngoprasert (2004) and Simchroen and Dungchantrasiri (2008). Male biased estimate of sex ratio in camera trap studies was common in other large cat species such as Janguar, in which the sex ratio ranging from 0.8 to 4.5 males per female (Wallace *et al*., 2003; Maffei *et al*., 2004; Silver *et al*., 2004; Miller and Miller, 2005; Miller 2006; Soisalo and Cavalcanti, 2006; Salom- Perez *et al.*, 2007; Foster, 2007). Such a skewed sex ratio is expected in a population if the sexes differ in ranging behaviour. Theoretically, a female bias sex ratio is expected under the classic cat social organization in which the larger home range of male overlaps with the smaller ranges of multiple females (Sunquist, 1981; Smith, 1993; Nowell and Jackson, 1996; Jenny 1996; Karanth and Chundawat, 2002; Oden and Wegge, 2005; Harmsen, 2006). The detected ratio can be influenced by number of male transients who are moving through the sampling area in search of territory (Foster, 2007) and high levels of male movement and overlap will shift the bias towards males (Harmsen, 2006).

5.4.2 Tests for Population Closure and Model Selection

Closed capture- recapture population models assumes that the population is closed both demographically and geographically during the sampling period. Otis *et al*. (1978) suggested a shorter duration of survey to satisfy the assumption of closure. Longer duration in our survey I (125 days) raised the concern for closure assumption, but the closure test in CAPTURE (Otis *et al.*, 1978; Rexstad and Burnham, 1991) indicated that the population closure was not violated. Although, a sampling duration of 2- 3 three months is considered appropriate for large cats such as tiger (Karanth and Nichols, 1998; 2000; 2002), snow leopard (Jackson *et al*., 2006) and Jaguar (Silver *et al*., 2004), but some researchers have extended their sampling periods in order to achieve sufficient captures of animals in low density area. Kawanishi and Sunquist (2004) used capture- recapture data of 10- 13 months to estimate tiger abundance and Wang and Macdonald (2009a) increased sampling duration 250 days for estimating tiger and leopard in high altitude mountains of Bhutan, and test result of population closure supported the assumption that sample population was closed.

CAPTURE program selected model M_o as appropriate model (model selection criteria 1) and M_h was selected as next best (> 80). Given the robustness of the estimator under model M_h (Burnham and Overton, 1979, Karantha and Nichols, 1998) and the fact M_o is unlikely to reflect the true situation, M_h is preferred over M_o, although the M_h estimates are less precise (larger confidence intervals) than the Mo estimates (Foster 2007). Estimated capture probabilities of Chitwan leopard (0.104 and 0.116 under M_o and 0.083 and 0.099 under M_h jackknife) are higher than the estimates from Sariska Tiger Reserve (0.07, Chauhan *et al*., 2005); Satpura Tiger Reserve (0.03- 0.08 under M_o and 0.02- 0.07 under M_h) and Sariska TR (0.04 under M_o and M_h) (Edgaonkar, 2008); and Jigme Singhe Wanchuk National Park (0.04, Wang and Macdonald, 2009a) lower than the estimates from Huai Kha Khaeng Wildlife Sanctuary (0.33- 0.44, Simchroen and Dungchantrasiri, 2008) and Kaeng Krachen NP (0.27 using M_h, Ngoprasert, 2004). The capture probabilities of Chitwan leopard are above the 0.05 threshold suggesting a reliable and precise density estimates (Harmsen, 2006).

5.4.3 Population and Density

The study is the first rigorous estimates of leopard densities using capture- recapture models applied to camera-trap data covering whole of the Chitwan National Park irrespective of habitat types, altitude, disturbances and accessibility. In contrast, most contemporary estimates of leopard density are based on selected sample survey area from a park (Kostyria *et al*., 2003; Chauhan *et al*., 2005; Edgaonkar, 2008; Ghoddoust *et al*., 2008; Simacharoen and Dungchantrasiri, 2008; Henschel, 2008; Harihar *et al*., 2009; Wang and Macdonald, 2009a), but they are extremely valuable for the conservation of species and also serve as base line data for monitoring of the leopard. In this study MMDM and estimated density was very similar among the surveys irrespective of the trapping polygon size (MCP).

In this study, densities estimated using the effective sampling area calculated by merging circular buffers of MMDM size around each trap locations and subtracting the portion of area that lay outside of the natural habitats gave results that were similar to the Bayesian SECR Models for both years, while densities calculated using half MMDM were larger (Table 5.7 and 5.8). The Bayesian SECR Models also gave similar population estimates (Nsuper) with high precision (Table 7.6 and 7.8).

Table 5.9. Number trap locations, trap efforts, MCP polygon of trapping area, effective sampling area and estimated density of leopard in various studies

Study Area	Number of trap locations	Trap Nights	Trap efforts (nights)	CT area (km^2)	Buffer (km)	ESA (km^2)	Density (individuals/100km^2)
Primorsky Krain, Russia[1]	NA	NA		765	4.85	1548.0	1.2
Sariska TR, India[2]	10	10	100	23.75	0.45	68.0	23.0
Churna 1, Satpura TR, India[3]	16	76	1,216	NA	NA	152.2	8.0±2.5
Churna 1, Satpura TR, India[3]	16	75	1,200	NA	NA	149.2	9.3±2
Kamti, Satpura TR, India[3]	20	53	1,060	NA	NA	119.3	7.5±2.8
Lagda, Satpura TR, India[3]	20	33	660	NA	NA	122.7	7.3±5.1
Sariska TR, India[3]	12	33	330	NA	NA	44.4	30.9±12.1
Gabon[4]	15	45	675	29.0	0.0	0.0	0.0
Gabon[4]	23	62	1,426	89.0	2.99	281	4.58
Gabon[4]	31	45	1,395	106.0	2.9	232	12.32
Huai Kha Khaeng WS, Thailand[5]	39	16.67	650.13	42.86	1.59	126.93	7.88
Huai Kha Khaeng WS, Thailand[5]	49	12.65	720.79	57.86	2.33	191.26	5.21
Huai Kha Khaeng WS, Thailand[5]	56	14.71	823.76	96.93	1.81	226.44	4.86
Sariska TR, India[6]	35	67	2,345	109.6	-	213.8	7.0±0.20
Chilla, Rajaji NP, India[7]	30	15	1,350	52.65	1.16	86.72	14.99
Jigme Singhe Wangchuk NP, Bhutan[8]	81	50	4,050	-	0.0	1542.07	1.04±0.01
Chitwan, 2008/09[9]	257	15	3.855	463.98	2.15	851.6	4.34±1.46
Chitwan, 2010[9]	310	15	4,650	969.56	2.19	1403.35	4.06±1.83

Source: [1] Kostyria *et al*. (2003); [2]Chauhan *et al*. (2005); [3]Edgaonkar (2008); [4]Henschel 2008; [5]Simacharoen and Dungchantrasiri (2008); [6]Sankar *et al*. (2009), [7]Harihar *et al*. (2009; [8]Wang and Macdonald (2009a); [9]This study

Estimated densities of leopard in Chitwan were lower than the estimates from India (Chauhan *et al*., 2005; Edgaonkar, 2008; Harihar *et al*., 2009) and remote area of African Rainforest (Henschel, 2008), close to the estimates from Thailand (e.g. Simacharoen and Dungchantrasiri, 2008) and higher than in Bhutan (Wang and Macdonald, 2009a) (Table 5.9) and Souwest Primorsky Krai (1.2 leopards $100km^{-2}$). Density estimates of this study is comparable to the estimates from Huai Kha Khaeng Wildlife Sanctuary using radio telemetry (4 leopards 100 km^{-2}, Rabinowitz, 1989), Serengeti (3.8-4.5 100 km^{-2}, Schaller, 1977), Kruger (3.4 100 km^{-2}, Pienaar, 1969) and Wilpattu National Park in Sri Lanka (3.4 100 km^{-2}, Eisenberg and Lockhart, 1972). In general carnivore densities are associated with density of prey base (Karanth *et al*., 2004b) and other carnivores (Carbone *et al*., 1999) as well as human disturbance (Woodroffe, 2000), but recently Oden *et al*. (2010) reported interference competition rather than food competition is a limiting factor for the leopard population, whose distribution was restricted to the margins of the tiger territories in Bardia.

Lower estimates of density of leopard in Chitwan than other contemporary studies can be attributed to: (i) the big sampling area with varying level of prey base and disturbances, and (ii) presence, interaction and interference competition with tiger (Seidensticker, 1976; Sunquist, 1981, McDougal, 1988; Odden *et al*. 2010), which has high density in Chitwan ($8.03/100km^2$, Karki *et al*. 2009). Nevertheless, leopards are not common in habitat where tiger density was high. In Chitwan, leopards surviving either on the Churia hill depend on low density prey or on the peripheries of the park, sandwiched between prime tiger habitat, on the one side, and dense human habitation on the other, dependant on both natural prey and domestic livestock. Tiger push leopard out from the prime habitat to human habituation (McDougal, 1988) where leopards are beaten or poisoned to death. During 2007 to June 2009, 7 leopards were killed by human in Chitwan (Chapter 7). Thus, humans as well as and tigers are responsible to reduce leopard population and density.

There is growing concern about the size of effective sampling area for density estimates of wide- ranging species using camera traps (Harmsen, 2006; Maffei and Noss, 2008; Foster, 2007; Sharma *et al*., 2010). Various researchers have reported that the smaller survey areas are associated with inflated density estimates with wide

Standard Errors (Cuellar *et al*., 2006; Harmsen, 2006; Jackson *et al*., 2006; Dillon and Kelly, 2007; Maffei and Noss, 2008). Maffei and Noss (2008) suggested that the survey area should be at least four times the average home range size of the target species. Some of the contemporary estimates of density using camera trap data may not meet the size criteria for male leopards and one likely to overestimate the density (Table 5.9).

5.5 CONCLUSIONS

This study provides first rigorous estimate of leopard densities using both non-spatial capture- recapture and Bayesian spatially-explicit capture-recapture Models during 2008/09 and 2010 covering whole of the Chitwan National Park irrespective of habitat types, altitude, disturbances and accessibility. The study provides benchmark density estimates against which future monitoring can be compared. Although the capture probabilities were high but 15 sampling occasions used in this study appear inadequate to estimate leopard population and density. Like tiger, leopard also showed trap avoidance behavior and males were more camera friendly than female. The population and density estimates from Chitwan were lower than that was expected and it indicates the status of leopard in area with high tiger density. Humans as well as and tigers are jointly contributing to reduced leopard population in Chitwan, Nepal.

Chapter 6

FEEDING HABITS AND PREY SELECTION BY LEOPARDS IN CHITWAN

6.1. INTRODUCTION

The leopard (*Panthera pardus*) has a widest geographic distribution among all the wild cats and it occur in variety of habitats in south Asia, Indo- China, sub-Saharan Africa and Eastern part of Russia (Nowell and Jackson, 1996). As a habitat generalist species (Bailey, 1993; Maan and Chaudhary, 2000), the leopard is able to live and thrive in almost all types of habitats including dense forest, open country, rocks and scrubs (Prater, 1993); grasslands and even in the mountain cliffs, where sufficient hide out and prey is available (Scott, 1988; Bailey, 1993). Its response on habitat and food varies according to the habitat it occupies and prey availability (Seidensticker *et al.* 1990; Bailey, 1993; Daniel, 1996). Leopards can easily survive in human dominated areas by changing its dietary habits to include the livestock and dogs (Gugginsberg, 1975; Nortan *et al,.* 1986; Seidensticker *et al.,* 1990; Martin and de Meulenaer, 1993; Daniel, 1996; Edgaonkar and Chellam, 2002; Goyal *et al*. 2007; Chauhan, 2008).

Leopard feeds primarily on other vertebrates, particularly medium-sized ungulates, but it preys on a variety of animals that range in size from small birds/rodents to sambar or a young buffalo (Schaller, 1972; Essenberg and Lockart, 1972; Rabinowitz, 1989; Seidensticker *et al*., 1990; Johnsingh, 1992; Bailey, 1993; Karanth and Sunquist, 1995; Grassman, 1999). Recent analysis of 33 studies on leopard feeding ecology revealed that leopards preferentially prey upon species within a weight range of 10–40 kg, even if prey outside this weight range is more abundant (Hayward *et al*., 2006a).

Carnivores are known to shift to alternative prey or 'buffer species' when preferred prey are scarce (Murdoch, 1966; Bergerud, 1983; Jedrzejewski *et al.,* 2000). Leopards have been recorded to switch to smaller- bodied prey in areas where medium sized ungulates are scarce (Ramakrishnan *et al*., 1999; Sankar and Johnsingh, 2002) and/or livestock and dogs (Seidensticker *et al*., 1990; Edgaonkar and Chellam, 2002; Goyal *et al*., 2007; Chauhan, 2008; Shah *et al*., 2009). But the predator species exceeding

21.5 kg body mass, and particularly felids and canids, tend to specialize on vertebrate prey near the predator mass (Carbone *et al*., 1999), and it has been suggested that sub-optimal predation in large carnivores may be an early indicator for a population at risk of extinction (Hayward, in press)

Little information is available regarding the feeding ecology and predatory patterns of leopard in Terai (Seidensticker *et al*., 1990; Eliassen, 2003; Wegge *et al*., 2009; Harihar *et al*., 2010). In Chitwan and also other protected areas of Terai, leopards and tiger are sympatric species at the top of food chain. Because of high human pressure in the Terai, the forests outside the protected areas are heavily degraded, and the protected areas are increasingly becoming a forested island within human dominated matrix. Populations of primary prey species are heavily depleted outside the protected areas in Nepal Terai (Shrestha, 2004). The southern parts of buffer zone (Someshor hill) of Chitwan National Park (CNP) support very low population of prey species in general and particularly chital in comparison to CNP (Gurung *et al*., 2006; 2007). This study was designed to understand the foraging ecology of leopard by comparing prey composition in diets between prey rich and prey poor areas. Specifically, the study: (1) determines the diet composition of prey species in leopard scats; (2) ascertains the relative biomass of principal prey in diets and (3) estimate selectivity of major prey species by leopard.

6.2. METHODS

The study was carried out in the Chitwan National Park (CNP) and Buffer Zone (BZ) lies in south central inner Terai and Churia range. The CNP with 932 km^2 area is surrounded by a 750 km^2 multiple use area as buffer zone (Chapter 2).

6.2.1 Prey Availability

Three different areas representing dominating mature Sal forest, areas where human habitation have been recently resettled and regenerating forest in the buffer zone were selected for line transect sampling. A total of 34 transects; 12 in Sal dominated forest, 10 in areas where villages were resettled and 12 in regenerating forest in the buffer zone were used for prey sampling (Figure 6.1). Prey species was sampled from the elephant back (Tamang, 1982) through the line transects (Burnham *et al*. 1980; Karanth and Sunquist, 1992; Buckland et al., 1993; Laake *et al*., 1999) and each transect was monitored four times during summer 2008 in the morning between 6.00 and 10.30. For each transect, total length, the number of groups, group size and composition, sighting distance measured with a laser range finder (Bushnell Yardage Pro 400), sighting angle measured with compass (Silva, RANGER 515 CL Compass) and geographic coordinates recorded with a GPS (Garmin GPS MAP 60 CXS) were recorded for every prey species encountered. The sighting distance and angles for species occurring in clusters were recorded to the center of the cluster.

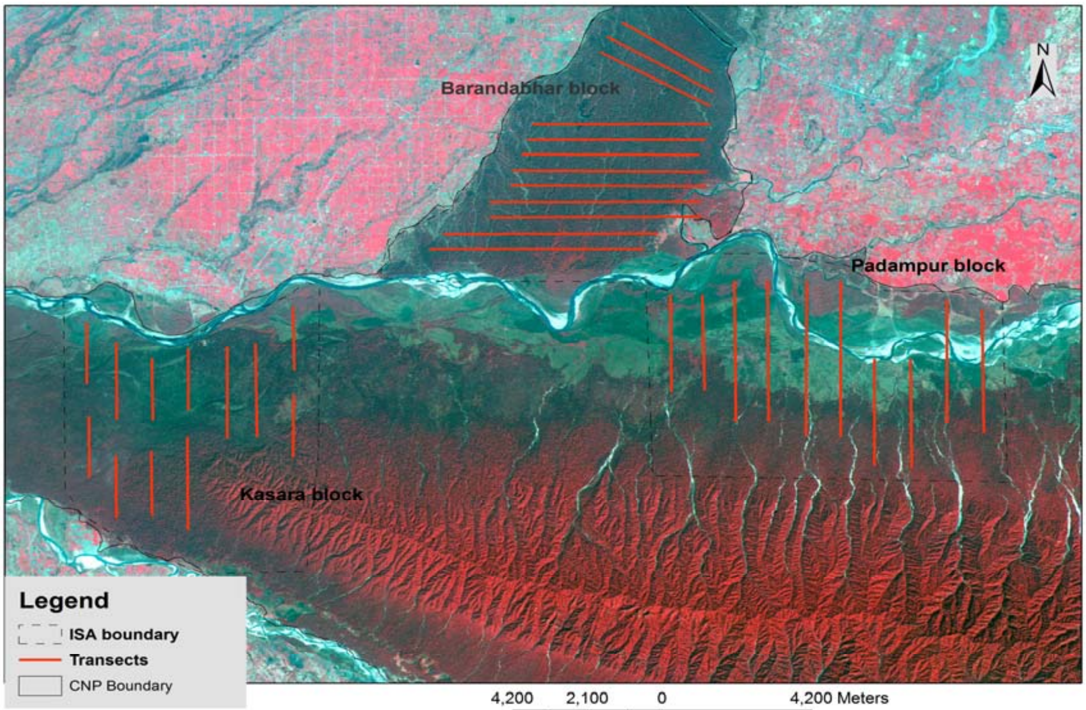


Figure 6.1 Map showing line transects in Chitwan National Park and Buffer Zone, Nepal

6.2.2 Leopard Diet Analysis

Leopard's diet was determined by identifying the prey remains in the scats because scat samples provide more accurate diet information than kill monitoring (Karanth and Sunquist, 1995). Scat analysis is a non- destructive tool in examining the diets of carnivore species (Rabinowitz, 1989; Johnsingh, 1992; Bailey, 1993; Mukherjee *et al.,* 1994; Karanth and Sunquist, 1995; Grassman, 1999; Ramakrishnan *et al*., 1999; Sankar and Johnsingh, 2002; Edgaonkar and Chelam, 2002; Das, 2006; Edgaonkar, 2008; Chauhan, 2008).

6.2.2.1. Scat Collection

The scat samples were collected systematically as well as opportunistically along trail and dirt roads in the CNP and BZ. Scat samples were collected systematically from March through May 2007 and November 2007 through May 2008 (Figure 6.2); and opportunistic collection was made during May- June 2008 from Someshor hill in southern part of BZ and between November 2008 and February 2009 from various parts of the park. Systematic scat collection was done in 27 routes (9 in BZ and 18 in CNP) with a length between 2 to 3 km. Leopard scats were identified from other co-existing carnivore species based on their size, shape and adjacent sign of leopard presence (tracks or scrapes) (Nortan *et al.*, 1986; Rabinowitz, 1989; Edgaonkar and Chellam, 2002). There are three sympatric carnivores in Chitwan; tiger, leopards and dhole. Dhole scats are mostly found in cluster (Johnsingh, 1983) and the dhole is uncommon in most part of the CNP. The leopard scats were distinguished from tiger by associated signs and pugmarks, size and appearance. Leopard scats were more coiled than tiger scats, shorter in distance between successive constrictions.

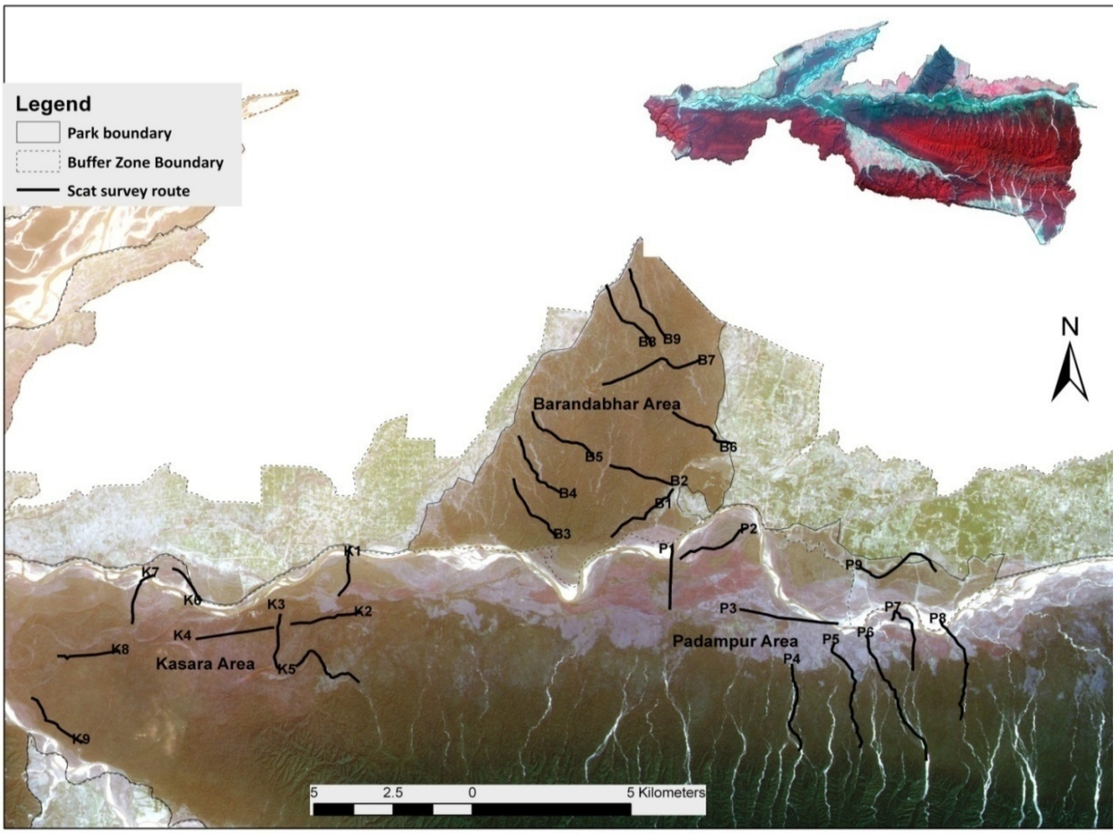


Figure 6.2 Map showing scat collection routes in Chitwan National Park and Buffer Zone.

The location, date, approximate age (fresh- shiny and smelling and old- intact but not smelling), associated marking signs and geographic coordinates were recorded for each scat using handheld Global Positioning System receiver. These samples were sun dried, whenever necessary and preserved in tagged polythene bags and labeled with date, age, place and geographic location; and taken to the laboratory for analysis.

6.2.2.2 Reference Hair Samples

Reference samples of potential wild and domestic prey species were prepared from hair samples of known species, obtained from the Museum of the Central Department of Zoology, Tribhuvan University (TU), Natural History Museum, Tribhuvan University; dead animal from the field; and domestic animals in the buffer zone around the CNP. In order to obtain good quality slides, the hairs were cleaned with water followed by ether-alcohol mixture and dried on blotting paper. Hair profile, cuticular and medullar slides were prepared according to the methodology of Teerink (1991), De Marinis and Asprea (2006) and Bahuguna *et al*. (2010). Hair samples were examined grossly and microscopically with features such as colour, thickness, medullar configuration, and cuticular scale patterns (Brunner and Coman, 1974; Amerasinghe, 1983; Teerink, 1991; Oli, 1993; Mukherjee *et al*., 1994; De Marinis and Asprea, 2006). Hair profiles, cuticular and medullary patterns were studied.

(i) Hair Profile

Cleaned hairs were placed on a glass slide, covered by a cover slip and examined under compound microscope to record features such as root structures, colour and pigments.

(ii) Cuticular Characteristics

The scale patterns of the hair have been studied with microscopy. Saturated gelatin solution was prepared by mixing granular gelatin powder in boiling water and a few grains of methylene blue were added to it to obtain better contrast. A thin layer of gelatin was applied to a slide using a glass rod and gelatin was allowed to cool for about five minutes. Cleaned dry hair was placed side by side and allowed the gelatin to set for about 30 minutes and the hair was removed using forceps. The cuticular pattern left in the gel was then examined under microscope (Olympus) at 400 x magnification with digital camera attached for micro- photography (Annexure 6.1).

(iii) Medullary Patterns

The medulla is comprised of shrunken cells which may or may not contain pigment. Spaces within these cells are filled with air and appear as dark areas under the microscope. Pieces of hair were treated with xylene for about 30 minutes to displace air spaces in the medulla, thus allowing a clear observation of the structure and position of cells. Then the hair samples were mounted in xylene, examined under microscope (400X) and microphotographs were taken (Annexure 6.2).

6.2.2.3. Scat Sample Analysis

Air- dried scats were taken to the laboratory of the Central Department of Zoology, Tribhuvan University. In the lab, all scats were dissected, soaked in warm water, washed through 1- 2 mm fine mesh- sieve and remains such as hairs, bones, hooves, teeth, scales, claws, quills, etc. and were separated for identification of prey eaten by leopards (Grobler and Wilson, 1972; Mukherjee *et al.,* 1994; Henschel and Ray, 2003). Following Mukherjee *et al*. (1994), 20 prey hairs were randomly sampled from each scat, and eight hair per samples was used for cuticular and medullary preparation and remaining 12 hair were used only for profile examination (Bonnin, 2008). Hair was identified by microscopic comparison of the features such as general appearance, color, pigment, length, width, medullary width and cuticular patterns with reference hair (Mukherjee *et al.,* 1994; Bonnin, 2008). Rodents and bird taxa were not identified to species level.

6.2.3. Determination of Sample Size Adequacy

To examine whether the scat sample- size reflected accurately the diet of the leopards, all scats were randomized and the percentage frequency of each prey item in the diet was plotted cumulatively, at an interval of 10 scats. This was continued until all scats were included, and the cumulative frequency of occurrence of different prey species was used to test the effect of sample size on the results. An asymptote of the frequencies of scats was considered sufficient to quantify that prey item in the diet reliably (Mukherjee *et al.,* 1994).

