# Università degli Studi di Ferrara

DOTTORATO DI RICERCA IN

" **BIOLOGIA EVOLUZIONISTICA E AMBIENTALE**"

CICLO XXIV

COORDINATORE Prof. GUIDO BARBUJANI

# ECOLOGY AND CONSERVATION OF TIGER *Panthera tigris* AND LEOPARD *Panthera pardus* IN A SUBTROPICAL LOWLAND AREA, NEPAL

Settore Scientifico Disciplinare BIO/05

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## ABSTRACT

Ecology and conservation of tigers *Panthera tigris* and leopards *Panthera pardus* are studied in this thesis. The study was carried out between 2008 and 2011 in the Shuklaphanta Wildlife Reserve (SWR), a subtropical lowland area in Nepal. Both these large carnivores are sympatric in many parts of their distributional ranges in Asia. Due to poaching, habitat loss and prey depletion, the tiger is already considered an endangered species globally, whereas leopard is nearly threatened. The present study addresses the ecology and conservation of these sympatric carnivores in one densely settled area situated within the Terai Arc Landscape of Nepal, where the tiger population recently declined by about sixty percent within a decade long period. Because carnivore ecology is largely governed by their prey, understanding the feeding ecology and behavioural flexibility of felids in prey selection is essential to address their conservation requirements. The prey selection by the two carnivores were quantified by scat analysis and the distance sampling line transect method in an area of about 250 $km^2$. Results obtained from camera trapping were used to quantify the activity patterns as well as the status and spatial behaviour of the tigers and leopards. In addition, non-invasive genetic analysis of their scats were made to identify the minimum number of tigers and leopards in SWR. For the genetics part, the Karnali floodplain area (ca. 100$km^2$) of Bardia National Park (BNP) located 150 km further east was also included. On average, 131 and 175 individual prey animals per $km^2$ were estimated during the dry seasons of 2010 and 2011, respectively. Of these, 62-63% was wild prey and 38% were domestic animals. Individually, swamp deer was the most abundant wild prey, followed by chital, rhesus, langur, hog deer, wild boar, nilgai and muntjac in 2010. However, in 2011 chital was the most abundant among wild prey, followed by swamp deer, rhesus, hog deer, langur, wild boar, muntjac and nilgai. The analysis of 194 tiger and 42 leopard scats showed the occurrence of 12 and 14 prey species, respectively. Tiger and leopard diets were composed of a large quantity of wild ungulates (77% for tigers and 51% for leopards). The relative occurrences of prey items (wild ungulates) in the diet differed significantly between tiger and leopard ($G=11.12$; $df=1$, $p<0.001$). Medium sized prey species, such as chital were most common in the tiger diet, whereas small species showed up most frequently in the leopard diet, followed by medium sized species. Tigers consumed more large prey than the leopards did. The niche overlap values indicated a great dietary overlap of tiger than leopard. Camera trapping data showed that both tigers and leopards were photo-captured more frequently at night than during the day thus indicating that both have a nocturnal activity, however, tigers were found to have more diurnal activity than leopards. Variances in time use, temporally or spatially, have been recognized as behavioural characteristics that may motivate coexistence. In general, between 11AM- 5PM leopards were less active than tigers, probably to avoid the hottest period of the day, and because of a preference for the small sized prey that are most active during dusk and dawn. Concentration within certain areas and limited diurnal activity of leopards indicated the existence of temporal niche segregation between these cats. Camera trapping identified 11 individual tigers (six males and five females) and 9 leopards (five males and four females) in SWR. The genetic analysis identified only 5 tigers and 4 leopards from SWR, and 6 tigers from the Karnali floodplain of BNP. Population density of tigers in SWR was estimated at between 1.8 and 2.9/100 $km^2$, while that for leopards was estimated at between 1.8 and 2.6/100 $km^2$ during the study period. From 9 tigers in SWR. I calculated an average home range (HR) of 36.6 $km^2$, with male HR (43.3 $km^2$) being 1.45 times larger on average than those of females (29.9 $km^2$). Among leopards (n=7) an average HR of 17.9 $km^2$, was recorded, with males HRs (26.6 $km^2$) 2.86 times larger than those of females (9.3 $km^2$). The HRs of all male tigers overlapped each other at least partially and almost completely in some cases. HRs of male tigers overlapped more than those of female tigers, and male HRs overlapped with more than one individual female. Leopard HRs tended to overlap less than those of tigers, with values ranging up to 7 $km^2$ for females to 2-24 $km^2$ for males (overall mean 8.83 $km^2$). As displayed by the tiger, male leopard HRs tended to overlap with those of several females. The data suggested that even though there was 12 to 18 % median overlap between tiger and leopard HRs, there was a clear spatial separation between them. Leopards were more restricted to the periphery of the reserve, while tigers occupied the core or mostly undisturbed areas of the reserve. This research provides the first set of data on tigers, leopards and their prey in SWR, Nepal during the dry season. However, immediate needs for further research on wildlife disease, especially focused on large carnivores, and human-disturbance in the reserve including prey availability in the eastern selection of the reserve area, an issue which was not included in this study. Furthermore research is needed on predator-prey relation with the inclusion of trans-boundary wildlife corridor utilization and the link between the smaller protected areas in the trans-border level.

# ECOLOGIA E CONSERVAZIONE DELLA TIGRE *Panthera tigris* E DEL LEOPARDO COMUNE *Panthera pardus* IN UN'AREA SUBTROPICALE DEL NEPAL

## RIASSUNTO

L'ecologia della tigre *Panthera tigris* e del leopardo comune *Panthera pardus* è stata studiata tra il 2008 e il 2011 nella Shuklaphanta Wildlife Reserve (SWR), un'area subtropicale del Nepal. Entrambi questi carnivori vivono in simpatria in gran parte dei loro areali di distribuzione in Asia. A causa del bracconaggio, della perdita di habitat e della rarefazione delle prede, la tigre è già considerata una specie in pericolo di estinzione su scala globale, mentre il leopardo comune è quasi in pericolo. Questo studio ha analizzato aspetti di ecologia e conservazione di questi carnivori simpatrici in un'area con abbondanti insediamenti umani, nel Terai (Nepal), dove la popolazione di tigre si è ridotta di *c.* il 60% nell'ultimo decennio. Dal momento che l'ecologia dei carnivori è largamente influenzata dalla presenza delle prede, lo studio dell'alimentazione e della flessibilità trofica nella selezione delle prede è essenziale per indirizzare le misure di conservazione dei predatori. La selezione delle prede è stata valutata con il metodo del *distance sampling*, in un'area di *c.*250 km$^2$. Il *camera trapping* è stato utilizzato per stimare ritmi di attività e comportamento spaziale di tigri e leopardi. Inoltre, analisi genetiche di campioni fecali hanno consentito di stimare il numero minimo di tigri e leopardi nell'area di studio. Per la stime numeriche, è stata considerata anche la pianura alluvionale del Karnali (*c.* 100 km$^2$) del Bardia National Park (BNP), 150 km a est. In media, 131 e 175 prede / km$^2$ sono state stimate nelle stagioni asciutte del 2010 e 2011, rispettivamente. Di queste, il 62-63% erano prede selvatiche e il 37-38% domestiche. Nel 2010, il barasingha è stato la preda più abbondante, seguito da chital, macaco, langur, cervo porcino, cinghiale, nilgai e muntjac. Al contrario, nel 2011 il chital è stato la preda più abbondante, seguito da barasingha, macaco, cervo porcino, langur, cinghiale, muntjac e nilgai. 12 e 14 specie preda sono state trovate in 194 campioni fecali di tigre e 42 di leopardo comune, rispettivamente. Le diete di tigre e leopardo comune sono risultate composte da un'ampia quantità di ungulati selvatici (tigre: 77%; leopardo comune: 51%). Le frequenze relative di comparsa degli ungulati selvatici nella dieta è risultata significativamente diversa tra tigre e leopardo. Prede di dimensioni medie, come il chital, sono risultate più frequenti nella dieta della tigre, mentre specie piccole sono comparse più frequentemente nella dieta del leopardo, seguite da specie di dimensioni medie. La tigre ha utilizzato più prede di grandi dimensioni rispetto al leopardo. La sovrapposizione alimentare tra i due felidi è risultata ampia. Entrambi i carnivori sono stati rilevati, mediante *camera trapping*, più frequentemente di notte che durante il giorno. La tigre ha mostrato una maggiore frequenza di attività diurna rispetto al leopardo comune. Queste differenze nell'uso del tempo potrebbero favorire la coesistenza tra i due felidi. In generale, tra le 11 AM e le 5 PM, il leopardo comune è stato meno attivo della tigre, probabilmente per evitare le fasi più calde del giorno e a causa dell'attività crepuscolare delle sue prede principali.

L'utilizzo di aree circoscritte e la ridotta attività diurna del leopardo comune suggeriscono l'esistenza di segregazione temporale con la tigre.

Il *camera trapping* ha identificato 11 individui di tigre (6 maschi e 5 femmine) e 9 di leopardo comune (5 maschi e 4 femmine) nella SWR. Le analisi genetiche hanno identificato solo 5 individui di tigre e 4 di leopardo comune nella SWR, oltre a 6 tigri nella pianura del Karnali. La densità di tigri nella SWR è risultata 1.8-2.9 ind/100 $km^2$, mentre quella di leopardi comuni è risultata 1.8-2.6 ind/100 $km^2$. Le dimensioni medie delle aree familiari (*home range*, HR) di tigre (*n* = 9 individui) sono risultate 33.6 $km^2$. Gli HR maschili (43.3 $km^2$) sono risultati 1.45 volte più grandi di quelli femminili (29.9 $km^2$), in media. Per il leopardo comune (*n* = 7), sono stati stimati HR di 17.9 $km^2$, in media. Gli HR maschili (26.6 $km^2$) sono stati 2.86 volte più ampi di quelli femminili (9.3 $km^2$). Gli HR di maschi di tigre hanno sempre mostrato sovrapposizione, talvolta totale. La sovrapposizione tra HR maschili è risultata più alta di quella tra HR femminili; inoltre gli HR di ogni maschio di tigre hanno mostrato sovrapposizione con quelli di più di una femmina. Gli HR dei leopardi hanno mostrato una minore sovrapposizione intra-specifica rispetto a quelli di tigre. Come per la tigre, gli HR di ogni maschio di leopardo hanno mostrato sovrapposizione con quelli di più di una femmina. Una chiara separazione spaziale è stata riscontrata tra tigre e leopardo comune, con una sovrapposizione mediana interspecifica del 12-18%. I leopardi sono risultati maggiormente confinati nelle zone periferiche dell'area di studio, mentre le tigri hanno occupato la porzione centrale, meno disturbata, dell'area. Questa ricerca fornisce i primi dati su tigre, leopardo comune e loro prede nella SWR, durante la stagione asciutta. C'è urgente bisogno di informazioni su patologie (per i grandi carnivori, soprattutto), sul disturbo antropico e sulla disponibilità di prede all'esterno della SWR. Ulteriori informazioni sono necessarie sulle relazioni predatore-preda, analizzando anche l'uso delle aree di corridoio ecologico, che fungono da connessione tra le piccole aree protette nella fascia esterna alla SWR.

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# INTRODUCTION

# CHAPTER 1

## 1. INTRODUCTION

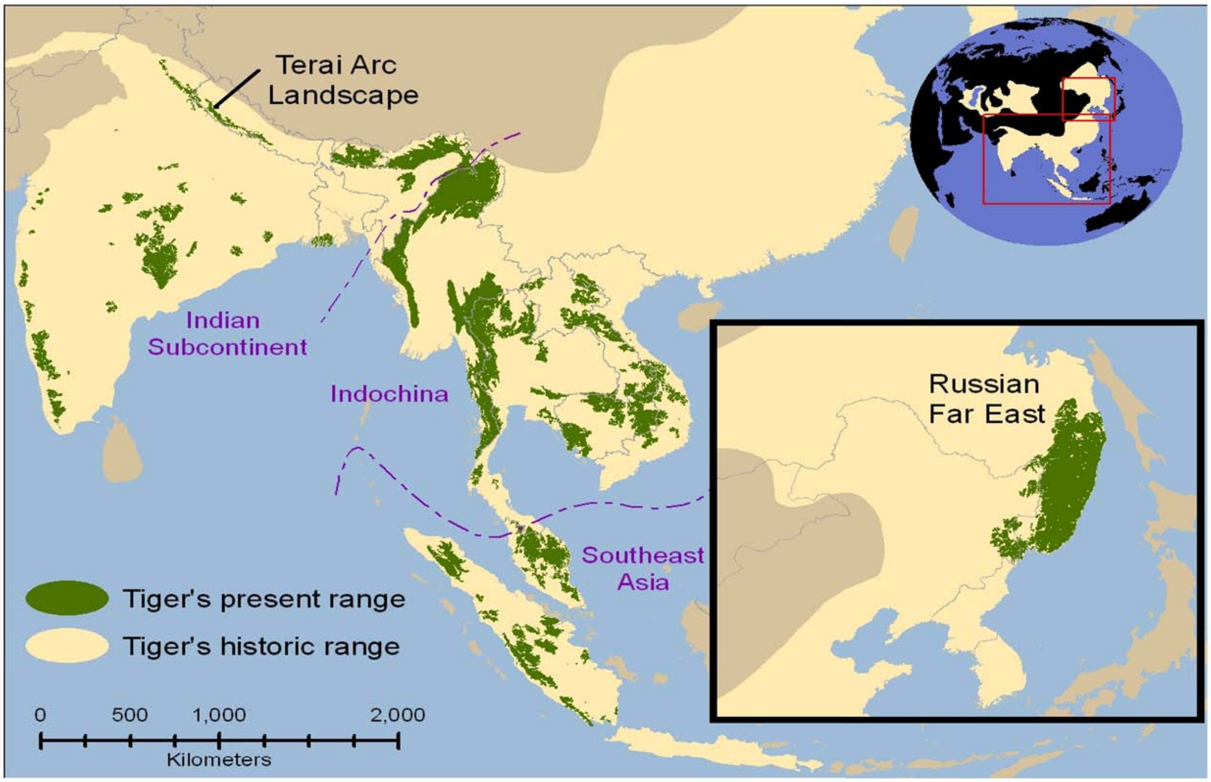
Large mammalian carnivores are normally susceptible to landscape change because of their low population density, inadequate resources of habitat requirements, prey base, which is greatly dominated by human influences, and other trails that decreases ecological resilience (Weaver *et al.* 1996). Their conservation is one of the most challenging tasks for conservationists globally. Large carnivores received a high proportion as the most focal species for conservation due to because the position they occupy in ecosystem. Their foraging, spatial behaviour and distribution patterns often strongly reflect in the landscape level of conservation. Large carnivores with large area requirement are considered as umbrella species, on the assumption that the area of habitat requirement to support a viable population will protect sufficient habitat for other numerous co-occurring species with smaller area requirements (Noss *et al.* 1996). In the ecological studies, large carnivores such as tigers and leopards are the most vital components, where these species are sympatric in similar habitats, serving as umbrella species across a wide range of habitats and are functionally important components of the ecosystem.

The tiger *Panthera tigris* is the largest felid in the world it is extremely endangered globally, whereas the leopard *Panthera pardus* is 3 to 4 times smaller in body size (Seidensticker 1976) and is also declining in abundance. Both these large predators are sympatric in many parts of their distributional ranges in Asia. They are important species within their ecosystems; the tiger is considered as the top predator and the leopard the co-predator in the area. Due to poaching, prey depletion and habitat destruction, they are now mostly restricted to protected habitats (PAs and some outside PAs). Owing to above reasons, three sub-species, the Bali tiger *Panthera tigris balica*, the Caspian tiger *Panthera tigris virgata* and the Javan tiger *Panthera tigris sondaica* have already become extinct from the wild (Table 1.1). The tiger occurs over a wide range of geographical regions, from tropical forests of southern Asia to the temperate and boreal forests of the Russian Far East (Figure1.1). However this distribution has been reduced significantly over the last century with the growth of the human population (Sunquist, Karanth & Sunquist 1999, Schaller 1967). Currently, tigers survive in fragmented population in thirteen countries (Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Russia, Thailand and Vietnam) including Nepal. At present the species occupies 40% less habitat than a decade ago, and only 7% of their historic range, and is estimated at around 3000-3500 individuals (Dinerstein *et al*. 2006, Sanderson *et al*. 2006). Initially, eight subspecies had been characterized based on physical characteristic and geographical distribution (Herrington 1987, Nowell & Jackson 1996). Of these eight, only five were known to exist in the wild (Weber & Rabinowiz 1996). Recently, Luo *et al.* (2004) described that six existing subspecies of tigers have been identified on the basis of distinctive molecular markers (Luo *et al.* (2004) cited in IUCN, 2012) (Table 1.1).

**Table 1.1. Subspecies of tigers and their region**

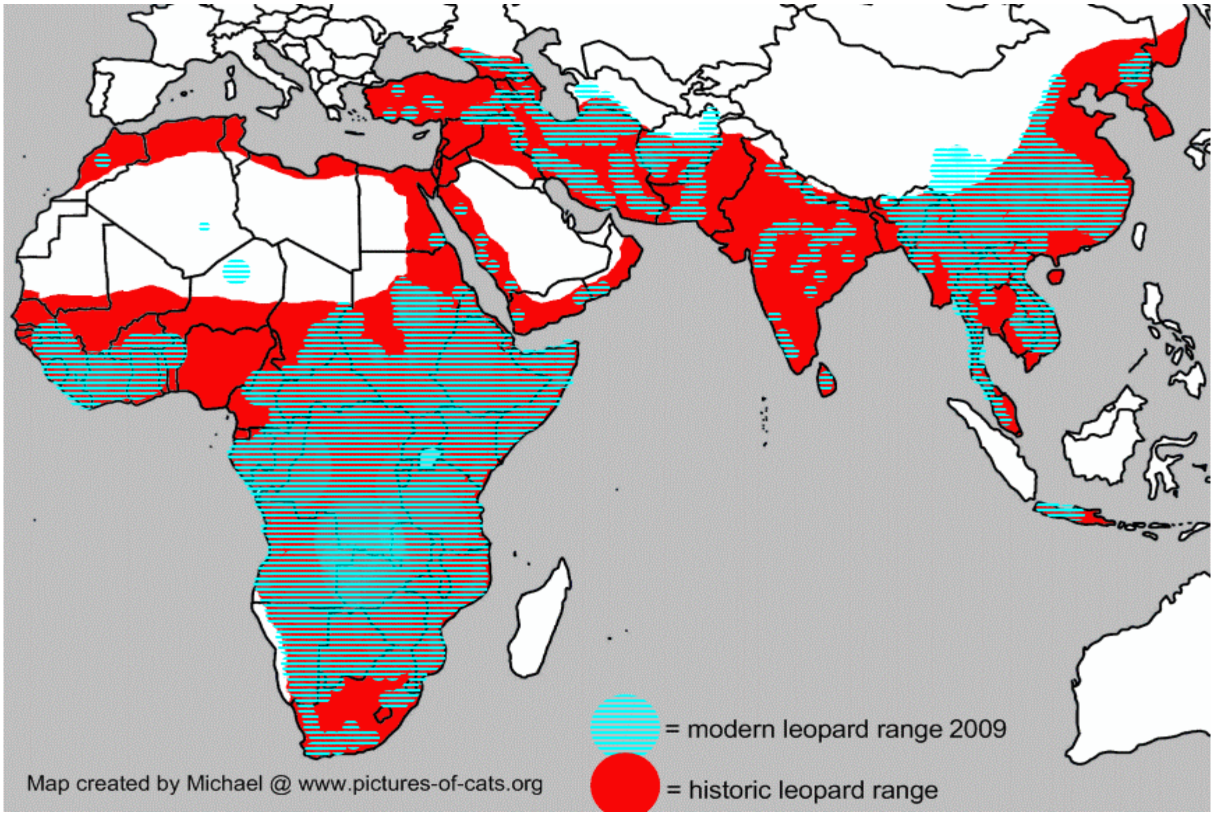
| **Subspecies** | **Region** |
|---|---|
| Amur Tiger *Panthera tigris altaica* | Russian Far East & northeastern China |
| Northern Indochinese Tiger *P. t. corbetti* | Indochina north of the Malayan peninsula |
| Malayan Tiger *P. t. jacksoni* | Peninsular Malaysia |
| Sumatran Tiger *P. t. sumatrae* | Sumatra |
| Bengal Tiger *P. t. tigris* | Indian sub-continent |
| South China Tiger *P. t. amoyensis* | (This subspecies has not been directly observed in the wild since 1970s and is possibly extinct) |
| **Three subspecies previously recognized on the basis of morphology are extinct:** | |
| Bali Tiger *P. t. balica* Schwarz, 1912 | Bali |
| Javan Tiger *P. t. sondaica* (Temminck, 1844) | Java |
| Caspian Tiger *P. t. sondaica* (Illiger, 1815) | Dry river valleys of the Takla Makan, Western slope of the Tianshan mountains, Amudarya and Syrdarya river valleys, shores of the Caspian sea, Elburz mountains, eastern Turkey, Tigris and Eupharates river valleys. |

***Source: IUCN 2012,***



Source: http://upload.wikimedia.org/wikipedia/commons/c/c8/Tiger_map.jpg

Figure 1.1. Historic and present range of tigers



Source: http://www.picture-of-cats.org/Leopard-Habitat.htm

Figure 1.2. Historic and present range of leopards

Leopard is the most widespread member of the large felids (Myers, 1986) being existent throughout Asia, Africa, the Middle East and South Eastern Europe (Bailey 1993, Nowell & Jackson 1996, Uphyrkina *et al.* 2001) (Figure 1.2). Nevertheless, they are declining in large parts of their range due to habitat loss and fragmentation, and hunting for trading and pest controlling reasons. Because of their extensive distribution, ecological flexibility and cryptic habits, the leopard has so far received little scientific consideration. Leopards are found widely in the forests of the Indian sub-continent, through Southeast Asia and into China, although they are becoming increasingly rare outside protected areas. Regardless of conservation efforts, the populations of both species (tigers and leopards) are known to be declining throughout their ranges. According to genetic analysis, nine subspecies of leopard are recognized, with all continental African leopards attributable to the nominate form (Miththapala *et al.* 1996, Uphyrkina *et al.* 2001 cited in IUCN 2012) (Table 1.2).

**Table 1.2. Subspecies of leopards and their region**

| Subspecies | Region |
|---|---|
| *Panthera pardus pardus* (Linnaeus, 1758) | Africa |
| *Panthera pardus nimr* (Hemprich & Ehrenberg, 1833) | Arabia |
| *Panthera pardus saxicolor* (Pocock, 1927) | Central Asia |
| *Panthera pardus melas* (Cuvier, 1809) | Java |
| *Panthera pardus kotiya* (Deraniyagala, 1956) | Sri Lanka |
| *Panthera pardus fusca* (Meyer, 1794) | Indian sub-continent |
| *Panthera pardus delacourii* (Pocock, 1930) | Southeast Asia into southern China |
| *Panthera pardus japonensis* (Gray, 1862): | Northern China |
| *Panthera pardus orientalis* (Schlegel, 1857): | Russian Far East, Korean peninsula and north-eastern China |

The recognition of *P. p. melas* and *P. p. nimr* was based on very small sample sizes and is considered tentative.

Based on morphological analysis, Khorozyan *et al.* (2006) recognize *P. p. tulliana* (Valenciennes, 1856) in western Turkey and *P. p. sindica* (Pocock, 1930) in Pakistan, and possibly also parts of Afghanistan and Iran. They also consider *P. p. ciscaucasica* (Satunin, 1914) as the senior synonym for *P. p. saxicolor*.

***Source: IUCN 2012***

More studies on leopards have been carried out in African region (e.g. Hamilton 1976, Bertran 1982, Bailey 1993, Jenny 1996, Bothma *et al.* 1997, Stander *et al.* 1997, Mizutani and Jewell 1998) compare to other places of their range. The few studies on leopards in the Indian sub-continent usually come from studies that are focused on tigers (Seidensticker 1976, Sunquist 1981, Karanth and Sunquist 1995, Wegge et al. 2009, Odden and Wegge 2005).

In Nepal, tigers can be found only in lowland Terai PAs with just few animals recorded outside PAs, whereas leopards can be found in all the protected areas in the lowland and also outside protected areas, in the lowland Terai and in highland protected areas (for example in Sagarmatha National Park, Lovari, et al 2009).

This study addresses the ecology and conservation of these sympatric carnivores in one densely settled area situated within the Terai Arc Landscape of Nepal. The main problems of wildlife conservation in Nepal is poaching and the conversion of tropical forest habitat to a human-dominated landscape through illegal encroachment for settlements and agriculture. Given that carnivore ecology is largely governed by their prey, understanding the feeding ecology and behavioural flexibility of felids in prey selection is essential for addressing their conservation requirements (Sunquist & Sunquist 1989, Seidensticker & McDougal 1993). However, the mysterious, solitary and nocturnal habits of tigers and leopards, along with their wide-ranging movements, have limited our knowledge of their feeding ecology and how this may diverge under varying environmental circumstances (Sunquist 1981). Recent studies on the food habits of tigers and leopards show that these felids have substantial dietary overlap (Andheria *et al.* 2007, Wang and Macdonald 2009, Wegge *et al.* 2009), with both species preying on large as well as small-sized ungulates (Johnsingh 1983, Karanth and Sunquist 1995, Sankar and Johnsingh 2002, Ramesh *et al.* 2009). This probably leads to competition for prey and therefore each cat species can affect prey availability for the other species.

Ecologically similar and closely related species in sympatry may differ in their activity patterns to avoid interspecific encounter competition. Activity patterns of large sympatric carnivores are influenced by prey availability (Zielinski *et al.* 1983, Karanth & Sunquist 2000), seasonal variation in prey abundance (Lourens and Nel 1990; Zub *et al.* 2009), human disturbance (Beckmann and Berger 2003; Griffiths and Schaik 1993, Kolowski *et al.* 2007), interspecific competition (Hayward and Slotow 2009, Hunter and Caro 2008, Romero-Muñoz *et al.* 2010) and intra-guild predation (Palomares and Caro 1999). The knowledge of activity patterns provides a scientific basis for the development of conservation plans for endangered species (Hwang and Garshelis 2007), such as tigers and leopards. In Nepal activity patterns of carnivores have not been studied extensively. Activities of particularly elusive, nocturnal animals are often difficult to assess without the use techniques such as radio telemetry or camera traps. The only studies of activity patterns of large carnivores in Nepal are from Bardia National Park (common leopard: Odden & Wegge, 2005) and Chitwan National park (tigers and leopards: Seidensticker 1976; tiger: Sunquist 1981).

Whenever the ecology of these species is poorly understood, and population dynamics are not carefully considered, conservation resources are likely to be poorly allocated. Complete counts of carnivore populations are often impractical, expensive, and time-consuming (Balme *et al.* 2009). However, reliable estimates of population trends are critical for their conservation as they play an important role in providing standardized data for future management decisions. In addition, home range is the fundamental measure of space use by territorial animals, such as tigers and leopards. Species have their intra-sexual restricted territories with one to several females residing inside one male's territory (McDougal, 1977). Competition for mates is the proximate factor determining male territoriality, whereas food, cover and a secure place to raise young are the critical resources for which females will complete, these factors thus playing an important part in determining animal population densities (Sunquist 1981). In Nepal, most studies of the behavioural ecology and home range use of tigers and leopards have been conducted in Chitwan and Bardia National Parks using radio telemetry (Seidensticker 1976, Sunquist 1981, Smith 1984, Wegge *et al.* 2009, Odden and

Wegge 2005). Similar studies have also been carried out in India (Karanth and Sunquist, 1995, 2000) and Thailand (Rabinowitz, 1989, Grassman, 1999). However, no such studies have been conducted in the Shuklaphanta Wildlife Reserve (henceforth SWR) in the far western lowland Terai of Nepal.

## 1.1. AIMS

This study aims at gathering information on the population and behavioural ecology of tigers and leopards in the SWR in lowland Terai of Nepal, in order to support site-specific conservation and management policies. The study objectives are: (a) to analyse the prey selection of tigers and leopards in SWR using scat analysis and distance sampling of prey; (b) to quantify the activity patterns of these two sympatric carnivores, using camera traps; and (c) to identify the present status of tigers and leopards in SWR and to describe their spatial behaviour using noninvasive techniques such as camera trapping and genetic analysis of their scats. For the scat genetics part, samples from the Karnali floodplain area of Bardia National Park were also included.

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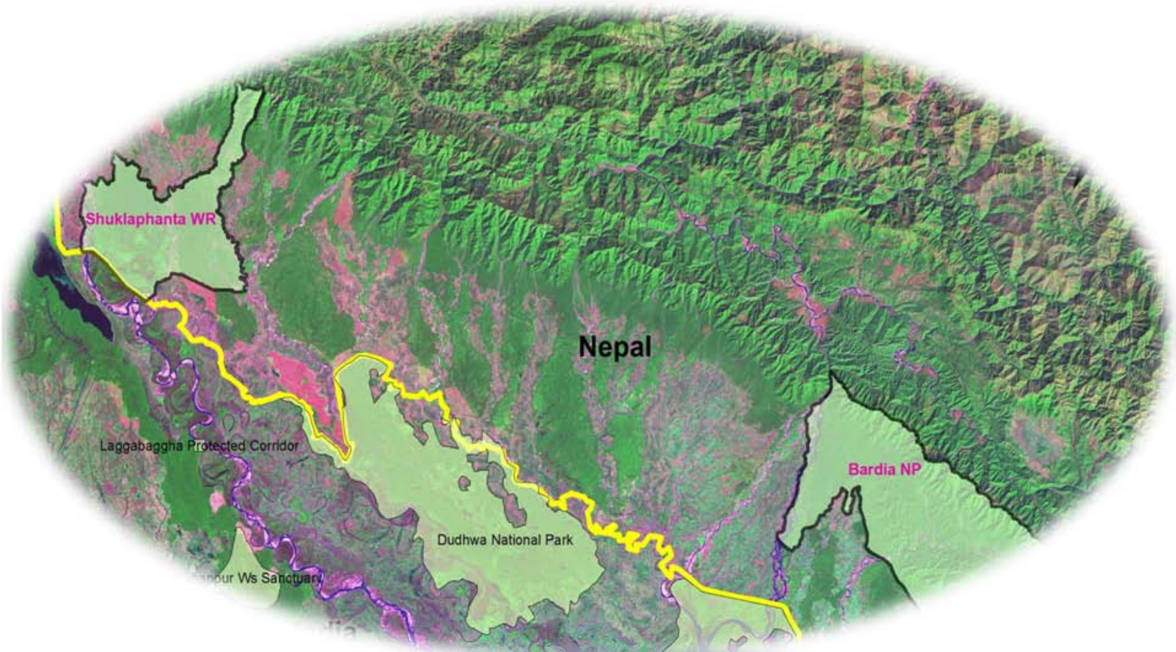
# CHAPTER 2

# STUDY AREA



## CHAPTER 2

## 2. STUDY AREA

The present study was carried out in the Shuklaphanta Wildlife Reserve (SWR) and Bardia National Park (BNP), Nepal. More details about these areas follow below.

### 2.1. Shuklaphanta Wildlife Reserve

At the beginning, the reserve was a sanctuary and later, in 1964, it was declared as a Royal Shikhar Reserve (RSR), and therefore it hunting was forbidden (Bhatta & Shrestha 1977). In 1976 the reserve was officially declared as the Royal Shuklaphanta Wildlife Reserve, covering an area of 155 Km$^2$, in order to protect Nepal's last largest remaining herd of swamp deer (*Cervus duvauceli duvauceli*), one of the major prey species of tigers. In 1981 the reserve was extended to its present size of 305 km$^2$ (Figure 2.1).

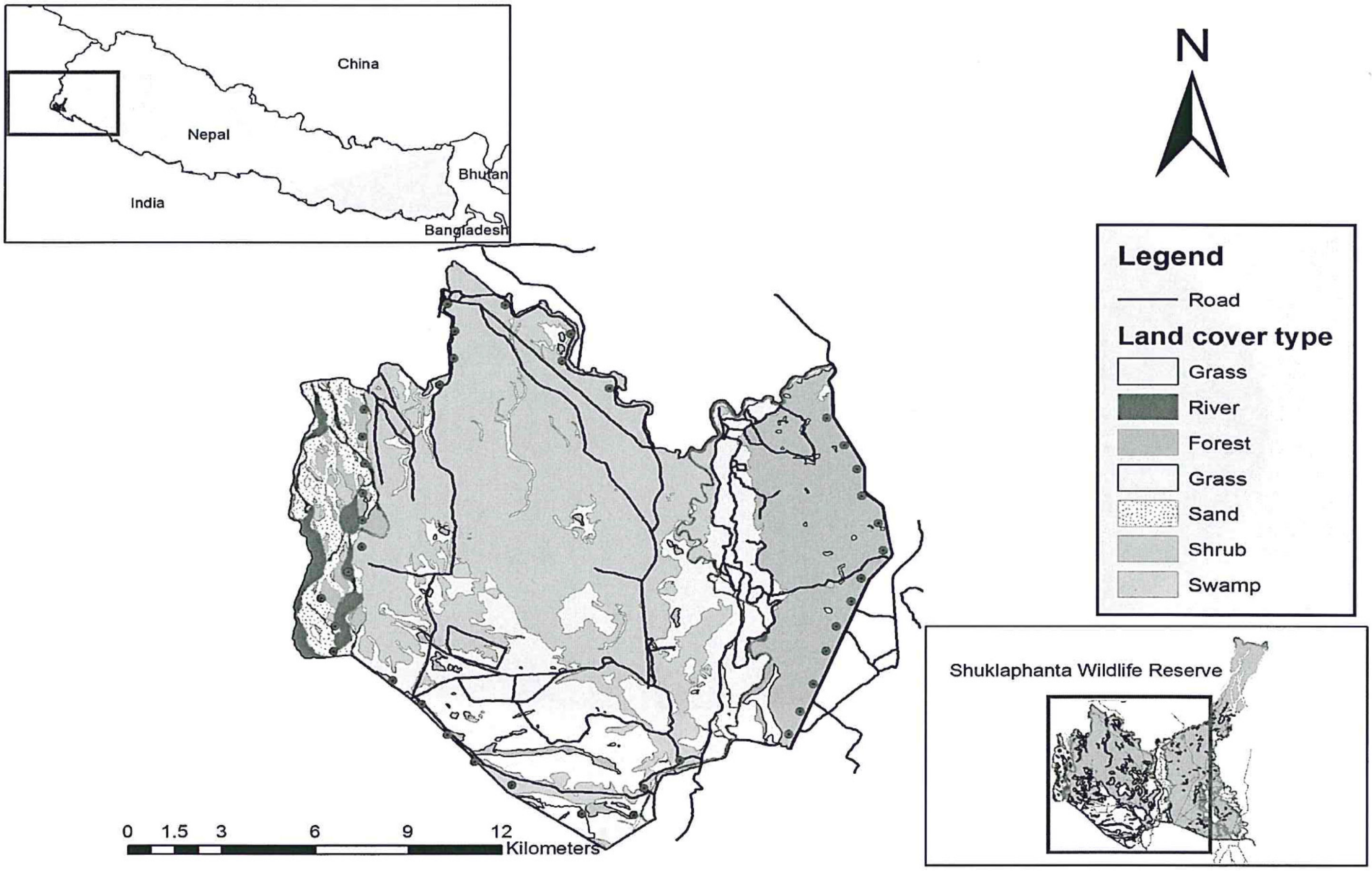


**Figure 2.1. Map showing the Shuklaphanta Wildlife Reserve**

### 2.1.1. Location

The Shuklaphanta Wildlife Reserve is located in the Kanchanpur district the southwestern corner of the far western Terai region in the west most area of Nepal. It is located between $28^0$ 45’ 16’’ and $28^0$ 57’ 23’ N and $80^0$ 06’ 04’’ and $80^0$ 21’ 40’’ E. The reserve is generally a flay plane with elevation ranging from 90m to 300 m above mean Sea level. It is bordered to the east and west by the rivers Syali and Mahakali, respectively. The northwestern adjoins the agricultural land settlements of Bhimdutta Municipality. The northeastern boundary follows the Mahendra-Highway and the crest of the churia hills. The southern and western boundary adjoins agricultural land and the international border between Nepal and India. The reserve is surrounded by a Buffer Zone (BZ) covering an area of 243.5 $km^2$, consisting of approximately 80% human settlements and very poor/inadequate forest resources. In the BZ of the Reserve, one (1) Municipality and eleven (11) Village Development Committees (agricultural land and human settlements) are located.

### 2.1.2. Geology and soil

The Reserve area is a generally flat Terai lowland with the deposits of Gangatic alluvia. This Terai region consists of alluvial sediments which were deposited by the north river systems and their tributaries (Schaaf 1978). The alluvia are transferred from the Churiya and the Himalayan Mountain ranges, where the large river arise and vary from fine silts to clays. The common soil types that are met within the SWR are loamy soils, sandy loam, loam, sity loam and clay loam (Bhatta & Shrestha 1977). These soil types have variable chemical composition which ranges from slightly acidic to moderately alkaline. In the Khair-sisso and mixed type forest, the soil is sandy-loam with stones and gravel comprising 75 per cent of it, in the sal forest the range varies from loam to sandy loam with high organic content, in the grassland areas they are clay loam and sticky and in the churiya the soil consists mainly of sandstone, conglomerates, quartzite, shales and micaceous sandstone (Bhatta & Shrestha 1977).

### 2.1.3. Climate

The Reserve's climate is subtropical monsoonal documenting a wet period from June until September of heavy rainfall (above 90% per year) and a dry period between October and May (Figure 2.2 a).

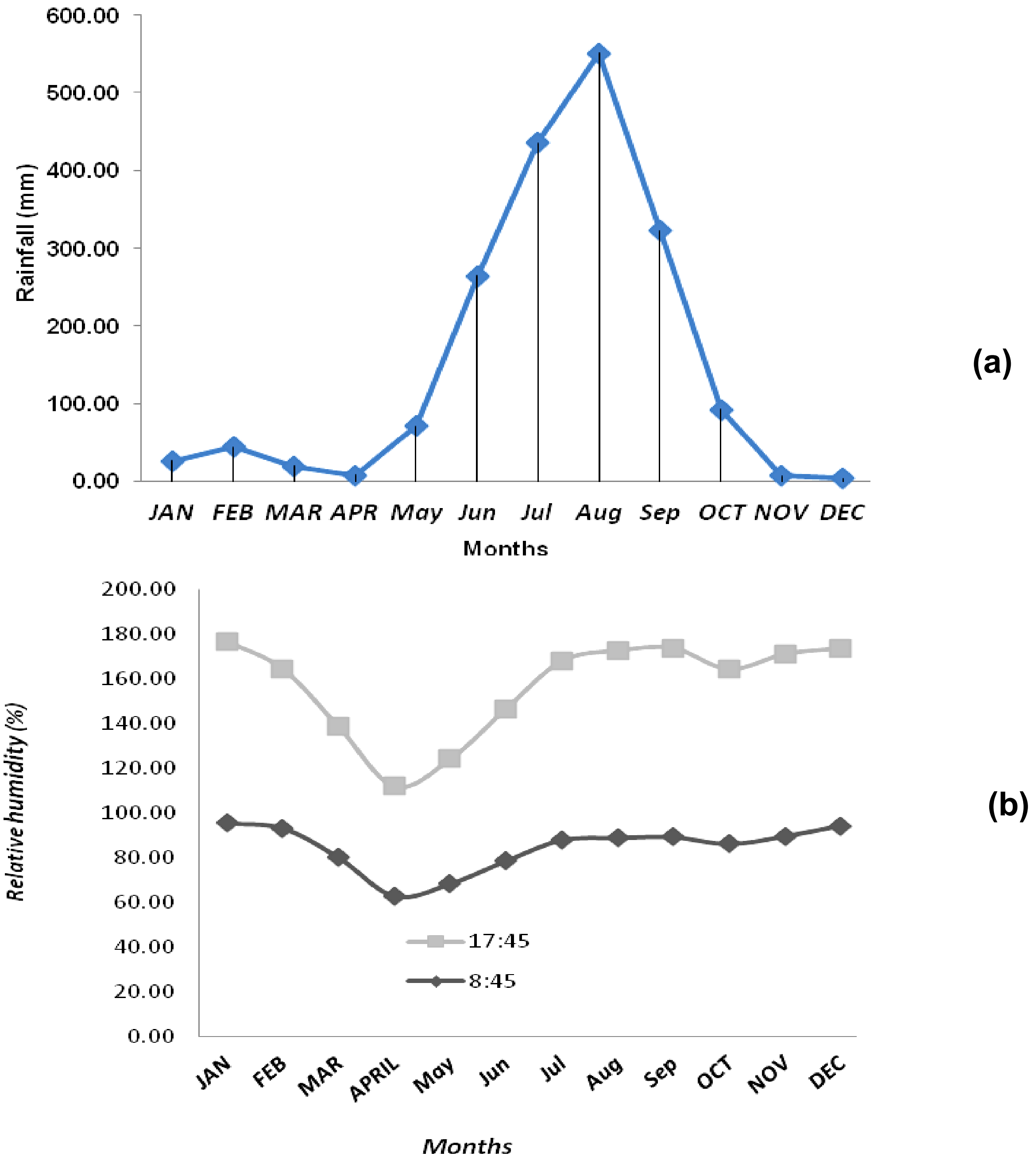


**Figure 2.2.** **(a & b)**
**Mean monthly rainfall (a) and relative humidity (b) for 12 years from 1999 to 2010, recorded at Mahendranagar, Kanchanpur (source: GoN Dept. of Hydrology and Meteorology)**

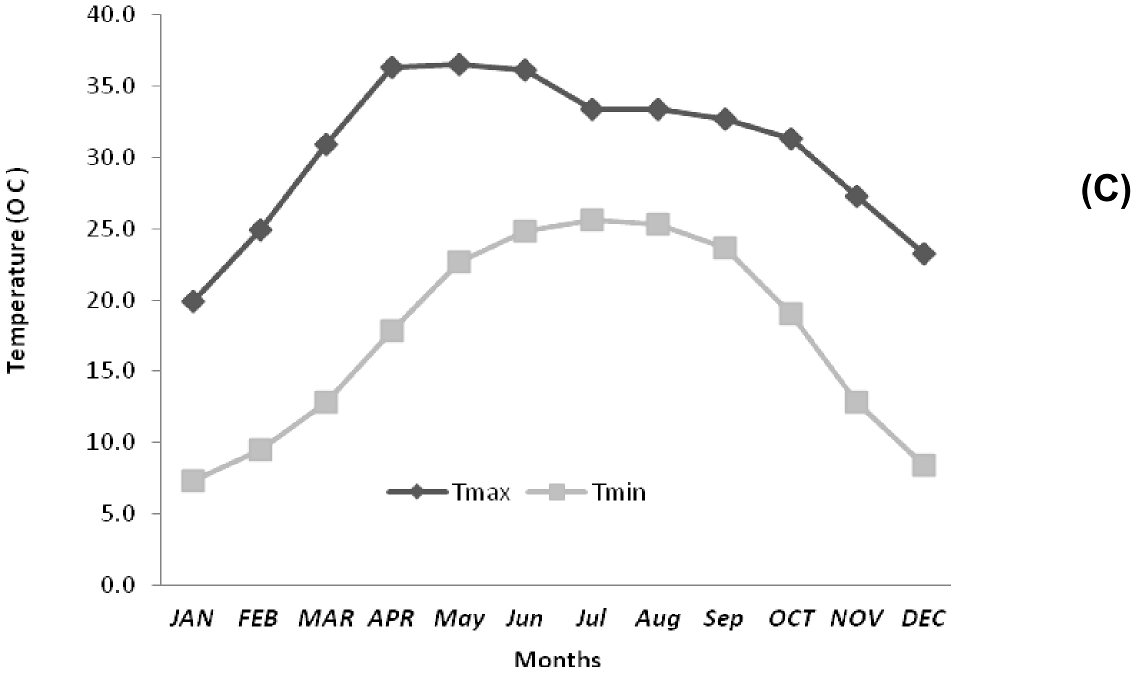


**Figure 2.2. (c) Mean monthly temperature (c) for 12 years from 1999 to 2010, recorded at Mahendranagar, Kanchanpur (source: GoN Dept. of Hydrology and Meteorology)**

Between 1999 and 2010, the highest rainfall (2843 mm) was recorded in the year 2009 and lowest (1055 mm) in 2006. The mean maximum temperature was recorded during the month of May ($36.5^0$C) and mean minimum in January ($7.4^0$C) (Figure2.2.b.). The recorded mean relative humidity reached its maximum value (95.40 %) during the month of January and the minimum one (49.06 %) in April (Figure 2.2.c).

### 2.1.4. Vegetation

Generally the vegetation types of Shuklaphanta Wildlife Reserve were classified into forest, grassland, wetlands and floodplains (DNPWC 2006, Rijal & Yonzon 2003). Schaaf (1978) distinguished eight different habitat types in the reserve, viz. Sal forest, Sal Savanna, Mixed deciduous forest, Khair-Sissoo forest, Lowland grasslands, Dry grassland, Seasonally-wet grassland and Lowland savannas. The Reserve is dominated by Sal forest (climax vegetation type) and approximately one-third of the reserve is covered by grassland (Balson 1976). The Sal (*Shorea robusta*) forest is associated with *Terminalia alata, Lagestroemia parviflora, Cleistocalyx operculatus, Adina cordifolia, Dillenia pentagyna, Bauhinia malabarica, Ficus semicordata* and *Ficus* *racemosa.* Riverine forest is dominated by *Trewia nudiflora, Syzyzium cumini*, *Mallotus philippensis, Acacia catechu, Ficus racemosa, Ehretia laevis, Ficus glomerata, Butea frondosa, Dalbergia sissoo and Aegle marmelos.* Grasslands are a variety of short and tall grasslands in small and large patches. Tall grasslands are dominated by *Themeda spp, Saccharum spontaneum, Saccharum bengalensis, Narenga porphyrocoma, Desmostachya bipinnata and Phragmites karka.* The short grassland is dominated by *Imperata cylindrica, Vetivera zizanoides, Saccharum spontaneum* and *Cynodon dactylon.*

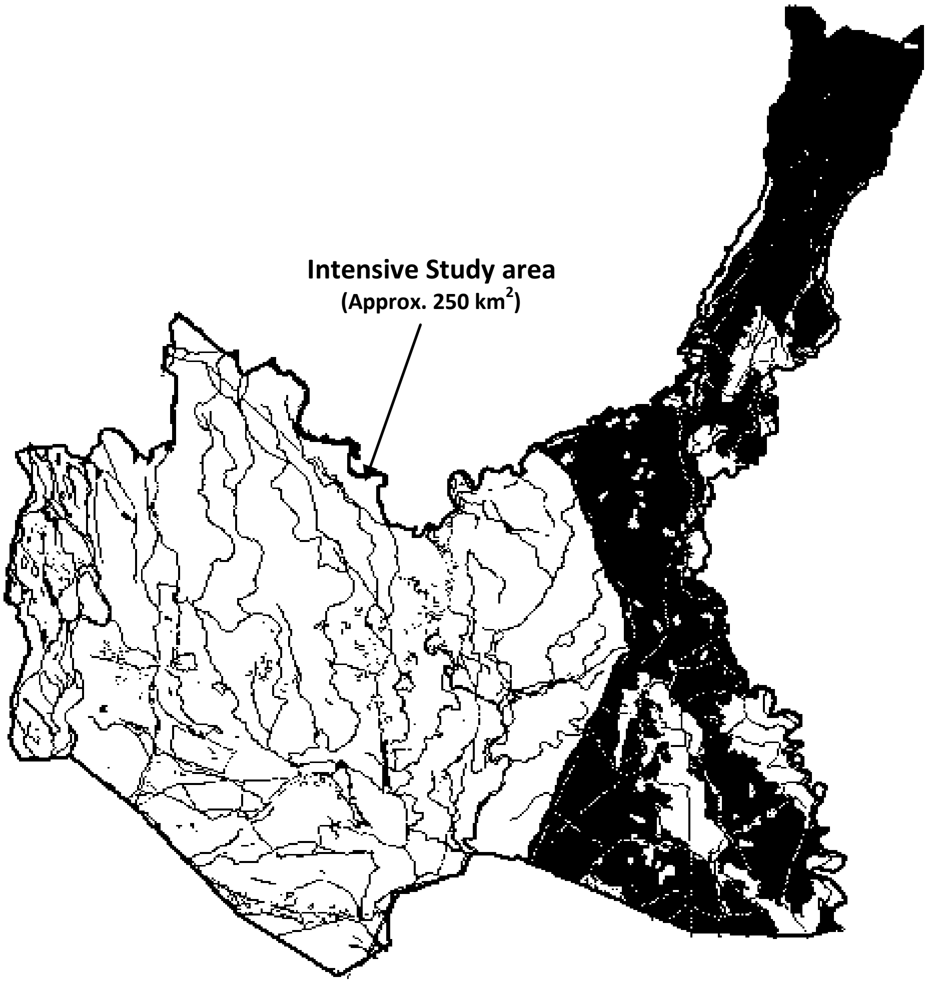
### 2.1.5. Fauna

Shuklaphanta Wildlife Reserve is wealthy in biodiversity. The large grassland stretched covers an area of over 54 $km^2$ providing prime habitat to endangered swamp deer *Cervus duvauceli duvauceli*, locally known as "*Barashinga"*. More than 45 species of mammals including the endangered one-horned rhinoceros *Rhinoceros unicorns*, wild elephant *Elephas mixmus,* hispid hare *Caprolagus hispidus.* The two major predators are the tiger *Panthera tigris tigris* (endangered) and the leopard *Panthera pardus* (nearly threatened) including other small carnivores such as fishing cat *Prionailurus viverrinus*, jungle cat *Felis chaus*, large civet *Viverra zibetha*, small civet *Viverricula indica* and Asian palm civet *Paradoxurus hermaphroditus.* The potential prey species are chital *Axis axis*, swamp deer, hog deer *Axis porcinus*, wild boar *Sus scrofa*, sambar deer *Cervus unicolor*, barking deer *Muntiacus muntjak*, nilgai *Boselaphus tragocamelus*, common langur *Presbytis entellus*, and rhesus macaque *Macaca mulatta*. More than 349 species (Subedi *et al.* 2003) of birds including endangered and threatened bengal florican *Huboropsis bengalensis*, Lesser florican *Sypheotides indicus*, swamp francolin *Francolinus gularis*, sarus crane *Grus antigone*, and white-rumped vulture have been recorded in the Reserve. Shrestha *et al.* (2008) also recorded five species of amphibians and twenty species of reptiles from the Reserve.

## 2. 2. INTENSIVE STUDY AREA

### 2.2.1. Shuklaphanta Wildlife Reserve

The intensive study area is commonly known as the western sector of the SWR, however some part of the eastern sector is also included in this research. The remaining part of the eastern sector was not included in this research because the area is more disturbed with both illegal livestock grazing and anthropogenic activities (Personal observation). The main study area is approximately 250 $km^2$ (Figure 2.3).