6.2.4 Data Analysis

6.2.5.1 Prey Population Density

Population density was estimated for each prey species using program DISTANCE 6.0 release 2 (Thomas *et al*., 2006). Model selection and degree of truncation was determined separately for each species. The estimated density was used to calculate prey biomass multiplying the species density (D) with its average estimated unit weight (Tamang, 1982; Wegge *et al*., 2009).

6.2.5.2. Occurrence of Prey

Diet data was expressed in terms of both frequency of occurrence (proportion of scats containing each food items) and relative frequency of each food items (number of times a specific item was found) as a percentage of all items identified (Ackerman *et al*., 1984). Prior to calculating of frequency of occurrence, scats containing more than one prey item were given equal values by counting each prey items as ½ (or 0.5), if two species/taxa occurred in one scat, as 1/3 (or 0.33), if three species/taxa occurred, and so on (Karanth and Sunquist, 1995). Frequency of different prey species in leopard scats were analyzed separately for summer and winter seasons.

6.2.5.3 Estimation of Prey Biomass and Numbers

Although frequency of occurrence has been widely used to quantify carnivore diet, this measure can overestimate the presence of small sized prey (Ackerman *et al*., 1984) and underestimate the presence of large sized mammalian prey (Weaver, 1993). Smaller sized prey species with more hair per unit body mass produces more scats per unit prey weight consumed and are overestimated in carnivore diets (Floyd *et al*., 1978; Ackerman *et al*., 1984). To minimize biases, I estimated relative proportions of biomass consumed by leopard using the correction factor: $\mathbf{Y = 1.98 + 0.035\ X}$ developed by Ackerman *et al.* (1984) from feeding trails on cougar *Felis concolar concolar* L., where y is the weight (in kg) of the prey consumed per scat and X is the average live weight of the prey. Prey live weight estimates were based on published references (Seidensticker, 1976a; Dinerstein, 1980; Tamang, 1982; Karanth and Sunquist, 1995). Estimates of Y is the biomass consumed per collectible scat for a prey species.

The relative biomass of each prey species was calculated separately for: (i) CNP and prey rich area in the BZ (Barandabhar), (ii) prey poor area in the BZ (Someshor hill), and (iii) overall study area by multiplying the value of Y for each prey type. Prey rich and prey poor habitat has been categorized on the basis of our prey survey data and previous research on the relative prey base estimation (Gurung *et. al*., 2006; 2007).

6.2.5.4 Prey Selection

The observed frequency of prey items in scats was compared to expected values derived from their density estimates to test the hypothesis of nonselective predation of leopard (Manly *et al*., 1972). In case of no selectivity, prey species is expected to be taken by predator at the rate equal to the relative frequency of its availability. Any statistically significant deviation, whether positive or negative, would indicate preference or avoidance of that prey type (Edgaonkar, 2008). The expected proportion of scats from a kill of a particular prey species was computed using multinomial likelihood estimator equation (Link and Karanth, 1994).

$$\prod_i = d_i \lambda i / \sum_i d_i \lambda i$$

Where prey species i has population density di, and λi (λi= X_i/Y_i derived from Ackerman's equation) is the average number of field collectable scats produced by predator species from a single kill of species i.

Prey selection was determined by comparing the Πi to the observed proportion based on samples of predator scats in the program SCATMAN v2.0 (Hines, 2002). Inputs of the program are estimated values of d_i and λ_i, and variation associated with these parameters. SCATMAN uses a $\chi 2$ goodness-of-fit test to test the null hypothesis of zero prey selection (Manly et al., 1972; Chesson, 1978) and adds a parametric bootstrap to correct for over dispersion (Link and Karanth, 1994). Estimated group density of prey species was used to determine expected scat frequencies (Karanth and Sunquist, 1995). One thousand bootstrap replications were performed and the coefficient of variation in scat production rates was set at 40% of the mean level (Hines, 2002). Five major prey species namely; chital, sambar, hog deer, barking deer and wild pig were included in selectivity estimation.

6.3. RESULTS

6.3.1. Prey Availability

Prey species recorded on 530 km survey during summer 2008 were chital (*Axis axis*), barking deer (*Munticus muntjac*), hog deer (*Axis porcinus*), sambar (*Rusa unicolor*), wild pig (*Sus scrofa*), gaur (*Bos gaurus*), macaque (*Macaca mulatta*) and langur (*Semnopithecus hector*) in the Chitwan National Park and Barandabhar Corridor Forest in buffer zone. Preliminary analysis revealed that the detection frequencies of gaur, Rhesus macaque and langur were below the minimum of 40 detections recommended for analysis in the DISTANCE (Burnham *et al*., 1980; Buckland *et al*., 1993), hence density and group density, and also biomass was estimated only for chital, sambar, hog deer, barking deer and wild pig. CNP and BCF harbor high density of (110.31 individual km^{-2}) of wild ungulate prey species (Table 6.1). Among the ungulates, chital was most abundant followed by wild pig, hog deer, sambar and barking deer.

Table 6.1 Density and biomass estimates of major prey species during summer 2008 in the northern part of the Chitwan National Park and Buffer Zone, Nepal.

Species	n	Mean group	Group			Individuals			Biomass (kg km^{-2})
			D_G (SE)	CV (%) D_G	95 % CI	D_I (SE)	CV (%) D_I	95 % CI	
Chital	327	10.36	7.96 (0.92)	11.67	6.30-10.05	92.75 (12.68)	13.68	70.80-121.51	5008.5
Sambar	110	2.1	2.22 (0.31)	14.04	1.68-2.94	4.81 (0.73)	15.17	3.56-6.50	952.38
Hog deer	76	2.35	2.28 (0.65)	28.77	1.29-4.03	5.10 (1.51)	29.73	2.84-9.17	168.3
Barking deer	120	1.27	3.33 (0.40)	12.02	2.63-4.22	4.39 (0.54)	12.39	3.44-5.60	74.63
Wild pig	98	3.04	2.87 (0.51)	17.78	2.02-4.07	9.07 (1.84)	20.38	6.09-13.50	408.15
All prey	**720**	**5.80**	**19.76 (1.63)**	**8.27**	**16.78-23.27**	**110.31 (10.66)**	**9.66**	**91.23-133.38**	**6611.96**

n: number of groups observed, D_G: density of groups (number of groups km^{-2}); D_I: Density of individuals (number of animal km^{-2}); CV: coefficient of variation of density of groups (D_G) and density of individuals (D_I), SE: standard errors; 95% CI: confidence intervals of density estimates of groups and individuals.

6.3.2. Diet Analysis

A total 351 prey items (mean per scat 1.34 ± 0.54 SD) were identified from of 263 scats of leopard collected from the CNP and BZ between March 2007 and February 2009. A minimum of 15 different prey taxa were consumed by leopards. Species level identification for 7 items of avian prey and 19 items of rodent prey was not possible and these items have therefore been grouped as bird spp and rodent spp respectively, therefore the total number of prey species is likely to be higher. Nearly 73% of total scats had a single prey item, 23.57% had two and 3.42% had three items per fecal sample. Scat analysis revealed that 78.57% of leopard diet constitutes wild ungulates, 3.55% primates, 6.21% birds and rodents and 11.67% livestock and dogs (Table 6.2). At the species level, chital comprised 46.13% of the relative frequency of occurrence, but detected in 59% of all scats.

Table 6.2 Composition of leopard diet in the Chitwan National Park and Buffer Zone, Nepal

Prey	Entire year		Summer	Winter
	Count (n= 351)	Relative frequency of occurrence (%) (n= 263)	Relative frequency of occurrence (%) (n= 135	Relative frequency of occurrence (%) (n= 128)
Chital	155	46.13	42.84	49.62
Sambar	34	11.28	10.99	11.59
Hog deer	16	5.07	4.44	5.73
Gaur	12	3.23	4.44	1.95
Barking deer	16	5.32	4.70	5.99
Wild pig	30	7.54	7.65	7.42
Macaque	8	1.71	2.22	1.17
Langur	7	1.84	2.98	0.65
Rodent	19	4.62	4.44	4.81
Bird	7	1.59	2.10	1.04
Goats	26	5.83	5.67	5.99
Sheep	4	1.52	1.86	1.17
Cattle	8	2.03	2.84	1.17
Buffalo	2	0.83	0.98	0.65
Dog	7	1.46	1.85	1.05
Total	**351**	**100**	**100**	**100**

6.3.2.1. Seasonality in Leopard Diet

I identified 184 prey items (mean per scat: 1.36 ± 0.54 SD, N = 135) from 15 taxa for summer season and a total of 168 different prey items (mean 1.31 ± 0.53, N = 128) from 14 taxa for winter season. Chital was most abundant prey both summer and winter diets of leopard, and sambar and wild pig are other important among the wild ungulates (Figure 6.3). Remains of chital were higher in the scats collected during winter where as the occurrence of both species of monkeys and gaur was higher during summer season than winter (Table 6.2).

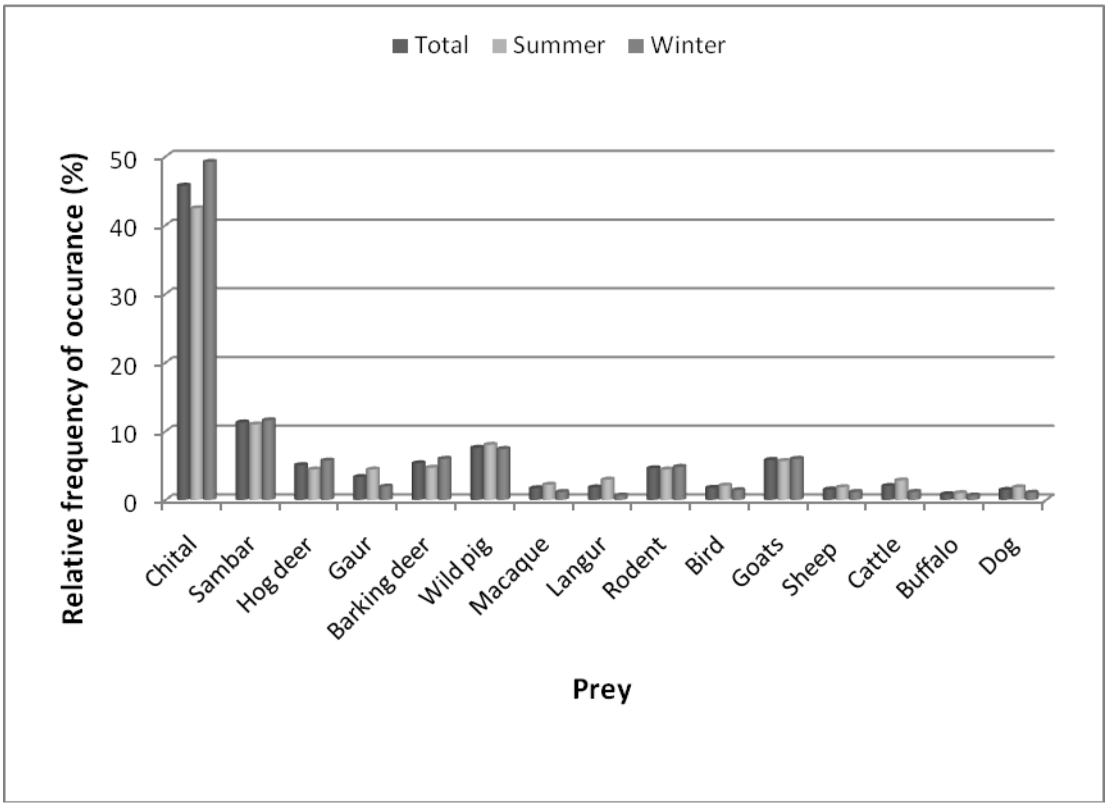
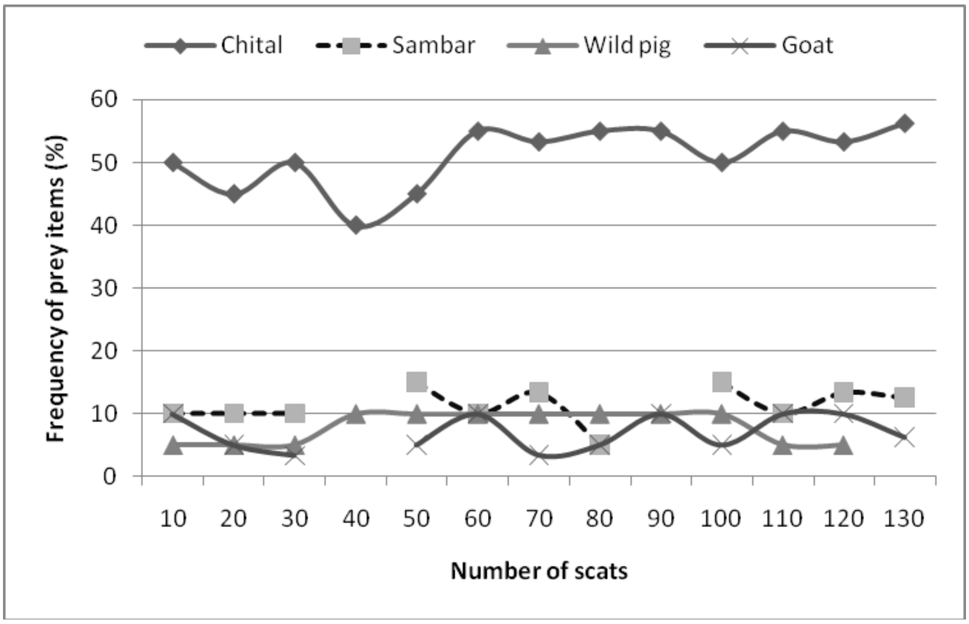


Figure 6.3 Overall and seasonal comparison of prey remains (frequency occurrence) in leopard scats.

6.3.2.2. Sample Size Needed for Diet Estimation

After successive draws of ten scats from the total scat samples, the proportions of four major prey species (chital, sambar, wild pig and goat) in scats tends to stabilize at 60 scat and 50 scat samples during winter and summer season respectively (Figure 6.4).

a)



b)

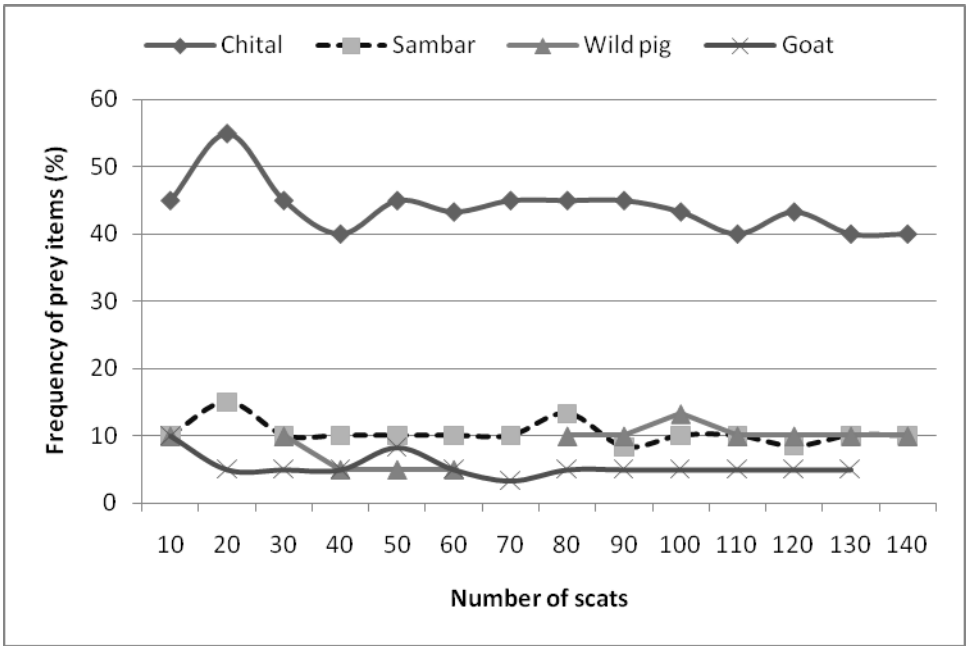


Figure 6.4 Effect of sample size on the frequency of occurrence of most important prey species in winter (a) and summer (b) season in scats of leopard in Chitwan National Park and buffer zone, Nepal

All the prey species in leopard diet were identified after analysis of 50 scat samples in winter diet and 60 samples in summer diet (Figure 6.5).

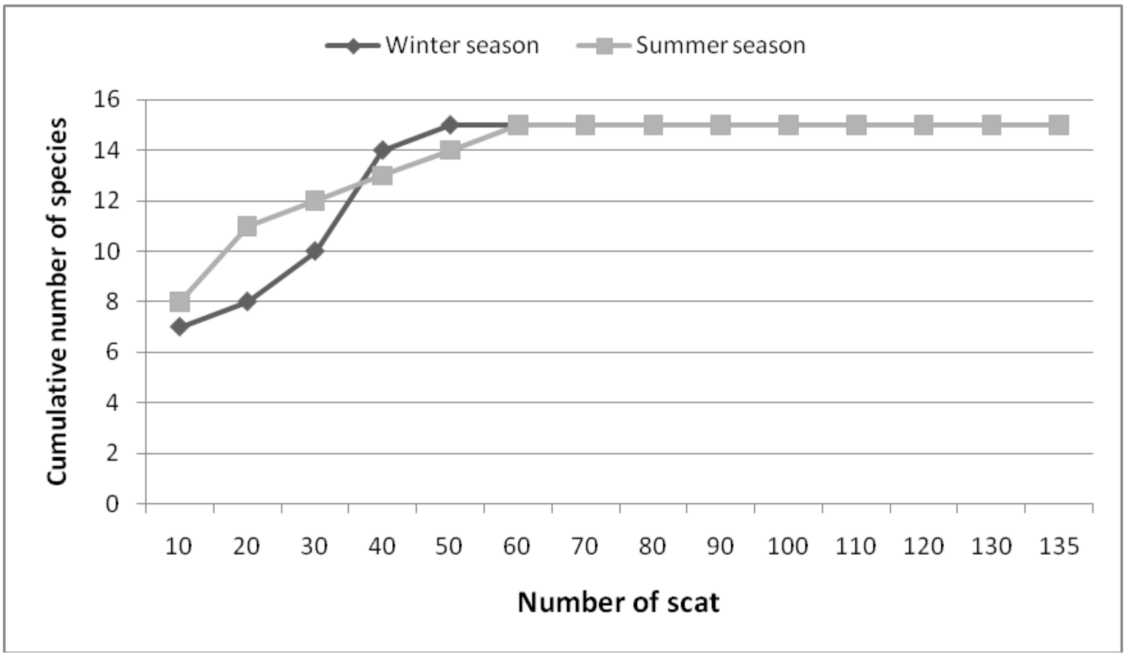


Figure 6.5 Relationship between number of scat analyzed and number of prey species found in leopard diet.

6.3.2.3. Body Size Classes of Leopard Prey Species

Wild prey species found in the leopard scats were categorized on the basis of body mass into large (sambar and gaur), medium (chital, hog deer, barking deer and wild pig), small (bird spp and rodent spp). Likewise domestic prey species were also classified into large (cattle and buffalo) and small (goat, sheep and dog). Significant proportion (64.06%) of leopard diet consists of medium wild prey species followed by large wild, small wild and small domestic prey species. Relative frequency of occurrence of medium sized wild prey was slightly lower in summer diets (61.83%) than winter (64.28%), the lower contribution of medium sized wild prey was compensated by large wild, small wild and domestic animals during summer season (Figure 6.6).

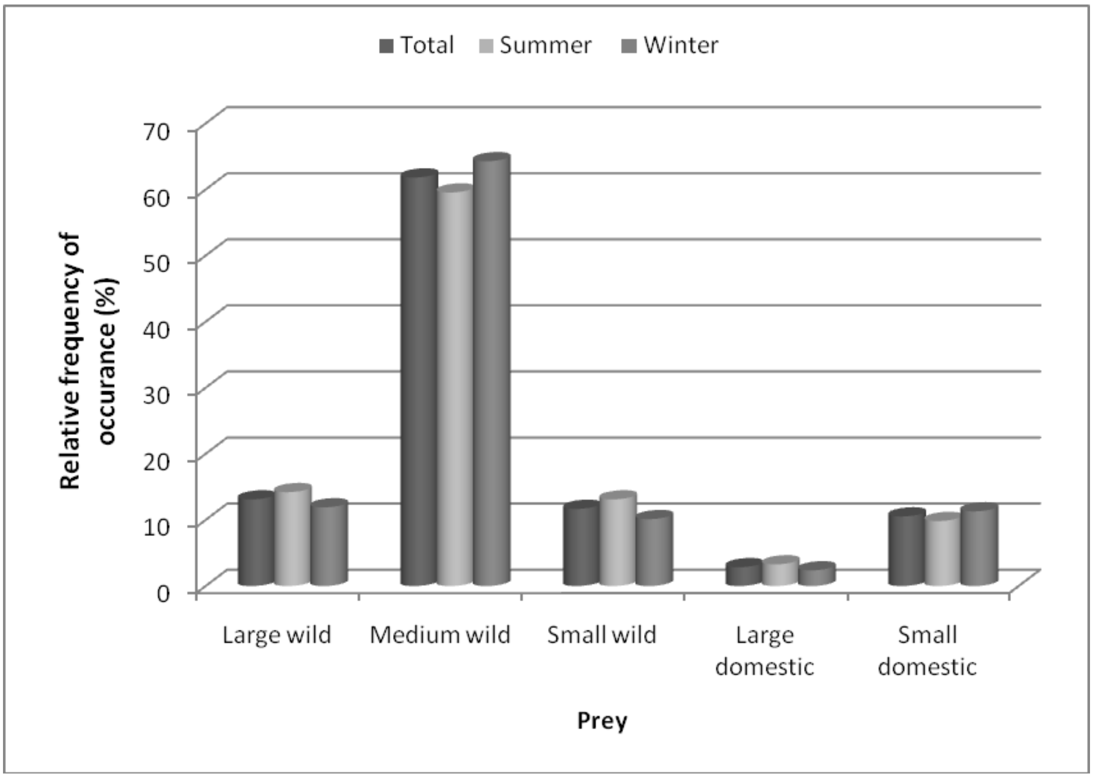


Figure 6.6 Body size categories of the prey remains in the leopard scats

6.3.2.4. Relative Biomass Consumption

Estimated biomass contribution of different prey species to the diets of leopard using the equation developed by Ackerman et al., (1984) gave better evaluation of the of prey contribution in diet. In terms of relative biomass contribution, chital is the single most important species that contribute 49.50% of total biomass consumed by leopard in Chitwan National Park and Buffer Zone (Table 6.3). Chital is followed by sambar and wild pig relative biomass of 13.75% and 7.24% respectively.

Biomass assessment from the fecal remains of leopard in Chitwan clearly revealed that the leopard diet mainly consist of medium sized prey (Table 5.3). In terms of frequency of occurrence, wild ungulates contributed 78.57% of leopard diet but biomass contribution was 84%. Biomass contribution of domestic prey was 12.70% of total biomass consumed by the leopard.

Table 6.3. Estimation of relative biomass and relative number of prey individuals consumed by leopard population in Chitwan National Park and Buffer Zone (n= 263), Nepal

Prey species	No. of scats containing prey Species	Corrected frequency of occurrence (%) (A)	Body weight (kg) (B)	Correction factor (kg/scat) (C)	Relative biomass consumed (%)[a] (D)	Relative number of individuals consumed (%)[b] (E)
Chital	155	46.13	48	3.66	49.50	23.57
Sambar	34	11.28	62	4.15	13.75	5.06
Hog deer	16	5.07	33	3.14	4.66	3.23
Gaur	12	3.23	85	4.96	4.69	1.26
Barking deer	16	5.32	20	2.68	4.18	4.78
Wild pig	30	7.54	37	3.28	7.24	4.47
Macaque	8	1.71	6	2.19	1.10	4.18
Langur	7	1.84	8	2.26	1.22	3.48
Rodents	19	4.62	0.1[1]	1.98	0.13	30.95
Birds	7	1.59	1.8[1]	2.04	0.84	10.65
Goat	26	5.83	26	2.89	4.94	4.34
Sheep	4	1.52	27	2.93	1.32	1.10
Cattle	8	2.03	120	6.18	3.68	0.70
Buffalo	2	0.83	150	7.23	1.76	0.27
Dog	7	1.46	12	2.40	1.02	1.96

[a]D = (A × C) / ∑ (A × C)

[b]E = (D ÷ B) / ∑ (D ÷ B)

[1]No correction factor, see text

6.3.2.5. Diet Composition of Leopard in Different Habitat

At least 14 and 13 different prey species were identified from CNP; and buffer zone area respectively. The diet composition of leopards was presented separately for national park, prey rich habitat in the buffer zone (Barandabhar Corridor Forest) and prey poor habitat (Someshor hill). I found similar diet composition between NP and prey rich habitat in the buffer zone, but it was very different in the prey poor habitat (Figure 6.7). Chital contributed significant proportion (over 52%) of biomass in CNP and prey rich habitat in BZ, while in prey poor habitat its contribution was 14.32% of total diet. In prey poor habitat livestock, primates, birds and rodents contributed 50.78% of leopard diet against 11.67% in the CNP.