**Intensive Study area**
**(Approx. 250 $km^2$)**

**Figure: 2.3. Map showing the intensive study area in SWR.**

### 2.2.2. Bardia National Park

In Bardia National Park, study was concentrated only in Karnali floodplain for genetic components, which is approximately 100 Km$^2$. Bardia National Park is located in the southerwestern part about 150 km east from Shuklaphanta Wildlife Reserve (Figure2.4). BNP covers an area of 968 Km$^2$. The altitude ranges between 152m above msl and 1441m above msl (Dinerstein 1979a). The climate is sub-tropical with three main seasons, namely dry winter (November-February), hot dry (March-June) and monsoon (July-October). The area undergoes heavy rainfall above 90% (1560-2230 mm) similar to SWR, between June and September. The minimum temperature is 5 $^0$ C during winter and maximum 45$^0$ C during the monsoon.

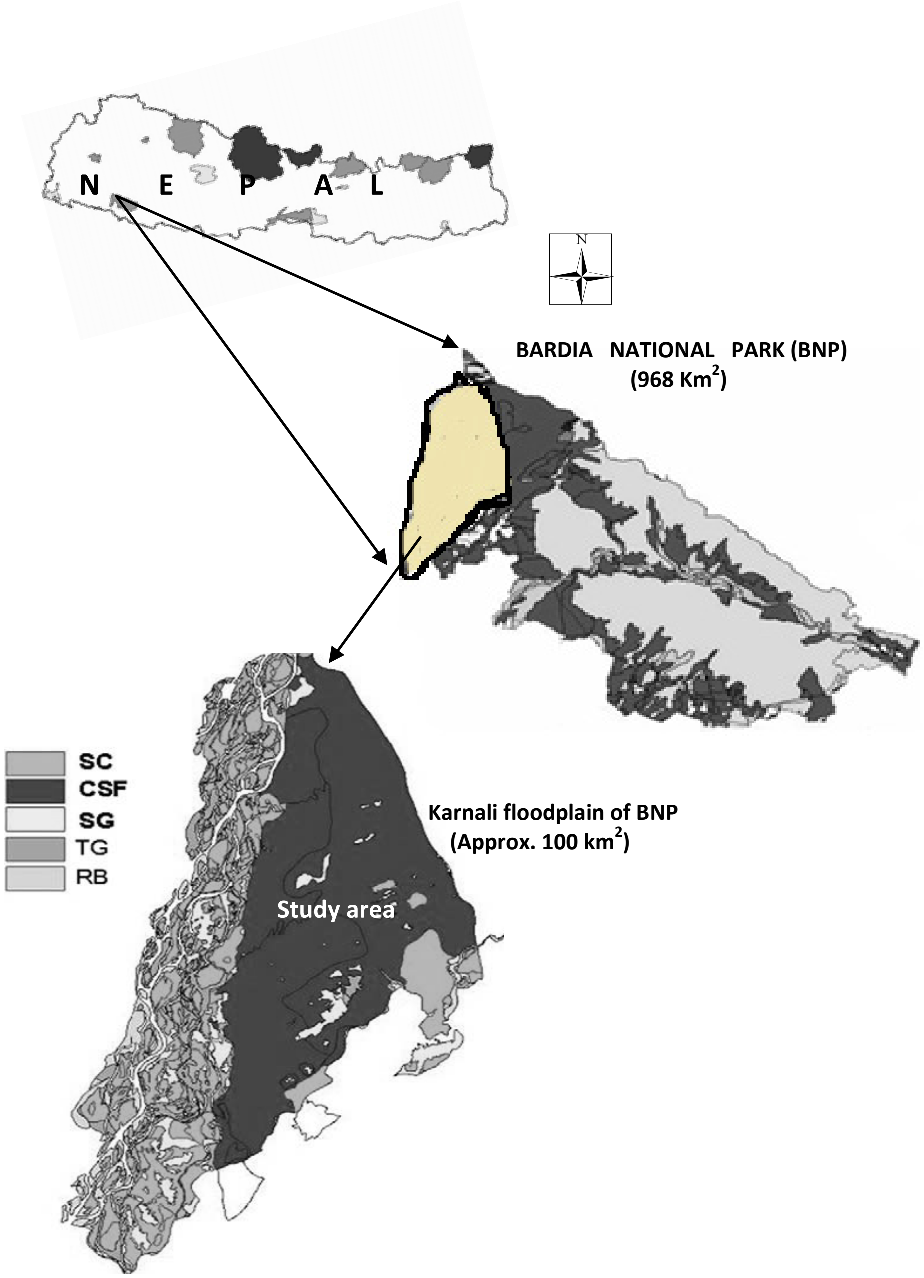


Figure: 2.4. Map showing Bardia National Park and the intensive study area.

The park consists of deciduous vegetation. Dinerstein (1979a) classified vegetation into six major types, later modified into seven major types by Jnawali and Wegge (1993). Sharma (1999) further classified and described 17 different sub-types.

Out of 17 habitats, 15 are covered with vegetation. The most important vegetation type is Sal forest, dominated by sal *Shorea robusta*. Wegge *et al*. (2009) divided habitats into four main types, two forest types and two grasslands types: (i) climax Sal forest (CSF) consisted of Sal forests with small, interspersed patches of Terminalia forest, (ii) successional forest (SF) consisted of all forest types other than Sal forest, (iii) Savannah grasslands (SG) included all Imperata-dominated vegetation types, (iv) tall floodplain grasslands (TG) were dominated by *Saccharum spontaneum*.

The diverse vegetation provides habitats for fifty-five species of mammals including tiger *Panthera tigris tigris*, leopard *Panthera pardus* wild elephant *Elephas maximus*, greater one horned rhinoceros *Rhinoceros unicornis*, swamp deer *Cervus duvauceli duvauceli*, four horned antelopes *tetracerus quadricornis*, fresh water Gangetic dolphin *Platanista gangetica* and Himalayan black bear *Urus thibetanus.* Other mammals are spotted deer *Axis axis*, sambar deer *Cervus unicolor*, hog deer *Axis porcinus*, Muntjac *Muntiacus muntjak*, nilgai *Boselaphus tragocamelus,* sloth bear *Melursus ursinus*, wild boar *Sus scrofa*, pangolin *Manis panthdactyala*, striped hyena *Hyanea hyena*, wild dog *Cuon alpines* and common otter *Lutra perspicillata*. The park harbours about 400 resident and migrant birds species, and two species of crocodiles, marsh mugger *Crocodilus palustris* and gharial *Gavialis gangeticus* (Dinerstein 1979a).

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# CHAPTER 3

# PREY SELECTION OF TIGERS *Panthera tigris* AND COMMON LEOPARDS *Panthera pardus*

# CHAPTER 3

# PREY SELECTION OF TIGERS *Panthera tigris* AND COMMON LEOPARDS *Panthera pardus*

## ABSTRACT

Prey selection of the two sympatric large carnivores, tiger *Panthera tigris tigris* and leopard *Panthera pardus,* has been evaluated in the Shukalphanta Wildlife Reserve (SWR), Nepal, during the dry seasons between 2008 and 2011. The Distance line transect method and scat analysis were used to estimate density of prey species and to determine food habits, respectively. The 250 km$^2$ intensive study area was found to have high prey density of 131 and 175 individual animals/km$^2$ during the dry seasons of 2010 and 2011, respectively. Wild prey (chital, hog deer, muntjac, swamp deer, wild boar, nilgai, langur and rhesus) were estimated to compose around 62-63% and domestic (cattle, buffalo and goat/sheep) 38%-37% of the prey in 2010 and 2011, respectively. Among the wild preys, swamp deer (32 animals/km$^2$) was the most abundant during 2010, followed by chital (26 animals/km$^2$). In 2011, chital (41 animals/km$^2$) was the most abundant followed by swamp deer (32 % animals/km$^2$). Large-sized prey made up 55.7% and 55.6%, medium-sized prey 21.1% and 23.9%, and small-sized prey 23.2% and 20.4% of the overall densities in 2010 and 2011, respectively. The analysis of 194 tiger and 42 leopard scats showed the occurrence of 12 and 14 prey species, respectively. Around 73% of the tiger scats contained remains of one prey species, 26.8% of two prey species and 0.5% of three prey species. In terms of frequency of occurrence in the tiger scats, medium-sized prey made up the majority, followed by large and then smaller prey species. A high proportion of chital contributed to this. However, in terms of prey biomass, tiger preyed mainly on large sized prey. Fifty percent of leopard scats contained remains of one prey species, 36% of two prey species and 14% of three prey species. Small prey species made up the majority of the leopard diet, followed by medium species, whereas large prey contributed little to the leopard diet. Tiger and leopard diets were composed of a large quantity of wild ungulates (77% for tigers and 51% for leopards). The relative frequency of occurrence of wild ungulates in the diet differed significantly between tiger and leopard. Feral domestic dogs, rodents and birds were not recorded in tiger scats, but they were present in the leopard diet. There was a high dietary overlap between tiger and leopard. Muntjac, wild boar, hog deer, nilgai, buffalo and chital were consumed more by tiger than expected, whereas swamp deer, langur, rhesus and cattle were consumed less in relation to their availability. For the leopard, muntjac, wild boar, hog deer, langur, buffalo, goat/sheep and chital were consumed more than expected, and swamp deer, rhesus and cattle were consumed less than availability. This study was the first in SWR, suggesting that the study area part of SWR has abundant wild prey density. Both tiger and leopard seem mostly dependent on wild prey, however, considerable proportions of domestic prey were observed in diet, bringing challenges for the management of the Reserve.

**Key words:** *food habits, line transect***,** *tiger, leopard, prey selection, scat analysis; Nepal.*

## 3.1. INTRODUCTION

A broad understanding of the feeding habits of felids and their behavioural flexibility in hunting is essential for addressing their conservation requirements (Seidensticker & McDougal 1993). However, the mysterious, solitary and nocturnal habits of tigers and leopards, along with their wide-ranging movements, have limited our understanding of their feeding ecology and how this may diverge under varying environmental circumstances (Sunquist 1981).

Resource availability influences feeding habits, which, in turn, may lead to interspecific competition for scarce key-resources with more than one user (De Boer & Prins 1990). Competing species may show evolutionary response, leading to ecological divergence (Pianka 1973, Schoener 1974). In extreme cases, competition may lead one species to disappear locally (Bengtsson 1989). Competition between carnivores may include resource exploitation and behavioural interference, especially through interspecific killing and kleptoparasitism (Palomares & Caro 1999, Donadio & Buskirk 2006). In particular, killing the inferior competitor is a widespread tactic among carnivores, with negative effects on the population size of victim species: interspecific differences in body size and diet, as well as taxonomic relatedness, are factors influencing the level of competition (*e.g.* Palomares & Caro, 1999; Donadio & Buskirk, 2006).

Interacting species can avoid resource competition by specialising on different prey species. Well-known examples of systems that exhibit such niche partitioning include the interactions between tiger *Panthera tigris*, common leopard *Panthera pardus*, dhole *Cuon alpinus* (Karanth & Sunquist 2000, Johnsingh 1983), cougar *Puma concolor* and bobcat *Lynx rufus* (Hass 2009), and cougar and jaguar *Panthera onca* (Foster *et al.* 2010). Interference competition may also be decreased by temporal segregation in the same habitat (as reported for the lion *Panthera leo*, cheetah *Acinonyx jubatus* and wild dog *Lycaon pictus* (Schaller 1972, Mills & Biggs 1993)), by habitat separation (e.g. Iberian lynx *Lynx pardinus*, common genet *Genetta genetta* and Egyptian mongoose *Herpestes ichneumon* (Palomares *et al.* 1995)), by both temporal and spatial separation like in the cheetah, lion and spotted hyaena *Crocuta crocuta* (Durant 1998), but also by preying on different species, e.g. wild dog and lion (Mills & Gorman 1997) and tiger, common leopard and dhole (Karanth & Sunquist 1995).

Tiger is the largest endangered felid and it is found in small populations in various habitat types: temperate forests, tropical forests and mangrove forests, where they mostly prey on small to large ungulates, depending on the availability of prey species within their range (Sunquist & Sunquist,1989, Støen & Wegge 1996). The common leopard is often a sympatric large felid, considered as the most successful large wild cat because of its adaptable killing and feeding behaviour (Bertram 1999). This species is widespread throughout Asia and Africa (Myers 1986, Bailey 1993, Nowell & Jackson 1996). Both species are near-threatened because of continuous poaching and loss of habitat across their range. The number of individuals of both species has been decreasing in the last decade (Henschel et al. 2008, Chundawat *et al.* 2011 cited in IUCN 2012).

Knowledge of the feeding biology, as well as availability and distribution of prey base is crucial to secure the long term survival of these large carnivores (Milla 1992), and to increase awareness of their conservation needs. While poaching and habitat degradation have been shown to play a role in their population declines, low prey availability due to prey habitat loss could also be an important factor. Prey availability and distribution can exert a strong influence on prey selection and hunting success (Fuller *et al.* 1992), as well as activity patterns and spatial distribution.

Tigers and leopards are stalking predators and are expected to kill more opportunisticly as opposed to dhole, which is a coursing predator (Schaller 1967). Nepal is one of the tiger range countries with more than 150 adult tigers and has committed to double the number by 2022. The Terai Arc Landscape, which bridges Nepal and India, is one of the priority Tiger Conservation Landscapes (Sanderson *et al.* 2006) with at least 5 core breeding sites (Ranganathan *et al*. 2008). Tigers and leopards are sympatric through most of the tiger's range including the lowland Terai of Nepal, and play an important role in influencing population levels of prey species. Recent studies on the food habits suggest that tigers and leopards have substantial dietary overlap (Andheria *et al.* 2007, Wang & Macdonald 2009, Wegge *et al*. 2009), with both species preying on large as well as small size ungulates (Johnsingh 1983, Karanth & Sunquist 1995, Sankar & Johnsingh 2002, Ramesh *et al.* 2009). This probably leads to competition for prey and therefore each cat species can affect prey availability for the other species.

The leopard consumes almost every animal that it can kill, from the smallest peafowl, porcupine up to the buffalo (Rabinowitz 1989, Seidensticker *et al.* 1990, Karanth & Sunquist 1995, Sankar & Johnsingh 2002, Andheria et al. 2007). In Asia, leopards are found to prefer prey species within the range of 10 to 40 kg, with an average prey weight of 23 kg (Hayward *et al.* 2006, Odden & Wegge 2009, Odden *et al.* 2010, Bhattarai & Kindlmann 2012), and in Africa their diet was found to consist of at least 92 species within the range 20-80 kg (Mills & Harvey 2001).

Prey selectivity can be defined as the killing of prey types in frequencies that are different from those expected based on their availability in the environment (Chesson 1978). Prey choice by large felids, which ultimately determines the food habits of these predators, plays a key part in determining their life history strategies, including movement, habitat selection, social structure, geographical distribution and reproductive success (Sunquist & Sunquist 1989). Tiger prey selection seems to vary. Biswas & Sankar (2002), provided data which suggest that tigers relied more on medium-sized prey followed by the large sized prey regardless of an ample supply of large prey in the area. Similar results were recorded by Bhattarai & Kindlmann (2012) from Chitwan National Park, Nepal. Karanth & Sunquist (1995) suggest that in the absence of large prey, tigers would remove non-selectively medium-sized prey. In contrast, Støen & Wegge (1996) and later (Wegge *et al.* 2009) demonstrated that tigers show significant selection among medium-sized prey species when large prey was scarce. Sambar, which are commonly taken by tigers in other areas, were not preyed upon by Badia and Shuklaphanta tigers. This was thought to occur due to scarcity of sambar in both areas (Karnali floodplain, Bardia and present study area).

In Nepal, studies have been conducted on prey selection of tigers and leopards in Chitwan National Park (Seidensticker 1976, Smith *et al.*1998, Bhattarai & Kindlmann 2012) and Bardia National Park (Støen & Wegge 1996, Wegge *et al*. 2009, Odden & Wegge 2009, Odden *et al.* 2010), but no such scientific study has been conducted in SWR. Studies on prey selection are therefore likely to be crucial for guiding management authorities on how to best conserve these carnivores. Where other drives of population decline can be controlled (eg. poaching, habitat loss) an understanding of the limits imposed by prey availability and selection may be a key factor in the management of sustainable predator populations, and may contribute to achieving the commitments made by the Government.

This study therefore examines prey selection by tigers and leopards in the SWR.

The specific aims of this study are:

i) to estimate the density of major prey species,

ii) to determine the composition of tiger and leopard diets and their prey preferences, and

iii) to determine the degree of overlap between the diets of these two cat species.

## 3.2. METHODS

### 3.2.1. Study area:

The study was carried out in the far western lowland Terai of Nepal in the SWR (305 km$^2$) between 2008 and11. The reserve is sub tropically monsoonal with heavy rainfall from June to September (the monsoon season), thus access is restricted during this time. For this reason, all sampling was conducted during the dry period between October and May. Reserve is bordered to the east by the Syali river, to the west by the Mahakali river, to the south by the Nepal-India border, and to the north by the Mahabharat range. The focal study area covers approximately 250 km$^2$ of the relatively intact western part of the reserve. In contrast, the eastern area is under intense pressure from illegal livestock grazing and other anthropogenic activities. SWR is one of the tiger bearing protected areas of Nepal, lying in the middle of the Terai Arc Landscape. It is connected through a narrow strip of forest corridor with the Kisanpur Wildlife Sanctuary, India in the south. Shuklaphanta forms a protected island in the centre of a densely settled area (except for its southern part), which presents a challenge for the conservation of large cats. Schaaf (1978) distinguished eight different habitat types in the reserve. A large area of grasslands (ca 54 km$^2$) located in the southern belt of the reserve provides the prime habitat for the endangered swamp deer *Cervus duvauceli duvauceli*. Tigers and leopards are the two main large predators in the area. The potential main prey species are chital *Axis axis*, swamp deer, hog deer *Axis porcinus*, wild boar *Sus scrofa*, sambar deer *Cervus unicolor*, barking deer *Muntiacus muntjac*, nilgai *Bosephalus tragocamelus*, porcupine *Hystrix indica,* common langur *Presbytis entellus*, and rhesus macaque *Macaca mulatta*. Buffalo and cattle are in the peripheral areas of the reserve make additional prey base for tigers. Similarly, feral dogs, goats etc were included in leopards' diet. Details of the study area are given in chapter 2.

### 3.2.2. Estimation of prey availability

The line transect Distance sampling method was used to estimate densities of prey species (Buckland *et al.* 1993, Thomas *et al.* 2009). This method has been widely used in tropical landscapes (Karanth & Sunquist 1992, 1995, Biswas & Sankar 2002, Bagchi *et al.* 2003, Jathanna *et al.* 2003, Karanth *et al.* 2004, Wegge & Storaas 2009). In total, 20 permanent line transects, spaced 1 km apart and measuring approximately 220 km in total, were laid across the study area (Figure 3.2).

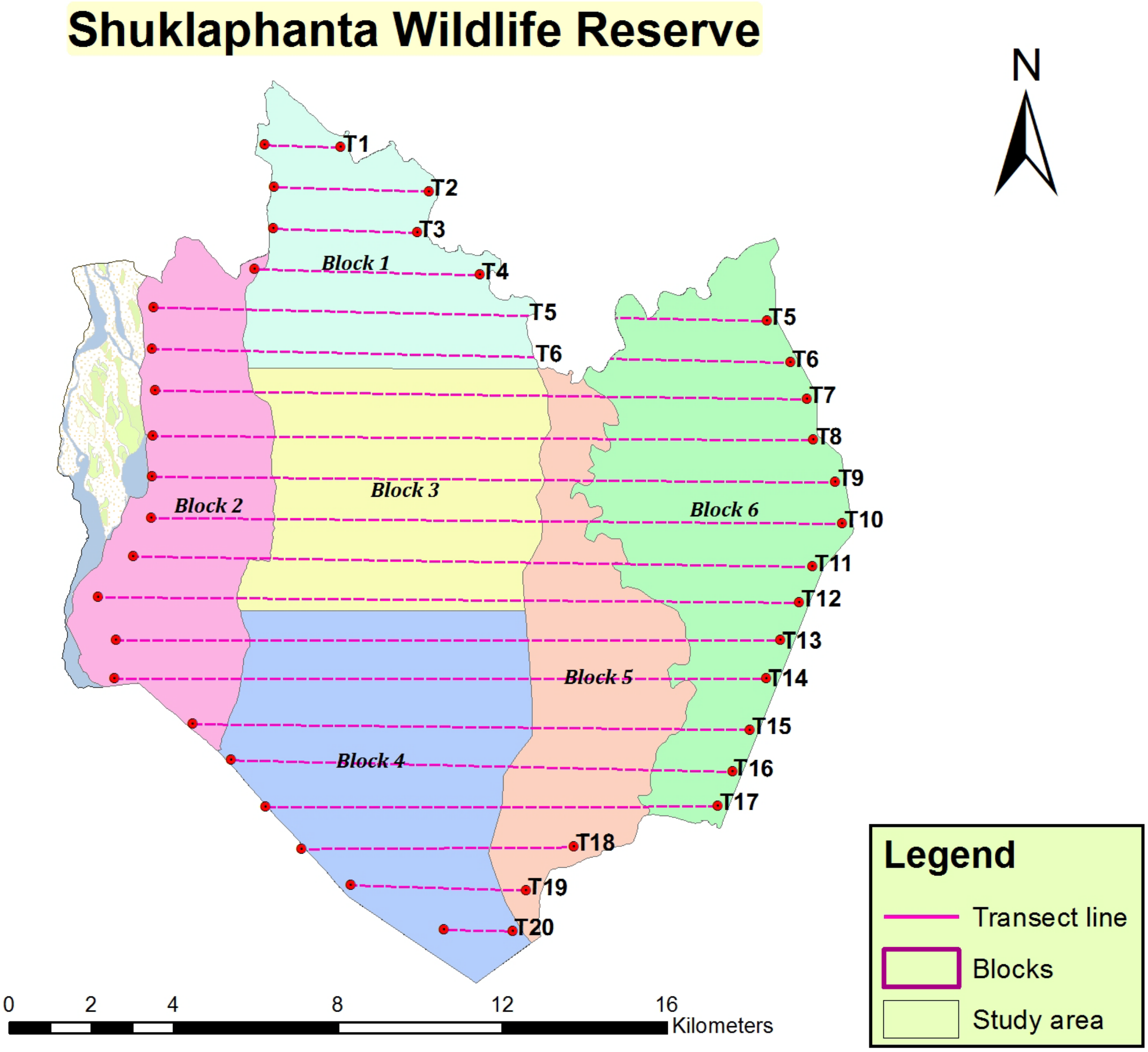

**Figure. 3.2. Map showing the line transects and blocks in the study area**

These transects were prearranged in six blocks, each block covering a minimum of 25 $km^2$ of the area. As recommended by Wegge & Storaas (2009), they were sampled from elephant back. All surveys were carried out at dawn and dusk during the dry seasons, because prey species are than easier to observe since they were most active during these periods and they could be counted from the elephant back. The reserve becomes impenetrable during the monsoon seasons.

In SWR, the large grassland (> 50 $km^2$) is inhabited by swamp deer. Direct counts from observation towers, vehicles and elephants were made to estimate the swamp deer abundance. For this, each elephant walked along the transect carrying its driver and one observer, while two observers were located in each of the three towers used during the counts. Where vehicles were used, two observers were located on the back of each pickup. On every line transect, a record was made of the number of individuals in every observation of prey species, the angle between the transect and the observation (using a compass), and the distance from the observers on the transect to the observation (using a range finder).

### 3.2.3. Data analysis distance

The data from the line transects were analysed for all prey species using the Distance program version 6.0 (Thomas *et al.* 2009). This program allows for the inclusion of covariates other than distance from the line in its detection function (c.f., Marques & Bukland 2003, 2004, Marques *et al.* 2007). The distribution of data on the distances from the transect to the animals was examined for each species to detect signs of evasive movements, shown by and increased abundance at a great distance from the line transect. The data were truncated (shortened) and distance intervals were selected based on goodness of fit before selecting models using the AIC (Akaike Information Criterion). The “Half normal” detection function was to the best model, built as a function of the covariates. The covariates could be related to the individual detections (e.g. group size or animal behaviour), the observer (e.g. observer ID) or the environment (e.g. habitat, weather or percentage of canopy cover), and were both continuous covariates and qualitative factors (e.g. Marques *et al.* 2007, Thomas *et al.* 2010). Using the selected model, the program Distance generates estimates of group density ($D_G$) and individual density ($D_I$) with coefficients of variation and confidence intervals.

### 3.2.4. Reconstruction of diet

*Scat collection and analysis*

Scats of tigers (N=194) and leopards (N=42) were collected systematically by searching jungle roads and trails on foot and bicycle, from October to May (2009-11). The wet seasons, between later part of June and September, are dominated by monsoon floods, which wash out or quickly decompose the scats, preventing sample collection. Initially, scats of tigers and leopards were distinguished by size and associated signs e.g. pugmarks (Biswas & Sankar 2002, Andheria *et al.* 2007). Later, samples were also checked through DNA analyses and only samples whose origin had been confirmed genetically were used for dietary analysis. Scats that could not be assigned to species were therefore excluded. Samples were preserved in paper bags, with relevant information attached (name of assumed species, date of collection, degree of freshness, coordinates and any sign associated with the scats). Samples were air dried and stored for laboratory analysis.

Reference slides were made from hair samples of potential prey species from both specimens found dead in the reserve and from live individuals in the Central Zoo, Kathmandu. The slides were prepared according to Teerink (1991), Mukherjee et al. (1994b) and De Marinis & Asprea (2006).

Fine sieves, with 1mm and 3mm meshes, were used to wash scats and separate hair from bones, hooves and other material. Hairs were then washed in warm water with detergent, rinsed in distilled water, dehydrated in 70% ethanol and dried on filter paper (Ramakrishnan *et al.* 1999). The isolated hairs were attributed to species by means of macroscopic analysis under a stereomicroscope. Twenty individual hairs were randomly selected from each scat for analysis (Mukherjee et al. 1994a, b, Karanth & Sunquist 1995, Støen & Wegge 1996) and compared with reference slides and photographic keys using parameters such as appearance of the hair, colour, cortex pigmentation, medullary patterns and relative length (Koppikar & Sabnis 1976a, b, Karanth & Sunquist 1995, Bonnin 2008).

### 3.2.4. Data analysis

*Data based on first- source information*

Prey data were analyzed using absolute frequency of occurrence (A) (number of occurrence of each prey species/ total number of scats x 100), relative occurrence (RO) (number of occurrence of each prey species, when present / total number of occurrence x 100) (e.g. Cavallini & Lovari 1991), and the percentage of volume (V) estimated visually from the remains of each prey in scats (estimated volume of each prey species/ total estimated volume x 100) (Kruuk & Parish 1981). Frequency of occurrence in scats alone may not reveal the overall importance of prey items in the diet of these two felids. Therefore, the volume of each prey item in terms of corresponding food intake was estimated by eye for each scat (c.f. Kruuk 1989). The estimated volume, when present (%), versus the frequency of occurrence (%) of the prey species was plotted to show the relative importance of prey items (e.g. Kruuk 1989).

*Data based on assumptions*

Body weights of prey depend upon density of local populations, age classes, sex and habitat quality, which are all parameters hard to assess from prey remains in scats and they are locally quite variable. Geist (1978) showed that mature animlas in dense populations of a species may differ in body size, reproductive features and social behaviour from those of colonizing, young populations, i.e. maintenance vs. colonizing phenotypes. Furthermore, estimates of the quantity of meat consumed by predators are often subjective, because the carcass has been checked and weighted over time, and the species and number of predators/scavengers feeding upon a carcass are hard to assess. Moreover, the number of individuals preyed upon may only be estimated by continuous monitoring of radio tagged predators (c.f. Molinari-Jobin *et al.* 2004, Molinari-Jobin *et al.* 2007, Odden & Wegge 2009). Thus, assumptions should be taken with caution, unless supported by local data.

The frequency of occurrence (A) is misleading, because the hairs of small prey species show up more often in scats per unit prey weight consumed than those of larger prey species (Ackerman *et al.* 1984). To correct this bias, the relative number of prey species killed by tigers and leopards was estimated using the regression equation ($Y= 1.980+0.035X$) modified by Ackerman *et al.* (1984) for the cougar (*Felis concolor:* adapted from Floyd *et al.* 1978), where Y is used as a correction factor and multiplied by the frequency of occurrence to correct for the over-representation of smaller prey species. X represents the average body weight of each prey species (kg). Average weights of prey species were obtained from Schaller (1967), Dinerstein (1980), Karanth & Sunquist (1995), Odden *et al.* (2005) and Odden & Wegge (2007).This regression equation has been used widely in dietary studies of large carnivores (e.g. Karanth & Sunquist, 1995; Andheria *et al.* 2007, Wegge *et al.* 2009, Wang & Macdonald, 2009; Klare *et al.* 2011, for review). The relative biomass $D=(AxY)/\sum(AxY)$ x 100 (the proportion of meat of a specific prey item in the predator's overall diet), and the relative number of prey species consumed $E=(D/X)/\sum(D/X)$ x 100 (the proportion of that prey species taken among all prey consumed by the predator), was also calculated using a correction factor (Y) (Andheria, Karanth and Kumar. 2007).

Prey species were classified into three different classes in terms of their mean body weight. Species with a mean weight between 5kg to 30kg were classified as "small prey" (hog deer, muntjac, langur, rhesus, porcupine, goat, sheep and dog), >30 to 150 kg as "medium prey" (chital and wild boar) and >150 kg as "large prey" (swamp deer, sambar deer, nilgai, cattle and buffalo).

### *Estimation of prey selection*

Prey selection of tigers and leopards was estimated by comparing the percentage occurrence of each prey item in the scat (*i.e.* usage), with the estimated density of the same prey species in the study area (*i.e*. availability).This was conducted separately for each prey species.

Prey selection was measured using the Ivlev's Electivity Index (Ivlev 1961).

$E_i = r_i - a_i / r_i - a_i$, where

$r_i$ = % occurrence of prey items in the predator scats.

$a_i$ = availability (% proportion of prey species in the environment)

$E_i > 0$ means that prey species *i* has been consumed more than its relative availability in the environment, *i.e*. it has been "selected".

*Diet diversity and overlap*

Diet diversity was calculated using the standardized index of trophic niche breadth ($B_{sta}$) (Colwell & Futuyma 1971). The standardized index formula is: $B_{Sta}=B-1/B_{max}{}^{-1}$, Where B ($B=\Sigma_n 1/ p^2{}_i$) is the Levins's index of niche breadth (Levins 1968), $B_{max}$ is the total number of prey species recognized (N=16). $B_{sta}$ values range between 0 (minimum niche breadth) and 1 (maximum niche breadth).

Pianka's niche overlap index (Pianka 1973) was used to measure the diet overlap between tiger and leopard. The index ranges from 0 (no overlap between the 2 species) to 1.0 (complete overlap between the 2 species).

$$\text{Pianka's index} \qquad O_{tl} = \frac{\Sigma_n \, p_{it} \, p_{il}}{\sqrt{\Sigma_n \, p^2{}_{it} \, \Sigma_n \, p^2{}_{il}}}$$

where $p_i$ is the proportion of prey species *i* observed in the diet of tiger *t* and leopard *l.*

Differences between the tiger and the leopard diets were assessed using a G- test on the frequency of occurrences of prey items in scat samples. For these comparisons, both prey size and prey type were used.

## 3.3. RESULTS

### 3.3.1. Availability of prey species

The estimated densities of groups and individuals of prey species available in the study area during the dry seasons of 2010 and 2011 have been summarized in Tables 3.1 and 3. 2.

Table 3.1. Estimated group (**$D_G$:** number of clusters/km$^{-2}$) and individual (**$D_I$:** number of individuals/km$^{-2}$) densities of prey species between **March- May 2010** (after annual grass harvest). **$C_V$**: coefficient of variation; **$C_I$**: 95% confidence intervals.

| Species | Number of animals encountered | $D_G$ (km$^{-2}$) | $C_vD_G$ (%) | $C_ID_G$ (km$^{-2}$) | $D_I$ (km$^{-2}$) | $C_vD_I$ (%) | $C_ID_I$ (km$^{-2}$) |
|---|---|---|---|---|---|---|---|
| Chital *Axis axis* | 547 | 5.00 | 16.85 | 3.59-6.97 | 25.88 | 20.91 | 17.21-38.92 |
| Hog deer *Hyelaphus porcinus* | 54 | 3.01 | 30.04 | 1.68-5.41 | 4.08 | 31.16 | 2.23-7.46 |
| Muntjac *Muntiacus muntjak* | 2 | 0.17 | 78.70 | 0.04-0.68 | 0.17 | 78.70 | 0.04-0.68 |
| Swamp deer *Cervus duvauceli* ** | 1737 | - | - | - | 32.17 | - | - |
| Wild boar *Sus scrofa* | 31 | 0.40 | 36.89 | 0.20-0.82 | 1.78 | 48.01 | 0.70-4.52 |
| Nilgai *Boselaphus tragocamelus* | 23 | 0.23 | 51.19 | 0.09-0.60 | 0.86 | 69.27 | 0.22-3.32 |
| **Ungulates** | | **8.81** | | | **64.94** | | |
| Langur *Semnopithecus schistaceus* | 79 | 0.68 | 44.27 | 0.29-1.58 | 6.03 | 56.52 | 2.06-17.61 |
| Rhesus macaque *Macaca mulatta* | 102 | 0.97 | 32.55 | 0.52-1.83 | 9.53 | 38.62 | 4.52-20.08 |
| **Primates** | | **1.65** | | | **15.56** | | |
| Cattle *Bos* sp. | 1349 | 0.96 | 37.05 | 0.47-1.95 | 33.76 | 86.40 | 7.18-158.64 |
| Buffalo *Bubalus bubalis* | 138 | 0.45 | 43.60 | 0.20-1.03 | 6.13 | 51.81 | 2.31-16.31 |
| Goat/sheep *Capra hircus* /*Ovis aries* | 521 | 0.17 | 61.86 | 0.05-0.53 | 10.55 | 63.99 | 3.27-34/06 |
| **Livestock** | | **1.58** | | | **50.44** | | |
| **Total** | | **12.04** | | | **130.94** | | |

** Total count (see Methods)

Table 3. 2: Estimated group (**$D_G$:** number of clusters/km$^{-2}$) and individual (**$D_I$:** number of individuals/km$^{-2}$) densities of prey species between **February and April 2011** (after annual grass harvest). **$C_V$**: coefficient of variation; **$C_I$**: 95% confidence intervals.

| Species | Number of animals encountered | $D_G$ (km$^{-2}$) | $C_vD_G$ (%) | $C_ID_G$ (km$^{-2}$) | $D_I$ (km$^{-2}$) | $C_vD_I$ (%) | $C_ID_I$ (km$^{-2}$) |
|---|---|---|---|---|---|---|---|
| Chital | 672 | 5.24 | 16.74 | 3.77-7.29 | 40.97 | 28.17 | 23-73-70.73 |
| Hog deer | 185 | 4.08 | 29.22 | 2.31-7.20 | 11.56 | 32.41 | 6.19-21.61 |
| Muntjac | 4 | 0.34 | 60.48 | 0.11-1.04 | 0.34 | 60.48 | 0.11-1.04 |
| Swamp deer** | 1743 | - | - | - | 32.28 | - | - |
| Wild boar | 30 | 0.75 | 28.13 | 0.43-1.30 | 0.90 | 37.54 | 0.43-1.87 |
| Nilgai | 1 | 0.07 | 99.05 | 0.01-0.36 | 0.07 | 99.05 | 0.01-0.36 |
| **Ungulates** | | **10.48** | | | **86.12** | | |
| Common langur | 117 | 0.78 | 36.03 | 0.39-1.56 | 11.37 | 57.76 | 3.68-35.08 |
| Rhesus macaque | 146 | 1.55 | 30.53 | 0.86-2.81 | 12.53 | 37.51 | 6.09-25.80 |
| **Primates** | | **2.33** | | | **23.90** | | |
| Cattle | 2312 | 0.52 | 41.11 | 0.23-1.13 | 63.28 | 49.27 | 25.02-160.1 |
| Buffalo | 73 | 0.23 | 45.18 | 0.10-0.53 | 1.84 | 51.04 | 0.70-4.81 |
| **Livestock** | | **0.75** | | | **65.12** | | |
| **Total** | | **13.56** | | | **175.14** | | |

** Total count (see Methods).

On average, 131 and 175 individuals belonging to all prey species were estimated to occur per km$^2$ during the dry seasons of 2010 and 2011, respectively. Of these, 61.5% individuals were wild prey and 38.5% were livestock in 2010, whereas in 2011, 62.8% were wild prey and 37.2% were livestock (Tables 3.1 and 3.2).

Large-sized prey made up 55.7% and 55.6%, medium-sized prey 21.1% and 23.9%, and small-sized prey 23.2% and 20.4% of the overall individual densities in 2010 and 2011, respectively. Individually, swamp deer was the most abundant wild prey, followed by chital, rhesus, langur, hog deer, wild boar, nilgai and muntjac in 2010. However, in 2011 chital was the most abundant wild prey, followed by swamp deer, rhesus, hog deer, langur, wild boar, muntjac and nilgai (Table 3.1 and 3.2).

### 3.3.2. Composition of tiger and leopard diets

The results of the tiger and the leopard diets have been summarized in Tables 3.3 and 3.4 and Figures 3.3 and 3.4. The analysis of 194 tiger and 42 leopard scats showed the occurrence of 12 and 14 prey species, respectively. 72.7% of tiger scats contained remains of one prey species, 26.8% of two prey species and 0.5% (one scat) of three prey species. Medium-sized prey made up the majority of the diet, followed by larger and then smaller prey species. 50% of leopard scats contained remains of one prey species, 35.7% of two prey species and 14.3% of three prey species. Small prey species made up the majority of the diet, followed by medium species, whereas large prey contributed little to the leopard diet (Table 3.3 & 3.4).

Tiger and leopard diets were found to be composed of a large quantity of wild ungulates (77% for tigers and 51% for leopards) (Figure 3.4). The Relative occurrences (RO) of prey items (wild ungulates) in the diet was significantly higher in tiger compared to leopard ($G=11.12$; $df=1$, $p<0.001$). Big domestic animals were the second (13%) most recorded prey species for tigers, whereas primates were the second (12%) most important prey for leopards. Small domestic animals and dogs showed the same importance (each category: 9%).

Table 3.3. Prey species, absolute frequency or frequency of occurrence (A Occ.), relative occurrence (R Occ.) and percentage of volume (Vol.), for tigers (**1= year 2009, N=79 scats; 2= year 2010, N=48; 3= year 2011, N=67**) and leopards (**1= year 2009, N=11; 2= year 2010, N=16; 3= year 2011, N=15**).

| Prey | A Occ.(%) | 1 | 2 | 3 | R Occ. (%) | 1 | 2 | 3 | Vol. (%) | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***TIGER*** | | | | | | | | | | | | |
| ***Large prey*** | | | | | | | | | | | | |
| Swamp deer | **20.2** | 19.0 | 20.8 | 20.9 | **15.9** | 14.9 | 17.2 | 15.7 | **19.3** | 18.2 | 20.2 | 19.5 |
| Sambar deer *Cervus unicolor* | **1.8** | 3.8 | 0.0 | 1.5 | **1.4** | 3.0 | 0.0 | 1.1 | **1.8** | 3.8 | 0.0 | 1.5 |
| Nilgai | **1.7** | 0.0 | 2.1 | 3.0 | **1.3** | 0.0 | 1.7 | 2.2 | **1.6** | 0.0 | 1.8 | 3.0 |
| Cattle | **4.9** | 0.0 | 4.2 | 10.4 | **3.8** | 0.0 | 3.4 | 7.9 | **2.3** | 0.0 | 4.2 | 2.8 |
| Buffalo | **12.6** | 11.4 | 14.6 | 11.9 | **10.0** | 8.9 | 12.1 | 9.0 | **10.6** | 7.5 | 14.3 | 10.1 |
| | **41.2** | | | | **32.4** | | | | **35.6** | | | |
| ***Medium prey*** | | | | | | | | | | | | |
| Chital | **32.4** | 29.1 | 29.2 | 38.8 | **25.4** | 22.8 | 24.1 | 29.2 | **26.5** | 21.0 | 25.2 | 33.4 |
| Wild boar | **12.8** | 8.9 | 14.6 | 14.9 | **10.1** | 6.9 | 12.1 | 11.2 | **9.6** | 7.4 | 10.7 | 10.8 |
| | **45.2** | | | | **35.4** | | | | **35.6** | | | |
| ***Small prey*** | | | | | | | | | | | | |
| Hog deer | **17.6** | 27.8 | 14.6 | 10.4 | **13.9** | 21.8 | 12.1 | 7.9 | **15.1** | 23.3 | 12.0 | 10.0 |
| Muntjac | **10.7** | 12.7 | 10.4 | 9.0 | **8.4** | 9.9 | 8.6 | 6.7 | **8.3** | 10.7 | 9.6 | 4.6 |
| Langur | **5.0** | 6.3 | 4.2 | 4.5 | **3.9** | 5.0 | 3.4 | 3.4 | **2.5** | 4.9 | 0.6 | 2.1 |
| Rhesus macaque | **2.8** | 1.3 | 4.2 | 3.0 | **2.2** | 1.0 | 3.4 | 2.2 | **0.7** | 0.2 | 1.1 | 0.8 |
| Sheep | **1.8** | 3.8 | 0.0 | 1.5 | **1.4** | 3.0 | 0.0 | 1.1 | **0.4** | 0.4 | 0.0 | 0.9 |
| | **37.9** | | | | **29.8** | | | | **27.1** | | | |
| ***LEOPARD*** | | | | | | | | | | | | |
| ***Large prey*** | | | | | | | | | | | | |
| Swamp deer | **9.6** | 9.1 | 6.3 | 13.3 | **6.0** | 6.7 | 3.6 | 7.7 | **5.4** | 3.4 | 5.3 | 7.6 |
| Cattle | **4.3** | 0.0 | 6.3 | 6.7 | **2.5** | 0.0 | 3.6 | 3.8 | **2.6** | 0.0 | 1.0 | 6.7 |
| Buffalo | **4.2** | 0.0 | 12.5 | 0.0 | **2.4** | 0.0 | 7.1 | 0.0 | **2.9** | 0.0 | 8.6 | 0.0 |
| | **18.1** | | | | **10.8** | | | | **10.9** | | | |
| ***Medium prey*** | | | | | | | | | | | | |
| Chital | **39.6** | 54.5 | 31.1 | 33.3 | **25.7** | 40.0 | 17.9 | 19.2 | **30.0** | 43.4 | 19.8 | 26.7 |
| Wild boar | **7.4** | 9.1 | 6.3 | 6.7 | **4.7** | 6.7 | 3.6 | 3.8 | **2.0** | 1.4 | 1.0 | 3.6 |
| | **47.0** | | | | **30.4** | | | | **32.0** | | | |
| ***Small prey*** | | | | | | | | | | | | |
| Hog deer | **16.9** | 18.2 | 12.5 | 20.0 | **10.6** | 13.3 | 7.1 | 11.5 | **14.9** | 15.4 | 11.5 | 17.8 |
| Muntjac | **11.5** | 9.1 | 18.8 | 6.7 | **7.1** | 6.7 | 10.7 | 3.8 | **10.7** | 9.1 | 16.4 | 6.5 |
| Langur | **11.6** | 9.1 | 12.5 | 13.3 | **7.2** | 6.7 | 7.1 | 7.7 | **9.5** | 9.1 | 10.6 | 8.8 |
| Rhesus macaque | **7.4** | 9.1 | 6.3 | 6.7 | **4.7** | 6.7 | 3.6 | 3.8 | **4.2** | 9.1 | 2.6 | 0.9 |
| Porcupine *Hystrix indica* | **6.4** | 0.0 | 12.5 | 6.7 | **3.6** | 0.0 | 7.1 | 3.8 | **4.1** | 0.0 | 6.8 | 5.6 |
| Goat | **8.6** | 0.0 | 12.5 | 13.3 | **4.9** | 0.0 | 7.1 | 7.7 | **2.8** | 0.0 | 6.3 | 2.0 |
| Sheep | **4.3** | 0.0 | 6.3 | 6.7 | **2.5** | 0.0 | 3.6 | 3.8 | **0.7** | 0.0 | 1.0 | 1.0 |
| Dog *Canis* sp. | **12.8** | 0.0 | 25.0 | 13.3 | **7.3** | 0.0 | 14.3 | 7.7 | **6.2** | 0.0 | 8.2 | 10.4 |
| | **79.5** | | | | **47.9** | | | | **53.0** | | | |
| ***Other*** | | | | | | | | | | | | |
| Bird sp. | **4.8** | 9.1 | 0.0 | 6.7 | 2.9 | 6.7 | 0.0 | 3.8 | 0.8 | 1.4 | 0.0 | 1.1 |

Table 3. 4. Prey species, average body weight (x̄), correction factor (Y), estimated relative biomass consumed (D) and estimated relative number of prey individuals (E), of tigers (**1= year 2009, N=79 scats; 2= year 2010, N=48; 3= year 2011, N=67**) and leopards (**1= year 2009, N=11 scats; 2= year 2010, N=16; 3= year 2011, N=15**).

| Prey | x̄ (kg) | Y (Kg/scat) | D (%) | 1 | 2 | 3 | E (%) | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| ***TIGER*** | | | | | | | | | | |
| ***Large prey*** | | | | | | | | | | |
| Swamp deer | 159 | 7.5 | **24.0** | **24.1** | **25.1** | 22.7 | **8.6** | 7.6 | 9.2 | 9.0 |
| Sambar deer | 212 | 9.4 | **2.7** | 6.0 | 0.0 | 2.0 | **0.7** | 1.4 | 0.0 | 0.6 |
| Nilgai | 169 | 7.9 | **2.0** | 0.0 | 2.6 | 3.4 | **0.8** | 0.0 | 1.0 | 1.3 |
| Cattle | 180 | 8.3 | **6.0** | 0.0 | 5.5 | 12.4 | **2.1** | 0.0 | 1.8 | 4.4 |
| Buffalo | 273 | 11.5 | **22.9** | 22.1 | 26.8 | 19.8 | **4.8** | 4.0 | 5.7 | 4.6 |
| | | | **57.5** | | | | | | | |
| ***Medium prey*** | | | | | | | | | | |
| Chital | 55 | 3.9 | **19.7** | 19.1 | 18.2 | 21.8 | **20.4** | 17.4 | 19.3 | 25.0 |
| Wild boar | 38 | 3.3 | **6.6** | 5.0 | 7.7 | 7.1 | **9.5** | 6.5 | 11.8 | 11.8 |
| | | | **26.3** | | | | | | | |
| ***Small prey*** | | | | | | | | | | |
| Hog deer | 27 | 2.9 | **8.3** | 13.7 | 6.8 | 4.4 | **16.8** | 25.4 | 14.7 | 10.3 |
| Muntjac | 17 | 2.6 | **4.4** | 5.5 | 4.3 | 3.3 | **14.4** | 16.1 | 14.7 | 12.3 |
| Langur | 8 | 2.3 | **1.8** | 2.4 | 1.5 | 1.5 | **12.5** | 15.0 | 11.0 | 11.5 |
| Rhesus macaque | 8 | 2.3 | **1.0** | 0.5 | 1.5 | 1.0 | **7.2** | 3.0 | 11.0 | 7.7 |
| Sheep | 25 | 2.9 | **0.8** | 1.8 | 0.0 | 0.6 | **1.7** | 3.6 | 0.0 | 1.6 |
| | | | **16.3** | | | | | | | |
| ***LEOPARD*** | | | | | | | | | | |
| ***Large prey*** | | | | | | | | | | |
| Swamp deer | 159 | 7.5 | **14.7** | 16.5 | 8.1 | 19.6 | **2.6** | 3.1 | 1.3 | 3.3 |
| Cattle | 140 | 6.9 | **5.4** | 0.0 | 7.4 | 8.9 | **1.0** | 0.0 | 1.3 | 1.7 |
| Buffalo | 140 | 6.9 | **4.9** | 0.0 | 14.8 | 0.0 | **0.9** | 0.0 | 2.6 | 0.0 |
| | | | **25.1** | | | | | | | |
| ***Medium prey*** | | | | | | | | | | |
| Chital | 48 | 3.7 | **30.5** | 48.0 | 19.7 | 23.7 | **17.8** | 30.0 | 10.3 | 13.2 |
| Wild boar | 38 | 3.3 | **5.0** | 7.2 | 3.6 | 4.3 | **3.7** | 5.7 | 2.3 | 3.0 |
| | | | **35.5** | | | | | | | |
| ***Small prey*** | | | | | | | | | | |
| Hog deer | 27 | 2.9 | **10.2** | 12.8 | 6.3 | 11.4 | **10.4** | 14.2 | 5.8 | 11.2 |
| Muntjac | 17 | 2.6 | **5.7** | 5.6 | 8.3 | 3.3 | **8.9** | 9.3 | 12.2 | 5.2 |
| Langur | 8 | 2.3 | **5.2** | 4.9 | 4.9 | 5.9 | **17.7** | 18.5 | 15.2 | 19.5 |
| Rhesus macaque | 8 | 2.3 | **3.4** | 4.9 | 2.4 | 3.0 | **12.0** | 18.5 | 7.6 | 9.8 |
| Porcupine | 14 | 2.5 | **2.8** | 0.0 | 5.3 | 3.2 | **5.2** | 0.0 | 9.5 | 6.1 |
| Goat | 20 | 2.7 | **4.2** | 0.0 | 5.8 | 6.9 | **5.5** | 0.0 | 7.2 | 9.3 |
| Sheep | 25 | 2.9 | **2.3** | 0.0 | 3.1 | 3.7 | **2.3** | 0.0 | 3.1 | 3.9 |
| Dog | 12 | 2.4 | **5.5** | 0.0 | 10.3 | 6.2 | **11.8** | 0.0 | 21.5 | 13.8 |
| | | | **41.5** | | | | | | | |

Average body weight (X̄) of prey species was taken from Schaller (1967), Dinerstein (1980), Ackerman et al (1984), Alkon (1987), Karanth and Sunquist (1995), Bagchi et al.( 2003), Andheria et al.( 2007), Odden & Wegge (2007), Ramesh et al. (2009), Wang & Macdonald (2009), and Wegge et al. (2009).