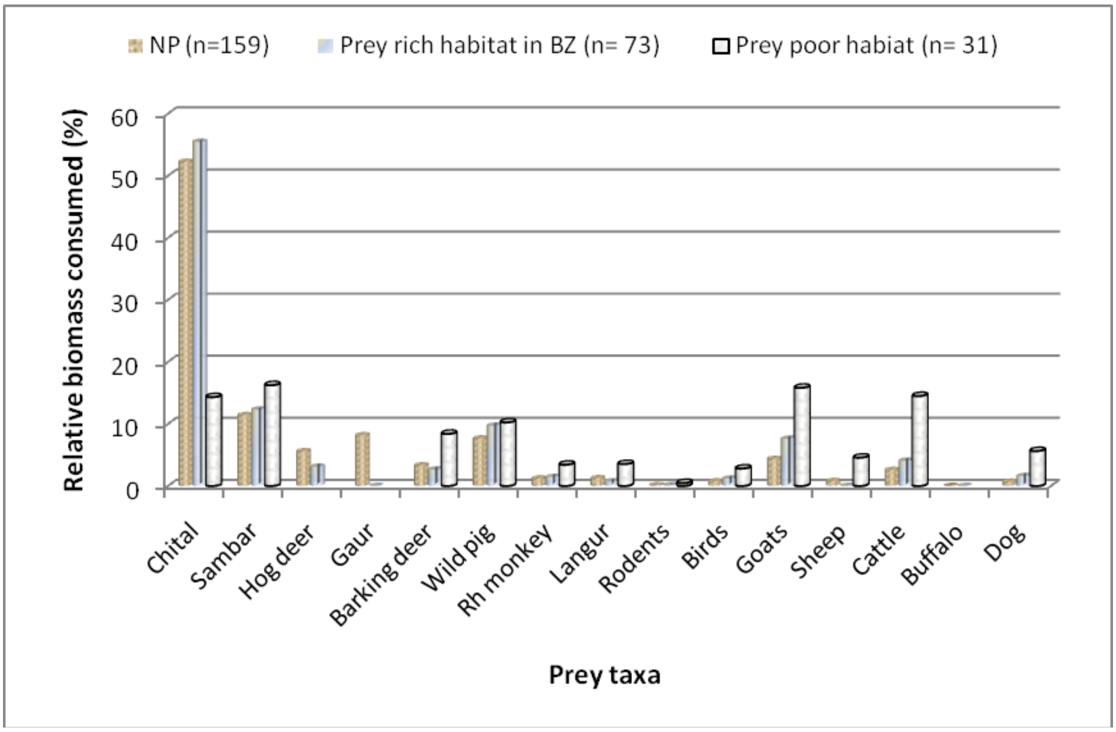


Figure 6.7 Percent contribution of prey biomass by prey species/taxa in leopard diets in different habitats of Chitwan National park and buffer zone.

6.3.2.6. Prey Selection

Prey selectivity in leopard diet was evaluated using group density of prey species in bootstrap simulation in program SCATMAN. Multinomial likelihood ratio test confirmed non- random predation by leopard ($\chi 2$ = 20.66, dF = 4, P< 0.001). Selectivity estimates using group density revealed that the leopard consumed chital in greater proportion (P= 0.209) than availability, and hog deer (P= 0.36), barking deer (P= 0.44) and wild pig (P= 0.46) were taken less than expected and consumption of sambar was in proportion to its availability (Table 6.4).

Table 6.4 Results of prey preference analysis using program SCATMAN. Adjusted *P*-value based on *B* =1000 bootreps to correct for over dispersion.

	Prey species				
	Chital	Sambar	Hog deer	Barking deer	Wild pig
Frequency of occurrence	121.0	29.67	13.33	14.0	19.83
Expected	92.15	29.28	25.82	21.93	28.63
$\chi 2$	16.91	0.006	6.95	3.22	3.16
Adjusted *P*- value	0.24	0.97	0.32	0.46	0.51
SE	0.01	0.0007	0.01	0.01	0.01
λ_i	13.12	14.94	10.52	7.46	11.30
D_G	7.96	2.22	2.28	3.33	2.87
SE (D_G)	0.92	0.31	0.65	0.4	0.51

6.4. DISCUSSION

6.4.1 Prey Abundance

Estimated density of overall wild prey species (110.31 ± 10.66 km^{-2}) in northern part of Chitwan National Park and Buffer Zone was among the highest across the protected areas in Terai (Seidenstiker, 1976b; Dinerstein, 1979; Tamang, 1982; Harihar, 2005; Wegge *et al*., 2009; Malla, 2009) where as chital is dominating prey species (92.75 ± 12.68 km^{-2}).

6.4.2. Diet Composition

The prey spectrum of leopards in and around Chitwan National Park, had a minimum of 15 taxa including at least 10 wild and 5 domestic species, and is found to be as diverse as other areas in Nepal (Eliassen, 2003, Wegge *et al*., 2009; Aryal and Kreigenhofer, 2009) and south Asia (Karanth and Sunquist, 1995; Sankar and Johnsingh 2002; Edgaonkar and Chellam, 2002; Ramakrishanan, *et al*., 1999; Edgaonkar, 2008; Wang and Macdonald, 2009b). Previous studies revealed that the wild prey diversity in the leopard diet in south Asian forest ranged from 4 taxa (Johnsingh, 1983) to 11 taxa (Karanth and Sunquist, 1995; Edgaonkar and Chellam, 2002). Relatively high diversity of domestic prey species (n= 6) was reported from

Bhutan (Wang and Macdonald, 2009b). High prey diversity in the leopard diet in this study could be attributed to the coverage of diverse habitats with different level of prey availability (Bhuju *et al*. 2007, Gurung *et al*. 2007). Owing to the opportunistic hunting of the leopard, the total number of prey species recorded depends very much on sample size (Bodendorfer *et al*., 2006). In general, number of prey species reported in leopard scats from south Asia was lower than that reported from south East Asia (eg 23 sp- Rabinowitz, 1989) and African tropical forest (eg. 32 sp- Hope-Dominic, 1984; 37 sp- Hart *et al*., 1996; 25 sp.- Ososky, 1998; 30 sp- Henschel *et al*., 2005). The most diverse prey in leopard diet (37 species) was recorded so far in literature from Comte- National Park, West Africa (Bodendorfer *et al*., 2006).

Low seasonal differences in the leopard diet in Chitwan can be explained by the non migratory pattern of major prey species except gaur. The gaur migrated from Churia hills to lower elevation during summer in search of water and forage as river and streams in the hills dried up; the pattern was reflected in the leopard scats that mostly collected from lower elevations. There was a gap in scat collection from the remote Churia hills of CNP during this study to make conclusive evidence for seasonal differences of contribution of gaur in leopard diets.

In consistence with previous research (Mukherjee *et al*., 1994; Henschel *et al*., 2005; Wang and Macdonald, 2009b), the leopard scats in my study mostly contained one (73%), occasionally two (24%) and rarely three (3%) items; consequently the two measures, the frequency of occurrence and relative occurrence, did not differ considerably.

The wild ungulates comprised the bulk of prey biomass (84%) in leopard diet in Chitwan (Table 6.4) as elsewhere in the protected areas of Nepal (Eliassen, 2003; Wegge *et al*., 2009) and India (Karanth and Sunquist, 1995; Ramakrishnan *et al.*, 1999; Andharia *et al*., 2007; Edgaonkar, 2008, Harihar *et al*., 2010).

My result clearly revealed that the medium-sized wild ungulate prey species (chital, hog deer, barking deer and wild pig) comprised < 70% of the prey biomass of leopards where as the chital biomass (49.98%) contribution was most important. Other studies from Nepal (Eliassen, 2003, Wegge *et al*., 2009) and India (Johnsingh, 1983; Karanth and Sunquist, 1995; Ramakrishnan *et al*., 1999; Sankar and Johnsingh, 2002; Andheria *et al*., 2007) also showed that chital was the most important wild prey species for leopard. Preference of chital by leopard is probably related to their ideal size and grouping tendency (Bailey, 1993). Usually leopards prefer to predate on medium sized prey species between 10 and 40 kg (Santiapillai *et al.*, 1982; Johnsingh, 1983; Bailey, 1993). Body size of chital (25- 50 kg) is similar to the prominent leopard prey species in other areas, namely tufted deer weighing 20- 35 kg (Kenneth, 1993), Thomson's gazelle (*Gazella thompsoni*), southern reedbuck (*Redunca arundinum*), and impala (*Aepyceros melamus*) weighing 20- 70 kg (Kuruuk and Turner, 1967; Schaller, 1972) and wild goat (*Capra aegargus*) weighing 24- 42 kg (Macdonald, 1985; Schaller, 1967). Hayward *et al.* (2006) while reviewing 33 research papers found that the leopard preferred prey species mostly weight between 10 to 40 kg, with 25 kg most preferred.

Other medium sized ungulate species viz hog deer, barking deer and wild pig respectively contributed 4.6%, 4.2% and 7.2% of biomass intake of leopards in Chitwan. The lower densities (Table 6.1) of these species possibly explaining their occurrence in the leopard scat. Hog deer's contribution for Chitwan leopard diet was much higher than for Bardia leopard where its contribution was slightly more than 1% (Eliassen, 2003, and Wegge *et al*., 2009). If we limit our effort only in areas where hog deer occurs, we can expect much higher contribution to predator diet because of its solitary habit and ideal size for predation by leopard. Reported contribution of barking deer in leopard diet ranged from 0.5% in Pauri Garhwal (Chauhan, 2008) to 21.6% in Rajaji NP (Harihar *et al*., 2010). However, wild pig's contribution to the diet of leopard in Bardia (~10%, Eliassen, 2003; Wegge *et al*., 2009) and Dhorpatan Hunting Reserve (14.63%, Aryal and Kreigenhofer, 2009) was significant, but studies in India indicated that the wild pig constitute <5% of leopard diet (Johnsingh, 1983, Karantha and Sunquist, 1995; Ramakrishnan *et al*., 1999; Karanth and Sunquist, 2000; Sankar and Johnsingh, 2002; Edgaonkar and Chellam, 2002; Edgaonkar, 2008) except Bandipur (8.4%, Andharia *et al*., 2007). Common argument for lower contribution of wild pig in leopard diet was its aggressive and retaliatory behavior which can cause serious injury to the predator. Eisenberg and Lockhart (1972) also suggested that wild pigs were too aggressive and dangerous to be tackled by leopards in Sri Lanka (also see, Ramakrishnan *et al*., 1999)

Sambar is second most important prey species of leopard in Chitwan as indicated in the frequency of occurrence (11.28%) in diet (Table 6.2). The reported contribution of Sambar in the leopard diet in terms of frequency of occurrence ranged 6.11% in Bandipur (Andheria *et al*., 2007) to 52.8 in Satpura Tiger Reserve (Edgaonkar, 2008) (see Table 5.6) and Sambar is generally considered as preferred prey species of leopard (Johnsingh, 1983; Ramakrishnan *et al*., 1999; Sankar and Johnsingh, 2002). The proportion of large ungulates (gaur) in leopard diet was considerably lower (3.23%) in my study as compared to the reports from Nagarhole (7.3%, Karanth and Sunquist, 1995) and Bandipur (9.56%, Andharia *et al*. 2007).

Chital, sambar, barking deer and wild pigs has significant contribution to leopard diet in Chitwan. Review of research reports revealed that among the study areas where all of these four species coexist chital has the highest frequency of occurrence except Satpura Tiger Reserve where sambar is a major prey species. The study clearly revealed that the chital and any one of three species comprise bulk of leopard diet in terms of frequency of occurrences (Table 6.5).

In Chitwan NP and prey rich habitat in the BZ, primates and rodents, and domestic preys were less important as their contribution was only 11.67% of biomass, but their contribution was significant (50.78%) in the prey poor habitat. The ratio of relative abundance of wild prey species in prey poor and prey rich habitat was estimated to be 1: 6.1 (Gurung *et al*., 2006; 2007), hence due to lack of suitable prey species like chital, leopard switched to sub optimal prey (rodents and birds) and secondary prey (livestock). Report on the remains of *Macaca* sp in leopard scat was not common in areas where medium sized prey species were abundant (Seidensticker, 1983; Edgaonkar and Chellam, 2002), but significant proportion of primates, rodents and other mammals, and birds were reported from Sariska (59.8%, Sankar and Johnsingh, 2002), Mudanthurai (42.28%, Ramakrishnan *et al*., 1999), Sanjay Gandhi National Park (37.5%, Edgaonkar and Chellam, 2002) and Dachigam (26.4%, Shah *et al*., 2009). Remains of wild ungulates in these study areas were about or less than 40% of frequency of occurrence in leopard diet, in comparison to 78.57% in Chitwan and 76.5% in Nagarhole. Leopards are known to predate on sub optimal prey species whenever medium sized wild ungulate prey species are scarce (Bothma and LeRiche, 1986; Ramakrishnan *et al*., 1999).

Table 6.5 Frequency of occurrence of major prey species in leopard *Panthera pardus* diets reported in studies from Nepal, India and Bhutan

Species	Chitwan[1]	Bardia (I)[2]	Bardia (I)[3]	Naga-rhole[4]	Bandipur (I)[5]	Bandipur (II)[6]	Sariska[7]	Mudu-malai[8]	Mudan-thurai[8]	SGNP[9]	STR[10]	PG[11]	JSW NP[12]	DHR[13]	Dachi-gam[14]	Rajaji 2005/06[15]	Rajaji 2007/08[15]
No of scats	263	103	95.	535		111	125	185	111	90	-	428	113	147	96	44	22
Chital	46.13	44.7	46.7	43.7	51	45.8	20.8	67.22	24.32	9.1#	20.2	-	-	-	-	45.3	13.5
Sambar	11.28	-	-	13.5	14	6.11	20	11.66	9		52.8	-	16.8	-	-	37.7	27
Hog deer	5.07	1.3	1.1	-	-	-	-	-	-		-	-	-	-	-	-	-
Gaur	3.23	-	-	7.3	-	9.56	-	0.56	-	-	-	-	-	-	-	-	-
Barking deer	5.32	-	-	7.5	-	1.53	-	2.23	8.33		-	0.7	8.8	17.7	-	3.8	21.6
Barasingha	-	2.6	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wild pig	7.54	10.5	10.0	4.5	-	8.4	-	1.11	3.7	-	2.1	0.5	5.3	14.63	-	-	-
Primates	3.55	9.2	9.0	7.1	10.0	9.16	6.4	2.79	10.17	11.4	10.9	-	4.4	3.71	21	3.8	13.5
Rodents	4.62	10.5	-	-	0.0	9.16	45.6	1.67	7.41	26.1	3.1	4.9	-	-	15.7	-	-
Other small mammals	-	-	*	9.7	11.2	8.4	2.4	3.91	24.07	-	8.8	-	-	9.76	-	3.8	2.7
Birds	1.59	4.0	*	-	-	-	4.8	-	-		3.6	-	-	2.55	0.8	-	-
Livestock	10.21	17.1	21	-	6.0	2.29	-	6.14	8.33	14.8	1.6	57.9	41.6	4.52	18.3	5.7	21.8
Dog	1.46	-	-	-	-	-	-	2.79	6.48	63.7	-	48	2.7	-	21	-	-
*others	-	-	11.0[1]	-	-	-	7.2[2]	-	-	5.7	-	-	8[3]	24.71[4]	19.2[5]	-	-

Others= [1] Small mammal and birds; [2] Nilgai; [3] Goral; [4] Goral (2.35%), Blue ship (5.99%), Serrow (8.03%), Himalayan tahr (1.16%) and Musk deer (7.18); and [5] Serrow (0.8%) and Hangul (18.4%).

Source: [1] present study; [2] Eliassen (2003); [3] Wegge *et al*. (2009); [4] Karanth and Sunquist (1995); [5] Johnsingh (1983); [6] Andharia *et al*. (2007); [7] Sankar and Johnsingh (2002), [8] Ramakrishnan *et al*. (1999); [9] Edgaonkar and Chellam (2002); [10] Edgaonkar (2008); [11] Chauhan (2008); [12] Wang and Macdonald (2009b), [13] Aryal and Kreigenhofer (2009); [14] Shah *et al*. (2009); [15] Harihar *et al.*, (2010).

Remains of livestock in leopard scats in fringe area would have been more likely since leopards are frequently found near human settlement (MacDougal, 1988; Seidensticker *et al*., 1990; Eliassen, 2003), and Chitwan National Park hold good population of tiger which likely displace leopard from prime habitat to fringe area where they encounter with livestock.

Abundance of principal prey species determines the prey choice of predators (Bailey, 1993; Bothma and Coertze, 2004; Khan, 2004). Carnivores are likely switched to secondary or sub optimal prey when the primary prey species is scarce (Hamilton, 1981; Seidensticker *et al*., 1990; Santiapillai and Ramono, 1992; Bailey, 1993). Switching of leopard to secondary prey (livestock and dog) was documented by Edgaonkar and Chellam (2002), Chauhan (2008) and Shah *et al*. (2009) in areas where primary prey species were scarce. In Chitwan leopard predation on domestic prey was not the result of scarcity of prey but its preference to fringe habitat and interference competition (Odden and Wegge, 2010) with much superior predator the tiger.

6.4.3 Prey selection

Results of prey selectivity analysis using Program SCATMAN revealed that leopard's predation on chital were greater in proportion than availability and sambar in accordance to its availability. Contrary to expectation, the barking deer, hog deer and wild pig were not selected. Selection for chital by leopard in this study indicates selection for the most abundant prey species, in contrast to the study in Bardia, where both tiger and leopard were not selective to the most abundant prey (Elliassen, 2003; Wegge *et al*., 2009). Reported studies indicates that where chital was a major part of the leopard diet, the chital densities were quite high as compared to sambar density (Johnsingh, 1983; Karanth and Sunquist, 1995, Andheria et al., 2007). Bailey (1993) also made similar observation in Kruger National Park that impala was the most abundant ungulate species as well as in the diet of leopard. Wegge *et al*. (2009) found in Bardia that the consumption of hog deer and barking deer by leopard was less frequent than expected and wild pig was much higher. Leopard in Chitwan found to be avoided prey species of low density (barking deer) and having limited distribution (hog deer). Prey selectivity in carnivores is a function of prey size (Karanth and

Sunquist, 1995; Hayward *et al*., 2006a; 2006b) and based on foraging theory (Stephens and Krebs, 1986), which states that the most profitable prey is that measured by the ratio of energy gain to prey- handling time. Leopard prefers to catch prey species weighing between 10 and 50 kg (Hayward *et al*., 2006a). Among the prey species selected by leopard in Chitwan, chital would appear to be the most profitable prey species with respect to energy gain to prey handling time.

The number of prey species eaten by leopard in Chitwan is comparable to the mean mammalian prey species eaten by leopard, and much higher than the average 8 different prey species reported by tiger irrespective of environment (Sunquist and Sunquist, 2002). The higher plasticity in the diet is one of the reasons that leopards can survive in areas from which tigers are disappearing.

Diet composition varied from the three different sites of the study area. This indicates plasticity in the diet of leopards in the study area. The diet studies of leopard based on the collection of scats during short- term surveys from localized areas may not be representative of the entire study area and the selection of prey species by predator depends on the density and distribution patterns. In order to accurately estimate diet, a long-term monitoring to see seasonal difference and wide coverage of area are necessary.

Chapter 7

HUMAN - LARGE FELID CONFLICTS AROUND CHITWAN NATIONAL PARK: PATTERNS AND PERCEPTIONS ON LIVESTOCK DEPREDATION

7.1 INTRODUCTIONM

Large cats are declining globally; the conflict with human is a major challenge in their conservation across their range (Nowell and Jackson, 1996). Human population growth and associated increase in rates of resources use, habitat modification and fragmentation is forcing wild animals to live in increasing proximity to humans (Inskip and Zimmerman, 2009). In such circumstances, competition between carnivores and people is inevitable for space and food resources, often leading to severe conflicts. Human- carnivore conflicts most commonly involve killing of livestock, occasionally involve attacks on human and animal persecution in retaliation (Saberwal *et al*., 1994; Nowell and Jackson 1996; McDougal, 1999, Woodroffe, 2000; Treves and Karanth, 2003; Gurung *et al*., 2008, Thapa, 2009).

In particular, large cats are predisposed to conflicts with human because of their large home range and dietary requirements that often overlap with people (Linnell *et al*., 2001; Macdonald and Sillero-Zubiri, 2002). Human-carnivore conflict appears to be increasing in frequency in many areas (Treves and Karanth, 2003), presenting a significant threat to wild felids (Inskip and Zimmerman, 2009). The conflict between large cat and people can be the most serious cause of carnivore mortality in human dominated areas (Arthreya *et al*., 2004; Goyal *et al*., 2007) as well as in and around protected areas (Gurung *et al*., 2008; Blame *et al*., 2010). Livestock depredation is the greatest source of conflict with humans as well as major underlying cause for the disappearance of large cats from considerable areas of their former range (*e.g*. tiger *Panthera tigris* from most parts of China, Nowell and Jackson, 1996).

All species of large cats are reported to kill livestock across the world. Livestock depredation by tigers (*Panthra tigris*), lions (*Panthera leo*), leopards (*Panthera pardus*) and snow leopards (*Uncia uncia*) in Asia (Chakrabarti, 1992; Chellam and Johnsingh, 1993; Oli *et al*., 1994; Jackson and Wangchuk, 2001; Mukherjee and

Mishra, 2001; Karanth and Madhusudan, 2002; Mukherjee, 2003; Arthreya *et al*. 2004; Wang and Macdonald, 2006; Goyal *et al*., 2007; Tamang and Baral, 2008; Sangay and Vernes, 2008; Bhattarai, 2009; Dar *et al*., 2009), lions (*Panthera leo*), cheetahs (*Acinonyx jubatus*), leopards (*Panthera pardus*) in Africa (Patterson *et al*., 2004; Woodroffe *et al*., 2005; Kolowski and Holekamp, 2006; Holmern *et al*. 2007) and jaguar (*Panthra onca*) and puma (*Puma concolor*) in Neotropical countries (eg. Rabinowitz, 1986; Hoogesteijn *et al*., 1993; Polisar *et al*., 2003; Mazzolli *et al*., 2002; Conforti and Azevedo, 2003; Zimmerman *et al*. 2005; Palmeira *et al*., 2008) has been a serious issue of conflict between human and large cats.

A multitude of factors influence the occurrence and scale of conflict between human and felids (Inskip and Zimmerman, 2009). The depredation rate has been reported to be correlated with habitat availability, quality and connectivity (Woodroffe and Ginsberg, 1998; Mazzolli *et al*., 2002, Loveridge, 2002), abundance of native prey species (Saberwal et al, 1990; Nowell and Jackson, 1996; Edgaonkar and Chellam, 1998; Pedersen *et al*., 1999; Polisar *et al*., 2003; Athreya *et al*., 2004; Bagchi and Mishra, 2006; Johnson *et al*., 2006; Kolowski and Holekamp, 2006), relative availability of different size class of livestock (Kolowski and Holekamp, 2006), livestock husbandry and management practice and characteristic of settlements (Weber and Rabinowitz, 1996; Ogada *et al*., 2003; Mishra *et al*., 2003; Thirgood *et al*., 2005; Rao *et al*., 2002; Herfindal *et al*., 2005; Kolowski and Holekamp, 2006), proximity to natural habitat, cover condition and water availability (Mizutani, 1995; Rao *et al*., 2002; Stahl et al., 2001; Vijayan and Pati, 2002; Madhusudan, 2003; Athreya *et al*., 2004; Nugraha, 2005; Michalski *et al*., 2006; Woodroffe *et al*., 2007, Sangay and Vernes, 2008).

In Nepal, three species of large cats: tiger, leopard and snow leopard have been reported as notorious livestock killer (Oli, 1994; Tamang and Baral, 2008; Thapa, 2009; Bhattarai, 2009) causing substantial financial losses to rural communities. Livestock depredation issue is more serious around the protected areas, where predators are more likely to encounter the domestic animals.

Of the different protected areas of Nepal, Chitwan National Park (CNP) has been renowned for successful conservation of many threatened species including tigers and leopards. On the other hand, both tigers and leopards are notorious predators of livestock (Karanth and Madhusudhan, 2002). Livestock rearing is an integral part of the subsistence economy of people living in the buffer zone of CNP, but their livelihoods are threatened by livestock depredation (Sharma, 1991; Nepal and Weber 1995).

In Chitwan, human - large cats conflict is not a new issue but till mid 1990s forests outside the CNP were heavily degraded and conflict was confined along the park border (McDougal, 1987). Since 1996, a major change in forest management around the park has been initiated under buffer zone management program (Gurung, 2008). Local communities, supported by government policy, began to manage portions of the national forests for a more sustainable supply of forest products and to increase ecological services that these forests provided (Gurung, 2008). Forest restoration has led to the recovery of ungulates and occupancy of large cats as well. The large cats have to co-exist with livestock in these restored patches that are interspersed with dense human habitations and crop fields. As a consequence, ten- fold increase in human casualties due to tiger has been reported in the buffer zone since 1998 (Gurung *et al*., 2008) and similar rise in livestock depredation and financial loss to the poor people can be expected. People who live in closest proximity to the protected areas tend to be in the lowest income category (Gurung, 2008; Dar *et al*., 2009).

Realizing the fact that the conflict can reduce local tolerance towards carnivores and can create hostile situation, Government of Nepal has initiated conservation and development programs within the buffer zone (BZ) under fourth amendment of National Park and Wildlife Conservation Act (1973) in 1992. The legislation provides provision of channeling back 30% to 50% of the park revenue directly to the buffer zone communities for implementation of conservation and community development program. In addition, the CNPBZ is paying partial compensation for human and livestock casualties in the buffer zone. A mechanism has been established to speedily verify the loss by wild animals and process the application to the buffer zone management committee (BZMC). Initially 25% amount of the price of animals was paid, but recently the relief amount has been increased to 50%.

Despite these efforts to resolve conflicts, there has not been done a review of leopard – human conflicts covering entire buffer zone area of the CNP. Any attempt to mitigate human–carnivore conflict (Arthreya, 2006; Arthreya and Belsare, 2007;

Goyal *et al*., 2007) and improve science based conservation of the culprit species requires a comprehensive understanding of the conflict patterns (Dar *et al*., 2009) and perceptions.

Therefore, the aim of this chapter is to assess patterns and perceptions of livestock depredation by large cats with reference to leopard in the buffer zone of the Chitwan National Park. Amongst the large cats, leopards are relatively more common, resilient and can adapt to a range of habitats (Nowell and Jackson, 1996) due to plasticity in habitat use and diets. Therefore, leopard can be important species to understand livestock depredation patterns in the buffer zone of CNP. Specifically, I investigated the: (1) extent of livestock kills by leopards and compared with the kills by tigers, (2) spatial and temporal patterns of livestock depredation; (3) financial impacts of livestock depredation; and (4) local perceptions towards the large cat species and their conservation.