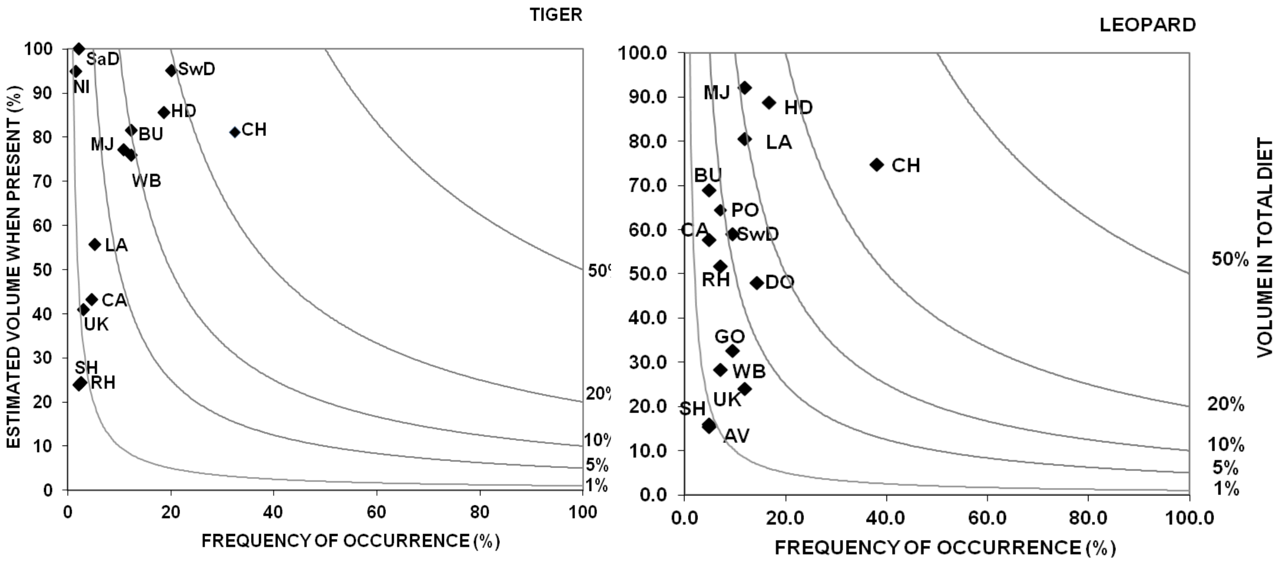

**Figure** 3.3. Estimated volume of tiger and leopard prey species *versus* their frequency of occurrence. Isopleths connect points of equal relative volume in the overall diet. **CH**: chital, **HD**: hog deer, **MJ**: muntjac, **SwD**: swamp deer, **WB**: wild boar, **SaD**: sambar deer, **NI**: nilgai, **LA**: langur monkey, **RH**:rhesus monkey, **PO**: porcupine, **CA**: cattle, **BU**: buffalo, **GO**: goat, **SH**: sheep, **DO**: dog, **AV**: bird, and **UK**: unknown.

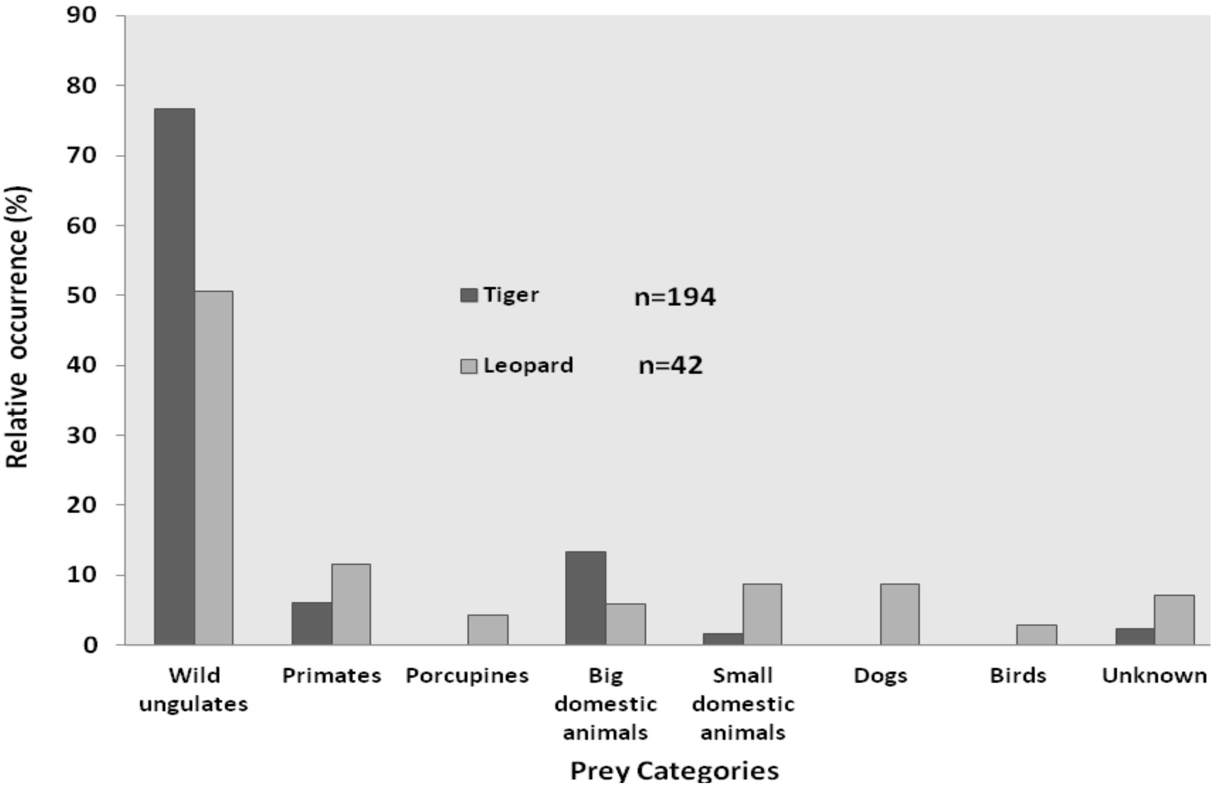

**Figure: 3.4. Comparison of the tiger and the leopard diets during the dry season**

Dogs, rodents and birds were not recorded in tiger scats, but they were present in the leopard diet. Medium prey species such as chital were the most common in the tiger diet, whereas small species showed up relatively often in the leopard diet, followed by medium species. Large prey such as swamp deer was relatively uncommon (Table 3.2 and Figure 3.3) for leopards. There was a significant difference in the proportion consumption of large prey between the tiger and the leopard (G=7.46; df=1, p=0.006). Tigers consumed more large prey than the leopards did.

### 3.3.3. Diet breadth and overlap

The comparative diet diversity (trophic niche breadth, % occurrence) and degree of niche overlap of the tiger and the leopard are presented in Table 5. The Levin's trophic niche breadth, measured using occurrence, was narrower in 2011 than in 2009 and 2010 for the tiger, whereas for the leopard, it was narrower in 2009 than in 2010 and 2011. Similarly, in 2011, the niche breadth, measured on estimated volume, was narrower for the tiger, whereas for the leopard it was wider in 2010 than in 2009 and 2011.

**Table: 3. 5. Standardized Levin's index of trophic niche breadth (BSta) and Pianka's index of trophic niche overlap (O) of the tiger and the leopard, based on relative occurrence (RO%) and estimated volume (V%).**

| | Niche breadth | | | | | | Niche overlap | | |
|---|---|---|---|---|---|---|---|---|---|
| | Tiger | | | Leopard | | | | | |
| | $B_{sta}$ | | Prey | $B_{sta}$ | | Prey | O | | |
| **Dry season** | **RO(%)** | **Vol ( %)** | **N** | **RO(%)** | **Vol ( %)** | **N** | **RO(%)** | **Vol ( %)** | **N** |
| **Total** | 0.55 | 0.48 | 12 | 0.67 | 0.47 | 14 | **0.85** | **0.86** | 16 |
| 2009 | 0.63 | 0.59 | 10 | 0.54 | 0.44 | 8 | 0.83 | 0.76 | 11 |
| 2010 | 0.66 | 0.57 | 10 | 0.78 | 0.63 | 13 | 0.73 | 0.76 | 14 |
| 2011 | 0.51 | 0.40 | 12 | 0.77 | 0.51 | 13 | 0.77 | 0.82 | 16 |
| **Seasonal** | | | | | | | | | |
| Autumn | 0.58 | 0.53 | 10 | 0.80 | 0.52 | 11 | 0.66 | 0.66 | 14 |
| Winter | 0.59 | 0.50 | 12 | 0.51 | 0.32 | 11 | 0.79 | 0.78 | 15 |

The niche breadths measured on relative occurrence and volume were similar in both autumn and winter for the tiger, whereas, niche breadth measured both with occurrence and volume was larger in autumn than in winter for the leopard (Table 3.5). The niche overlap values indicated a great dietary overlap of tiger and leopard (Table 3.5).

### 3.3.4. Estimation of prey selection

The Ivlev's Electivity Indices of prey selection at species level by tiger and leopard are shown in Figure 3.5. Muntjac, wild boar, hog deer, nilgai, buffalo and chital were consumed by tigers more than expected based on the relative availability of these individuals. Swamp deer, langur, rhesus and cattle were consumed less in relation to their availabilities, in both years (Figure 3.5).

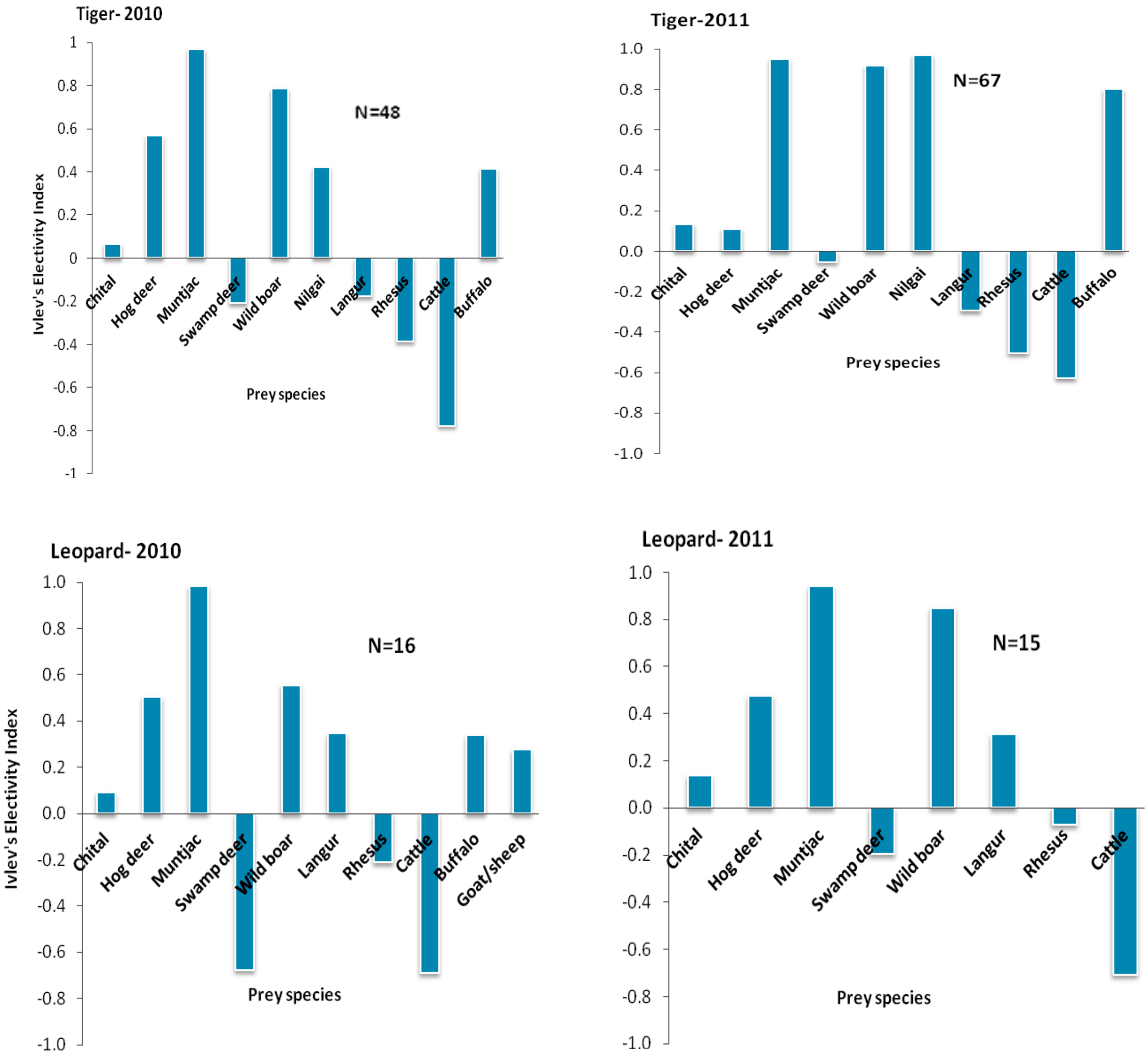

**Figure 3.5. Prey selection by tigers and leopards (dry season).**

For the leopard, the prey species muntjac, wild boar, hog deer, langur, buffalo, goat/sheep and chital were consumed more than expected based on their relative availability, but swamp deer, rhesus and cattle were underutilized in relation to their availability in 2010. In 2011, muntjac, wild boar, hog deer, langur and chital were predated more than their relative availabilities. Rhesus monkeys were consumed slightly less than availability and swamp deer and cattle were preyed upon less than their availability (Figure 3.5).

## 3.4. DISCUSSION

The wild ungulate densities estimated in this study, when compared with that of other tropical forest areas in Nepal, revealed that SWR harbours a high density of chital and swamp deer. The large area of grassland in the core of the reserve and the heterogeneous habitat favour a high density of prey species (Eisenberg & Seidensticker 1976). Swamp deer are true grazers and congregate in the large grassland of the core area and chital are uniformly distributed in different habitats. Four other prey species (muntjac, hog deer, wild boar and nilgai) were lower in density when compared to the densities of chital and swamp deer.

The results from the scat analysis, in terms of absolute frequency showed that tiger preys mainly on medium sized followed by large species. The high proportion of chital contributed to this. However, in terms of tiger prey biomass, large sized prey (swamp deer, sambar, nilgai, cattle and buffalo), comprised 57.5% the biomass of prey consumed, followed by 26.3% medium sized prey (chital and wild boar), and 16.3% of small sized prey (hog deer, muntjac, langur, rhesus, and sheep) (Table 3.4). Previous diet studies have provided similar results when comparing the prey biomass consumption by tigers (Karanth & Sunquist 1995, Karanth & Stith 1999, Karanth *et al.* 2004, Andheria *et al.* 2007, Wang & Macdonald 2009, Harihar *et al.* 2011). Tigers are, on average, three to four times larger than leopards (Seidensticker 1976), thus they have the capacity to hunt larger prey species, such as sambar and swamp deer, to satisfy their high energetic requirements. Nonetheless, the proportion of large-sized prey found in the present study is lower than that reported in studies from India and Bhutan (Biswas & Sankar 2002, Harsha *et al.* 2004, Wegge *et al*. 2009), where medium-sized prey were found to contribute a higher proportion in the diet of tigers. Støen & Wegge (1996) reported that this was probably due to a scarcity of large prey species in their study area, as well as their distribution pattern.

Among species, swamp deer contributed the most prey biomass (24%) to the diet of tigers in the present study area. Swamp deer were also recorded in a small percentage in the diet of tiger in Bardia, Nepal (Støen & Wegge 1996) and in Khana, India (Schaller 1967). In terms of frequency of occurrence and percentage of volume of prey items consumed, chital contributed the highest proportion (32.4% and 26.5%, respectively) to the tiger diet in SWR and are therefore identified to be one of the principal prey species, like was also reported from the nearby Bardia National Park (Wegge *et al.* 2009).

Sambar was found to contribute only 2.7% of the total diet of the tiger. This finding is different from studies by Biswas & Sankar (2002), Karanth *et al*. (2004), Andheria *et al*. (2007) and Sankar *et al.* (2010), where sambar contributed to more than a quarter of the biomass of tiger prey within their study areas. This dissimilarity in results is probably due to the low density of sambar in our study area, as reported for Bardia (Wegge *et al.* 2009, Støen & Wegge 1996). In SWR, swamp deer appear to replace sambar in the diet.

In contrast, small sized prey dominated the leopard diet (Table 3.4), contributing 41.5% of the prey biomass, followed by medium (31.7%) and large sized prey (25.1%). This may be one of the fundamental findings for understanding what makes the coexistence of tigers and leopards in SWR. Previous results from other areas are consistent with these findings (Henschel *et al.* 2005), indicating that leopards prefer prey species with a body mass between 10-40kg. Leopards are known to prey on a wide variety of prey species, which makes them the most adaptable predator among the big cats (Eisenberg & Lockhart 1972, Johnsingh 1983, Rabinowitz 1989, Ahmed & Khan 2008). Predation on small sized prey appears to be advantageous when large and medium-sized preys are relatively uncommon. However, the present study area was abundant in both large and medium size prey, and leopard diet showed the less proportion of large and medium than of small prey. Probably due to the large prey distribution is only in the core area, for example swamp deer was recorded mostly in the large grassland, which is located in the core area and could also due to leopard concentrated in the periphery of reserve, where the chance of predation on domestic prey.

Small-sized prey (hog deer 10.2%, muntjac 5.7%, langur 5.2%, rhesus 3.4% and porcupine 2.8%) contributed 27.4% of the prey biomass in the leopard diet, whereas large-sized prey (swamp deer) only contributed 14.7%. However, studies elsewhere (Seidensticker 1976, Johnsingh 1983, Mukherjee *et al.* 1994a,b, Karanth & Sunquist 1995, Karanth & Sunquist 2000, Andheria *et al.* 2007, Ramesh *et al.* 2009, Wang & Macdonald 2009) mostly reported high abundance of sambar remains in leopard scats, most likely due to high sambar densities in those areas. On the contrary, no sambar remains were found in leopard scats in the present study. Balme *et al.* (2007) concluded that leopards prefer to hunt in habitats where prey is easier to catch, rather than where prey is more abundant.

A substantial part of the diet of both tigers and leopards was found to consist of domestic species (19.3% and 34.2%, respectively), although preying on domestic animals outside the reserve was not recorded in the case of tiger, probably due to the availability of adequate nomadic livestock inside the reserve. Wild prey contributed 77.6% of the prey biomass and 80.8% of the estimated volume, whereas domestic animals contributed 22.4% of prey biomass and 15.1% of estimated volume. When considering only wild prey, then the medium sized prey (35.5% of prey biomass) dominated the leopard diet, which is similar to what was reported by previous researchers working in Bardia National Park, Nepal (Odden & Wegge 2009) and in India (Andheria *et al.* 2007). Harsha *et al.* (2004) suggested that in the absence of large prey species, tigers have adapted to smaller prey and take domestic livestock only rarely. Tigers are known to prey on domestic animals when these are readily available (Sunquist 1981, Tamang 2000, Bagchi *et al.* 2003) and with severe declines in natural prey species across the tiger's range, it is likely that domestic livestock has become a major source of food for tigers in South Asia (Schaller 1967, Madhusudan 2003). Leopards are frequently reported killing domestic stock in the fringes of reserves and in buffer zone areas (Nowell & Jackson 1996, Tamang & Baral 2008). Livestock depredation by tiger and leopard has escalated the human wildlife conflict across their range creating greater challenges for management authorities (Mishra 1997, Tamang

2000). Leopards may also be hunting in the buffer zones surrounding the study area, creating similar problems. In Bardia, leopards are known to prey on smaller domestic animals within the buffer zones of the park, and tigers generally prey upon larger domestic animals if they are illegally grazed within the park (Støen & Wegge 1996).

Dogs, rodents and birds were found to contribute little to the leopard diet, and were not recorded in the tiger scats. However, Sankar & Johnsingh (2002) and Johnsingh (1993) reported a high proportion of rodents in leopard scats. Comparison of tiger and leopard diets in SWR revealed that both species were selecting mainly wild ungulates, with tigers selecting large to medium size prey and leopards selecting small and medium sized prey.

High selection of small and medium-sized prey by tiger, as a result of reduced densities of larger ungulate species, may lead to competitive exclusion of other carnivores such as leopards and dholes, which preferentially feed on smaller prey (Karanth & Sunquist 1995).

Wegge *et al.* (2009) showed that both tiger and leopard in BNP predated less on the common prey species such as chital and hog deer than expected, and it was therefore unlikely that competition for food was the predominant reason for any displacement of leopards. Instead leopards used areas of low quality within the home ranges of the tigers and the fringe areas of the reserve/park to avoid tigers (Odden *et al.* 2010).

The Pianka index value indicated high dietary overlap between tiger and leopard diets. The consumption of wild ungulates such as chital, hog deer, swamp deer, wild boar and muntjac by both predators, explain at best the large overlap of their diets. Similar results on diet overlap between tiger and leopard have been reported in earlier studies elsewhere (Andheria *et al.* 2007, Wang & Macdonald 2009).

This study provides the first set of data on the food habits of tigers and leopards in Shuklaphanta Wildlife Reserve, Nepal during the dry seasons. The results indicate that the abundance of main prey species densities is higher than in other protected areas in

Nepal Terai, except from the southwestern part of Bardia National Park (Wegge *et al.* 2009). The western part of SWR is relatively well protected compared to the eastern part. Hence, with a higher degree of protection and habitat management, as well as enforced exclusion of grazing livestock, wild prey densities in the eastern part of the reserve will increase and be able to support more tigers. This could also eliminate livestock predation and reduce human-predator conflicts.

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# CHAPTER 4

# ACTIVITY PATTERNS OF TIGERS AND LEOPARDS

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## ABSTRACT

The temporal activity patterns of the tiger *Panthera tigris* and leopard *Panthera pardus* were studied in Shuklaphanta Wildlife Reserve in the far western lowlands of Nepal. The field study was carried out during three consecutive winters (2008-2011) using camera traps. A total of 25-30 paired sets of camera devices were used, with a total of 334 days and nights (24hrs), covering an area of about 250 $km^2$. Both tigers and leopards were photo captured more frequently at night than during the day, confirming their predominantly nocturnal habits, however, tigers activity was also found to have a larger diurnal component than leopards. Leopards were also found more active in the fringe areas of the reserve while tigers were more restricted to core areas. There were partial, but not complete overlaps in observations between 02:00hr and 05:00hr, with periods of peak activity during the hours of dawn and dusk. Concentration within certain areas and limited diurnal activity of leopards indicate the existence of temporal niche segregation between these two cat species.

**Key words:** *felids, carnivore; activity rhythms; camera trapping; diel activity; Nepal.*

## 4.1. INTRODUCTION

Diel activity patterns have evolved to cope with the time structure of the environment, and different activity patterns have profound implications for species' physiology, ecology and evolution (Kronfeld-Schor & Dayan 2003, Pianka 1973). Activity patterns may even vary within species, example: between seasons or in relation to sex, age or breeding state. The obvious dissimilarity of activity patterns between species suggests that timing of activity is a crucial characteristic for survival, and that the distinctive temporal strategies reflect different ecological constraints (Halle & Stenseth 2000). Hayward & Slotow (2009) suggested that species use of time is inescapably linked to morphological and physiological adaptations. However, not all mammals exhibit simple unimodal, diurnal or nocturnal activity pattern. More complex or multimodal patterns, such as crepuscular activity (showing bimodal peak activities, at dawn and dusk), are common among carnivores (Gittleman 1986, Ramesh *et al.* 2012). Theory suggests that temporal segregating among competitors and between predators and their prey may facilitate coexistence in ecological communities (e.g., Schoener 1974, Wiens *et all.*1986, Richards 2002), while interspecific competition between carnivores generally increases when species have similar morphology, or diet (Morin 1999). While, the role of temporal segregation in structuring communities has never been a strong focus of ecology, several studies have also accumulated that attach ecological significance to activity patterns (e.g., Kenagy 1973, Kunz 1973), and others have shown competition or predation-induced shifts in activity patterns (e.g. Fenn & MacDonald 1995, Alanara *et al.* 2001).

Activity patterns of large sympatric carnivores are influenced by prey availability (Zielinski *et al.* 1983, Karanth & Sunquist 2000), seasonal variation (Lourens and Nel 1990; Zub *et al.* 2009), human disturbance (Beckmann & Berger 2003, Griffiths & Schaik 1993, Kolowski *et al.* 2007), interspecific competition (Hayward & Slotow 2009, Hunter & Caro 2008, Romero-Muñoz *et al.* 2010) and intra-guild predation (Palomares & Caro 1999).

In the sub-tropical lowland Terai of Nepal, two dominant large carnivores (the tiger, *Panthera tigris*, and the common leopard, *Panthera pardus*) exit, influence the ecosystems they inhabit. Habitat loss (degradation and encroachment), poaching and prey depletion are serious threats in almost all tiger range countries, causing great concern to conservationists (Sunquist *et al.* 1999). Effective conservation management of these species relies on systematic information on how they interact with each other, as well as their surroundings. Knowledge of activity patterns provides a scientific basis for the development of conservation plans for endangered species (Hwang and Garshelis 2007), such as tigers and leopards.

Activity patterns of elusive nocturnal animals are often difficult to assess without the use of costly techniques such as radio telemetry, and with the exception of a few such investigations, the activity patterns of tigers and leopards have not been studied, and still less so in Nepal. The only studies of activity patterns of large carnivores in Nepal are from Bardia National Park (common leopard: Odden & Wegge 2005) and Chitwan National park (tigers and leopards: Seidensticker 1976, tiger: Sunquist 1981). In contrast Karanth & Sunquist (2000), recorded that activity patterns of tigers in Nagarahole National Park in, India as being is less diurnal than those of leopard. Tigers were generally active between sunset and sunrise (Sunquist 1981), most activity at night with resting between mid morning and mid afternoon (Schaller 1967). Leopards are primarily nocturnal, but showed less activity than tiger during daytime (hottest part of the day) (Sunquist 1981).