7.2 METHODS

7.2.1 Data Collection

7.2.1.1 Livestock Predation

I collected depredation data from the BZMC and buffer zone use committee (MZUC), where complaints are registered against wildlife damage. Since 1998, a mechanism has been established to verify the wildlife damage and process the application to the BZMC. In local BZUC, victims report about livestock attack including date, place, number and type of livestock and species involved. The complaint is verified in the field by representative from the CNP and BZUC as they have the responsibility for verification and processing the complaints. Field investigations follow complaints registered as soon as possible. Field investigators diagnose wildlife species involved in depredation by examining circumstances surrounding the kill such as by examining indirect evidences including marks on carcasses, pug marks (size, shape, carcass dragging) and scats, if available (size, consistency, shape), as well as occasional direct observations in fields near the site. The field report is sent to the BZMC at park headquarter, where the BZMC decide on compensation. Initially 25% amount of the price of lost animal was paid, but recently the amount has been increased to 50%.

Compensation payments are based on the immediate market value of the lost property.

I analyzed 4 year validated claims filed between March 2005 and February 2009 for analysis. I organized data according to date, season, and months of incidents for each livestock loss and predator involved. I analyzed depredation data of leopard and compared with tiger in relation to geographic, seasonal, or species specific patterns of livestock.

7.2.1.2 Attitude Survey

A preliminary analysis of complaints, discussion with park staff and review of literature indicated that livestock depredation patterns were not uniform among the villages as well as management sectors. Therefore, I selected 9 villages from 36 Villages Development Committees (VDCs)/Municipalities, representing all the four sectors and different levels of livestock predation to understand the perceptions of local people on large conservation. I selected Bachhauli and Piple VDCs from eastern sector, Gardi and Ayodhyapuri from southern sector, Jagatpur and Meghauli from the central sector and Agyouli, Kawasoti and Rajahar from western sector. One ward (smallest political unit; village) from each of selected VDC and 20 household from each of selected ward was used for structured questionnaire survey (Figure 7.1). These households were selected randomly (*e.g.* every third house) until a sample size of 20 was reached in each ward.

Household structured questionnaire surveys were conducted as one-on-one interviews between March and June 2009. I used a mixture of closed-and open-ended questions to assess respondent's perceptions towards large cats (Annexure 3). The questions covered demographic and socio-economic variables of respondent such as name, sex, age, level of education, occupation, livestock holding (type and number of livestock kept) and purpose of keeping livestock. Respondents were asked about the circumstances surrounding their livestock kill between the period 2007 and 2009, including the carnivore species responsible, based on direct sightings and indirect signs left such as pug mark, and mark left on the carcass.

Figure 7.1. Map of Chitwan National Park and Buffer Zone showing 36 villages/municipalities and survey villages

Other questions were on the type and number of livestock killed, place, location (inside village or outside village in grazing near village), date, time and season of attack, livestock guarding and available habitat, which covered the respondent's background (age, ethnicity, education, etc.), livestock holding and losses in the year 2007- 2009. Questionnaires also covered the perception of people on leopard and tiger, important driving factors determining perceptions and current compensation system and seek their suggestions for coexistence between people and cats.

7.2.2 Data Analysis

I used simple descriptive statistics to analyze categorical variables on livestock depredation and perceptions. Livestock depredation events were summarized using proportions of loss for each predator with respect to year, season, month and livestock type. Killed livestock were categorized into type, and age category (adult, sub adult and young). The livestock types were further classified into large (having weight more 150 kg, cattle and buffalo) and small (having weight less than 100 kg, goat, sheep, pig) based on their body size. A Chi- square (χ^2) test was used to show association between predators and prey size, and between season and years. Similarly, correlation (r) was used to test relationships between predation loss and total heads of livestock holdings and small body sized livestock holdings.

7.3 RESULTS

7.3.1 Livestock Holding

A total of 180 households from 9 village development committees (VDCs) were interviewed. Of them 84% hold some type of livestock. The mean number of livestock per household was 5.8±0.22 (SE) including buffalo (1.3 ± 0.8), cattle (1.3 ± 0.11), goat (2.7 ± 0.16), sheep (0.4 ±0.1) and pig (0.1 ±0.04). The mean number of livestock holdings ranged from 4.6 to 7.4 heads for management sectors and 4.5 to 7.5 for villages (Table 7.1). Of the different livestock types, goats comprised 45.4% followed by cattle (23.2%), buffalo (22.4%), sheep (6.8%) and pig (2.4%).

Table 7.1 Average (Mean ± SE) livestock heads per household in selected Villages Development Committees (VDC) in the buffer zone of the Chitwan National Park, Nepal (2009).

Sector	VDC	Buffalo	Cattle	Goat	Sheep	Pig	Total
East	Bachchhauli	2.3±0.35	1.5±0.36	2.8±0.45	0.45±0.45	0.0	6.8±0.80
	Piple	1.2±0.17	0.7±0.16	2.9±0.38	0.0	0.0	4.9±0.49
	Mean	**1.8±0.21**	**1.1±0.20**	**2.82±0.29**	**0.2±0.22**	**0.0**	**5.8±0.48**
South	Ayodhyapuri	1.6±0.16	2.1±0.32	2.9±0.27	0.3±0.26	0.6±0.28	7.50.15
	Gardi	1.4±0.18	2.2±0.38	2.7±0.32	0.8±0.37	0.0	7.2±0.39
	Mean	**1.6±0.15**	**2.2±0.24**	**2.6±0.22**	**0.6±0.23**	**0.3±0.14**	**7.4±0.37**
Central	Jagatpur	1.6±0.25	0.7±0.17	2.9±0.24	0.3±0.26	0.2±0.12	5.8±0.54
	Meghauli	1.1±0.321	1.3±0.30	2.4±0.41	0.3±0.24	0.3±0.17	5.4±0.53
	Mean	**1.35±0.17**	**1±0.17**	**2.7±0.31**	**0.4±0.17**	**0.3±0.1**	**5.6±0.37**
West	Kawasoti	0.8±0.26	1.6±0.41	2.9±0.58	0.5±0.27	0.05±0.05	5.8±0.86
	Rajahar	1.2±0.21	0.6±0.21	2.6±0.73	0.0	0.0	4.5±0.54
	Agyouli	0.3±0.14	1.4±0.32	2.1±0.51	0.7±0.33	0.0	4.5±0.61
	Mean	0.7±0.13	1.2±0.19	2.5±0.35	0.4±0.14	0.01±0.01	4.7±0.44
Overall mean		**1.3±0.8**	**1.3±0.11**	**2.7±0.16**	**0.4±0.1**	**0.14±0.04**	**5.8±0.22**

7.3.2 Number of Attacks and Livestock Killed

Table 7.2 indicates number of livestock killed by leopard, tiger, rhinoceros and mugger crocodile from 2005 to 2009 in the buffer zone of CNP. The BZMC logged 386 different attacks by large cats on the livestock and two attacks on domestic birds (Duck and Chicken) over a period of four years from March 2005 to February 2009. Two big cats were determined to be responsible for fatal attacks on livestock: leopard accounted for 209 attacks (52.2 attacks/year) killing 230 heads of livestock with an average of 1.1 animals per attack (range from 1-4) and 57.5 heads per year, while tiger was responsible for 181 attacks (45.2 attacks/year) killing 215 animals with average of 1.2 animals per attack (range from 1- 6,) and 53.7 heads per year (Table 7.2). The leopards were reported for two instances of fatal attacks on duck (killing, n= 15) in Gardi village and Chickens (killing, n= 182) in Bagauda village in Madi valley.

Besides, the rhinoceros were reported for 2 fatal attacks on cattle, but these were aggressive assaults and not considered predatory events, and Mugger crocodile killed 3 goats. Damage of rhinoceros and crocodiles on livestock; and leopards on domestic birds were uncommon instances and have not been considered further in this study.

Table 7.2 Number of livestock killed by different wildlife species in the buffer zone of Chitwan National Park, Nepal (2005- 2009).

Category	**Livestock**	**Leopard**	**Tiger**	**Rhinoceros**	**Mugger crocodile**	**Total**
Livestock	Buffalo	4.0	27	0.0	0.0	31
	Cattle	3.0	54	2.0	0.0	59
	Goat	212	124	0.0	3.0	339
	Sheep	4.0	6.0	0.0	0.0	10
	Pig	7.0	4.0	0.0	0.0	11
	Total	**230**	**215**	**2.0**	**3.0**	**450**
Birds	Ducks	15	0.0	0.0	0.0	15
	Poultry	182	0.0	0.0	0.0	182
	Total	**197**	**0.0**	**0.0**	**0.0**	**197**

Livestock killed by leopard in night were 53%, whereas 47% were killed during day from the grazing grounds in nearby villages, while in case of tiger, 56% of reported kills took place during day from grazing places, whereas remaining 44% took place at night time from the night shelters. Both the cats showed phenomena of surplus killing. Approximately 91% leopard attack and 86% tiger attack resulted into killing of only one livestock, whereas surplus killing for leopard and tiger was approximately 9% and 14% of total attacks respectively.

7.3.3 Types of Livestock Killed by Leopard and Tiger

Both the cats killed more goats than expected given the availability of goats (45.45%) in terms of overall composition of livestock in the study area (Table 7.1). Leopard kills (n=230) were mainly of goats (92%), sheep and pig (5%) and large body sized livestock (3%) such as buffalo and cattle. Majority of tiger kills (n=215) were on goat (58%) followed by cattle (25%) and buffalo (13%), while sheep and pig together represented only 5% of total loss in terms of number of heads. In terms of kill on livestock types, leopard accounted 63%, 40% and 64% of the total kills of goats, sheep and pigs respectively, while tiger accounted for 87%, 95% and 37% of the kills of buffalo, cattle and goat respectively (Figure 7.2). There was a significant association between size of prey and types of predators (χ^2 = 91.97, P < 0.001, df = 1).

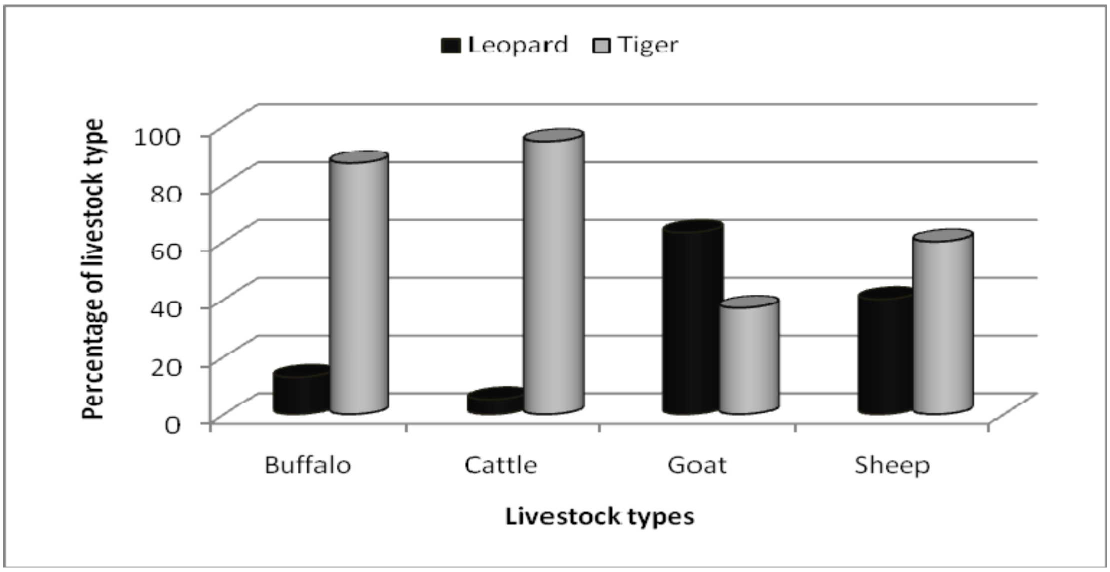


Figure 7.2 Percentage of kills by livestock type by leopard and tiger in the buffer zone of Chitwan National Park, Nepal.

7.3.4 Age Classes of Killed Livestock

Leopards were selective to small body sized livestock but tiger selected large body sized animals. Leopard killed adult goat (75%) more frequently followed by sub adult goat (16%) whereas other types of livestock were < 9%. In case of tiger, 32% and 58% of kills were large body sized and small body sized adult livestock (Table 7.3). Interestingly, leopard kill was not reported for adult buffalo and cattle, and young animals were not recorded for tiger kill.

Table 7.3 Livestock killed under different age categories by leopard and tiger in the buffer zone of Chitwan National Park, Nepal.

Livestock type/Age category	Leopard			Tiger		
	Adult	Sub adult	Young	Adult	Sub adult	Young
Buffalo	0.0	1.0	3.0	22	5.0	0.0
Cattle	0.0	3.0	0.0	46	8.0	0.0
Goat	173	38	1.0	115	8.0	1.0
Sheep	3.0	1.0	0.0	6.0	0.0	0.0
Pigs	5.0	2.0	0.0	3.0	1.0	0.0

7.3.5 Seasonal Patterns of Livestock Depredation

The majority (44%) of livestock kill by leopard occurred during monsoon season followed by winter (33%) and summer (23%), while majority of tiger depredation on livestock (41%) occurred during summer followed by monsoon (30%) and winter (29%) season (Table 7.4). There was a significant association of total livestock loss between seasons and years ($\chi 2 = 16.68$, $P = 0.011$, df = 6).

Table 7.4 Livestock depredation by leopard and tiger in relation to season in the buffer zone of the Chitwan National Park, Nepal (March 2005 to February 2009)

Livestock types	Seasons						Total
	Summer		Monsoon		Winter		
	Leopard	Tiger	Leopard	Tiger	Leopard	Tiger	
Buffalo	0.0	8.0	3.0	12	1.0	7.0	31
Cattle	1.0	23	2.0	14	0.0	17	57
Goat	46	57	93	38	73	29	336
Sheep	1.0	1.0	1.0	0.0	2.0	5.0	10
Pig	5.0	0.0	1.0	0.0	1.0	4.0	11

Depredation trends in relation to both small (goat, sheep and pig) and large (cattle and buffalo) body sized livestock by leopard and tiger indicating high depredation in monsoon and summer season respectively (Figure 7.3).

(a) small body sized livestock (b) large body sized livestock

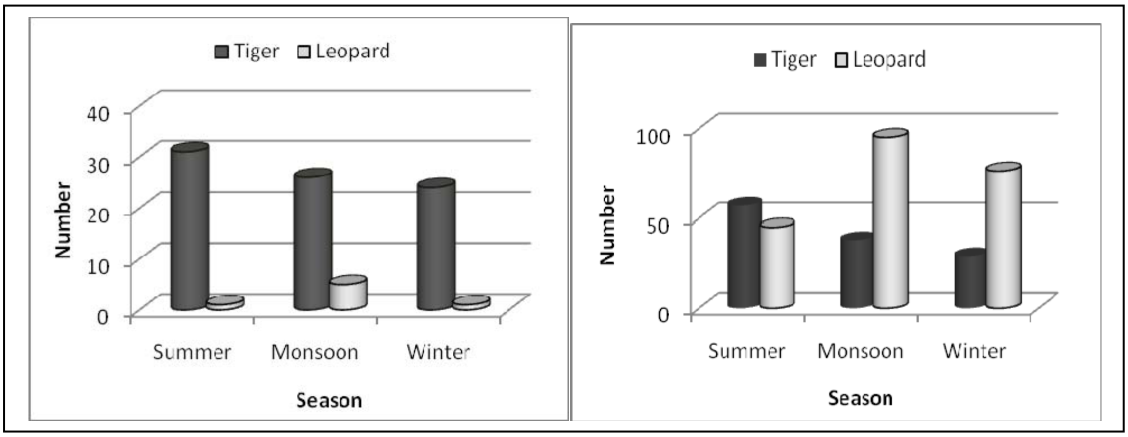


Figure 7.3 Seasonal patterns of (a) small body sized livestock and (b) large body sized livestock by tiger and leopard in the buffer zone of Chitwan National Park.

7.3.6 Temporal Patterns of Depredation on Livestock by Leopard and Tiger

The extent of livestock loss to both large cats varied from year to year (Figure 7.4). On an average, 57 and 54 livestock heads/year were killed by leopards and tigers respectively. The livestock depredation was relatively lower during the period between March 2006 and February 2007 than other years for both the cats.

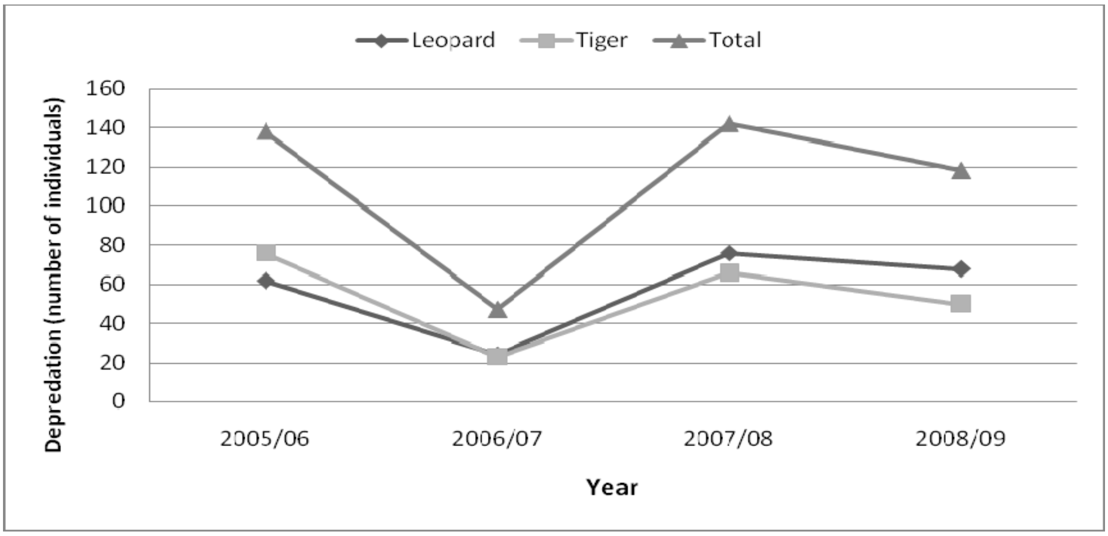


Figure 7.4 Annual variation of depredation by leopard and tiger in the buffer Zone of Chitwan National Park from March 2005- February 2009.

The results indicate that monthly variation in the number of livestock kills by both large cats. Highest and lowest livestock depredation by leopard was during July and

November respectively, whereas highest and lowest kill made by tiger were in March and August respectively (Figure 7.5).

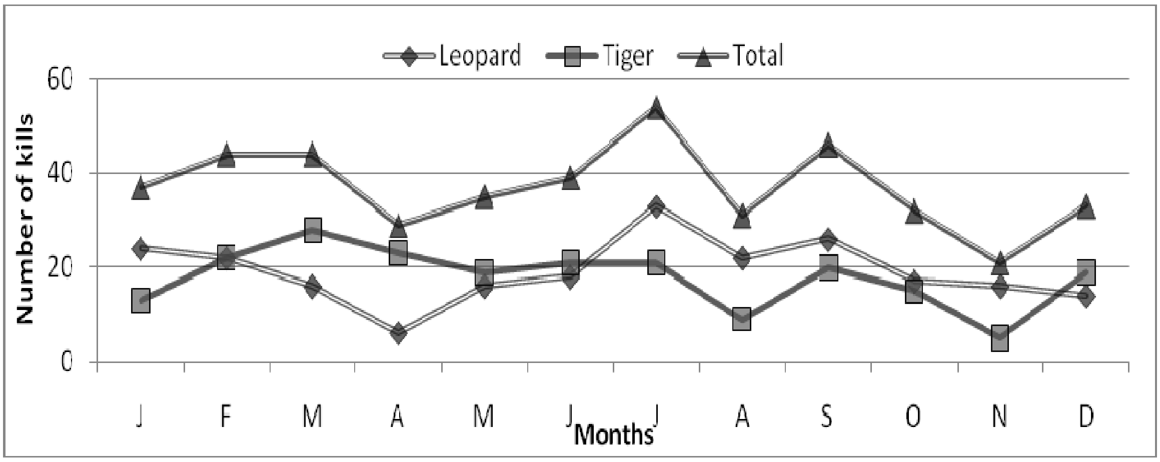


Figure 7.5 Monthly variations in livestock kill made by leopard and tiger in the Buffer Zone of Chitwan National Park during March 2005- February 2009.

7.3.7 Spatial Pattern of Livestock Depredation

The Buffer Zone of the Chitwan National Park is part of two municipalities and 34 village development committees in four districts *viz* Chitwan, Makwanpur, Parsa and Nawalparasi Districts. Two municipalities and 32 VDCs (except Narayani and Prasauni) are reported to having livestock depredation by large cats (Figure 7.6a). Livestock loss was not uniform among the villages. Relatively high proportion of livestock predation was reported from the Gardi village in south (17%) and Kumroj (11%), five villages shared 5- 10%, 6 villages 2.5- 5%, 19 villages experienced less than 2.5% of the total predation (Figure 7.6a). Leopard predation was recorded from 20 VDCs/Municipalities (Figure 7.6b), with the highest proportion (17%) from Gardi, 3 villages each reported over 10% and other 3 villages reported 5 to 10% of total loss. Leopard predation was reported only from 4 villages out of 15 in western sector, where tiger predation was more prevalent. Tiger predation was reported from 27 villages (Figure 7.5c), with higher proportion of loss was from Gardi village (17%) in south and Agyouli (14%) in the west sector. Five other villages reported 5- 10% of total tiger kills.

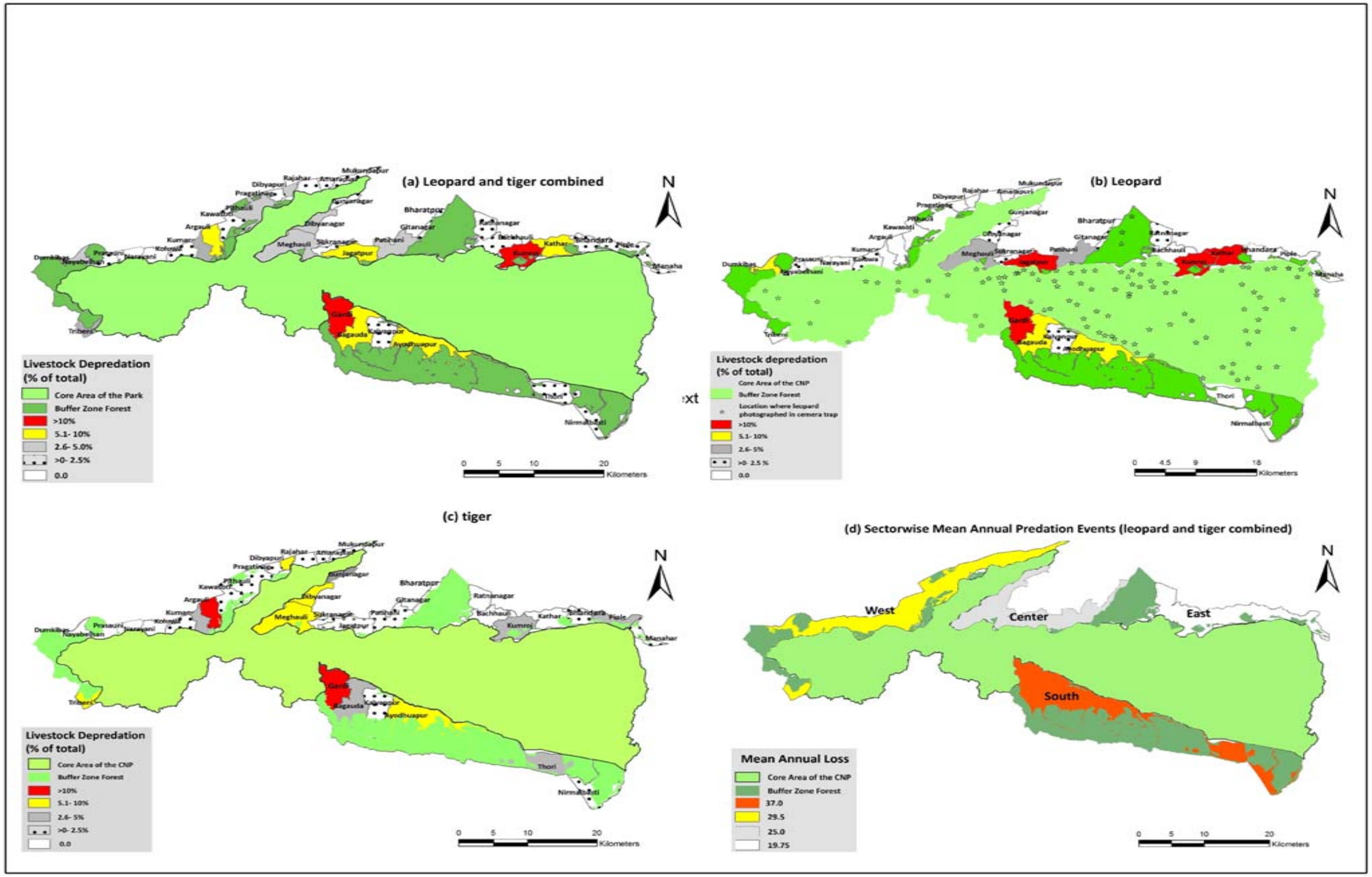


Figure 7.6 Chitwan National Park and Buffer Zone showing livestock predation prevalence (proportion of kills) in various villages for (a) leopard and tiger combined, (b) leopards and (c) tiger; and (d) sector wise mean annual livestock kill by leopards and tigers.

Among different management sector, the proportion of livestock predation was highest (33%) in south followed by west (27%), east (22%) and central sector (18%) (Figure 7.6d). On an average annual livestock heads killed by leopards was high in eastern (20) and central (19) whereas lowest in western sector (6). Average annual tiger depredation was 23 heads in the western sector followed by southern sector (18). An inverse relationship was found between leopard and tiger kills in different management sectors, except south sector where both predators killed high number of livestock heads (Figure 7.7).