Camera trapping is a non-invasive useful alternative to radio telemetry that is widely applied for identifying activity patterns of large mammals in various habitats (Kinnaird *et al.* 2003, Silveira *et al.* 2003, Tobler *et al.* 2008) and for studying elusive and nocturnal animals (Karanth and Nichols 1998, Wegge *et al.* 2004). This method can be used to recognize individuals from their body marking or patterns (Schaller 1967, Franklin *et al.* 1999, O’Brien *et al.* 2003) and can be applied to both tigers and leopards (Karanth & Nichols 1998, O'Brien *et al.* 2003). The main disadvantage of the camera trap method is that cameras are costly and require regular maintenance (Henke *et al.* 2003). In this study, we used camera traps to provide baseline data on the winter activity patterns of tigers and leopards to facilitate the conservation of these species in the sub-tropical habitat in SWR, Nepal. Sunquist (1981), for instance, noted that leopards were less active than tiger both during the day and at night, probably the activity patterns might have been influenced by the presence of tigers. Karanth & Sunquist (2000) observed that there was no temporal separation of predatory activities between tigers and leopards in Nagarhole, India. In this study, we therefore used our camera data to further test this observation, predicting that tigers were more diurnal than leopards.

## 4.2. MATERIAL AND METHODS

### *4.2.1. Study area*

This study was carried out in Shuklaphanta Wildlife Reserve (SWR) located in the far western lowland Terai of Nepal ($28^0$ 45’16’’ N and $28^0$ 57’23’’N and $80^0$06’04’’ and $80^0$21’40’’E). The Reserve occupies an area of 305 $km^2$ at an elevation between 90 and 300m above sea level. Climate is monsoonal with mean ($36.5^0$C) temperature recorded during the month of May and mean minimum ($7.4^0$C) in January and annual rainfall ranging between 1055 and 2843 mm with over 90% precipitation occurring between July and August (Bhatta 1999).

Schaaf (1978) distinguished eight different vegetation types in the reserve: Sal forest (*Shorea robusta*), Sal Savanna, Mixed deciduous forest, Khair-Sissoo forest, Lowland grasslands, Dry grassland, Seasonally-wet grassland and Lowland savannas. A large tract of grassland stretched in over 54 $km^2$ area provides prime refuge to endangered swamp deer *Cervus duvauceli duvauceli,* one of the major prey species for large felids in the reserve. In addition to the two major predators tiger *Panthera tigris tigris* and leopard *Panthera pardus* whose activity patterns are discussed here, more than 45 species of mammals including endangered one horned rhinoceros *Rhinoceros unicornis*, wild elephant *Elephas maximus,* hispid hare *Caprolagus hispidus* are found in the area. Among these, the potential prey species for the felids are chital *Axis axis*, swamp deer, hog deer *Axis porcinus*, wild boar *Sus scrofa*, sambar deer *Cervus unicolor*, barking deer *Muntiacus muntjak*, nilgai *Boselaphus tragocamelus*, common langur *Presbytis entellus*, and rhesus macaque *Macaca mulatta.* Details of the study area are given in chapter 2.

### *4.2.2. Data collection*

Camera traps were set up during three consecutive winters (December 2008 - April 2009, November 2009 - January 2010 and January 2011 - February 2011). Two types of passive cameras activated by either heat or motion sensors, were used: Moultrie feeders, 150 Industrial Road, Alabaster, AL35007, US and Stealth Cam, LLC,Bedford, TX, US. They were set at 113, 109 and 112 locations during the first, second and third winter, respectively.

The study area was roughly divided into five adjacent *sampling areas* (SAs), numbered from 1 to 5. Camera traps were successively placed in each SA, so as to cover systematically the whole study area. Within each SA, cameras were placed on forest/ grassland roads and trails in locations visited by tigers and leopards, at a spacing of 1.5- 2 km (Wegge *et al.* 2004). These locations were referred to as *sampling units* (SUs). Each sampling unit consisted of two cameras mounted on wooden poles or trees at a height of 45 cm, 4-7 meters apart, on both sides of the trail, facing each other in order to photograph both flanks of the animal. With this method individual animals can be identified unambiguously based on their body stripe patterns and markings (Schaller 1967, McDougal 1977, Karanth 1995, Karanth & Nichols 1998, O'Brien *et al.* 2003). More than 80% of camera traps were operating for 10-15 consecutive 24 hrs, except for locations with high risk of theft, in which case: cameras were activated for 17 hours (between 04:00PM and 09:00AM of the following day). Cameras were camouflaged in order to avoid detection by humans or animals wherever possible. The GPS position of each SU was recorded. In addition, date, time, and camera ID were automatically printed on every image. At the end of the data collection period, 239 images of tigers (133 in the first, 31 in the second, and 75 in the third winter) and 86 images of leopards (20 in the first, 18 in the second, and 48 in the third winter) were captured.

### *4.2.3. Statistical analysis*

The analysis of activity patterns was based on the number of images captured in each SU each year. Each day and night period was divided into 8 *time intervals* (TIs) of 3 hours, each labelled by numbers from 1 to 8, *i.e.* TI1 (11:00AM- 02:00PM), TI2 (02:00PM-05:00PM), TI3 (05:00PM-08:00PM), TI4 (08:00PM- 11:00PM), TI5 (11:00PM

02:00AM), TI6 (02:00AM-05:00AM), TI7(05:00AM-08:00AM) and TI8 (08:00-11:00AM). To assure independence between SU data, photos taken within each SA were pooled together and differences among time intervals were assessed based on the number of pictures recorded at SA level.

The null hypothesis $H_0$, that the number of photographs recorded at SA level (taken as an index of tiger and leopard diel activity) was not affected by time interval, was tested against the alternative hypothesis ($H_1$) that a difference exists between at least two TIs.

Theoretically, as nothing was known about the distribution of the number of photos at SA level, a nonparametric multivariate test for dependent data (the number of photos recorded in a SA, in the 8 intervals, cannot be considered independent) was used. The complexity of this testing problem was overcome by breaking down $H_0$ (equality of the 8 TIs) into 28 hypotheses $H_{jk}$ that j-th and k-th TIs did not differ (k>h=1,…,8). Each of these hypotheses can be assessed by using the difference between the numbers of photos in the two TIs, $t_{jk}$, as the test statistic. If $H_{jk}$ was true, the $t_{jk}$ would be small, thus large values indicate a difference between the two TIs. With $H_0$ in mind, the 28 marginal test statistics are jointly informative, and they may be combined to provide an overall test statistic. Pesarin (2001) suggests that the significance of each marginal statistic can be determined by a permutation procedure. The resulting p-values may be combined to obtain an overall statistic. In turn, the significance of the final statistic is obtained using the same permutations of data. Therefore, the dependence structure of the marginal statistics is non-parametrically determined by the permutation procedure.

$H_0$ implies that the TIs do not affect the number of images captured. Thus, the 8 values recorded in each SA are actually exchangeable among periods, *i.e.* they could be observed with the same probability in any other of the 8TIs=40, 320 possible permutations of these values. As there are 5 SAs, the possible permutations of the sample data are $40, 320^5$. Permutation procedures are based on the comparisons of the test statistics, calculated from the observed data, with the corresponding distribution computed from the possible permutations of data. As the possible permutations are 40, $320^5$, the exact permutation distribution is prohibitive to compute.

Accordingly, the p-values of each marginal statistic, $p_{jk}$, are determined on the basis of a random sample of 10,000 permutations. The significance values were combined using the Liptak combining algorithm (Pesarin 2001):

$$L = \frac{1}{10} \sum_{k>j=1}^{5} \Phi^{-1}(p_{jk})$$

where $\Phi^{-1}$ denotes the inverse of the standard normal distribution function, and the overall p-value of the final statistic (L) is determined once again by the 10,000 permutations of the sample data.

## 4.3. RESULTS

The total number of photographs of tigers and leopards recorded in each time period, for three consecutive winter seasons (2008-2011), is shown in Figure 4.2 (a, b, c) and Figure 4.3 (a, b, c), respectively. The number of photographs recorded in each SA and each time period for the same periods have been presented in Table 4.1 and Tables 4.2. Table 4.3 and 4.4 present the *$t_{jk}$s and $p_{jk}$s (cf. Material and Methods)* for each comparison and the overall significance of the global homogeneity test.

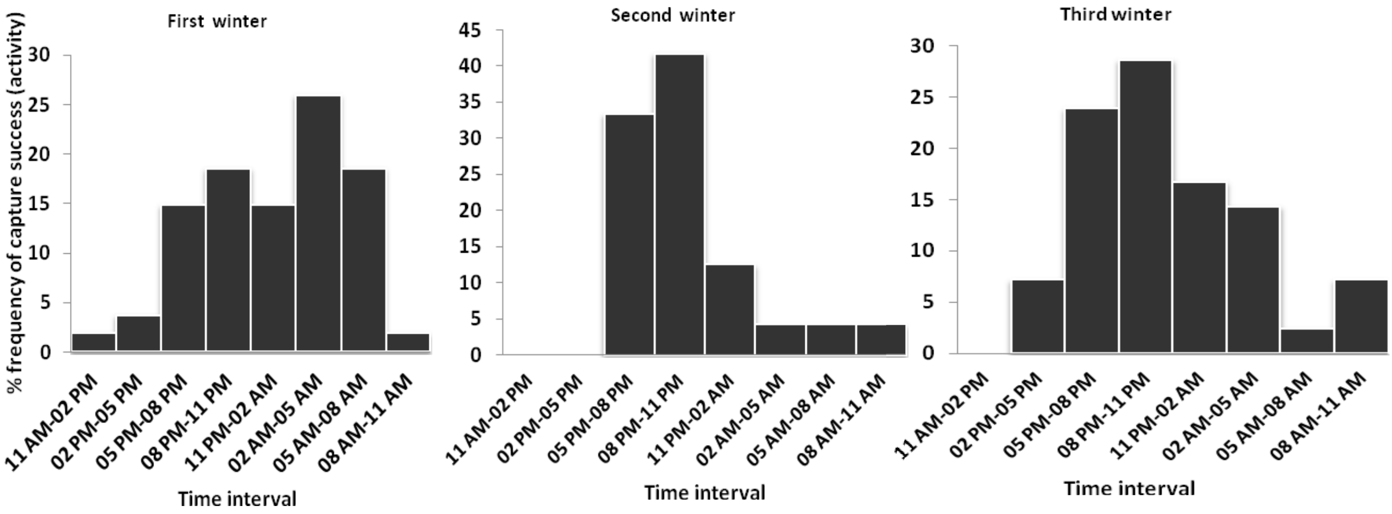
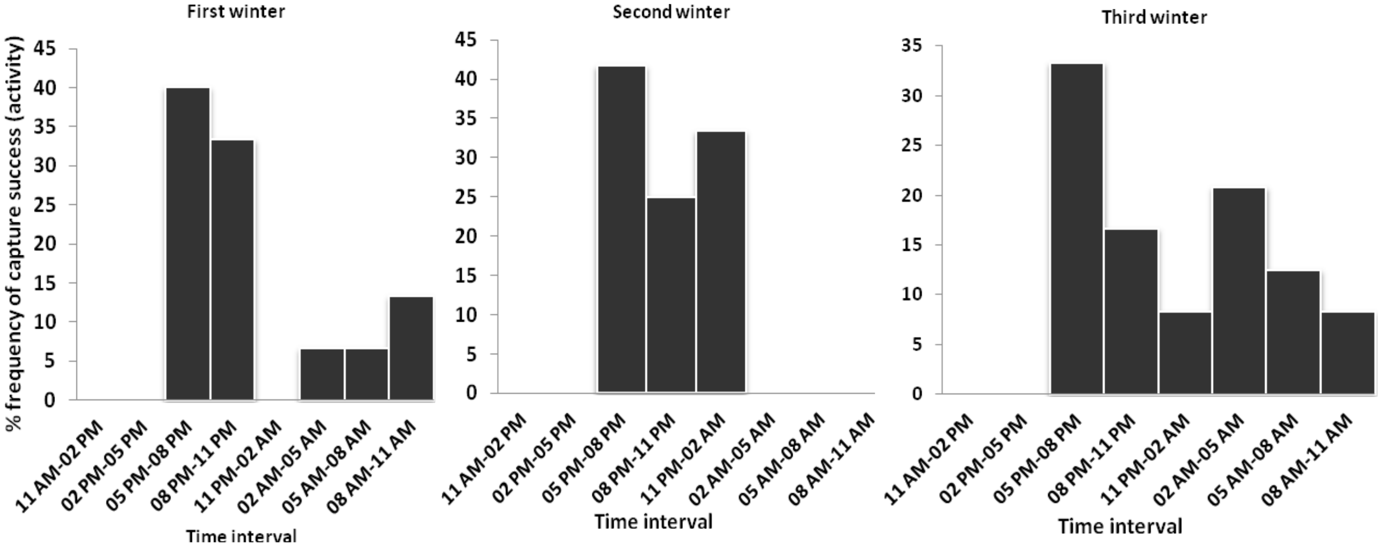

(a) (b) (c)

**Figure 4. 2 Activity patterns of tigers during winter (a) 1st year, (b) 2nd year & (c) 3rd Year.**



(a) (b) (c)

**Figure 4.3 . Activity patterns of leopards during winter (a) 1st year, (b) 2nd year & (c) 3rd Year.**

Tigers were active throughout the 24 hr cycle during the first winter, but they showed peaks of activity between 2AM and 5AM. In the second winter no activity was recorded between 11AM and 5PM, and tigers were active from 5PM to 11AM, reaching a peaks between 8PM and 11PM. In the third winter, no activity was recorded during 11AM to 2PM, and they were active throughout 21 hrs, and reached a peak between 8PM and 11PM (Table 4.1 and Fig.4.2). Each year leopard activity peaked between 5PM and 8PM, with no activity between 11AM and 05PM. In the second winter, on activity was recorded between 02AM and 11AM, but the other two winters activity was recorded during that time interval (Table 4.2 and Fig. 4.3). The activity patterns of the two cats overlapped in the dark period of the 24hr cycle, whereas leopard activity was extreme in the early evening between 5PM and 8PM (Fig.4.4 ).

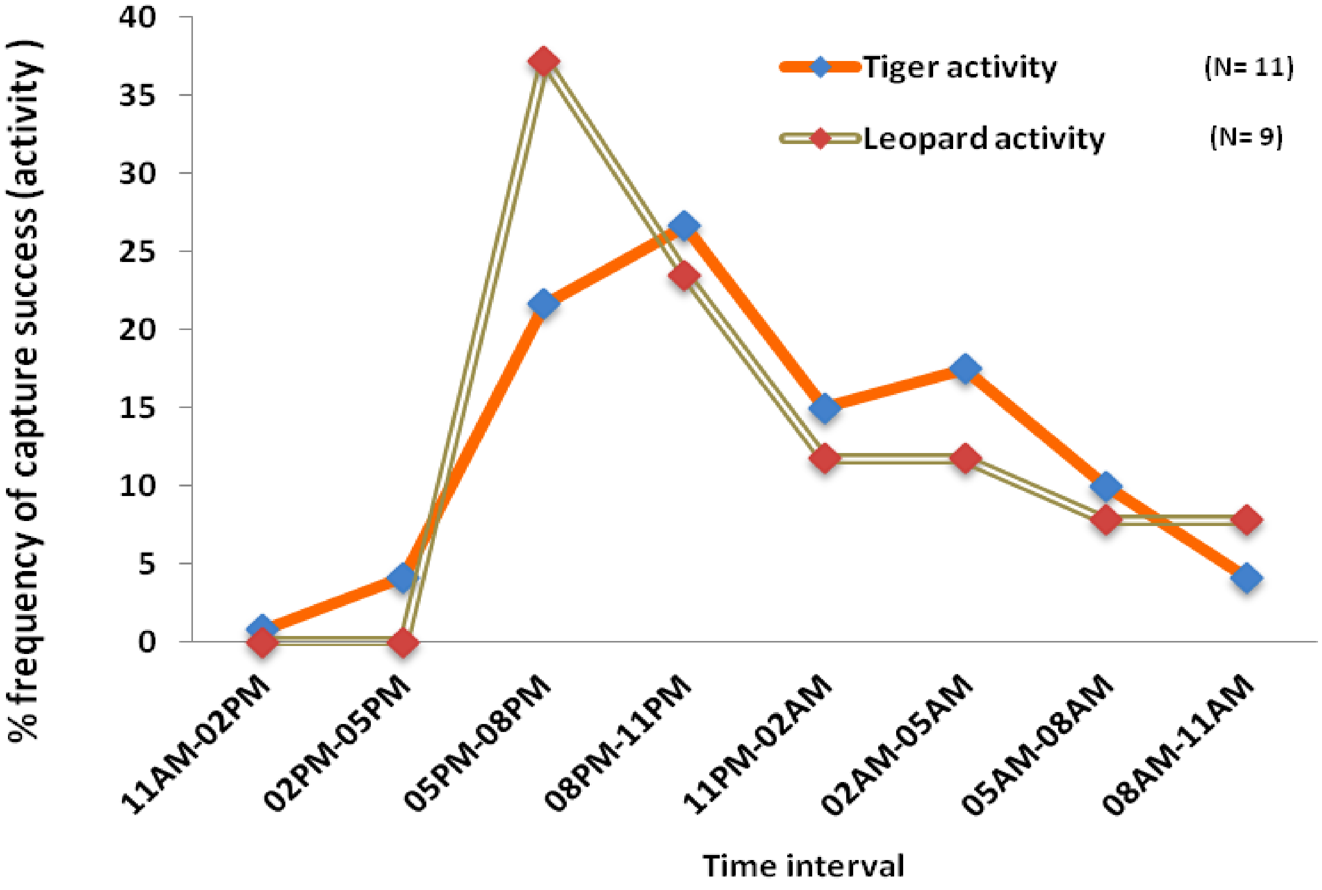


**Figure: 4.4. Activity patterns of tigers & leopards during the period of three winters**

Despite the high variability among SAs, a marked peak in the number of photos for both the tiger and the leopard was recorded during the 12 hours period of darkness between 05:00PM and 05:00AM (TI3, TI4, TI5 and TI6) (Tables 4.1 and 4.2), slowly decreasing from TI3-TI6 to TI2 and TI7, and reaching minimal or zero in the first and last intervals.

**Table 4.1. Total number of tiger photo events recorded in each sampling area (SA) for each time interval (TI) during three consecutive winters.**

**Tiger**

| First winter | TI1 | TI2 | TI3 | TI4 | TI5 | TI6 | TI7 | TI8 |
|---|---|---|---|---|---|---|---|---|
| Sampling area | 11AM-02PM | 02PM-05PM | 05PM-08PM | 08PM-11PM | 11PM-02AM | 02AM-05AM | 05AM-08AM | 08AM-11AM |
| SA 1 | 0 | 0 | 0 | 1 | 1 | 6 | 1 | 0 |
| SA 2 | 0 | 2 | 3 | 3 | 5 | 1 | 3 | 0 |
| SA 3 | 1 | 0 | 4 | 6 | 2 | 3 | 2 | 1 |
| SA 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| SA 5 | 0 | 0 | 1 | 0 | 0 | 4 | 3 | 0 |
| **Total** | **1** | **2** | **8** | **10** | **8** | **14** | **10** | **1** |
| **Second winter** | | | | | | | | |
| SA 1 | 0 | 0 | 4 | 2 | 0 | 0 | 1 | 0 |
| SA 2 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| SA 3 | 0 | 0 | 2 | 0 | 1 | 1 | 0 | 0 |
| SA 4 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| SA 5 | 0 | 0 | 2 | 5 | 0 | 0 | 0 | 0 |
| Total | **0** | **0** | **8** | **10** | **3** | **1** | **1** | **1** |
| **Third winter** | | | | | | | | |
| SA 1 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 0 |
| SA 2 | 0 | 1 | 5 | 3 | 2 | 2 | 0 | 2 |
| SA 3 | 0 | 2 | 2 | 2 | 1 | 0 | 0 | 1 |
| SA 4 | 0 | 0 | 3 | 4 | 1 | 1 | 0 | 0 |
| SA 5 | 0 | 0 | 0 | 3 | 1 | 2 | 0 | 0 |
| **Total** | **0** | **3** | **10** | **12** | **7** | **6** | **1** | **3** |

The formal assessment of $H_0$ confirmed the preliminary analysis of data. The overall hypothesis of homogeneity among periods was rejected for the tiger in all three winters (first winter *p*=0.058, second winter *p*=0.011 and third winter *p*=0.019) (Table 3). For the leopard, homogeneity was rejected for the first (*p*=0.016) and third winters (*p*=0.006; Table 4), and not for the second winter (*p*=0.108). The overall significance for the tiger was mainly due to the significant difference between the intervals TI3-TI6 and the extreme ones, TI1 (first winter *p*=0.068, *p*=0.009, second winter *p*=0.02, *p*=0.003 and third winter *p*=0.005, *p*=0.0006, *p*=0.06,) and TI8 (first winter *p*=0.064, *p*=0.009, second winter *p*= 0.04, p=0.009 and third winter *p*=0.54, *p*=0.013), as well as between the intermediate intervals TI2 and TI7 and the extreme ones. No significant differences were found between the TI3-TI6 and the intermediate intervals TI2 (first winter- *p*=0.208, *p*=0.211, second winter- *p*=0.338, *p*=0.664, third winter- 0.263, 0.387) and TI7 (first winter- *p*=0.620, 0.916, *p*=0.627, *p*=0.388, second winter- *p*=0.666, *p*=0.486, *p*=0.881, third winter- *p*=0.101, 0.165).

The first and third winter hypotheses of homogeneity were rejected for the leopard because of significance differences between TI3-TI6 and TI1 (*p*=0.006, *p*=0.024, *p*=0.0004, *p*=0.092, *p*=0.037) and TI8 (*p*=0.069, *p*=0.013). Significant differences were found also between TI3 and TI2 (*p*=0.007, *p*=0.0003), TI5 (*p*=0.007, *p*=0.011), TI6 (*p*=0.024), TI7 (*p*=0.026, *p*=0.039) and TI8 (*p*=0.013, *p*=0.069). Significant differences exist also between TI4 and TI2 (*p*=0.024), TI5 (*p*=0.026), TI6 (*p*=0.069), TI7 (*p*=0.07) and TI6 with TI2 (*p*=0.041).

**Table 4.2. Total number of leopard photo events recorded in each sampling area (SA) for each time interval (TI) during three consecutive winters.**

**Leopard**

| First Winter | TI1 | TI2 | TI3 | TI4 | TI5 | TI6 | TI7 | TI8 |
|---|---|---|---|---|---|---|---|---|
| Sampling area | 11AM-02PM | 02PM-05PM | 05PM-08PM | 08PM-11PM | 11PM-02AM | 02AM-05AM | 05AM-08AM | 08AM-11AM |
| SA 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| SA 2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| SA 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| SA 4 | 0 | 0 | 2 | 4 | 0 | 0 | 1 | 1 |
| SA 5 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | 0 | 6 | 5 | 0 | 1 | 1 | 2 |
| Second winter | | | | | | | | |
| SA 1 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 |
| SA 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SA 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SA 4 | 0 | 0 | 3 | 1 | 1 | 0 | 0 | 0 |
| SA 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | 0 | 5 | 3 | 4 | 0 | 0 | 0 |
| Third winter | | | | | | | | |
| SA 1 | 0 | 0 | 4 | 2 | 1 | 1 | 1 | 1 |
| SA 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SA 3 | 0 | 0 | 2 | 0 | 0 | 3 | 1 | 1 |
| SA 4 | 0 | 0 | 2 | 2 | 1 | 1 | 1 | 0 |
| SA 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | 0 | 8 | 4 | 2 | 5 | 3 | 2 |

The hypothesis of homogeneity was not rejected in the second winter because there was no significant difference found between TI1, TI2 and TI4 with TI6 (*p*=0.803, *p*=0.799, *p*=0.103), TI7 (*p*=0.798, *p*=0.800, *p*=0.101) and TI8 (*p*=0.805, *p*=0.810, *p*=0.108, *p*=0.809). No significant difference was found also between TI1, T2 and TI3 with TI4 (*p*=0.103, *p*=0.102, *p*=0.313), or between TI3 and TI4 with TI5 (*p*=0.530, *p*=0.531), and TI1 with TI2 (*p*=0.805), TI2 with TI6 (*p*=0.799), TI6 with TI7 (*p*=0.800) and TI7 with TI8 (*p*=801). However, significant differences were also found between TI3 and TI1 (*p*=0.014), TI2 (*p*=0.014), TI6 (*p*=0.013), TI7 (*p*=0.015) and TI8 (*p*=0.015). Significant differences (even if less marked) were detected between TI5 and TI1 (*p*=0.055), TI2 (*p*=0.053), TI6 (*p*=0.051), TI7 (*p*=0.051) and TI8 (*p*=0.054).

**Table 4.3** Differences (test statistics) between the number of total photos recorded in each pair of time intervals and their corresponding p-values achieved on the basis of 10,000 permutations of data in Table 1. $^{(**)}$ = significance (p < 0.05); $^{(*)}$ = significance (p <0.10).

**Tiger**

| **First winter** | | | **Second winter** | | | **Third winter** | | |
|---|---|---|---|---|---|---|---|---|
| **Comparison** | **Test statistic** | **p-value** | **Comparison** | **Test statistic** | **p-value** | **Comparison** | **Test statistic** | **p-value** |
| TI1 vs TI2 | 1 | 0.764 | TI1 vs TI2 | - | 0.879 | TI1 vs TI2 | 3 | 0.383 |
| TI1 vs TI3 | 7 | 0.147 | TI1 vs TI3 | 8 | 0.02 (**) | TI1 vs TI3 | 10 | 0.005 (**) |
| TI1 vs TI4 | 9 | 0.068 (*) | TI1 vs TI4 | 10 | 0.003 (**) | TI1 vs TI4 | 12 | 0.0006 (**) |
| TI1 vs TI5 | 7 | 0.157 | TI1 vs TI5 | 3 | 0.336 | TI1 vs TI5 | 7 | 0.06 (*) |
| TI1 vs TI6 | 13 | 0.009 (**) | TI1 vs TI6 | 1 | 0.667 | TI1 vs TI6 | 6 | 0.104 |
| TI1 vs TI7 | 9 | 0.067 (*) | TI1 vs TI7 | 1 | 0.670 | TI1 vs TI7 | 1 | 0.706 |
| TI1 vs TI8 | - | 0.921 | TI1 vs TI8 | 1 | 0.660 | TI1 vs TI8 | 3 | 0.378 |
| TI2 vs TI3 | 6 | 0.208 | TI2 vs TI3 | 8 | 0.022 (**) | TI2 vs TI3 | 7 | 0.055 (*) |
| TI2 vs TI4 | 8 | 0.098 (*) | TI2 vs TI4 | 10 | 0.003 (**) | TI2 vs TI4 | 9 | 0.014 (**) |
| TI2 vs TI5 | 6 | 0.211 | TI2 vs TI5 | 3 | 0.338 | TI2 vs TI5 | 4 | 0.263 |
| TI2 vs TI6 | 12 | 0.014 (**) | TI2 vs TI6 | 1 | 0.664 | TI2 vs TI6 | 3 | 0.387 |
| TI2 vs TI7 | 8 | 0.097 (*) | TI2 vs TI7 | 1 | 0.666 | TI2 vs TI7 | 2 | 0.54 |
| TI2 vs TI8 | 1 | 0.771 | TI2 vs TI8 | 1 | 0.668 | TI2 vs TI8 | - | 0.896 |
| TI3 vs TI4 | 2 | 0.632 | TI3 vs TI4 | 2 | 0.475 | TI3 vs TI4 | 2 | 0.528 |
| TI3 vs TI5 | - | 0.923 | TI3 vs TI5 | 5 | 0.133 | TI3 vs TI5 | 3 | 0.384 |
| TI3 vs TI6 | 6 | 0.194 | TI3 vs TI6 | 7 | 0.045 (**) | TI3 vs TI6 | 4 | 0.263 |
| TI3 vs TI7 | 2 | 0.620 | TI3 vs TI7 | 7 | 0.044 (**) | TI3 vs TI7 | 9 | 0.013 (**) |
| TI3 vs TI8 | 7 | 0.150 | TI3 vs TI8 | 7 | 0.04 (**) | TI3 vs TI8 | 7 | 0.054 (*) |
| TI4 vs TI5 | 2 | 0.634 | TI4 vs TI5 | 7 | 0.0429 (**) | TI4 vs TI5 | 5 | 0.177 |
| TI4 vs TI6 | 4 | 0.382 | TI4 vs TI6 | 9 | 0.009 (**) | TI4 vs TI6 | 6 | 0.098 (*) |
| TI4 vs TI7 | - | 0.916 | TI4 vs TI7 | 9 | 0.01 (**) | TI4 vs TI7 | 11 | 0.002 (**) |
| TI4 vs TI8 | 9 | 0.064 (*) | TI4 vs TI8 | 9 | 0.009 (**) | TI4 vs TI8 | 9 | 0.013 (**) |
| TI5vs TI6 | 6 | 0.212 | TI5vs TI6 | 2 | 0.482 | TI5vs TI6 | 1 | 0.71 |
| TI5vs TI7 | 2 | 0.627 | TI5vs TI7 | 2 | 0.486 | TI5vs TI7 | 6 | 0.101 |
| TI5vs TI8 | 7 | 0.150 | TI5vs TI8 | 2 | 0.48 | TI5vs TI8 | 4 | 0.269 |
| TI6vs TI7 | 4 | 0.388 | TI6vs TI7 | - | 0.881 | TI6vs TI7 | 5 | 0.165 |
| TI6vs TI8 | 13 | 0.009 (**) | TI6vs TI8 | - | 0.882 | TI6vs TI8 | 3 | 0.385 |
| TI7vs TI8 | 9 | 0.068 (*) | TI7vs TI8 | - | 0.889 | TI7vs TI8 | 2 | 0.538 |
| **Overall p-value**<br>**p=0.058** $^{(*)}$ | | | **Overall p-value**<br>**p=0.011** $^{(**)}$ | | | **Overall p-value**<br>**p=0.001**$^{(**)}$ | | |

## Table 4.4

Differences (test statistics) between the number of total photos recorded in each pair of time intervals and their corresponding p-values achieved on the basis of 10,000 permutations of data in Table 2. $^{(**)}$ = significance ($p < 0.05$); $^{(*)}$ = significance ($p < 0.10$).

### Leopard

| First winter | | | Second winter | | | Third winter | | |
|---|---|---|---|---|---|---|---|---|
| **Comparison** | **Test statistic** | **p-value** | **Comparison** | **Test statistic** | **p-value** | **Comparison** | **Test statistic** | **p-value** |
| TI1 vs TI2 | - | 0.827 | TI1 vs TI2 | - | 0.805 | TI1 vs TI2 | - | 0.847 |
| TI1 vs TI3 | 6 | 0.006 (**) | TI1 vs TI3 | 5 | 0.014 (**) | TI1 vs TI3 | 8 | 0.0004 (**) |
| TI1 vs TI4 | 5 | 0.024 (**) | TI1 vs TI4 | 3 | 0.103 | TI1 vs TI4 | 4 | 0.092 (*) |
| TI1 vs TI5 | - | 0.833 | TI1 vs TI5 | 4 | 0.055 (*) | TI1 vs TI5 | 2 | 0.351 |
| TI1 vs TI6 | 1 | 0.518 | TI1 vs TI6 | - | 0.803 | TI1 vs TI6 | 5 | 0.037 (**) |
| TI1 vs TI7 | 1 | 0.527 | TI1 vs TI7 | - | 0.798 | TI1 vs TI7 | 3 | 0.192 |
| TI1 vs TI8 | 2 | 0.297 | TI1 vs TI8 | - | 0.805 | TI1 vs TI8 | 2 | 0.353 |
| TI2 vs TI3 | 6 | 0.007 (**) | TI2 vs TI3 | 5 | 0.014 (**) | TI2 vs TI3 | 8 | 0.0003 (**) |
| TI2 vs TI4 | 5 | 0.024 (**) | TI2 vs TI4 | 3 | 0.102 | TI2 vs TI4 | 4 | 0.092 |
| TI2 vs TI5 | - | 0.827 | TI2 vs TI5 | 4 | 0.053 (*) | TI2 vs TI5 | 2 | 0.356 |
| TI2 vs TI6 | 1 | 0.520 | TI2 vs TI6 | - | 0.799 | TI2 vs TI6 | 5 | 0.041 (**) |
| TI2 vs TI7 | 1 | 0.529 | TI2 vs TI7 | - | 0.800 | TI2 vs TI7 | 3 | 0.185 |
| TI2 vs TI8 | 2 | 0.302 | TI2 vs TI8 | - | 0.810 | TI2 vs TI8 | 2 | 0.352 |
| TI3 vs TI4 | 1 | 0.520 | TI3 vs TI4 | 2 | 0.313 | TI3 vs TI4 | 4 | 0.091 |
| TI3 vs TI5 | 6 | 0.007 (**) | TI3 vs TI5 | 1 | 0.530 | TI3 vs TI5 | 6 | 0.011 (**) |
| TI3 vs TI6 | 5 | 0.024 (**) | TI3 vs TI6 | 5 | 0.013 (**) | TI3 vs TI6 | 3 | 0.192 |
| TI3 vs TI7 | 5 | 0.026 (**) | TI3 vs TI7 | 5 | 0.015 (**) | TI3 vs TI7 | 5 | 0.039 (**) |
| TI3 vs TI8 | 4 | 0.069 (*) | TI3 vs TI8 | 5 | 0.015 (**) | TI3 vs TI8 | 6 | 0.013 (**) |
| TI4 vs TI5 | 5 | 0.026 (**) | TI4 vs TI5 | 1 | 0.531 | TI4 vs TI5 | 2 | 0.349 |
| TI4 vs TI6 | 4 | 0.069 (*) | TI4 vs TI6 | 3 | 0.101 | TI4 vs TI6 | 1 | 0.576 |
| TI4 vs TI7 | 4 | 0.07 (*) | TI4 vs TI7 | 3 | 0.101 | TI4 vs TI7 | 1 | 0.569 |
| TI4 vs TI8 | 3 | 0.156 | TI4 vs TI8 | 3 | 0.108 | TI4 vs TI8 | 2 | 0.35 |
| TI5vs TI6 | 1 | 0.530 | TI5vs TI6 | 4 | 0.051 (*) | TI5vs TI6 | 3 | 0.191 |
| TI5vs TI7 | 1 | 0.527 | TI5vs TI7 | 4 | 0.051 (*) | TI5vs TI7 | 1 | 0.574 |
| TI5vs TI8 | 2 | 0.300 | TI5vs TI8 | 4 | 0.054 (*) | TI5vs TI8 | - | 0.846 |
| TI6vs TI7 | - | 0.826 | TI6vs TI7 | - | 0.800 | TI6vs TI7 | 2 | 0.348 |
| TI6vs TI8 | 1 | 0.525 | TI6vs TI8 | - | 0.809 | TI6vs TI8 | 3 | 0.191 |
| TI7vs TI8 | 1 | 0.524 | TI7vs TI8 | - | 0.801 | TI7vs TI8 | 1 | 0.578 |
| **Overall p-value**<br>**p=0.016 $^{(**)}$** | | | **Overall p-value**<br>**p=0.108** | | | **Overall p-value**<br>**p=0.006 $^{(**)}$** | | |

# DISCUSSION

Behavioural characteristics that allow spatial or temporal separation of potential competitors may facilitate coexistence. There was an evidence of temporal overlap in activity patterns between tiger and leopard. As predicted, present data indicating that tigers were more diurnal than the leopard. Probably, this was observed due to the dominated behaviour of tigers itself. Both species were more active during the dark period than during the day throughout the winter. However, leopards were less active or showing no activity during the day, between 11AM and 5PM, than tigers (Figure 4.4), perhaps because of avoiding the hottest period of the day and preferred preying mostly on the small size prey (Chapter-Prey selection) that are active during dusk and dawn. Data as well indicated that the leopards' activity was extreme in the early evening between 5PM and 8PM, whereas tigers showed the peak between 8PM and 11PM. From this, we can understand that there could be nature of avoidance even it was diminutive. In contrary, Karanth & Sunquist (2000) suggest that leopards are relatively more diurnal than tigers because they kill a relatively greater proportion of diurnal prey species such as langur and chital (Karanth & Sunquist 1995).

Several previous studies have also reported that tigers and leopards are more active at night than during the day (Schaller 1967, Sunquist 1981, Karanth & Sunquist 2000), strongly supporting this findings of the present study. However, the amount of nocturnal activity differs from site to site. Karanth & Sunquist (2000) did not indicate active temporal partition between the tiger and leopard in Nagarhole National Park, India. Sunquist (1981) suggested that tigers were mostly active at night and only occasionally during the day. Karanth & Sunquist (2000) also described that the rates of movement were relatively higher for both species during the night, with leopards more mobile than tigers. Seidensticker (1976) found that both tiger and leopard were active throughout the diel cycle. The present data indicated that tigers were active throughout the 24 hr cycle and leopards' mostly at dawn and dusk. The results also indicated that the predators may employ their activity pattern strategy in such a way to maximize the chance of encountering both nocturnal and diurnal prey species. Ecological circumstances differ in many respects in the course of the diel cycle, for example, day and night, and temperature. In this study, the activity periods of tiger and leopard were not observe bimodal as recorded by Ramesh *et al.* (2012). In Western Ghats, India, they suggest that the tiger may have bimodal peak activities, one after midnight until morning and another just after sunset with leopard more or less similar throughout the day, yet small bimodal peak activities during dawn and dusk. They described that tiger was mainly active at night; while it was cathemeral or active throughout the day, but less activity in the hottest hours of the day. Both species exhibiting less activity in the hottest hours of the day. Crepuscular and cathemeral activity patterns may allow individuals to adjust to habitat alterations or new disturbance events (i.e. human activity) compared to strict diurnal/nocturnal patterns, which constrain an individual to show activity just during those limited hours (Hill *et al.* 2003). The nocturnal and crepuscular activity patterns of tigers and leopards could be associated with the availability and distribution of their major prey species, as mentioned earlier. There was some overlap between tigers and leopards in their activity patterns between 5PM and 2AM, but not complete overlap. When comparing the activity patterns of these two sympatric species, tigers were more diurnal than leopards (Fig. 4.2 and 4.3), whereas Karanth & Sunquist (2000) suggested that leopards are comparatively more diurnal than tiger in Nagarahole, India. Temporal time separation has been suggested as a strategy adopted by sympatric tiger, leopard and dhole to allow coexistence (Karanth & Sunquist 2000). Though the peak activity of tigers, leopards and dholes were at different times, there was considerable overlap between the observed species. There were no evidence (photograph, pugmarks, scats etc.) indicating the presence of dholes during the study period. Eisenberg and Lockhart (1972) described that leopards are often active during the day period, since they are the only major carnivore in the Wilpattu National Park, Sri Lanka. In Bardia National Park, the total diel activities of male and female leopards were not significantly different, with males moving mainly at night, whereas females moved similar distances during day and night (Odden & Wegge 2005). Similarly, Seidensticker (1977) suggested that female with cubs spent more time during night than day. Probably, in order to avoid from infanticide. Such cases has been reported from early studies in tigers (Smith & McDougal 1991) and leopards (Iliany 1990, Bailey 1993).

The results of this study concur with previously published studies (Schaller 1967, Seidensticker 1976, Sunquist 1981, Odden & Wegge 2005) in terms of nocturnal behavior of both carnivores. Leopards can cope and co-exist with the tigers through feeding behaviour and shifting in activity patterns. Because they have the ability to exist within a decreased niche breadth or can shift their activity time and areas where the tiger is not present (Seidensticker 1976). Nevertheless, they were dependent on similar prey species (ungulates) such as chital, hog deer, etc with highly overlapping in diet (Chapter-Prey selection). Leopards, therefore, may avoid being active during the periods when tigers are more active in feeding etc. Hence, small temporal niche segregation may occur between the two species. The camera trap data presented here could therefore be important, as they provide the first information on activity patterns of two elusive large carnivores from the same area. However, further research is necessary to and is only possible by using new technology (GPS satellite telemetry), which will contribute new information for local conservation management.

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# CHAPTER 5

# SPATIAL BEHAVIOUR OF TIGERS AND LEOPARDS

# CHAPTER 5

# SPATIAL BEHAVIOUR OF TIGERS AND LEOPARDS

## ABSTRACT

Effective conservation management of large carnivores requires an understanding of their spatial behaviour. Tiger and leopard home ranges in Shuklaphanta Wildlife Reserve (SWR), Nepal were mapped using a camera trapping technique. Camera trap surveys were carried out during three consecutive winters between 2008 and 2011. A trial of noninvasive genetic sampling methods was also carried out using DNA extracted from scat collected during the study period from two areas (SWR and Bardia National Park). Microsatellite genotyping allowed the identification of the minimum number of predators using the study area. Camera trapping identified 11 individual tigers (six males and five females) and 9 leopards (five males and four females) in SWR. The genetic analysis identified only 5 tigers and 4 leopards from SWR, and 6 tigers from the Karnali floodplain of BNP. Population density of tigers in SWR was estimated at between 1.8 and 2.9 /100 km$^2$, while that for leopards was estimated at between 1.8 and 2.6 /100 km$^2$ during the study period. These population estimates indicate a decline in tigers in SWR relative to data available from ten years previously. Most home range (HR) studies of large carnivore have used radio telemetry; here camera trap data was used to calculate home range size using the minimum convex polygon approach. From nine tigers (four females and five males), the calculated average home range was 36.6 km$^2$, with male HR (43.3 km$^2$) being 1.45 times larger than that of females (29.9 Km$^2$). Among leopards (three females and four males) the average home range was 17.95 km$^2$, with males HR (26.6 Km$^2$), being 2.86 times larger than that of females (9.3 Km$^2$). The home ranges of all male tigers overlapped with each other at least partially and almost completely in some cases, with overlap ranges between 5 and 39 km$^2$. Home ranges of male tigers overlapped more than those of female tigers, and male home ranges overlapped with more than one individual female. Leopard home ranges tended to overlap less than those of tigers, with values ranging up to 7 km$^2$ for females to 2-24 km$^2$ for males (overall mean 8.83 Km$^2$). As displayed by the tiger, male leopard home ranges tended to overlap with those of several females, similar to the results found for this species in Chitwan National Park. Our data suggested that even though there was a 12 to 18 % median overlap between tiger and the leopard home ranges, there was a clear spatial separation between them. Leopards were more restricted to the periphery of the reserve, while tigers occupied the core or mostly undisturbed areas of the reserve, a pattern reported previously from BNP. There is a possibility to increase the number of tigers once the extension area of the reserve can be managed to increase the abundance of prey species.

**Key words:** *spatial ecology, non-invasive methods, large felids, camera trapping;Nepal.*

## 5.1. INTRODUCTION

The conservation of large terrestrial carnivores is of global concern, and an understanding of the spatial requirements of wide-ranging coexisting carnivores, such as tigers and leopards, is fundamental to conservation biology (Cornell & Lawton 1992). Both tigers and leopards are territorial, elusive, cryptic, solitary and predominantly nocturnal, with large home ranges covering diverse habitats, making the monitoring of their populations a challenging task for wildlife managers (Mech 1995).

Extinction rates have risen greatly in recent times, with mammals being the most vulnerable taxonomic group (Primack 2002). Tigers, along with sympatric species such as leopards, are among the most vulnerable to anthropogenic disturbance due to their large home range requirements, conflict with humans caused by predation of livestock and people, and decreasing prey populations (Sunquist 1981, Nowell and Jackson 1996). Changes in their habitats have caused the current global tiger range to decrease to around 7% of its historical extent and are continuing to threaten the survival of remnant populations of this large felid. In spite of more than four decades of considerable conservation efforts (Seidensticker et al. 1999), range contraction is still taking place, leading to further population decrease.

If the ecology of these species is poorly understood, and population dynamics are not carefully considered, conservation resources are likely to be poorly allocated. Complete counts of carnivore numbers are often impractical, expensive, and time-consuming (Balme et al. 2009). However, reliable estimates of conservation status and population trends are critical for their conservation as they play an important role in providing standardized data for future management decisions (Karanth & Nichols 1998, Karanth *et al.* 2003).

Among large carnivores, the leopard is among the least studied despite being the most abundant (Bailey 1993). However, due to habitat loss, haitat fragmentation, prey depletion, human conflict, and poaching, its geographic range has been reduced and the world-wide population has decreased in size and has become threatened and more isolated (Nowell & Jackson 1996, Inskip &  Zimmermann 2009). Poaching and wildlife trade are among the major causes of local declines as indicated by high trapping rates and frequent seizure of tiger/leopard skins (Karki et al. 2008). Human- wildlife conflicts and associate retaliatory killings pose additional threats to the survival of wild leopard populations.

Along with the many threats, recent studies have shown that poaching is one of the main factors reducing populations of large cats (e.g., Karanth & Stith 1999). Like all large carnivores, leopards must maintain home ranges that are large enough to provide them with sufficient prey throughout the year. The increasing proportion of land inhabited by humans therefore poses an increasing threat to leopard and tiger populations across their range. However, our poor knowledge of the ecology and conservation status of this species hinders our ability to properly assess its management needs, or to set area-specific priorities for conservation research and action.

Home range is the fundamental measure of space use by territorial animals, such as tigers and leopards. In Nepal, most of the studies of the behavioural ecology and home range usage of tigers and leopards have been conducted in Chitwan and Bardia National Parks using radio telemetry (Seidensticker 1976, Sunquist 1981, Smith 1984, Wegge et al. 2009, Odden & Wegge 2005). Similar studies have also been carried out in India (Karanth & Sunquist 1995, 2000) and Thailand (Rabinowitz 1989, Grassman 1999). However, no such studies have been conducted in SWR in the far western lowland Terai of Nepal. This area holds fairly good breeding populations of these two sympatric carnivores, and probably one of the densest populations of prey base in the region. Although a national census of tiger populations was carried out in the the lowland Terai protected areas, during 2008/09, priority was not given to leopards or not considered as part of the survey. The total number of tigers recorded was 121 individuals (Karki *et al.* 2009, Karki (2012) showing a decline in local populations of more than 70% in the SWR and more than 40% in BNP(Karki 2012). The Government of Nepal has committed to increasing the tiger population to 250 individuals by 2022, with resources devoted to the conservation and protection of the species, their prey and their prime habitats. It is therefore crucial to gain further ecological information from the currently studied areas. This study aims to investigate the abundance and spatial relationship of tigers and leopards of SWR. The information generated from the study is expected to contribute to the development of conservation plans for these large carnivores.

The most commonly used methods in estimating the population size of elusive carnivores are pugmark characteristics (Small wood and Fitzhugh 1993, Riordan 1998 and Sharma 2001), camera traps (Karanth 1995, Karanth and Nichols 1998, Karanth and Nichols 2000, Maffei *et al.* 2004, Silver *et al.* 2004 and Harihar 2005, Wegge et al. 2009) and non-invasive DNA-based techniques (Luo *et al.* 2004, Sastre *et al.* 2008, Sharma *et al.* 2009). However, pugmark characteristics have been found to be inaccurate (Karanth and Nichols 1998, Karanth *et al.* 2003). In this study in the SWR, the spatial relationships of the two species were studied using camera traps and genetic analysis.

Camera traps have proven to be an extremely useful tool in the study of the behaviour of cryptic animals such as tigers and leopards in the tropical habitats of India and Nepal (Karanth and Nichols 1998, 2000, 2002, Karanth *et al.* 2004, Wegge *et al.* 2004, Chauhan *et al*. 2005, Mondal 2006, Jhala *et al*. 2008, Edgankar *et al*. 2007). The images collected can be used to identify individuals by their body patterns (e.g. Karanth 1995), records from across specific areas providing information on home ranges and population dynamics. It is widely accepted across a range of taxa that differences in species home range size depend on the metabolic needs of the animals concerned (Harestad & Bunnel 1979). Estimating the size and shape of home ranges is common in studies of the distribution of animals (McNab 1963, Schoener 1968, Harestad & Bunnel 1979), with territoriality being one of the most important behavioural traits affecting the spatial organization of animal populations. Use of molecular tools is rapidly increasing in the field of wildlife conservation (Frankham *et al.* 2002). A few studies have be done in large felids using DNA markers (for example: Luo *et al*. 2004, Janêcka *et al.* 2008, Sharma *et al.* 2009, Lovari *et al*. 2009, Mondal *et al.* 2009, Wegge *et al*. 2012) for species screening, individual, sex identification and abundance estimation. While scientific understanding of ecological and demographic aspects of extant wild tiger populations has improved recently, little is known about their genetic composition and variability (Mondol *et al.* 2009). In this study we also used non-invasive genetic samples (scats) for individual identification to assess the minimum number of tigers and leopards along with camera trap data.

## 5.2. MATERIAL AND METHODS

### *5.2.1. Study area*

The study was conducted in two protected areas:

*Shuklaphanta Wildlife Reserve (SWR)*: The study was carried out in the western part of the SWR (305Km$^2$) located in the far western lowland Terai of Nepal (28$^0$45'16'' N and 28$^0$57'23''N and 80$^0$06'04'' and 80$^0$21'40''E). Climate is monsoonal with mean (36.50C) temperature recorded during the month of May and mean minimum (7.40C) in January and annual rainfall ranges between 1055 and 2843 mm, with and over 90% precipitation occurring between July and August. Schaaf (1978) distinguished eight different vegetation types in the reserve: Sal forest (*Shorea robusta*), Sal Savanna, Mixed deciduous forest, Khair-Sissoo forest, Lowland grasslands, Dry grassland, Seasonally-wet grassland and Lowland savannas. A huge tracts of grassland stretched in over 54 km2 area provides prime refuge to endangered swamp deer *Cervus duvauceli duvauceli*, one of the major prey species in the reserve. Two major predators tiger *Panthera tigris tigris* and leopard *Panthera pardus* are found in the area. The potential prey species are chital *Axis axis*, swamp deer, hog deer *Axis porcinus,* porcupine *Hystrix indica,* wild boar *Sus scrofa*, sambar deer *Cervus unicolor*, barking deer *Muntiacus muntjak*, nilgai *Boselaphus tragocamelus*, common langur *Presbytis entellus*, and rhesus macaque *Macaca mulatta*. Details of the intensive study areas are provided in the chapter 2.