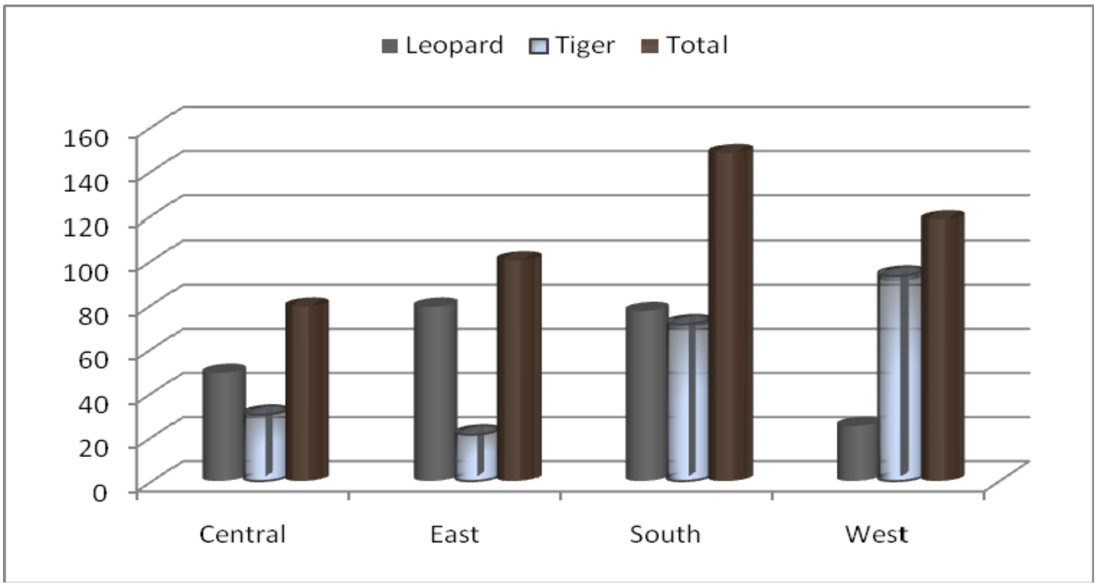


Figure 7.7 Distribution of average annual livestock loss in different management sector by leopard and tiger.

I tested the of predation loss with the average size of total livestock holding and average size of small body sized livestock holdings. The livestock depredation (by leopard and tiger combined) was found to be moderate positively associated (r= 0.5) with the total livestock holding and small body sized livestock holdings per household. Leopard depredation was also positively correlated (r=0.6) with both total livestock holdings and small livestock holdings, but tiger predation had weak association with size of livestock holdings (r= 0.2).

7.3.8 Economic Values of Loss

The economic value of 445 livestock loss to big cats within the buffer zone of CNP during March 2005 to February 2009 was NRs 4,008,410.00 (US $ 54,910.00), with annual loss of NRs. 1,002,103.00 (US $ 13,727.00) (Table 5). Leopard contributed 36.17% of the economic value of livestock depredation, while the economic impact of tiger was high (63.83%). In terms of economic loss by both large cats, goat (63.30%, US $ 34755.00) was the most important livestock followed by cattle (17.26%, US $ 9477.00) and buffalo (15.70, US $ 8620.00). Buffer Zone Management Committee was paying 25% of loss caused by the park animal in the Buffer Zone. During the period from March 2005 to February 2009, BZMC of CNP paid a sum of NRs. 1,002,103.00 (US$ 13,727.00) as partial compensation to the victims.

Table 7.5 Economic value (in US $) of recorded livestock kills by large cats in the buffer zone of Chitwan National Park, Nepal (March 2005 to February 2009).

Species	Buffalo	Cattle	Goat	Sheep	Pig
Leopard	168.00 (4)	128.00 (3)	18650.00 (212)	439.00 (4)	476.00 (7)
Tiger	8452.00 (27)	9349.00 (24)	16105.00 (124)	548.00 (6)	593.00 (4)

Numbers in parenthesis represent numbers of individuals killed.

7.3.9 Human Casualties and Leopard Kill

Over the four year period from March 2005 to February 2009, BZMC recorded 116 human casualties caused by tigers, leopards, sloth bears, rhinoceros, elephants, wild pigs, and mugger crocodile (Table 7.6). During the period, 30 individuals died and 86 injured, and the BZMC of CNP paid US $ 24,104.00 as relief money to the victims or their relatives. The attacks by sloth bear, rhinoceros, elephants, wild pigs and mugger crocodiles were aggressive assaults.

Leopard injured 11 people in four separate instances; two provoked instances resulted into the injury of 6 and 3 people in each. Similarly, tiger killed 11 persons and left injury to another 7 persons in 15 different incidences.

Table 7.6 Human casualties caused by different wildlife species around the Chitwan National Park, Nepal (March 2005 to February 2009).

Species	Death	Injury	Total	Compensation (in US $)
Tiger	11	7	18	6,201.00
Leopard	0	11	11	850.00
Sloth bear	2	28	30	3,381.00
Rhino	12	28	40	11,029.00
Elephant	4	5	9	1,964.00
Wild pig	1	6	7	535.00
Mugger Crocodile	0	1	1	143.00
Total	30	86	116	24,103.00

Three incidences of leopard attack injuring 10 persons occurred in eastern sector, while tiger attack was distributed as 8, 1, 4 and 5 respectively in the central, east, south and west sector of CNP. Leopard attacked people mostly during winter (3 incidences injuring 10 persons) and rainy season (1), while tiger mostly attacked during rainy (11) and winter (7) seasons. Over the four year period, BZMC paid US $ 850.00 as relief money to the victims of leopard attack; the amount was only 3.57% and 12.05% of the relief money paid to victims of all wildlife and large cats respectively.

I recorded deaths of seven leopards from January 2007 to June 2009; five in the buffer zone and 2 in north of BZ. Of these deaths, 3 were beaten to death, 2 poisoned on the carcasses of buffalo, 1killed on road accidents and 1 suspected to be poisoned.

7.3.10 Perceptions

Respondents (n=180) were representatives from Tharu (28.90), various hill groups (25%), Bramin/Chhetry (22%), Bote/Majhi/Mushahar/Darai (13%) and Tamang (11%) communities. Both men (68%) and women (32%) were interviewed. Respondent interviewed were of ages between 18 and 82 years but majority (64%) of them were of working age group (25 to 60). Main source of income for 78% respondents was farming and 22% depend on off farm activities (petty jobs, businesses, fishing and foreign employment). Of the total, 97% of all respondents were having one or more individuals of livestock. The educational level of the respondents was poor and only 26% had completed school education.

Prior to evaluating perceptions towards conservation leopards and tigers, I asked them if they knew or had seen each predator. All respondents had some knowledge of leopards and tigers, while only 18% and 23% had seen leopards and tigers respectively. Sixty one (33%) respondents had lost livestock between July 2007 and June 2009, and 66% and 34% of livestock loss was from night shelter and grazing ground, respectively. Of the total respondent who lost their livestock informed 13% of livestock were killed inside the park, thus victim could not register for compensation. Fifteen percent of total respondents (n=180) said that their livestock was killed by leopard whereas 21% said that they lost livestock due to tiger.

Of the total (n=180), majority of local people (94% or n=170) expressed a positive perception toward the conservation of CNP. Reasons for positive perception (n=170) can be categorized as revenue for socioeconomic development (32%); biodiversity values, fresh air and water (30%), availability of forest resources (25%), and employment and market related to tourism (13%). Of the 180 respondents 94% and 98% respectively expressed their views regarding leopards and tiger either positive or negative.

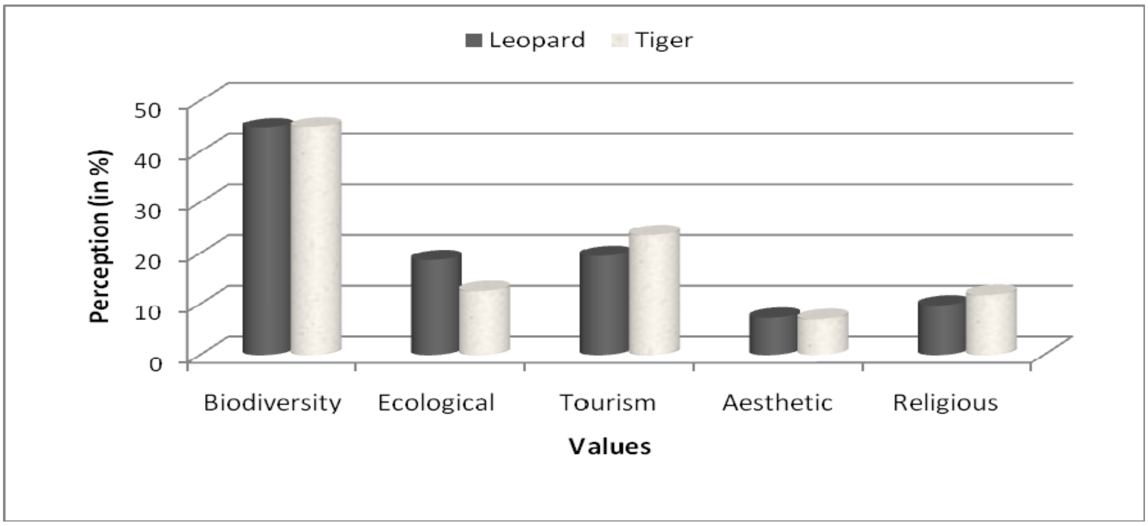


Figure 7.8 Positive perceptions on leopards and tiger among the local people.

Approximately 65%, 27% and 8% of respondents respectively liked, disliked and did not answer about the leopard presence in the forest nearby. Similarly, 68%, 28% and 4% of total respondents respectively favored, not favored and did not like to express their views regarding the presence of tiger in the forest around them. People who had positive beliefs towards leopard tended to show positive beliefs towards tigers. Positive perception towards leopard (n=123) and tiger (n=127) was due to the importance of these felid species in the natural ecosystem; economy due to tourism and recreation; aesthetic and religion/cultural (Figure 7.8). They also expressed the important ecological role of the large felids in regulating populations of wild ungulates and small carnivores. Perceived threats to damage livestock and attacking people as well as threats use of forest products due to the presence of predator are the main reasons for their negative attitudes towards leopards (n=47) and tiger (n=50).

Majority (47%) of the respondents (n=180) accepted a slight increase in the population of both leopards and tigers and 30% respondents preferred to maintain the population at a current level (Figure 7.9). Those who favored an increase in the population stated that these cats have been declining in the past and are threatened even in protected areas. However, some others opined for decrease (9%) and disappearance (4%) of the big felids because of perceived threats to livestock and people. Remaining 8% respondents did not like to express their views.

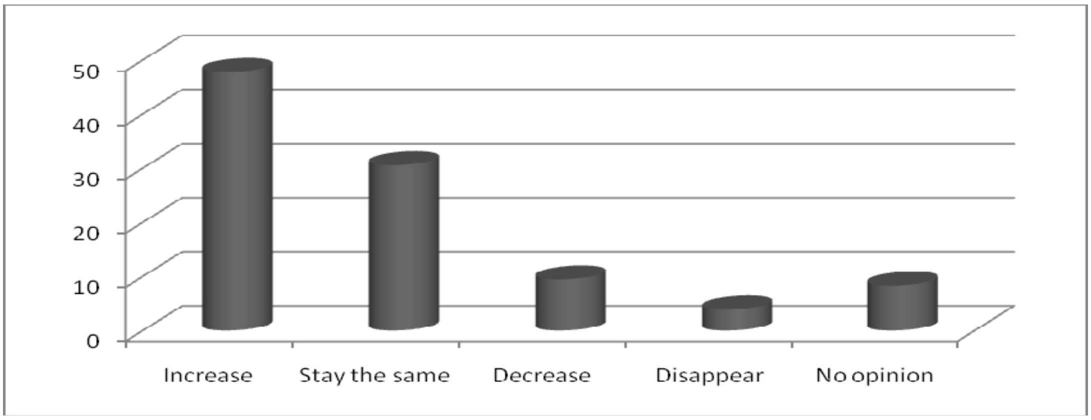


Figure 7.9 Opinion about the population change of leopards and tiger in Chitwan National Park

Majority of respondents were not satisfied with current compensation system given that it was a slow process and paid only 25% of the price of livestock that was killed by protected wildlife species. Perceived responses of local residents (n=180) for the coexistence of people with leopards and tiger were classified into four categories as: 1) improvement in damage compensation system to provide justified compensation and resources for damage prevention (49%); 2) developing system of rapid response of the problem animals particularly in case of human casualties (20%); 3) providing more information about the ecological role and status of leopards and tigers, education, increased public awareness (22%); and 4) others (9%), such as co-operation, more resources for research and monitoring, etc.

7.4 DISCUSSION

My study focused on the comparative analysis of the patterns of livestock predation by leopard and tiger, and tolerance and perceptions of local people related to these big cats. Livestock damage patterns were analyzed using compensation claims logged in the BZMC, and a survey with structured questions gave a deep insight into the attitudes of people.

7.4.1 Livestock Depredation and Prey Preference

Although the wild cats are specialized to prey on wild ungulates but when the opportunity arises, they may be opportunistic to rely on domestic species (Bailey, 1993; Treves and Karanth, 2003). Domestic livestock do not have anti-predatory strategy; hence, they are easy to kill with little effort (Linnel *et al*., 1999). Literature indicated that the depletion of wild prey forces the predators to switch to livestock as their food source (McDougal, 1987; Kolowski and Holekamp, 2006; Gusset *et al*., 2009). Drastic changes are taking place in landscape matrices in the landscape occupied by large to medium sized felids. There is a need to understand to felid behavior towards livestock depredation and interaction with humans for their long term viable conservation.

Four year data (March 2005- February 2009) from this study revealed that livestock depredation by large cats (leopard and tiger) were common in the periphery of the CNP. A total of 445 livestock heads were killed by leopard and tiger around CNP between March 2005 and February 2009. The mean number of livestock killed per attack by leopard was 1.1 individuals (range 1- 4) and tiger attack was 1.2 individuals. Most attacks involving death of single livestock head for leopard (91%) as well as tiger (87%), however surplus killing was also recorded for leopard (up to 4 individuals) and tiger (up to 6 individuals). Surplus killing was reported among cats and other carnivores (Kruk, 1972, Fox and Chundwat, 1988, Linell *et al*., 1999, Odden *et al*., 2002, Sangay and Vernes, 2008). Dar *et al*. (2009) reported that 46.6% of leopard attacks killed more than one animal in Machiara National Park, Pakistan.

The mean annual livestock heads killed by leopard (58) was slightly higher than that by tiger (54), but tiger killed mostly large body sized livestock (cattle and buffalo, Table 7.2) contributing higher economic loss than leopard. Human - carnivore conflict studies conducted in Bhutan (Wang and Macdonald, 2006; Sangay and Vernes 2008), Pakistan (Dar *et al*. 2009) and India (Goyal *et al*., 2007Chauhan, 2008) reported that the leopard as a main livestock predator in mountain areas, however, Tamang and Baral (2008) reported tiger was the main livestock predator around the Bardia National Park, Nepal.

Both leopard and the tiger showed diverse predatory behavior toward livestock with regard to the type and age of livestock attacked, time of the day and site; and patterns of livestock depredation. Results indicated that the leopard prefer to kill smaller body sized livestock primarily goats (92%), while the tiger killed small as well as large body sized livestock such as goats (58%), cattle (25%) and buffaloes (13%) (Figure 7.2). Previous research conducted in Nepal, India, Bhutan and Pakistan also showed that leopard predation on domestic animal comprises mainly of small body sized livestock and tiger preferred large body sized animals (Shekhar, 1988; Sharma, 1991; Studsrod and Wegge, 1995; Wang and Macdonald, 2006; Tamang and Baral, 2008; Sangay and Vernes, 2008; Dar *et al*., 2009). The domestic prey size preference by leopards and tigers in this study were similar to the size preference among wild ungulates. The leopard preferentially preyed upon the species less than 50 kg body weight, while the tiger usually took larger (50- 100 kg) wild prey (Seidensticker, 1976; Seidensticker and McDougal, 1993 Johnsingh, 1992; Karantha and Sunquist, 2000, Wang and Macdonald, 2006; Biswas and Sankar, 2002, Hayward *et al*., 2006).

Among the livestock, goats are most vulnerable to attack by both large cats. In my study area, both cat species killed goats more in proportion (92% for leopard and 53% for tiger) than availability (45%) while leopard killed large body sized livestock very less (4%) in proportion than availability (45%). Therefore, the patterns of livestock depredation by both leopards and tigers may not reflect availability. High rate of leopard depredation on small body sized livestock was reported by Sekhar (1988) in Sariska Tiger Researve, India; Wang and Macdonald (2006) in Jigme Singhe National Park, Bhutan and Dar *et al*. (2009) in Machiara National Park, Pakistan. Higher depredation rate on goats by large cats was probably related to the relative abundance of goats in comparison to other livestock, ease to kill and drag to a secure place. Thus, such selection may provide sufficient energy intake for carnivores, at least for leopards, as they have been known to take smaller body sized livestock than tiger.

Leopards were more nocturnal in the buffer zone of CNP in attacking livestock like reported other studies (Rabinowitz, 1989; Kolowski and Holekamp, 2006; Kissui, 2008), whereas tiger frequently attacked grazing livestock inside the forest (Tamang and Baral, 2008). Consistent with previous studies (Tamang and Baral, 2008; Dar *et al*., 2009; Bhattarai, 2009), present study has also indicated that livestock in the villages were kept in poorly constructed pens and were more vulnerable at night because the large cats could easily break such pens and kill the livestock.

7.4.2 Seasonal Pattern

Seasonality in livestock depredation by both species of cats was observed in the present study and frequency of depredation by leopards was more prevalent in monsoon and summer (Table 7.4, Figure 7.2). Increased livestock depredation incidents during the rainy season could be related to higher vegetative cover that probably provides adequate stalking cover for leopards and decreases the detection probabilities of carnivores by humans and livestock. Other studies have also reported relatively higher depredation on livestock during the rainy season (Bhadauria and Singh, 1994; Srivastav, 1997; Patterson *et al*., 2004; Woodroffe and Frank, 2005; Kolowski and Holekamp, 2006; Sangay and Vernes, 2008) and concluded that this may be because conditions are adverse for human activities and limiting the human presence close to the livestock. The observed higher incidences of tiger attacks on livestock during summer season may be because of limitation of grasses and fodder for stall feeding, therefore people grazed their livestock more often in the forest where livestock were more vulnerable to the predators. More livestock grazing has been reported in the deep forest during hot dry summer season (Regmi, 1998).

7.4.3 Spatial Patterns

Spatial patterns of livestock depredation by sympatric large cats are more complex and not clearly understood. Spatial variations in relative livestock depredation by large predators have been attributed to differences in relative densities of large carnivores, husbandry practices, or relative abundance of different livestock species (Kolowski and Holekamp, 2006). A close relationship has been reported between predator densities and livestock loss rates (Sagor *et al*., 1997; Stahl *et al*., 2001; Stoddart *et al*., 2001; Kolowsky and Holekamp, 2006), while other studies were unable to establish association of predator density with livestock depredation rates (Connor *et al*., 1998; Graham *et al*., 2005). Unfortunately, large cat density was not reported in the studies undertaken on depredation; however, observed high tiger depredation events in the villages of south, west and western part of the central management sector of CNP must be linked with high tiger density in areas close to these villages. The estimated density was 8.08/100 km^2 for tiger (Karki *et al*., 2009) and 4.34 animal/100 km^2 for leopard (Chapter 5) in CNP. I believe avoidance of tiger by leopard or displacement of leopard by tiger to the edge could be responsible to the spatial differences in the livestock predation. Such interference competition and displacement of leopard from prime habitat to fringe area was documented by McDougal (1988) and (Odden *et al*., 2010). Data clearly revealed that the leopard depredation was less where tiger depredation was high except in Gardi village (Figure 7.5a and b, Figure 7.6). The relative availability of preferred size classes of livestock has been reported to influence the involvement of predators in predation (Patterson *et al*., 2004; Kolowski and Holekamp, 2006). I used the average of livestock per household and small body sized livestock per household as surrogate to assess if there was any association between depredation rate and availability of livestock. There was positive moderate relationship between frequency of total depredation (r=0.5) and leopard depredation (r=0.6) with average holdings of total livestock and average small body sized livestock, suggesting increased number of small body sized livestock can influence predation particularly by leopard. A very weak positive correlation was found between tiger predation and size of livestock holdings, indicating that most of such depredations were opportunistic.

However, several studies have suggested that the native prey population density may have influence on the livestock depredation rates (Merggi and Lovari, 1996; Woodroffe *et al*., 2005; Kolowski and Holekamp, 2006) and depleted density prey species may force predators to switch to livestock as their food source (McDougal, 1987; Gusset *et al*., 2009; Kolowski and Holekamp, 2006) or predators killed livestock in areas where livestock densities are higher than wild prey densities (Woodroffe *et al*., 2005; Bagchi and Mishra, 2006). The prey density estimated in 2008 from three sites in the northern part of CNPBZ were 123.9 animals km^{-2}, 100 animals km^{-2} and 84.3 animals km^{-2} (Chapter 4), however, another estimates covering entire area of the park indicate native prey density of 62.6 animalskm^{-2} (Karki *et al.,* 2009). Availability of native prey population density at least from the northern part of the study area may not be low to support the hypothesis that livestock depredation is only a function of low prey density. Data from present study indicates that the large cats can depredate livestock even in areas with high density of native prey. Treves *et al*. (2004) reported that wolf (*Canis lopus*) depredation on livestock may also be high even in areas with high native prey densities. Thus it is difficult to identify single factor to contribute high livestock depredation by large carnivores. Holmern *et al.* (2007) reported that the high livestock depredation in the Serengeti National Park may be due to low natural prey densities inside and high livestock density around. In addition, individual behavior and physical condition of the predator can also be an important factor for disproportionate spatial loss of livestock, as Gurung *et al*. (2008) reported that the increased human killing by tiger was associated with occupation in prey poor area, physical impairment and aggressiveness. Therefore, several factors play role in spatial differences in the livestock depredation by large cat species.

7.4.4 Economic Values of Loss

Livestock keeping is a supplementary activity to the main occupation of crop farming in the buffer zone of CNP. Most people are subsistence farmers and 84% have some type of livestock (Table 7.1) and the livestock has the crucial role in their subsistence. Goats are the most abundant livestock in the area. Annual average economic loss from livestock depredation in the buffer zone of CNP was calculated to be NRs. 1,002,103 (US $ 13,727). If estimated average annual monetary loss for a household in the Buffer Zone of CNP, where total household was 36,193 (DNPWC, 2000), is not significant amount, but even smaller loss would have significant financial problem to the concern farmer. Livestock depredation prevalence around CNP was not uniform and some villages had higher economic loss than others. Large body sized livestock such as cattle and buffalo are economically important not only due to their high market price but also they are sources of manure, milk and draught power to the farmers in Nepal. Therefore, the depredation on cattle and buffalo is substantial economic losses.

7.4.5 Human Casualties and Leopard Deaths

Large cats are also a problem to human safety in Nepal (McDougal, 1987; Gurung *et al*., 2008, Bhattarai, 2009) and elsewhere (Khan, 1987; Miquelle et al., 2005). The conflict with human is the main cause of leopard mortality across its range (Nowell and Jackson, 1996; Negi 1996; Woodroffe, 2000; Sunquist and Sunquist, 2002, Chauhan, 2008). Concern for human safety combined with livestock loss due to depredation may aggravate the situation and result in retaliatory killings (Holmern *et al.,* 2007). In the buffer zone of CNP, no records available for human death by leopard which ranked fourth (= 11) in cases of human casualties after rhino (n= 40), sloth bear (n= 30) and tiger (n= 18) (see Table 7.6). Although, most (83%, n= 12) of the leopard related casualties occurred due to provocation or obstruction of route, but 5 leopard out of 7 recorded deaths were killed by human within the period of 2.5 years.

7.4.6 Perceptions

In the buffer zone of CNP, both the leopard and tiger were perceived as major livestock predators, however, a hostile situation has not yet been developed for conserving leopard and tiger. Combinations of several factors were responsible for observed positive perception. First, people are getting benefit from the CNP in terms of forest resources like collection of thatch grass, water for irrigation from Park's Rivers and fresh air. Second, under the buffer zone management regulation, CNP is allocating up to 50% of its revenue to the communities in the buffer zone for conservation and socioeconomic development. Third, involvement of the local community in buffer zone management activities through democratically elected committees. Other factors include real and potential benefits from tourism, aesthetic and religious values attached to the cats, partial compensation of loss and recognition of their area as a World Heritage Site. People consider the current compensation (50% of livestock value) is better than nothing and they expect that the amount may be increased in future. Similar, positive perception on tiger was reported by previous studies from Chitwan (Gurung, 2008) and Bardia (Bhattarai, 2009). Dar *et al*., (2009) reported positive perception on leopard among the local people around the Machiara National Park, Pakistan. In spite of these direct and indirect benefits, some people hold negative perception towards leopard (26.11%, n=180) and tiger (27.77%, n= 180) due to perceived threat to livestock depredation, human attack and use of forest product. Negative perceptions against the predators were commonly cited issue in areas where heavy livestock losses have been reported (Oli, 1994; Oli *et al.,* 1994, Mech, 1995; Mishra *et al*., 2003; Bagchi and Mishra, 2006; Lucherni and Merino, 2008). Negative perception around CNP can be reduced giving further emphasis on conflict mitigation and improving current compensation schemes in terms of amount of loss and promptness in processing the claims.

7.4.7 Management Implications

Human - large cat conflicts is a complex issue for management, especially in areas where predators are sharing land with human and livestock, and therefore needs to be managed carefully to achieve the goals of wildlife management and economic wellbeing of local people. The results of this study revealed the complexity in patterns of conflict. Both leopards and tigers are important livestock predators and leopard preferentially predate on small body sized livestock (goats) more frequently than the availability whereas tiger kill both small (goat) as well as large body sized (cattle and buffalo) livestock. Therefore, this study suggests the need for implementing livestock protection measures particularly for goats, for reducing the conflicts between people and large cats. This study also suggests for improving livestock pens, increasing vigilance in the grazing fields during the summer and rainy months to minimize livestock losses.

The findings of this study indicate that leopards were not serious threats to human life around CNP as most (83%) of leopard related human casualties (n=11) were the result of provocation. But human related leopard mortalities, if remains continue, can be a serious threat for survival of leopard population in future. Strengthening of the current participatory and benefit sharing buffer zone management program linked with conservation education targeting to the poorest people around CNP would be important steps forward for increasing their understanding and acceptance that large cats conservation.

Chapter 8
LEOPARD HABITAT USE IN CHITWAN NATIONAL PARK - LANDSCAPE ATTRIBUTES

8.1 INTRODUCTION

Leopards are the most widespread of large cats, occurring throughout sub-Saharan Africa, the Middle East, and much of tropical and temperate Asia (Nowell and Jackson, 1996). They occupy a diverse variety of habitats, ranging from tropical rain forests to semi deserts (Bailey, 1993; Nowell and Jackson, 1996), and from High Mountain up to 5,200 m in the Himalaya (Jackson, 1984) to the edges of urban areas (Shah *et al*., 2004; Blame *et al*., 2007). Because of their nocturnal and secretive nature, leopards often survive in close proximity to humans. However, a reduced prey base, poisoned baits for carnivore control, poaching for trade and direct conflicts with people over livestock predation have dramatically reduced leopard populations across its range (Nowell and Jackson, 1996; Nowak, 1999).

Ecological studies on the leopard have mostly focused on diet by analyzing scats, and behavior, activity patterns and home range using radio telemetry as a tool (Seidensticker, 1976a; Sunquist, 1983; Norton and Lawson, 1985; Rabinowitz, 1989; Bailey, 1993; Karanth and Sunquist, 1995; Jenny, 1996; Mizutani and Jewell, 1998; Grassman, 1999; Karanth and Sunquist, 2000; Marker and Dickman, 2005; Odden and Wegge, 2005), and some studies have inferred habitat use as well (Seidensticker, 1976a; Bailey, 1993; Marker and Dickman, 2005; Blame *et al*., 2007, Simcharoen *et al*., 2008). The broad habitat utilization of leopard has shown a tendency of utilization on the variety of forest and grassland habitats (Marker and Dickman, 2005). Recently, Simcharoen *et al.*, (2008) reported that the mixed deciduous and dry ever green forest types, flat slope and areas close to stream channels are important landscape features for leopard habitat selection.

Camera traps have now become available to study the abundance of cryptic animals, which can be identified by their coat patterns (Karanth and Nichols, 1998; Silver *et* *al*., 2004). Camera-trap photo- capture records can also provide information on home range, habitat use, daily and seasonal activity patterns, and population dynamics (Bitetti *et al*., 2006). However, these aspects have been rarely explored in camera-trap studies on felids, probably as a result of the small sampling effort or low population density of study animals, which have rendered inadequate data available for statistical analysis (Maffei e*t al*., 2005). More recently, camera trap data have been used to analyze species habitat use and selection (Bitetti *et al*., 2006; Ngoprasert *et al*., 2007; Bowkett *et al*., 2007; Monroy-Vilchis *et al*., 2009; Harmsen *et al*., 2010; Foster *et al.,* 2010), and habitat suitability modeling (Edganokar, 2008).

However, information on the habitat utilization of leopard, influence of landscape or habitat features and human activities on spatial distribution of this species is scarce (Ngoprasert *et al*., 2007; Goyal *et al*., 2007; Simcharoen *et al.*, 2008; Edgaonkar, 2008) and no study in Nepal has so far been done to quantify habitat use of leopard.

To manage habitats that protect carnivore species, we must understand habitat use patterns and evaluate the role of landscape and anthropogenic factors play in determining habitat use patterns. Landscape characteristics and anthropogenic activities would have a significant influence on leopard distribution as well as habitat use. To understand habitat utilization of leopard and determine the influence of landscape and anthropogenic factors on habitat use, I analyzed a large number of camera traps data (Chapter 5) combined with geographic information systems (GIS) in sampling habitat features at the trap sites. Specific objectives of the study were to: (i) determine distribution and habitat use of leopards on a landscape scale (between habitat types), (ii) evaluate landscape features and anthropogenic factors affecting habitat use, and (iii) prepare predicted probability of occurrence map (habitat suitability) based on the occupancy modeling. Information on leopard habitat use can be useful to model responses to different level of resource availability and threat scenarios. Determining the factors that influences leopard distribution and abundance is fundamental for long term conservation.

8.2 METHODS

8.2.1 Leopard Location Data

Camera trap photos were used to analyze large scale habitat use by leopard in Chitwan National Park and Buffer Zone (CNPBZ). Camera- trap data were collected across the study area from 566 locations, totaling 8,590 trap- nights during two successive winters (2008/09 and 2010) in all the available habitats of CNPBZ (detail description of camera trapping in Chapter 5). Leopard captures were counted at each station for 15 days.

8.2.2 Remote Sensing and Geographic Information System

8.2.2.1 Land Cover Classification

The primary remote sensing data used for this study was the ALOS (Advanced Land Observing Satellite) image (spatial resolution 10 m, Swath Width: 70km) from the Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) sensor. Two scenes of ALOS images were classified into 16 land cover types (Chapter 3) by combining unsupervised and supervised method using ERDAS IMAGINE 9.2. Latter, classes were lumped according to similarity of vegetation and elevation, and possible prey association (*e.g*. hog deer and riverbed complex, chital and flat terrain) into 8 habitat types: lowland Sal forest, mixed Sal forest, hill Sal forest, riverine forest, riverbed complex, tall grassland, short grassland and water body (Table 8.1). Then area of each habitat type that was available within the study area was calculated.

8.2.2.2 Landscape Attributes

A set of landscape and anthropogenic variables were created for each of camera trap station because of their possible effect on habitat use by the leopard. Classified land cover map and digital topographic maps were used for GIS analysis. Each camera trap site was categorized into 5 different categories; (1) main trail- wide trails used by human, domestic elephant as well as wild animals, (2) jungle road- unpaved road used for driving of vehicle, (3) animal trail- narrow trails in the forest mainly used by animals, (4) dry riverbed or sandbank and (5) streambed. At each camera trap location the nearest distances to forest edge, jungle road or main trail and water source (Figure 8.1a) were derived using geographic information system (GIS).

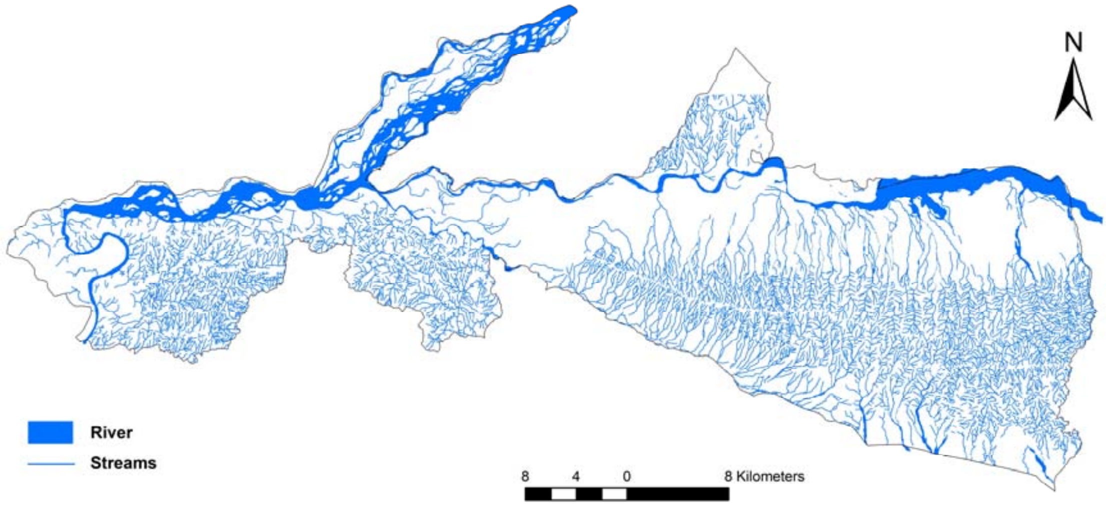
Table 8.1 Descriptions of habitat types used in analyzing habitat use of leopard in the Chitwan National Park and buffer zone (CNPBZ), Nepal.

Habitat classes	**Description**
Low land Sal forest	Sal dominated forest association in moist and flat areas, composed of *Shorea robusta*, *Terminalia alata, Semecarpus anacardium, Syzygium cumini, Dillenia pentagyna, Ficus hispida, Cleistocalyx operculatus, Semecarpus anacardium.*
Mixed Sal forest	Mixed Sal Forest occurred on the slightly elevated gentle slopes in Bhabar and the upper canopy composed of scattered *Shorea robusta* with *Terminalia alata*. Other tree species are *Terminalia sp*., *Adina cordifolia*, *Anogeissus latifolia*, Dilenia pentagyna, *Anogeissus latifolia, Lagerstroemia parviflora, Buchnania latifolia, Diospyros melanoxylon, Hymenodyction spp., Ficus sps, Cedrela toona*
Hill Sal forest	On the drier slopes of Churia range where Sal is associated with *Lagerstroemia parviflora, Adina cordifolia, Buchnania latifolia, Dilenia pentagyna, Bauhinia malabarica, Albizzia sp.,* etc.
Riverine forest	Riverine forest occurs along the rivers and older channels. *Acacia catechu* and *Dalbergia sissoo* forest association is found on the recent sandy alluvial deposits along rivers. *Trewia nudiflora, Bombax ceiba, Listea monosperma, Mallotus philippinensis, Ehretia laevis,* are other important species.
Riverbed complex	Graminoid species such as *Polygonum plebeium, Persicaria spp., Saccharum spontaneum*, and sedges like *Cyperus*, *Kyllinga* grows on exposed sand bank.
Short grassland	Short grasses such as *Cynodon dactylon*, *Chrysopogon aciculatus, Setaria pallid- fusca, Paspalpalium spp.,* and *Digitaria setigera.*
Tall grassland	Tall grasses represented by *Saccharum- Narenga* associations, *Arundo- Phragmites* associations.
Water body	Lakes and rivers

Information on the disturbance was collected during field survey and park records. Major human activity inside the park was tourism (presence of tourists and concessionaire hotels) and patrolling by conservation staff (park staff and Army protection force). Tourism related disturbance was measured as the number of tourists and number of vehicles using the access road inside the park per month. I have collected monthly records of tourist and vehicle entry during the months between November and March from the park, because these months correspond to camera trapping surveys. Mean monthly tourists visitation and vehicle drive was estimated for 6 different tourism zones (Annexure 4). In addition there were seven concessionaire hotels operated inside the park, those had vehicles, staff and domestic elephants using access to the park. Level of disturbance is assumed to be closely related to the distance from concessionaire hotels because the hotels are permitted to drive vehicles and keep domestic elephants. Based on the number of tourist visits, vehicular movement and proximity to the concessionaire hotels (Figure 8.1b), camera trap stations were classified into five disturbances levels; no (no vehicle, no human trails and > 4 km far from hotels), occasional (no vehicle but human trails exist and 3-4 km far from hotels), low (<300 tourist/months but no vehicles and 3 km far from hotels), moderate (300-500 tourists per month, <5 vehicles per day and 2-3 km far from hotels) and high (>500 tourist per month, >5 vehicles per day and within 2 km from hotels).

A digital elevation model (DEM) of the study area was created using 20 meter interval topographic contour lines (produced by Government of Nepal). The DEM is digital representations of map information in a raster form (regular grid with 30-m spacing of cells). Elevation and slope of each camera trap location were derived from DEM using Spatial Analyst extension (Environmental Systems Research Institute) of Arc GIS. Elevation was categorized into four classes <250m, 250- 350m, 350- 500^0m and >500m (Figure 8.2a). The slope was classified into 5 different types measured in degrees from level; flat slope was $0\text{-}10^0$, undulating was 10^0- 20^0, moderate was 20^0-30^0 and steep was more than 30^0 (Figure 8.2b).

(a)



(b)

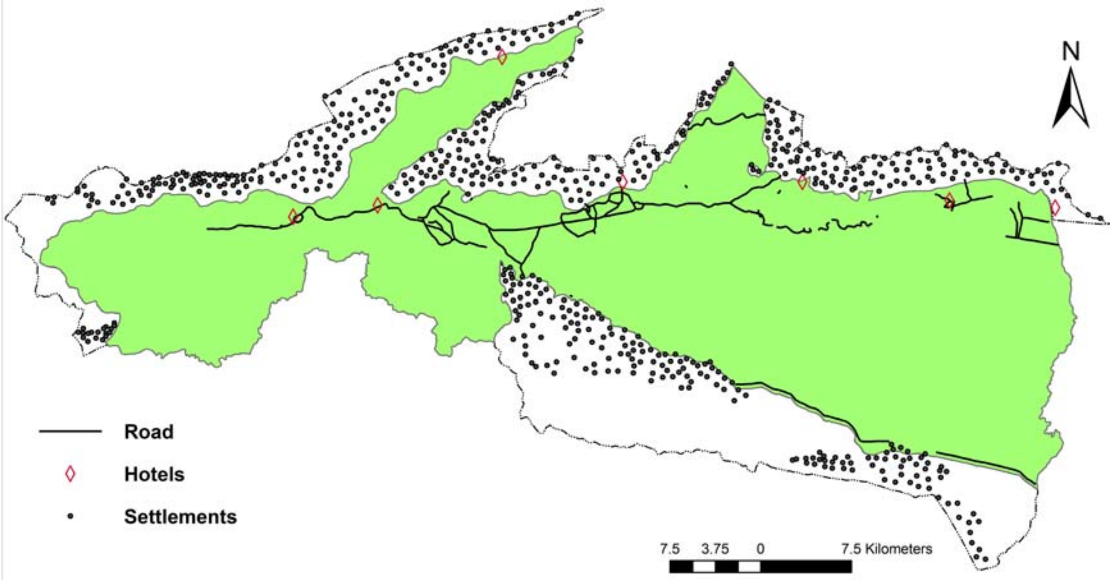
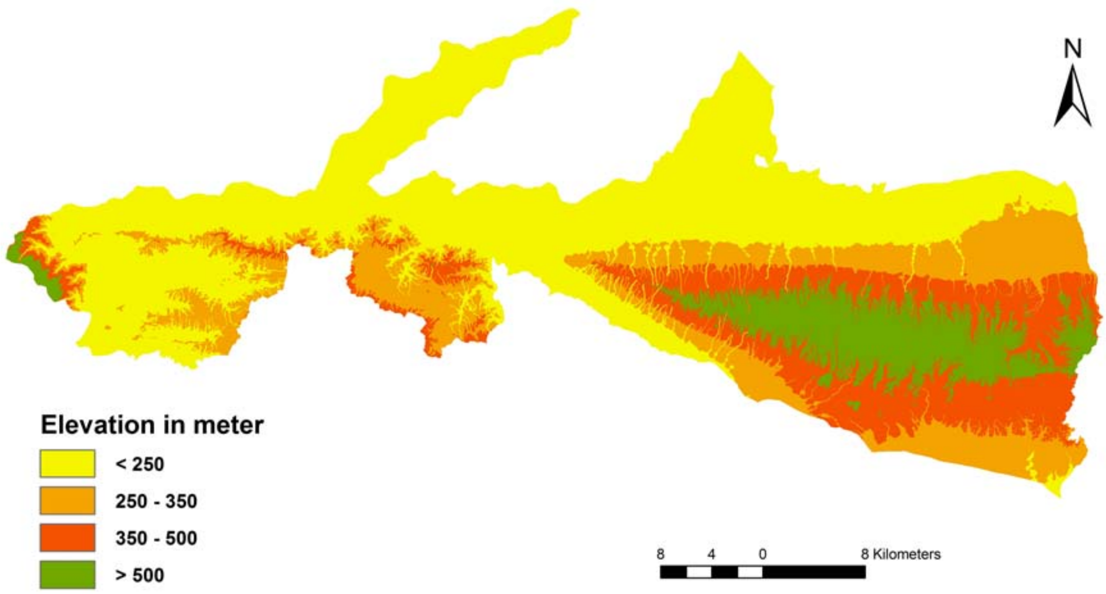


Figure 8.1. Map showing drainage system (a) and park roads and concessionaire hotels in the Chitwan National Park and settlements in the buffer zone (b).

(a)



(b)

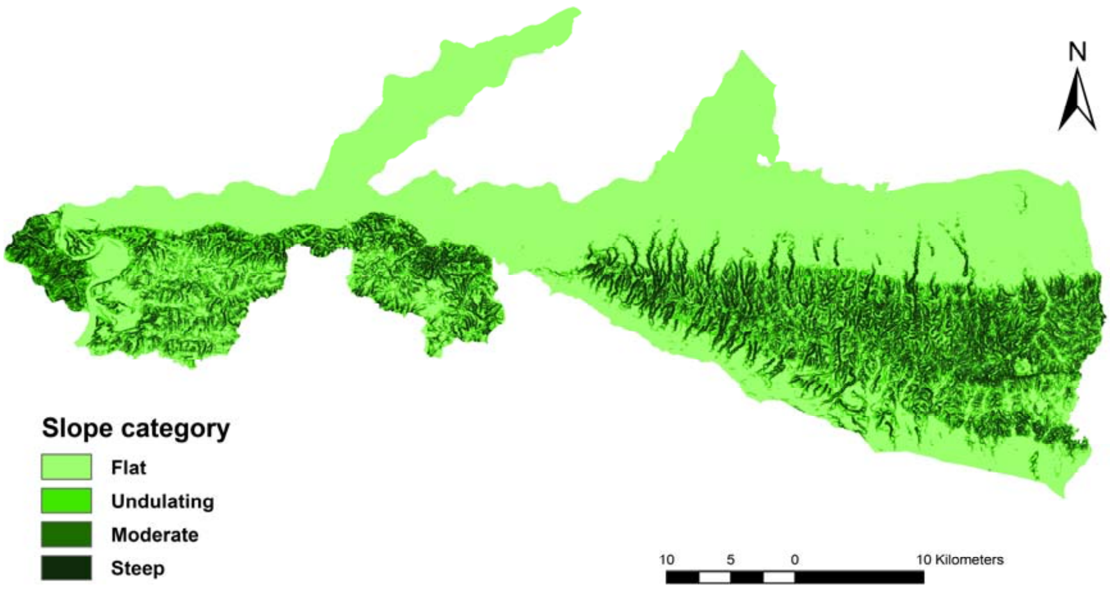


Figure 8.2. Map showing elevation zone (a) and slope category (b) of the study area.

8.2.3 Data Analysis

8.2.3.1 Measures of Habitat Utilization

Leopard photographs were sexed. Habitat use by leopards was determined at each camera trap location by three different measures as (1) presence-absence, (2) relative abundance index (RAI) and (3) total number of independent photo capture. Presence/absence and activity patterns were calculated for each leopard photographed. A relative abundance index (RAI) was defined by the number of independent photographs recorded per trap night and scaled up to 100 trap nights (O'Brien *et al*., 2003). The total number of independent capture (capture events) simply represented an index of how many times leopard used each location.

8.2.3.2 Habitat Classification of Camera Locations

Global Positioning System locations of all camera traps were overlaid on the classified habitat map. Camera trap locations were categorized according to habitat types (riverbed complex, riverine forest, tall grasslands, short grasslands, lowland Sal forest, mixed Sal forest and hill Sal forest) and types of trap sites (animal trail, human trail, jungle road, riverbed and streambed). For every station, distances were calculated to forest edge, jungle roads/trails, water body and point of other human disturbances using GIS.

8.2.3.3 Habitat Availability and Use Analysis

The individual camera stations were treated as the sampling units, assuming that associated habitat characteristics and capture rates were independent due to the wide spacing of trap sites (1- 2.5 km). For habitat availability and use analysis (Neu *et al*., 1974), proportions of camera trap locations in each habitat type were used to represent expected proportion of habitat usage. Camera traps were not placed in water body, hence area of water body was not considered for habitat use analysis. The conventional chi-square goodness-of-fit test was used to assess whether leopards were selecting particular habitat types by examining the photo capture locations in each habitat types. Preference or avoidance of particular habitat type was assessed using availability utilization approach based on Bonferroni simultaneous confidence intervals (Byers *et al*. 1984). Habitat selectivity was then defined by comparing availability (A) and utilization (U), using Ivlev's (1961) index of selectivity = $(U - A)/(U + A)$.

I also examined whether leopard detections are affected by other features on the landscape, such as distance from the forest edge, jungle road/main trails and water and altitude, to facilitate their movement and habitat use. Each of the camera trap location was classified into categories of distance to forest edge, distance to water, distance to roads, and altitudes, and examined distribution of leopard location in each of these categories using chi- square goodness-of-fit test. The distance from forest edge, water and road/main trails were derived from the digital topographic maps. Camera trap location was categorized into animal trail, riverbed, stream bed, jungle road or human trail.

8.2.3.4 Activity Patterns

Temporal patterns of habitat use were also determined based on the analysis of time printed in the photographs. Individual leopards were sometimes photographed by only one of the two cameras operating at a camera trap station, hence the photograph was considered as single independent capture, whether it was photographed by the two camera traps or only by one of them. On rare occasions, an individual was captured more than once in a sampling station during a short period of time (>30 minute), and to avoid pseudo-replication I only considered the first capture of that animal as a record. Activity hours were classified into 2 hours intervals based on the time printed on each photograph.

8.2.3.5 Detection Probability Mapping

Likelihood-based occupancy modeling approach (MacKenzie *et al*., 2002; MacKenzie and Bailey, 2004 MacKenzie *et al*., 2005, Mackenzie *et al*. 2006) was used to estimate site occupancy (ψ) and detection probability (*p*; the probability that the species detection) of leopard using camera trap data. Fifteen days of camera trapping data were pulled into 5 occasions for occupancy modeling. Leopard detection histories (H) were constructed for each camera trap site using a standard 'X-matrix format' (Otis *et al.*, 1978). Thus, for each site and each occasion, '1' indicated the detection (photograph) of a leopard, while '0' indicated the non-detection. Occupancy models were run using program PRESENCE v.3 (http://www.mbr-pwrc.usgs.gov/software/ resence.shtml).

Predicting species occurrence across large areas requires that site-specific information to serve as impute for predictive models. Land cover types, slope, elevation, NDVI value, level of disturbance, site type (trail types) and distance from road/main trail, water sources and settlements were used as covariates (Annexure 5). Land cover data and mean value of DEM and NDVI were extracted using 55- m radius polygon around each trap location. Spatial data used to generate the exploratory set of variables were derived from a land cover map and digital topographic maps. All analysis of spatial data was done using Arc GIS 9.3 (ESRI, Redlands, California, USA) and ArcView 3.3 software. Based on predicted probability of occurrence values of each site a predictive detection probability map was prepared for leopards.

8.3 RESULTS

A total of 178 independent photographs of leopards were obtained from 566 camera trap locations having 8750 camera trap nights. Out of 566 locations, leopards were captured from 112 trap stations during 15 days of sampling occasion in each station (Table 8.2).

Table 8.2 Number of camera traps, number of trap locations, trap effort and number of independent captures.

Survey	Total number of locations	Number of locations where leopard photographed	Trap effort	No of independent photographs
Survey I	256	43	3850	80
Survey II	310	67	4650	98
Total	**566**	**110**	**8750**	**178**

8.3.1 Habitat Availability and Use

The study area encompassed 1276.84 km^2. The most common habitat types in the study area were hill Sal forest (29.5%), lowland Sal forest (29%) and mixed Sal forest (14.5%), followed by riverine forest (7.8%), tall grassland (7.7%), riverbed complex (7.5%), water body (2.8%) and short grasslands (1.2%) (Table 8.3, Figure 8.3). Area of water body was not included in habitat use analysis because camera trap was not placed in the water body.

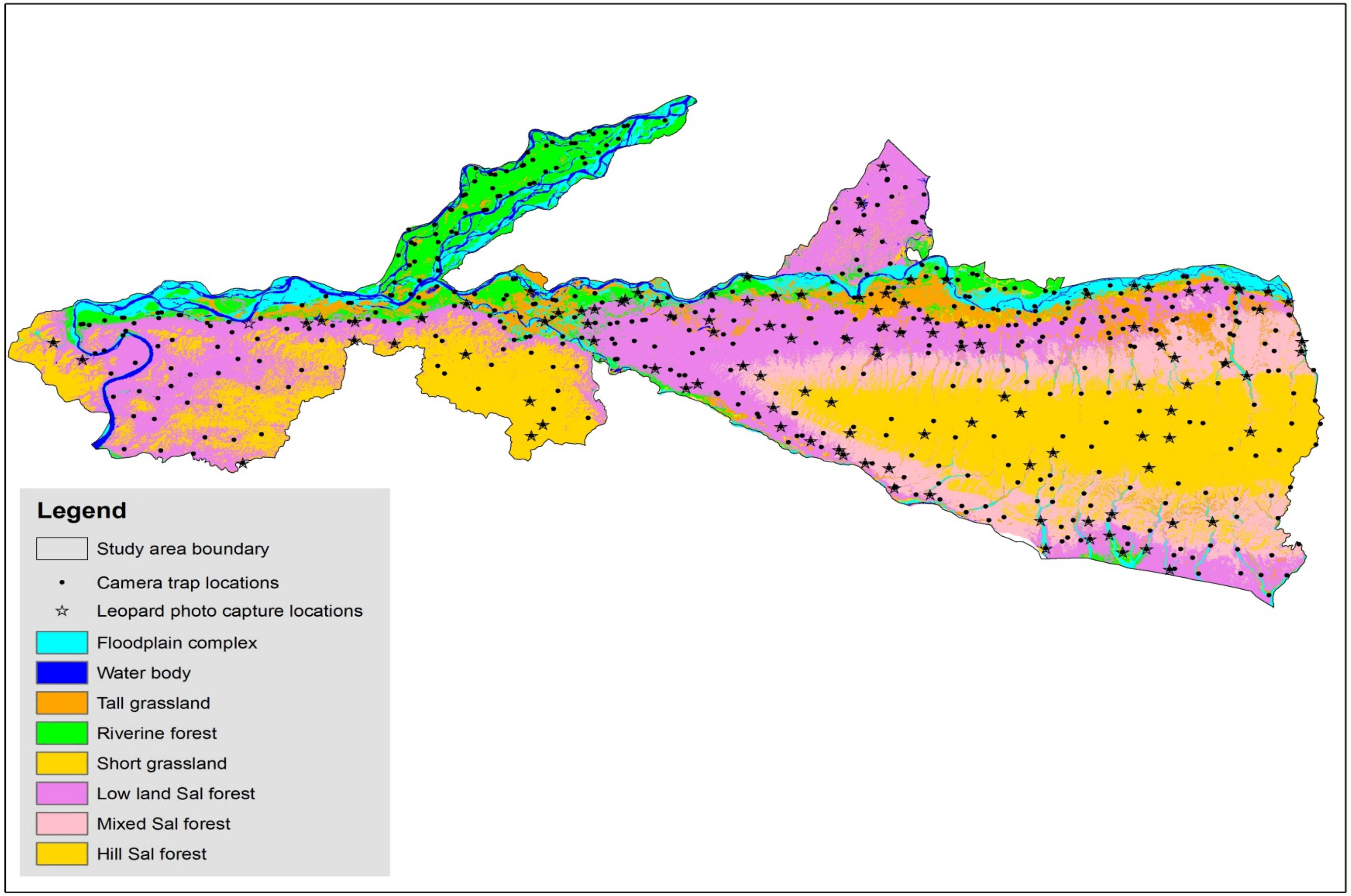


Figure 8.3 Distribution of camera trap locations and leopard photo- trapped locations during 2008/09 and 2010 surveys overlaid on a land cover map of the study area.

Majority of camera traps were located in lowland Sal forest (37.6%) followed by riverine forest (16.4%), mixed Sal forest (14.8%), hill Sal forest (12%) and tall grassland (11%), while riverbed complex and short grassland comprise only small fraction of total trap (8%). Approximately 37% of leopard capture locations and 43 % of independent capture were recorded in the lowland Sal forest. Both percentage of trap locations where leopard photo capture occurred and independent capture were more than the proportion of available trap locations in mixed Sal forest, hill Sal forest, tall grassland and short grassland habitat (Table 8.3). While, both the number of leopard visitation sites and independent captures were lower than the percentage of trap sites in riverine forest and floodplain habitat.

Table 8.3 Percentage of camera traps deployed, camera traps where leopard photo captured and independent captures under different habitat types in the study area.

Habitat types	**Trap (n= 566)**	**Trap locations where leopard photo captured (n= 112)**	**Independent capture (n= 178)**
Lowland Sal forest	37.6	36.6	42.7
Mixed Sal forest	14.8	21.4	18.0
Riverine forest	16.4	5.4	7.3
Hill Sal forest	12.0	16.1	13.5
Tall grassland	11.1	14.3	14.0
Riverbed complex	6.5	2.7	1.7
Short grassland	1.4	3.6	2.8

Estimated value of relative abundance index (RAI) was higher in short grassland habitat (4.17) followed by tall grassland (2.65), mixed Sal forest (2.54), lowland Sal forest (2.38) and hill Sal forest (2.3) (Figure 8.4). The RAI value was estimated to be low for riverine forest (0.93) and riverbed complex (0.54).

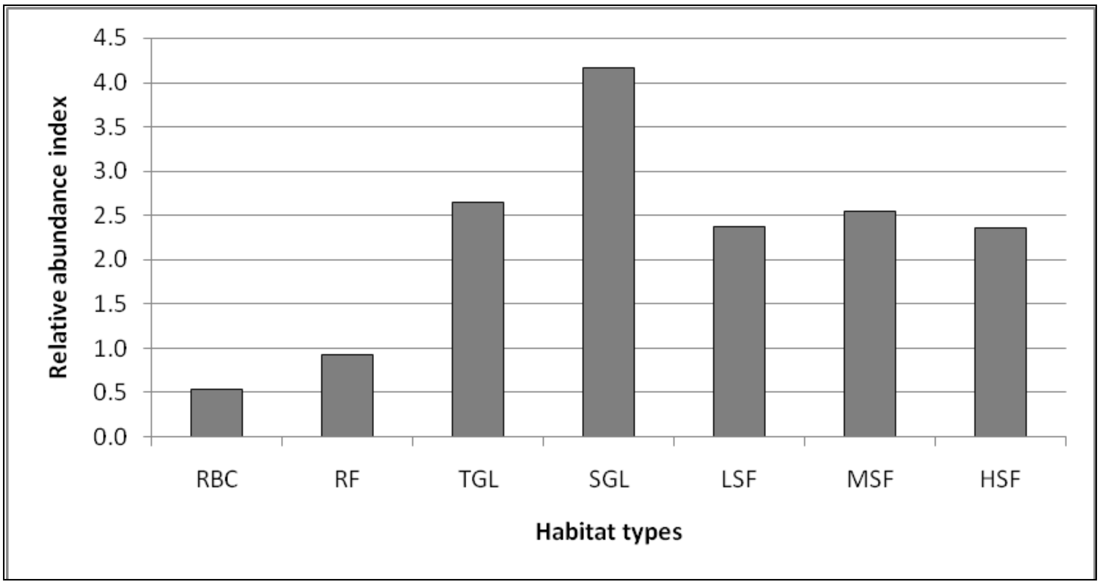


Figure 8.4. Relative abundance index of leopard in different habitat types in the Chitwan National Park, 2009/2010 (RBC- riverbed complex, RF- riverine forest, TGL- tall grassland, SGL- short grassland, LSF- lowland Sal forest, MSF- Mixed forest, HSF- hill Sal forest)

The distribution of all leopard photo trapped locations in each habitat type revealed that in general, leopards used habitat disproportionately to their availability (χ^2 = 12.65, df = 6, P = 0.04). More visits than expected occurred at short grasslands, tall grasslands, low land Sal forest, mixed Sal forest and hill Sal forest. In contrast, leopard visitation was less than expected in the riverbed complex and riverine forest.

Table 8.4 Bonferroni simultaneous confidence intervals for habitat selectivity by leopards in Chitwan National Park, Nepal.

Habitat types	**Expected proportion of usage**	**Actual proportion of usage**	**Bonferroni interval for habitat use**
Riverine forest	0.166	0.073	$0.011 \le \mathbf{P_1} \le 0.135$*
Riverbed complex	0.065	0.017	$0.00 \le \mathbf{P_2} \le 0.048$*
Hill Sal forest	0.118	0.135	$0.053 \le \mathbf{P_3} \le 0.217$
Lowland Sal forest	0.376	0.427	$0.308 \le \mathbf{P_4} \le 0.546$
Mixed Sal forest	0.148	0.180	$0.088 \le \mathbf{P_5} \le 0.272$
Short grassland	0.014	0.028	$0.000 \le \mathbf{P_6} \le 0.068$
Tall grassland	0.111	0.140	$0.057 \le \mathbf{P_7} \le 0.224$

* Significant at 95% level

Bonferroni simultaneous confidence intervals showed that leopard utilized riverine forest and riverbed complex significantly less than expected (Table 8.4). Lowland Sal forest, mixed Sal forest, hill Sal forest, short grassland and tall grassland were used more than their availability (Table 8.4, Figure 8.5).

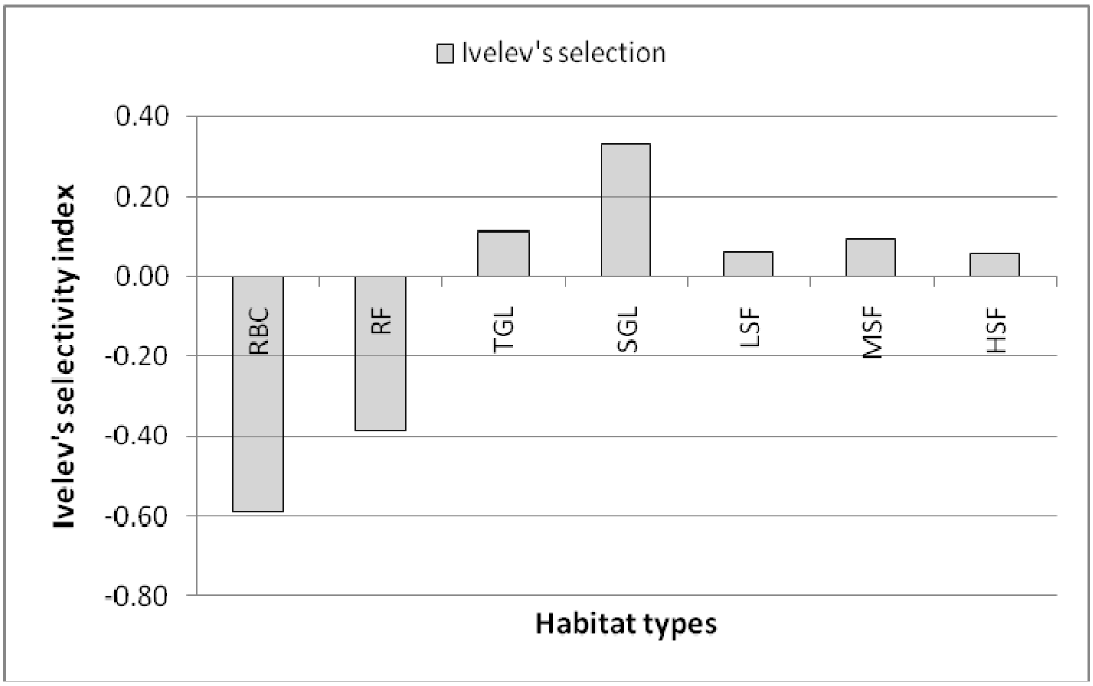


Figure 8.5. Habitat selection (Ivelev's selectivity index) by leopard in Chitwan National Park, Nepal (RBC- riverbed complex, RF- riverine forest, TGL- tall grassland, SGL- short grassland, LSF- lowland Sal forest, MSF- Mixed forest, HSF- hill Sal forest).

8.3.2 Effects of Landscape and Anthropogenic Factors on Habitat Use by Leopard

Camera trap placement was most frequent on main trails (188) followed by dry riverbed or river sand bank (118), animal trail (100), jungle road (92) and dry stream bed (68). Out of 178 independent photo capture of leopard, 38% took in trap placed on main trail followed by jungle road (16%), riverbed or sand bank (16%), stream bed (16%) and animal trail (16%). The proportion of leopard visitation sites was higher than availability in the main trails and small stream bed, but lower than availability at the river sand bank or dry riverbed and animal trail (Figure 8.6). However, the trail type did not significantly influence the trail use by leopard (χ^2 = 4.44, df = 4, P = 0.349).

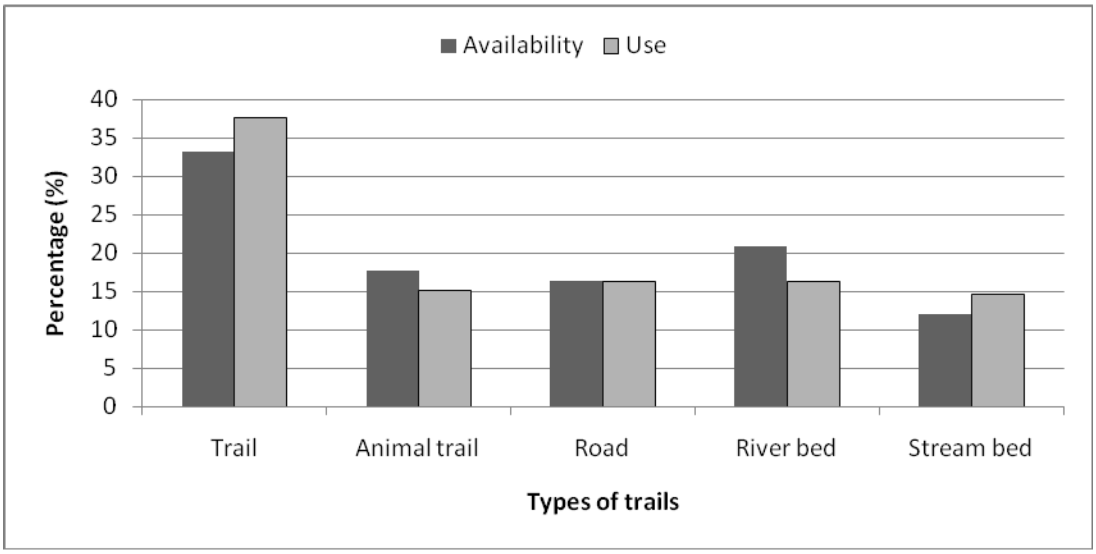


Figure 8.6 Availability and use of trail (site) types by leopards in Chitwan National Park and buffer zone, Nepal.

The influence of distance to forest edge and jungle road/main trail, and level of disturbance on leopard visitation to the trap site was evaluated by comparing proportion of independent captures to proportion of total camera trap sites in each category of distance and disturbance. Camera photo trap success clearly indicated that the leopard habitat use was affected by the human disturbances. The locations of leopard photo captures were not distributed as expected in each category of distance to forest edge (χ^2 = 8.256, df = 3, P= 0.041) while more than 90% captures occurred far from 1 km from the forest edge (Figure 8.7a). Similarly, the leopard visitation to camera trap site located at different category of distance from the jungle road/main trail inside the park was found to be disproportionate (χ^2 = 8.937, df = 3, P = 0.029). The proportion of independent photo- capture was lower than the proportion of trap deployment within 1 km from the road/main trail but higher than the availability in other categories (Figure 8.7b).

Majority of camera trap locations were placed on the sites with no (160) or occasional (152) instances of disturbances, followed by low (118), high (77) and moderate (59) level of disturbance. Approximately, 36% of capture occurred at site with no disturbance followed by occasional (31%) and low (16%) level of disturbance, while remaining 16% captures occurred at the sites with high and moderate level of disturbance (Figure 8.7c). Leopard was found to be sensitive to human disturbances (χ^2 = 11.34, df = 4, P= 0.04).

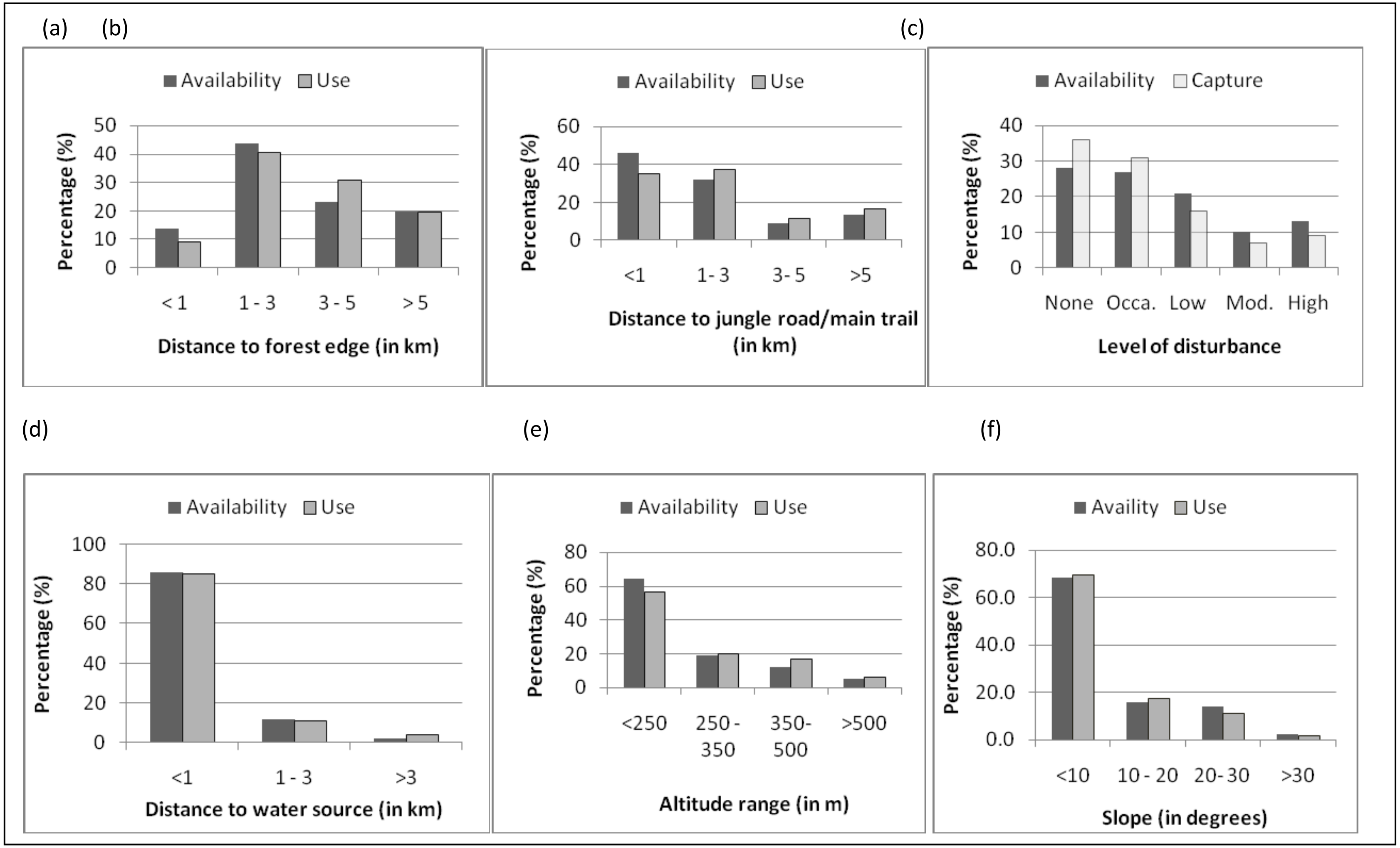


Figure 8.7 Habitat availability and use by leopard under different categories of distance to forest edge (a), distance to jungle road/main trail (b), level of disturbance (c), distance to water sources (d), altitudes (e) and slopes (f).

With respect to the distance to water, the distribution of leopards occurred according to the expectation ($\chi^2 = 3.171$, df = 2, P = 0.205) (Figure 8.7d) and water sources were within 4 km distance from all camera trap locations. The topographic variables did not significantly affect the visits of leopards at the camera trap locations. Leopard visited the traps at different altitude category ($\chi^2 = 5.53$, df = 4, P = 0.23) and slopes ($\chi^2 = 1.36$, df= 3, P= 0.71) as expected (Figure 8.7e and f).

8.3.3 Activities of Leopard

Leopard activity was found to be slightly higher during the night time (52%). Activity patterns showed, males were more nocturnal (62.4%) and females were more diurnal (61.4%), while both sexes were found to be crepuscular more active between 16.00-22.00 hours. Both male and female were nocturnal close to forest edges and points of human disturbance.

Male leopards were captured more often at night than during day. Male seem to have two peaks of activity, one before mid- nights (hours between 20 and 22) another early morning (02- 04 hrs) (Figure 8.8). However, female leopards were more active during day, but activity peak reached just before sun set.

Figure 8.8 Dailey activity patterns (percentage) of leopards at the Chitwan National Park and buffer zone, Nepal.

8.3.4 Site Occupancy

Based on camera trap photo captures of leopard, the raw detection rates was 19.96% (112/566 sites) for leopards. This value can be considered naïve estimates of occupancy (*i. e.,* they do not take into account probability of detection). Adjustment of covariates raveled actual occupancy of leopard was 35 % of the study area. A predefined time independent detection probability model was used for occupancy analysis [Logit (ψ) = -1.23 (±0.31) + 0.05 (±0.04) x slope + 0.07 (±0.04) x disturbance, -2log (likelihood) = 1145.42, AIC = 1153.42)]. Only disturbance and slope were found to be important for leopard detection (Table 8.5).

Table 8.5 Estimates of coefficients for covariates (Beta's) in occurrence model

Parameters	**Untransformed**		**Transformed**	
	β	SE	β	SE
Psi intercept (ψ)	-1.23	0.312	0.292	1.37
Slope in degree	0.05	0.039	1.051	1.04
Level of disturbance	0.07	0.037	1.073	1.04
Detection probability of intercept (p1)	-1.7	0.16	0.183	1.17

8.3.5 Predictive Probability of Occurrence Map

The map derived from site occupancy model results revealed that the leopards predicted detection probability was low in most part of the study area. Suitable areas for leopards were scattered into smaller patches (Figure 8.9).

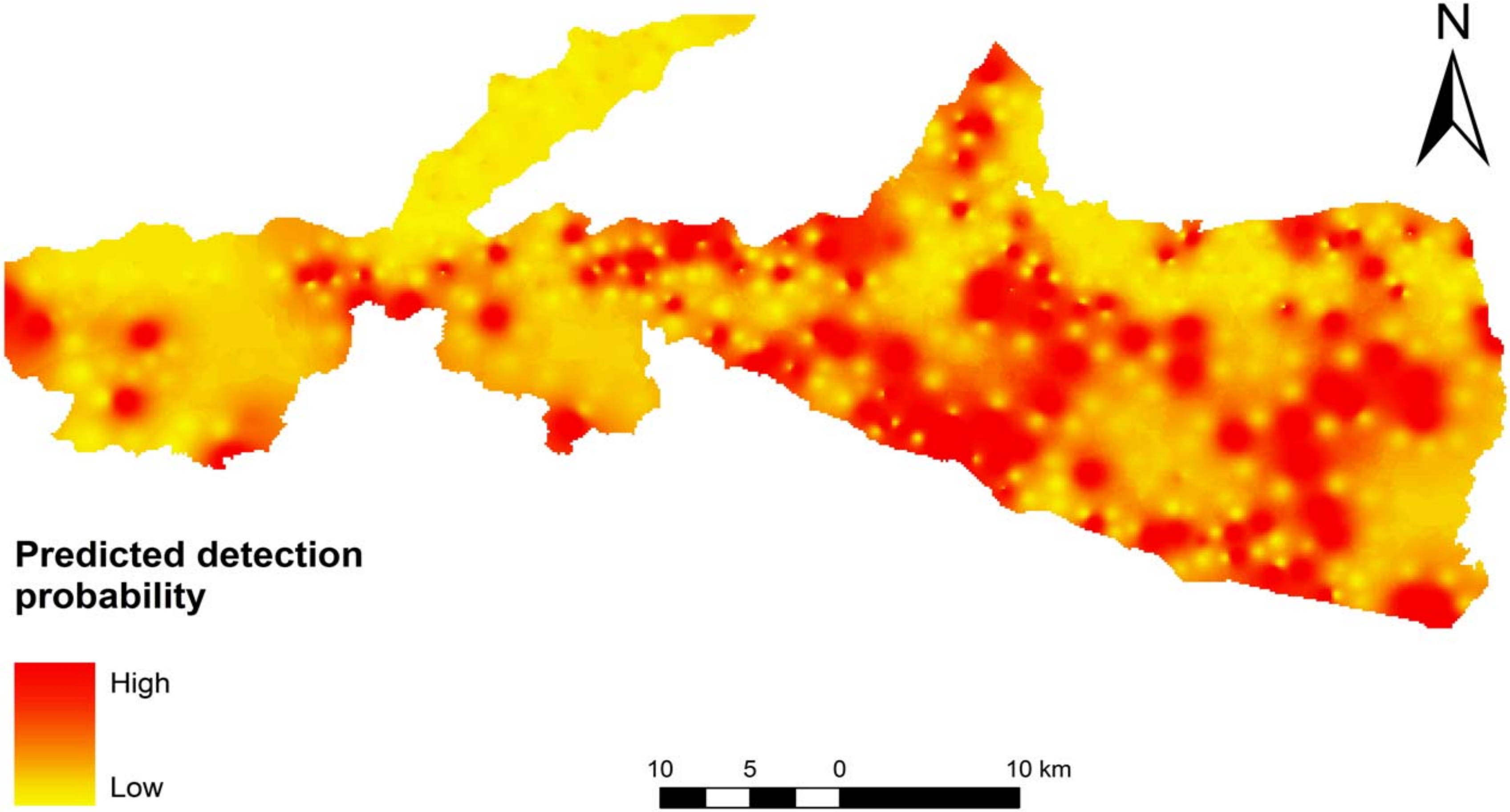


Figure 8.9. Predicted probability of leopard occurrence based on site occupancy.

8.4 DISCUSSION

8.4.1 Habitat Availability and Use

Analysis of habitat use and selection assumes that species choose those habitat components which will increase fitness, survival and reproductive success. This study focused on habitat use of leopard by analyzing short-term camera trap photo capture data. Large number of data sets and long term study would be required to determine variation in habitat selection for different seasons; however, this study provided some important information to describe large scale habitat selection by leopards during winter season in relation to various landscape attributes and anthropogenic disturbances. Landscape attributes and prey abundance appear to be the proximate factors driving resource selection in carnivores (Stephens and Krebs, 1986).

Use of all the available habitat types by leopards indicates their ability to inhabit a variety of habitat types. However, the camera trap photo-capture in various habitats indicated that leopard differed in the use of habitats available within the study area (χ^2 = 12.65, df = 6, P = 0.04). They preferred the grassland (tall and short) and Sal forest habitats whereas significantly avoiding riverine forest and riverbed complex (Table 8.4, Figure 8.5). Most important factors determining the habitat use by carnivore are availability of suitable prey and hunting success (Blame *et al*., 2007). The Sal forest and grassland habitats may provide leopards with key resources such as prey to hunt and cover for hunting and concealment. Like other cats, leopards rely on features of the landscape to approach their prey before attacking. Blame *et al*. (2007) reported that the leopards preferred hunting in habitats where prey is easier to catch rather than prey abundance. Therefore, prey density may not be an important factor for habitat selection by the leopards. Leopards need some sort of cover to minimize kleptoparasitism by keeping carcasses in trees, caves and large burrows or dragging them into dense vegetation (Sunquist and Sunquist, 2002). The probability of a kill occurring was greater in areas with intermediate cover levels, and these habitat types were favoured by leopards for hunting (Blame *et al.* 2007). Hence suitable habitat for hunting success can be an important mechanism for habitat selection. The Sal forests and grasslands in the study area provided adequate vegetative cover needed for leopards to successfully ambush and kill their prey.

Result of this study showed that leopards tended to avoid the most densely vegetated areas such as riverine forest and most sparsely vegetated areas in the seasonally flooded river beds. Avoidance of riverine forest by leopard could be related to decrease in prey encounter with increased vegetation density. Blame *et al*. (2007) also reported that the lower detectability of prey species in dense vegetation was the principal factor governing the decreased hunting by leopard and avoiding such habitat. Avoidance of riverbed habitat can be attributed to low vegetation coverage mainly of seasonal grass not adequate for leopard to hide and approach undetectably the prey species. In addition, the riverbed habitat in Chitwan is located along the park border which is subject to the human disturbance; a potential factor causing reduced use of such habitat by leopard. Edgaonkar (2008) reported that the good leopard habitat was associated with terrain ruggedness, sambar availability and percentage of forested areas. The distribution of chital which is most abundant (Chapter 4) and preferred prey species (Chapter 6) of leopard was mainly restricted to flat areas in grassland, riverine forest and lowland Sal forest, while the sambar was widespread in distribution. Optimal foraging theory, which predicts predators should choose the most profitable prey (MacArthur and Pianka, 1966), can be useful to understand the habitat use and selection by the leopard. However, profitability may be influenced by a combination of search time, encounter rates, and energetic costs of capture (Sunquist and Sunquist, 1989). The riverine forest which is much dense and difficult to move through, the high search time and low encounter rates may make hunting in those habitats unprofitable and therefore avoided by leopard.

8.4.2 Effects of Landscape and Anthropogenic Factors on Habitat Use by Leopard

At Chitwan leopards reported a higher capture rate on main trail used by human as well as animal, and streambed than on animal trails and dry riverbed or sand banks. The difference in trail use by leopard can be attributed to the fact that the main trail and streambed being used by prey species and becoming landmarks that big cats frequently use to demarcate their territories (Smith *et al*., 1989; Sunquist and Sunquist, 2002; Ghoddousi *et al*., 2008). The jungle road could be preferred travel lane for the leopard, but day time traffic could lower the use by leopard. Several authors have reported the preference of big cats for walking roads or trails instead through the forests (Karantha and Nichols, 2002; Carbone *et al*., 2001). Carbone *et al*. (2001) reported that camera-trap capture rates of tiger are much higher than those expected under a simple walk model, indicating that researchers place camera trap at places where tiger traps are maximized.

Although, leopards are reported to inhabit in close proximity to human habitats, where they prey upon livestock (Seidensticker, 1976a; Sunquist and Sunquist, 2002; Odden and Wegge, 2005), but the results of this study clearly indicate that they were sensitive to human disturbance. Frequency of leopard photo captures were not distributed as expected in each category of distance to forest edge (χ^2 = 8.256, df = 3, P= 0.041) and jungle road/tourist trail (χ^2 = 8.937, df = 3, P = 0.029). In particular, habitat use by leopard was lower than the availability within 1 km distance from the forest edge in this study area, as reported in Thailand, where leopard activities were negatively correlated with distance from the villages (Ngoprasert *et al*., 2007) and in India the agricultural land cover and livestock presence had negative effect on leopard (Edgaonkar, 2008). Similar negative impact of settlements on leopards was reported in the Congo basin (Henschel, 2008). Researchers have proposed three important reasons to explain lower level of activities of large predator along the forest edge and jungle roads; reduced prey abundance (Glanz, 1991; Bodmer *et al*., 1994; Carrillo *et al*., 2000; Robinson and Bennett, 2000; Johnson et al., 2006), poaching (Woodroffe and Ginsberg, 1998) or anthropogenic mortality (Blame *et al*., 2010) and disturbance due to human traffic (Ngoprasert *et al*., 2007). However, prey estimation in the northern part of the CNP and BZ (Chapter 4), which was conducted in areas close to park boundary did not support that prey abundance was low close to the forest edge and jungle roads. Therefore, sensitivity to variation in prey abundance may not be a likely explanation for the avoidance of forest edges by leopards (Ngoprasert *et al*., 2007). Although, direct poaching of leopard was not reported from the study area, but human- induced mortality (n= 5 confirm cases and 2 suspected) recorded at the buffer zone (Chapter 7) can partly explain the edge effect on leopard. Blame *et al*. (2010) also reported both natural and anthropogenic mortality was higher near the border than that closure to the core. The disproportionate habitat use of leopard in different category of distance to forest edge, jungle road/tourist trail and level of disturbance (χ^2 = 11.34, df = 4, P= 0.04), clearly indicated that leopards are sensitive to human disturbances. Human traffic is concentrated along the park border, in the jungle roads, tourist trails and around the concessionaire hotels. Proximity to forest edge and jungle roads/tourist trails are associated with high human disturbance and lower activity of leopard. Ngoprasert *et al*., (2007) demonstrated adverse effects on leopards from human presence and activity in the Kaeng Krachan National Park, Thailand.

The topographic variables and distance to water did not significantly affect habitat use of leopards. Water resource was not the limiting factor for leopard in Chitwan, because distance to nearest water sources was within 4 km for all trap locations. But, Ngoprasert *et al*., (2007) found that leopard use habitat in Kaeng Krachan National Park, Thailand was greater in closure to streams. Similarly, altitude and slopes did not limit the habitat use of leopard in Chitwan. The higher altitudes and slopes in the study area correspond to the least disturbed areas, as they are far from the human settlements. The Churia range can be considered as a complex topographic area that facilitates many species to find refuge from predators and from adverse human-induced environmental change.

However, more independent capture would have been desirable to describe detailed activity patterns and temporal habitat use of leopard, the photographic records obtained in this study (n= 178) provide adequate evidence of the general activity patterns for both male and female (Figure 8.8). The general activity periods of male and female leopards were different, males were more active during nights and females were more active in day. Both sexes were found to be crepuscular and more active between 16.00- 22.00 hours and both were nocturnal in areas with high human traffic. Odden and Wegge (2005) reported similar patterns of activity of radio collared male and female leopards in Bardia. Leopards in Kaeng Krachan National Park, Thailand were primarily diurnal and crepuscular (Ngoprasert *et al,* 2007). Leopards were diurnal in areas with no human traffic.

Apart from places with low human activity, leopards prefer areas with intermediate cover, as well as, gentle slopes. These habitat conditions offer important survival resources to leopard like camouflage, shelter, efficiency to secure preys and protection of their litter (Sunquist and Sunquist, 2002). Results of this study indicate that leopards were selective in habitat choice (Blame *et al*., 2007) and sensitive to anthropogenic disturbances (Ngoprasert *et al*., 2007). Therefore, this result supports the suspicion of previous researchers (Spong *et al*., 2000; Blame and Hunter, 2004;

Ray *et al*., 2005; Blame *et al*, 2007; Ngoprasert *et al*., 2007; Simcharoen *et al*., 2008) on the widely held view that leopards are 'super generalists' in habitat use and anthropogenic disturbances, and contradicts the general inference that leopard needs little dedicated conservation action.

The occupancy models incorporating predictor variables indicate that approximately 35% of sites were occupied by leopard across the study area. This was better than the naïve estimate of 0.1996, indicating the naïve estimate under represents the actual proportion of site occupancy. Regardless, the low proportion of sites occupied suggests that suitable habitat is not being filled by leopard. Lower site occupancy probability related to the low population density (Chapter 5) and short duration of camera trapping study for each site. Results of occupancy model indicate that the sites at the steep slopes and high disturbance were less likely to be occupied, implying that leopards avoid these areas. The occupancy model can provide important insight into the distribution, proportion of area occupied (*e.g.* abundance), and habitat requirements of a species and can help to refine habitat suitability (Sears, 2002).

Understanding how the predators use habitat components relative to the availability and how landscape attributes influence their choice is vital for predicting their survival across landscapes. In areas, where multiple carnivores live sympatrically, comparisons of man-modified to natural habitats are valuable for predicting human impact on coexistence (Foster *et al*., 2010). For example, the vulnerability of competitively inferior species within carnivore guilds may increase under pressure from human activity (Creel, 2001; Woodroffe, 2001). In Terai and most part of tropical Asia, leopards shared habitat with its superior competitor, the tiger. In such circumstances, the tiger is likely to displace leopard from core habitat to fringe area (Seidensticker, 1976a; McDougal, 1988; Odden *et al*., 2010, Harihar *et al*., 2011), where it attacks livestock with resulting persecution by people (Chapter 7). Therefore, a comprehensive study to understand influence of tiger on the resource selection by leopard is needed in future.

Chapter 9

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Conservation and management of leopard (*Panthera pardus*) is hampered due to lack of information on abundance, distribution and resources use. The purpose of the present study was to collect basic information on the ecology of the leopard in and around the Chitwan National Park, one of the last refuges for many large mammalian species in the Terai of Nepal. The study focused on characterizing land cover and landscape patterns, estimating population and density of leopards to generate baseline information on its status, investigating prey availability and selection, and leopard-human conflicts. The study also looked into habitat use by leopard to assess the landscape features and anthropogenic activities that influence the habitat use.

9.1 SIGNIFICANCE AND CONTRIBUTIONS

In this thesis, Chapter 3 presents an analysis of land cover and landscape patterns in the Chitwan National Park and buffer zone (CNPBZ) using high resolution remote sensing data. Advanced Land Observing Satellite (ALOS) imageries and ground truthing enabled to delineate 16 land cover types with high overall accuracy (85%) and Kappa Index of Agreement (83%). Most dominant land cover type was Sal forests associations (73%) followed by grassland associations (12%), riverine forest forest associations (7%), exposed surface and water body. Present classification was found compatible with the previous descriptions of the vegetation patterns and succession in the lowlands of Nepal. Use of high resolution satellite imagery provided increase in thematic resolution in mapping (increased number of classes) and more robust calculation of landscape metrics. Landscape of CNPBZ is composed of mosaics of various landscape elements with high spatial heterogeneity at a finer resolution.

Chapter 4 provides robust prey population estimates in the northern part of Chitwan National Park and buffer zone. Results indicate that the study area supports a high density (84.3 to 123.9 km^{-2}) and biomass (6966 kg km^{-2}) of ungulate prey species compared other protected areas in Terai. Chital and sambar contributed bulk of biomass (80%) like elsewhere in Nepal and south Asia. Substantial increase (309%) in density ungulate species was recorded in this study compared to previous study done in early eighties (Tamang, 1982). The increase has been mainly due to removal of livestock and human pressures and intensive habitat management. The sex ratios of all prey species (chital, sambar and wildpig), except barking deer, were in favour of females probably indicating male biased predation by carnivores.

Chapter 5 provides first rigorous population and density estimates of leopard in Nepal using camera trap surveys and analysis of data by both non-spatial capture- recapture and Bayesian spatially-explicit capture-recapture (SECR) models. Camera trapping was found to be an effective methodology to estimate leopard abundance. SECR models are advance analytical tool to estimate densities, because they overcome the problem of interpreting abundance and make use of the full information obtained by camera trapping data, including auxiliary spatial information. Although the capture probabilities were high (0.08 to 0.17) but sampling occasions (15 days) used in this study appears somewhat inadequate to estimate leopard densities. Leopards also showed trap avoidance behavior, males were more camera friendly than females. The population and density estimates from CNPBZ were lower than estimates from other contemporary studies from India. Lower density estimates in this study were probably related to (i) big sampling area with varying level of prey base and disturbances, and (ii) effect of presence, interaction and competition with tiger.

Chapter 6 describes food habits and prey selection by leopards. Analysis of 263 scats collected during 2007- 2009 revealed that the prey spectrum of leopards in and around CNPBZ was as diverse as in other areas in Nepal and south Asia. When data from both the seasons was compared, summer season diet was similar to winter diet. The medium sized ungulate particularly chital was dominant (46.13%) in leopard diet in prey rich habitat but in prey poor habitat leopard switched to sub optimal (rodents) and secondary prey (livestock). This difference in diet indicates that leopards are indeed opportunistic carnivores with highly flexible in feeding habits. Leopards selected most abundant prey and avoided prey species with low densities. The leopard's flexibility to adapt its foraging behaviour to a site specific prey base is a strategy for survival in human modified landscapes but it also predisposes the species to conflicts with humans.

Chapter 7 presents an evaluation of complex issue of management of human-large cat conflicts in the buffer zone of CNP. The results showed that both leopards and tigers were important livestock predators and leopard preferentially predate on small body sized livestock (particularly goats) more often, whereas tiger kills both small as well as large body sized livestock. Therefore, implementation of effective livestock protection measures particularly of goats is needed to reduce conflicts between people and large cats. Presently, leopards are not a serious threat for humans in Chitwan, but this situation may change in future. Despite the conflict, perceptions of people on the large felids were predominantly positive.

Chapter 8 provides information on habitat use of leopard based on availability and use. Though leopards are considered being generalist in their habitat use, but this study has supported the view that leopard is not a super generalist (Blame *at el*., 2007). There were significant differences among habitat types that leopards did use versus those they did not use. In Chitwan leopards prefer the grasslands and Sal forests, but avoid riverine forest and seasonally flooded river bed habitats. The Sal forest associations and grasslands comprise approximately 85% of the study area. Trap location types seem to have some role in determining the trap success. While it is known that leopards tend to avoid anthropogenic disturbances (Ngoprasert *et al.*, 2007), this research presents some evidence that the human activities may play an important part in this behavior. The topographic features did not affect habitat use of leopard in Chitwan. Though analysis was based on limited data sets but this study indicates variance with some preconceived notions about leopard ecology as it relates to habitat use. Leopards were selective for habitat, if there are choices.

9.2 SYNTHESIS

This study has provided new insights on several ecologically important aspects of leopard population and resource selection (prey and habitat) in which they appear to cope with changing environments, where habitats and food resources vary both temporarily and spatially. Availability of food resources in space and time can affect the diet selection, ranging patterns, habitat use and size and growth rates of population.

CNP is the one of the largest contiguous protected area in Nepal Terai and thus a key area for the conservation of leopards and other large mammals. The park has mosaics of heterogeneous landscape, intact population of medium and large sized ungulates, well distributed drainage systems, and large areas with relatively low level of disturbance, and positive perception of people living in the buffer zone. Hence, CNP is a good habitat for conservation of leopards and the present study has provided first base line information on leopard which would be of immense useful for comparing status of leopard in future.

9.3 MANAGEMENT IMPLICATIONS

The findings presented here represent the first detailed study of the leopard, and provide a good starting point from which to direct population monitoring and more dedicated management programs in future which may be undertaken in Terai Arc Landscape of Nepal. The following are the major management implications from this study:

- Data on land cover classification and landscape patterns generated by this study can serve as baseline spatial information which could be useful for monitoring changes in land cover and landscape dynamics in future. In addition, this spatial data can also be useful for research and management of wildlife species particularly associated with grasslands and riverine forests. Grasslands and riverine forests are the most dynamic, productive and heterogeneous part of Terai ecosystem which need to be assessed periodically by using high resolution remote sensing data.

- Northern part of CNPBZ supports intact population of prey hence a better protection and habitat management strategy is needed to maintain high prey population to support a relatively large population of predators. A park wide regular prey monitoring program requires an understanding of population dynamics and availability of prey species for predators, which in part this study has provided and can be used in formulating a monitoring program.

- The benchmark density estimates of this study will be useful for leopard monitoring in future. Long-term population monitoring using camera traps in and around CNP is needed to estimate leopard survival, recruitment, immigration and emigration. In addition to abundance estimate, camera trap data can be used to estimate occupancy, habitat use and interaction with other sympatric carnivores.

- A reduction in leopard-human conflicts is desirable for livestock owners, conservationists, and managers. Implementation of effective livestock protection measures (particularly goat) and strengthening of the current participatory and benefit sharing buffer zone management programs linked with conservation education targeting to the poorest people around the park would be an important step forward for enhancing their understanding and acceptance of the need for large cat conservation.

- The long term conservation of leopards entails a complex task of integrating ecological, economic and social factors in the planning of effective strategies. Therefore it will be important to devise a conservation plan that would bring ecological knowledge into the realm of the local community and ensure their active participation in a larger conservation scenario.

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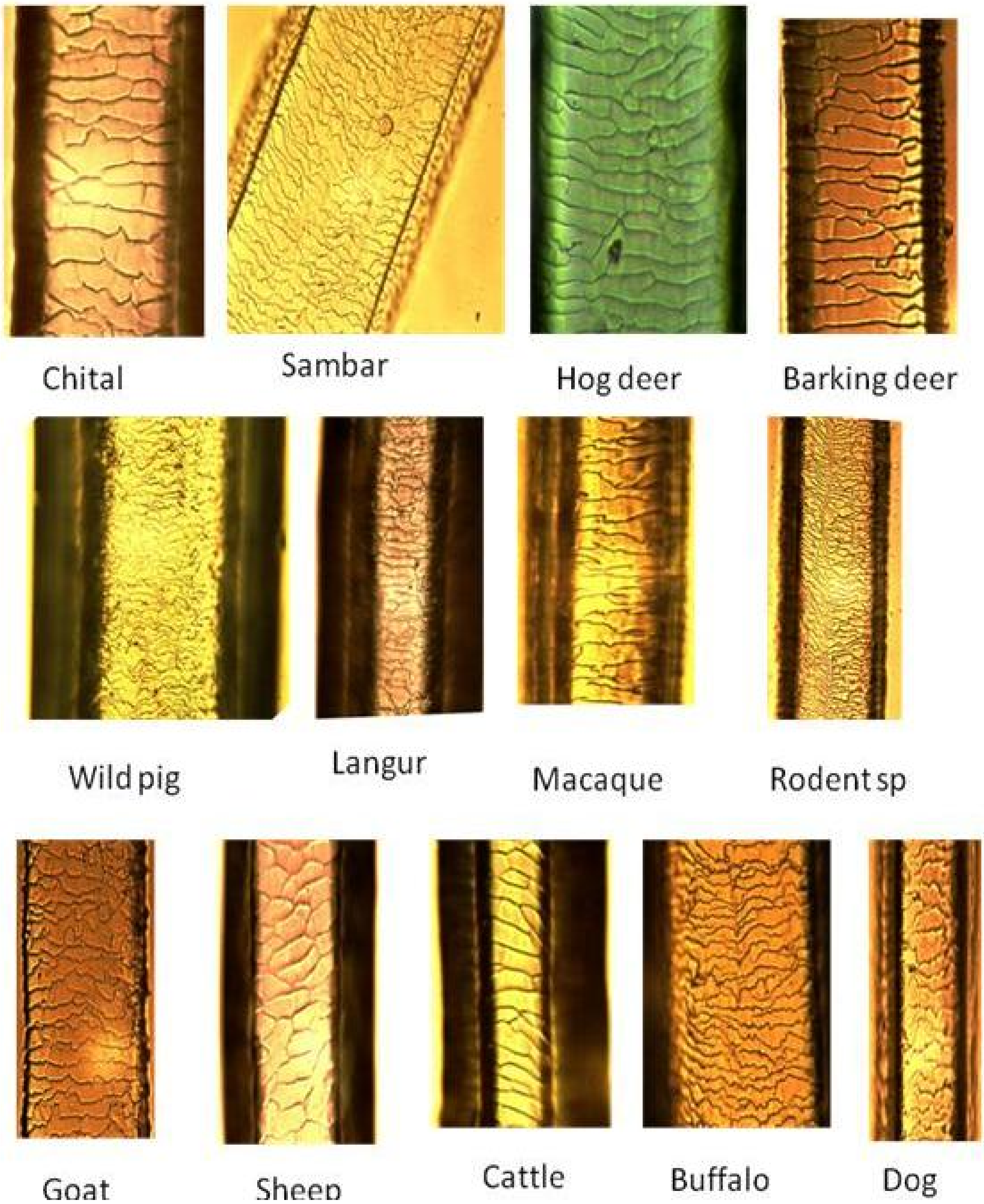
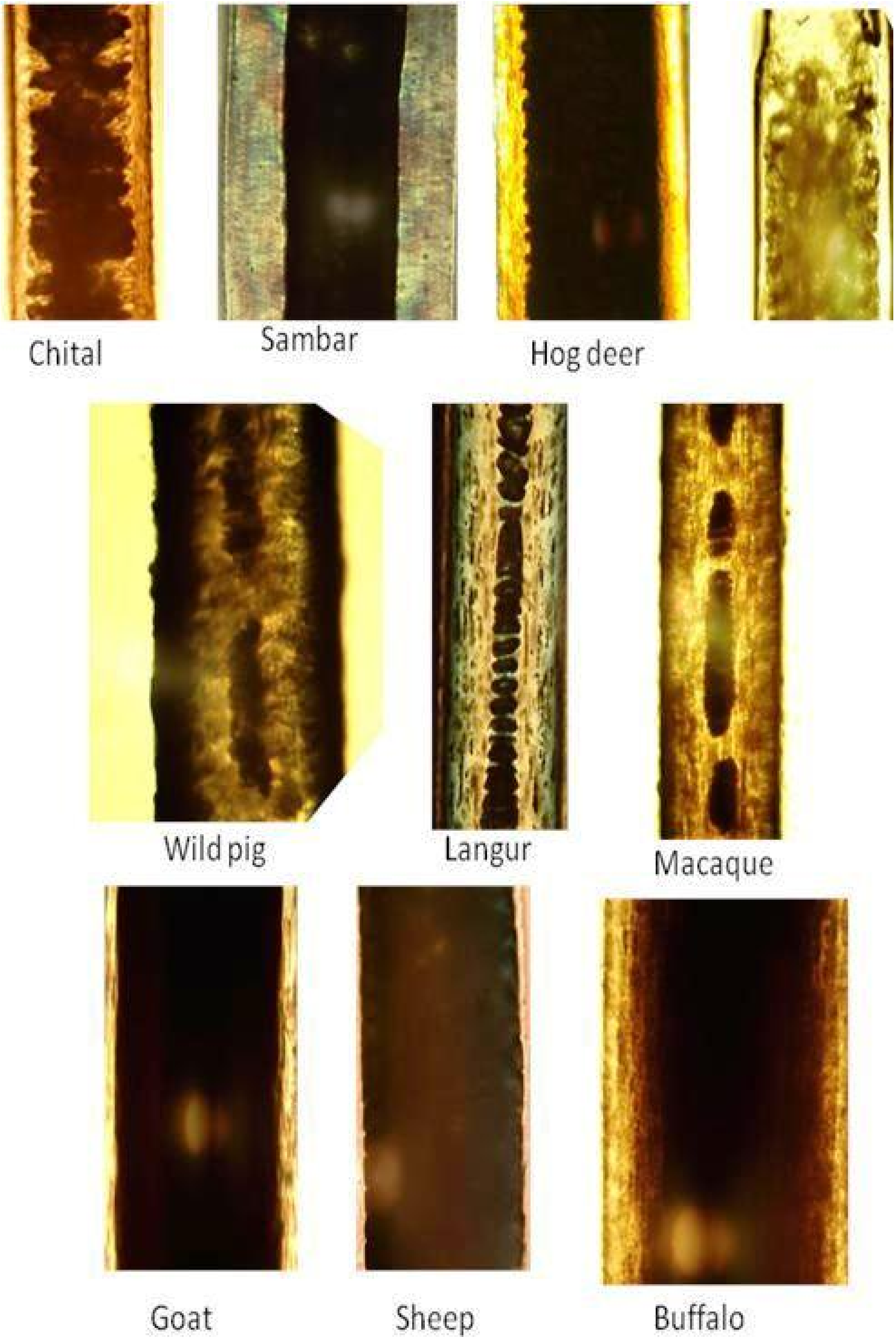
Annexure 1

Cuticular characteristics (magnification 400x) of some wild and domestic prey species.



Annexure 2

Medulla characteristics (magnification 400X) of some wild and domestic prey species.



Annexure 3

Survey Questionnaires for the Assessment of Human Attitudes towards large Cat, buffer zone of Chitwan National Park, Nepal

SN……………, Date……………………….….

Name: …..…………………………………………..… Age: ……… Sex: …… Education: .... Occupation: …………..………VDC: ………………… Ward No: ……… Village: ……..………………..……………………………

GPS Location: UTM X: …………………UTM Y: ……………… Altitude: ………..
1. How long you are living in this place? ……………………………………………

2. Number and type of livestock holdings

Buffaloes………, Cattle…… goats………, sheep ……… pigs ………, others ……..

3. Did you lost livestock to tiger/leopard in past 2 year, Yes…………, no………..
If yes, livestock type……………………………., number…………,
date……………… Place (Circle): i) inside the park, ii) in the community forest, iii) from night shelter, iv) Grazing ground, v) other …………………………….
Time of loss (circle one): i) Morning, ii) day, iii) evening………, iv) night……….
Did you receive any compensation: i) yes, ii) no, iii) did not apply for compensation.

4) In your opinion, what are the causes of livestock damage by tiger/leopard? Rank from high to low ( ) Insufficient prey base, ( ) No proper guarding in the grazing ground, ( ) Encroachment into the forest, ( ) Poor practice of keeping in night, other ………………………………………………………………………………………

5. Do you like tigers/leopard living in your neighboring forests? Yes …... No…... no idea…………………………………………………………………………………..

a) If yes because of (prioritize): ( ) Biodiversity value, ( ) Naturalistic value, ( ) Ecological importance in regulating small wild animal, ( ) tourism/economic value, ( ) beautiful animal, ( ) cultural value, ( ) other…………………........................

b) If you do not like tiger/leopard because they (prioritize): ( ) Damage livestock, ( ) Attack to people, ( ) threat to use of forest products, ( ) damage to pets, ( ) other negative beliefs………………………………………..……………………..…

6. In your opinion people-carnivore coexistence can be improved by (prioritize your opinion): ( ) Improving the damage compensation system, ( ) developing flexible and rapid system for response to individual problem animal, ( ) educating people and improving awareness, ( ) others …… ………………… ……… ………

7. Population of tiger/leopard should (circle one): i) Increase, ii) stay same, iii) decrease, iv) disappear, v) no opinion.

8. What is your opinion about the effectiveness of human- large carnivore conflict management program in Chitwan (circle one): i) Highly effective, ii) Effective, iii) Less effective, iv) Ineffective and v) no idea about such programs.

Annexure 4

Number of tourist entry and no of vehicle permitted in different parts of the Chitwan National Park (November 2009- April 2010).

Zone	Number of tourist entry (mean monthly)	No of vehicle permission (daily)
Sunachuri	545	6
Khagendramalli	242	6
Saurah, Kasara	7045	24
Bhimle	430	6
Laukhani	443	0
Amaltari	480	6

Annexure 5

Exploratory variables used for site occupancy and detection probability analysis

Variables
River bed
Water body
Riverine forest
Tall grassland
Short grassland
Lowland Sal forest
Mixed Sal forest
Hill Sal forest
Elevation (mean)
Slope
Level of disturbance
Distance to water
Distance to road/main trails
Distance to settlements
NDVI (Mean)