*Bardia National Park (BNP)*: The Karnali floodplain with 100 km2 of the BNP (968 km2) was also selected for the genetic analysis, focusing mainly on tiger. The area is located in the south western corner of the BNP bordered by the large Geruwa river in the west, the east–west highway in the north, and by human settlements and cultivated land in the east and south. Located about 150 km east of SWR. The climate is similar to SWR. A total of six different habitat types make up the Karnali floodplain: sal forest (66%); khair sissoo forest (11%), wooded grasslands (7%), floodplain grasslands (6%), riverine forest (5%) and small pockets of grasslands locally known as phantas (< 1%) (Jnawali & Wegge, 1993). Potential prey of the tiger in the study area include chital, sambar, hog deer, barasingha, muntjac, nilgai, wild boar, porcupine, langur and rhesus monkeys (Dinerstein, 1980). Tigers and leopards are the two major large carnivores from the area. Details of the intensive study area is presented in the Chapter 2.

### 5.2.2. Camera trapping

### Sampling design and Individual Identification

In SWR camera trapping were conducted for both tiger and leopard during three consecutive winters, between Dec 2008 and Feb 2011. Two passive types of cameras (Moultrie feeders, 150 Industrial Road, Alabaster, AL35007, US & Stealth Cam, LLC,Bedford, TX, US) activated by a heat and motion sensor were used. Camera devices were fixed in 334 locations. The study area was roughly divided into five adjacent *sampling areas* (SAs), identified with numbers from 1 to 5. In each SA, a minimum of 18 paired sets of camera devices were used during the trapping periods. Camera traps were successively deployed in each SA, so as to systematically cover the entire study area (Figure 5.1). Within each SA, camera traps referred to as *sampling units* (SUs) were put on forest/ grassland roads and trails in locations frequently used by tigers and leopards, fixed at a distance between 1- 2.5 km from each other (Wegge *et al.* 2004), referred to as *sampling units* (SUs).

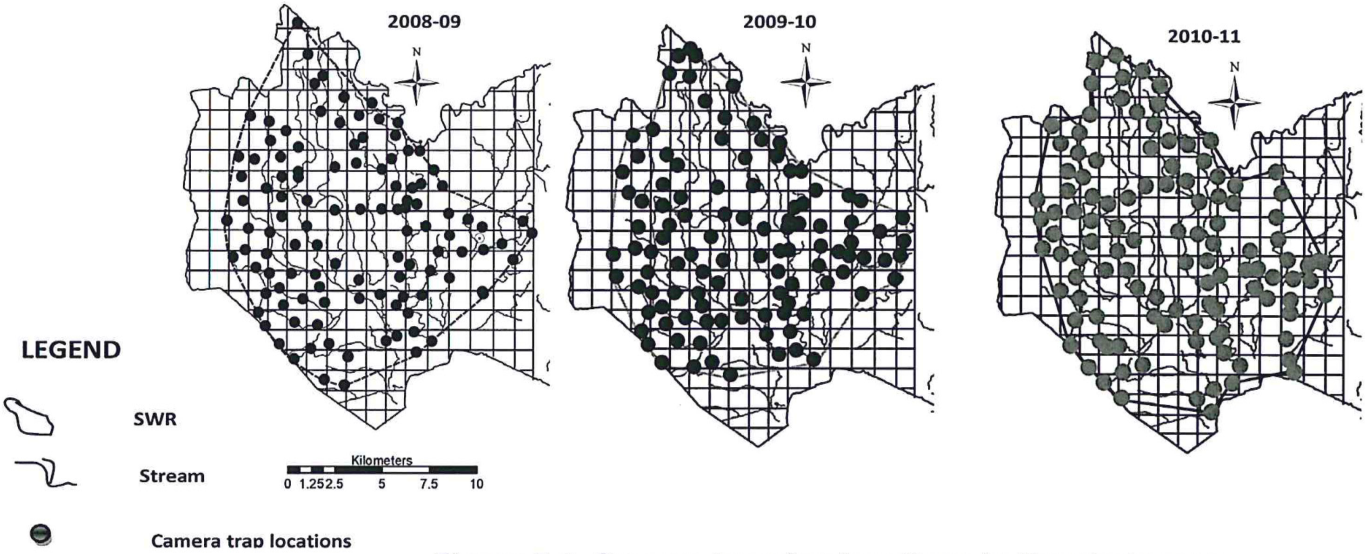

Figure 5.1. Camera trapping locations in the study area.

Figure 5.2 (a). Camera-trap photographs of the same male tiger from different locations, showing similar stripe patterns.

(b). Camera-trap photographs of two different female tigers, showing differences in stripe patterns.

(c). Camera-trap photographs of two different leopards, showing differences in body spot/mark patterns.

Each sampling unit consisted of two cameras mounted on wooden poles or trees on either side of the trail at a distance of 4-7m, adjusted to photograph both flanks of the animals. Because of this, individual animals could be identified unambiguously (Figure 5.2 a, b & c) with the help of their body stripe/spot patterns and markings (Karanth & Nichols, 1998, O'Brien *et al.* 2003). More than 80 percent of the cameras were operating 24 hours/day for 10 to 15 consecutive days. In areas where possibilities of theft occurred, cameras were active for 16-17 hours (between 04:00pm-09:00am). Camera traps were camouflaged and the GPS position of each SU was recorded.

*Effective sampling area and population density of tigers and leopards*

The effective sampling area and predator densities were estimated using the area recruitment method as described by Karanth and Nichols (1998). Animals located at the edge of a trapping grid are likely to utilize the area outside the perimeter of the grid, so a boundary "buffer" strip must be added. The effective sampling area (A) was estimated by adding this boundary strip (*W*) to the area of the trapping grid. The maximum distance moved (MDM) between two captures of each individual animal was used to estimate the mean maximum distance moved (MMDM).

$$MMDM = \left(\sum_{i=1}^{m} \mathrm{MDM}_i\right)/m$$

Where $MDM_i$ = the Maximum Distance Moved between recaptures for animal $i$

$MMDM$ = the Maximum Distance Moved (on average for all $\mathrm{MDM}_i$)

$m$ = the number of animals in the area that were caught at least twice.

Boundary strip width, $W = MMDM/2$

The population density (D) was calculated by the equation:

$$D = \frac{N}{A}$$

Where $N$ is the population size and $A$ is the effective sampling area.

### 5.2.3. Genetic analysis

The methods used for genetic analysis followed those of Lovari *et al.* (2009) and are reported below.

*DNA extraction:*

Total DNA was extracted from 84 scat samples from SWR and 61 scat samples from BNP, of which 55 were preserved in ethanol and 88 in silica using guanidinium thiocyanate and diatomaceous silica particles (Gerloff *et al.* 1995). DNA extracted from scats is often dilute, degraded and rich in PCR inhibitors, so careful laboratory procedures were applied to obtain reliable individual genotypes. All DNA extractions were carried out in an isolated room with strict precautions: exclusively reserved coats, pipettes and sterilized lab tools were used after a chemical decontamination of the workbench with commercial bleach. Negative controls, in which no DNA is present, were used to check for contamination.

*Mitochondrial DNA:*

Species identification was determined through the amplification of a 219 bp region of the mitochondrial cytochrome *b* gene using Cyt *b* (F) and Cyt *b* (R) primers (Buckley-Beason *et al*. 2006). Amplification reactions were performed in an isolated room under a hood with a HEPA filter, after decontamination with UV light. PCR products were purified using ExoSap (GE Healthcare, formerly Amersham Biosciences, Piscataway, NJ, USA) and sequenced with the forward primer using the BigDye Terminator kit v. 1 (Applied Biosystems, Foster City, CA, USA). Fragments were separated on an ABI Prism 3130XL and analysed using Sequencing Analyses 5.2 and SeqScape 2.0 (Applied Biosystems). BLAST software (http://www.ncbi.nlm.nih.gov), accessed sequences in order to identify the species for each sample (GenBank accession nos EF551002, EF056507, EF056506, *P. pardus*)

*Microsatellite loci:*

Single amplifications of nine microsatellite loci were attempted for all 145 samples using published primers **(FCA126, FCA132, FCA139, FCA161, FCA26, FCA58, FCA77, FCA8, FCA96, FCA43)** screened from domestic cats (Menotti-Raymond *et al.*1999). Each forward primer (which reads from 5’ to 3’ on the DNA strand) was labeled with 6-FAM or HEX ABI dye. PCR amplifications were performed in a Perkin-Elmer Model 9700 thermocycler (Applied Biosystems) using the following set of conditions: denaturation for 10 min at $94^0$C, a touchdown cycle for 30s at $94^0$C, $55^0$C for 30s decreased by $0.5^0$C in the next cycle for 10 cycles, $72^0$C for 30s, then 35 amplification cycles of $94^0$C for 30s, $50^0$C for 30s and $72^0$C for 30s, followed by an extension of 10 min at $72^0$C. Amplified products were separated on an ABI Prism 3130XL (Applied Biosystems) and analysed using Genemapper 4.0 and Genotyper 3.7 (Applied Biosystems).

Genotyping from scat DNA is prone to several problems, particularly allelic dropout (ADO) and amplification of false alleles. Allelic dropout is caused by the stochastic amplification of only one of the two alleles at a heterozygous locus while false alleles are due to the amplification of nonspecific DNA. Both errors are caused by low concentration of the DNA template and might lead to errors in individual identification. To overcome these problems, genotypes were determined from four independent replicates of each locus in each sample. After comparing replicates, a single locus genotype was accepted only if it showed a minimum of two identical heterozygous profiles or four identical homozygous profiles. Biological samples with identical multilocus genotypes were identified using Gimlet v. 3.1 (Valiere 2002). ADO and PCR amplification success rates among replicates were calculated in accepted genotypes using Gimlet v.3.1.

The probability of identity, $P_{(ID)}$, is the probability that two individuals drawn at random from a population will have the same genotype at multiple loci (Waits, Luikart & Taberlet

2001). Probabilities of identity in a population of unrelated individuals $P_{(ID)}$ or among siblings $P_{(ID)sib}$ were computed using GenA1Ex v.6 (Peakall & Smouse, 2006).

*Sex identification:*

Gender was identified through assessment of a short region of the zinc finger protein genes using primer P1-5EZ (Aasen & Medrano, 1990) and primer ZEXYRb (Mucci & Randi, 2007). The P1-5EZ marker was labeled with 6-FAM dye. In cats, homologous sequences of ZFXY genes, located on X and Y chromosomes, differ by a few base pairs in length (Pilgrim *et al*. 2005). A single fragment 177 bp long and two fragments 174 and 177 bp long were retrieved in females and males respectively. Fragments were separated on an automated ABI 3130XL and analyzed using Genemapper v.4 software and Genotyper v.3.7 software (Applied Biosystems). Four independent replicates of each locus were carried out in each sample.

### 5.2.4. Home range estimation

Data obtained from camera trapping were used to estimate the home range of individual tigers and leopards. All individuals captured at least four times in different sampling units or locations across (2008-2011) the winter periods were used in the home range study. Thus, home ranges of nine tigers and seven leopards were outlined using the Arc View 3.2 extension package Animal Movement. The Minimum Convex Polygon (MCP) method (Mohr 1947) was chosen for home range size calculation, because it has been widely used in home range analyses and therefore allows comparisons among studies. The Global Positioning System (GPS) coordinates, recorded for each animal captured in different sampling units, provided the location fixes for the MCP analysis. Compare to the telemetry study camera trapping provided low number of locations. Due to low number of photo-captured locations the home range might reflect an underestimate.

## 5.3. RESULTS:

### 5.3.1. Numbers and density of tigers and leopards

*Camera trapping:*

In the first winter, 7 individual tigers (4 males and 3 females) and 5 leopards (2 males and 3 females) were photo-captured in the study area (Table 5.1 and Figure 5.3). During the second winter, 5 tigers (2 males and 3 females) and 6 leopards (2 males and 4 females) were recorded and in the third winter, 8 tigers (4 males and 4 females) and 7 leopards (3 males and 4 females) were recorded.

**Table 5.1. The mean maximum distance moved (MMDM), effective area sampled by camera trapping (AW), minimum numbers and estimated tiger and leopard densities recorded during 3 successive winter in SWR, Nepal.**

| Period | Area with camera traps ($km^2$) * | MMDM (km) | | Strip width (km)W | | Effective Area ($Km^2$) AW | | Tiger | | | Leopard | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tiger | Leopard | Tiger | Leopard | Tiger | Leopard | Min. No. | Cumulative no. | Density (no./100$km^2$) | Min. No. | Cumulative no. | Density (no./100$km^2$) |
| Winter 2008-09 | 172.3 | 7.0 | 8.0 | 3.5 | 4.0 | 269.9 | 280.1 | 7 | 7 | 2.6 | 5 | 5 | 1.8 |
| Winter 2009-10 | 169.8 | 6.8 | 4.5 | 3.4 | 2.3 | 284.3 | 248.5 | 5 | 9 | 1.8 | 6 | 7 | 2.4 |
| Winter 2010-11 | 189 | 7.5 | 6.3 | 3.7 | 3.1 | 279.9 | 268.2 | 8 | 11 | 2.9 | 7 | 9 | 2.6 |

* Area enclosed by the straight line between the perimeter sampling units

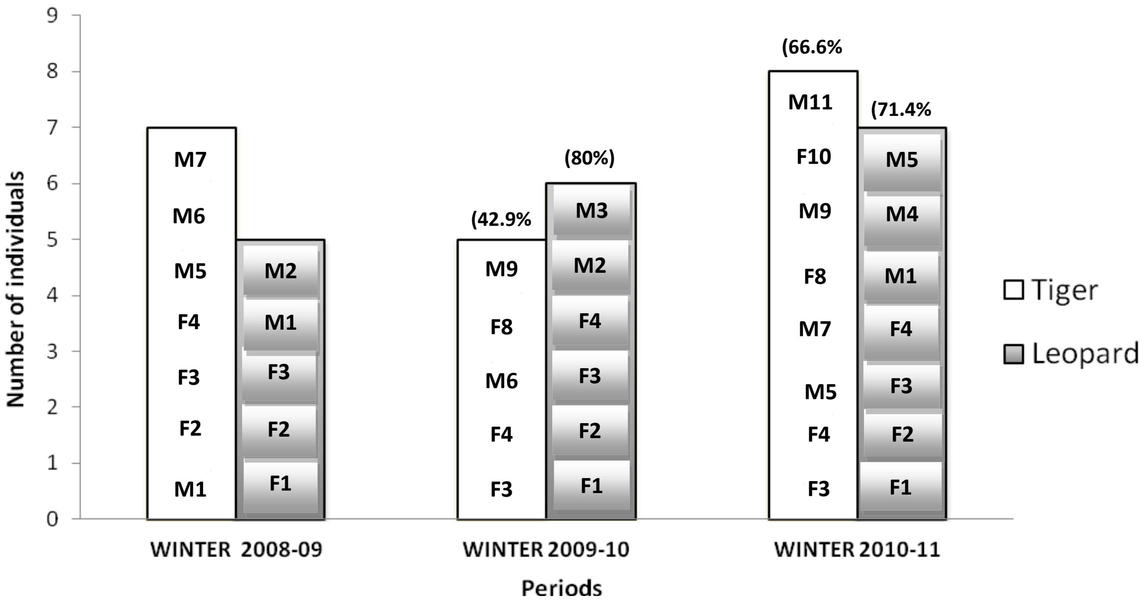

**Figure 5.3. Number of individual tigers and leopards photographed in different winters**

**M= male; F=female** Values in parentheses above the bars are the percentage of recaptures from the previous winters.
**Note: Four tiger cubs were photographed in winter 2008-09, Two tiger cubs were photographed and 4 were sighted with mother in winter 2010-11, No leopard cubs were ever photographed.**

Out of seven tigers captured in the 2008-09 winter, three tigers were recaptured in the second winter (2009-10). Two new tigers were photographed in the second winter (2009-10). Six, out of nine (winter 2008-09 and 2009-10) were recaptured in the third winter (2010-11) and 2 were new individuals (Figure 5.3).

Similarly, four out of five leopards captured in 2008-09 winter were recaptured in the following winter (2009-10). In addition two new leopards were captured in the second winter (2009-10). Five out of seven leopards captured in winter 2008-09 & 2009-10, were recaptured and two were new individuals in the third winter (Figure 5.3).

Estimated animal densities, based on the number of individuals photo-trapped and estimated effective sampling areas are shown in Table 5.1.

### 5.3.2. Genetic analysis:

*Minimum numbers of predators*

Out of 84 scat samples collected from tigers and leopards in SWR, 56 (tiger: 46, leopard:10) were positive and out of 61 tiger samples in BNP, 43 were positive. A minimum of five individual tigers and four leopards were identified from the SWR (Appendix 1). In Bardia National Park, a minimum number of six individual tigers were identified in the study area (ca. 100 sq km) (Appendix 2). The genetic analysis of scats samples provided 66 to 70% positive results on species identification, 20 to 32% genotype identification and 21 to 37% sex identification.

### 5.3.3. Home ranges

The individual putative home ranges of nine tigers (four females and five males) and seven leopards (three females and four males) are given in Table 5.2 and Figures 5.6, 5.7, 5.8 and 5.9.

**Table 5.2. Putative home ranges, estimated by the 100% minimum convex polygon (MCP), for tigers and leopards in SWR during 2009-2011.**

| SPECIES | INDIVIDUAL | NUMBER OF CAPTURES | HOME RANGE (Km$^2$) | Mean (SE) Km$^2$ |
|---|---|---|---|---|
| ***TIGER*** | FEMALE 2 (**F2**) | 9 | 21.9 | 29.9± 4.96 |
| | FEMALE 3 (**F3**) | 8 | 32.0 | |
| | FEMALE 4 (**F4**) | 25 | 22.6 | |
| | FEMALE 8 (**F8**) | 12 | 43.1 | |
| | MALE 1(**M1**) | 10 | 25.1 | 43.3± 14.84 |
| | MALE 5 (**M5**) | 10 | 25.2 | |
| | MALE 6 (**M6**) | 10 | 36.2 | |
| | MALE 9 (**M9**) | 18 | 102.1 | |
| | MALE 11 (**M11**) | 11 | 27.9 | |
| ***LEOPARD*** | | | | |
| | FEMALE 1(**F1**) | 4 | 4.6 | 9.3 ± 5.36 |
| | FEMALE 2 (**F2**) | 9 | 20.1 | |
| | FEMALE 3 (**F3**) | 5 | 3.4 | |
| | MALE 1 (**M1**) | 8 | 46.0 | 26.6± 12.37 |
| | MALE 2 (**M2**) | 6 | 49.8 | |
| | MALE 3 (**M3**) | 4 | 2.0 | |
| | MALE 5 (**M5**) | 7 | 8.8 | |

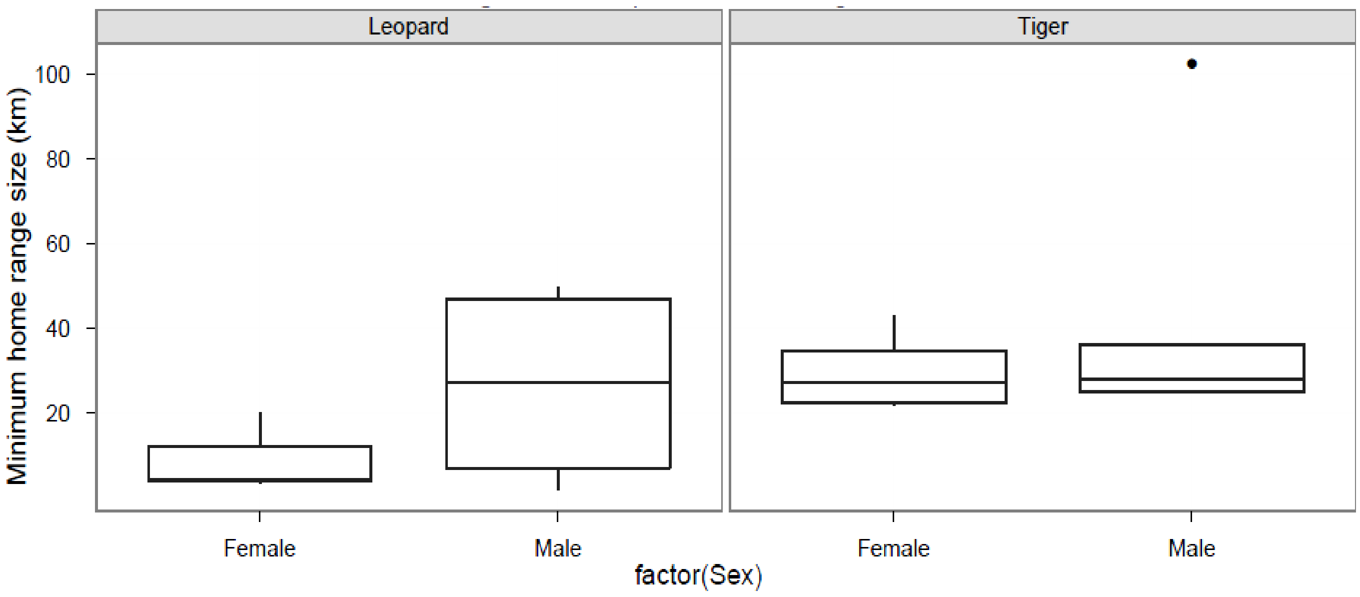

**Figure: 5.4 Tiger and leopard home range size**

Among tigers, female F8 and male M9 were estimated to have the largest home ranges (Table 5.2, Figures 5.6 & 5.7). The mean home range size for females was 29.9 ± 4.96 km$^2$ and for males it was 43.3 ± 14.84 km$^2$, but home range size between the tiger sexes were not significantly different (*t* =0.856, *P* = 0.216) (Table 5.2, Figure 5.4).
Among leopards, female F2 and male M2 had the largest home ranges (Table 5.2, Figures 5.8 & 5.9). The mean home range size for females was 9.3 ± 5.36 km$^2$ and for males it was 26.6 ± 12.37 km$^2$, however statistically not significantly different (*t* =1.281; *P* = 0.134).

Tiger home ranges were larger than those of leopard, however, this difference was not significant at the 0.05 level (x̄'s= 37.34, 19.24 km$^2$ *t*=1.58; *P*= 0.067). This was largely due to the high variation in male tiger home range sizes..

All male tigers had overlapping home ranges (Tables 5.3). The highest overlap was observed between male M1 and male M9.

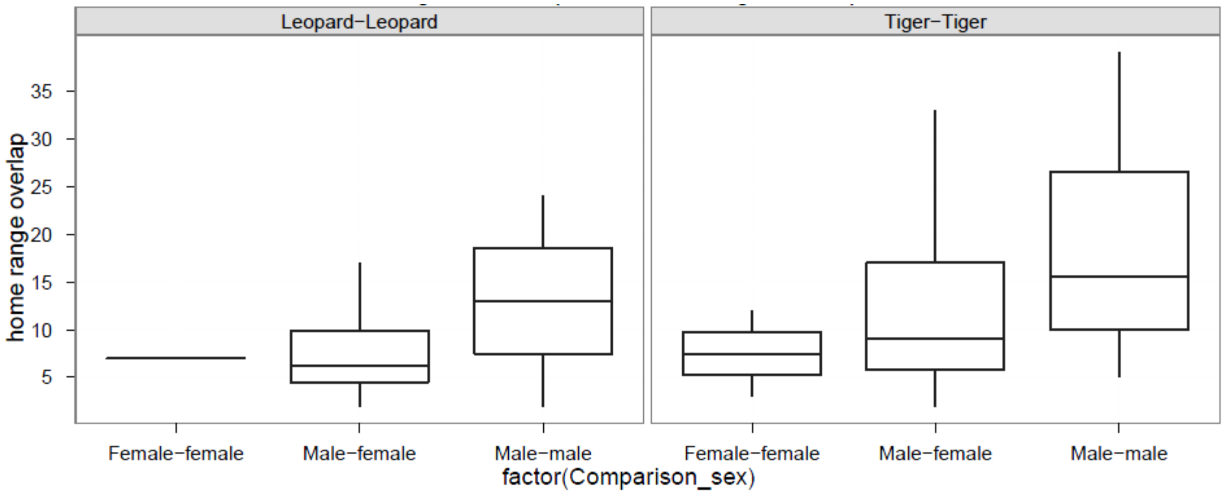

**Figure: 5.5. Tiger and leopard home range overlap**

Among female tigers, F2 overlapped with those of females F3 and F8. Most of the male tigers (M1, M5, M6 and M9) showed home ranges overlapping with three females. The highest overlap was between male M9 and F2.

Among male leopards, there was home range overlap between males M1, M2 and M3. The only overlap between females was between F2 and F3 (100%), the latter most likely F2's daughter. All males showed some degree of overlap, except for M5, which was caught on a camera trap in the far southwest corner of the reserve. However, there was overlap between two males (M2 & M3) and the home range of M1 during the study period.

**Table 5.3. Home range overlap within and between species. L, left, and R, right, indicate the individuals listed in the "species" column.**

| Species | Home range overlap | | | Species | Home range overlap | | | Species | Home range overlap | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | % | | | | % | |
| Tiger | (in km$^2$) | L | R | Leopard | (in km2) | L | R | Tiger/leopard | (in km$^2$) | L | R |
| **$M_t$1- $M_t$5=** | **8** | 20.5 | 21.1 | **$M_l$1- $M_l$2** | **24** | 40.7 | 35.3 | **$M_t$1- $M_l$1=** | **5** | 12.8 | 8.5 |
| **$M_t$1- $M_t$6 =** | **10** | 25.6 | 20.0 | **$M_l$1- $M_l$3** | **2** | 3.4 | 18.2 | **$M_t$9- $M_l$1=** | **18** | 15.7 | 30.5 |
| **$M_t$1- $M_t$9=** | **39** | 100.0 | 33.9 | **$F_l$2- $F_l$3** | **7** | 21.2 | 100.0 | **$F_t$2- $M_l$1=** | **6** | 18.2 | 10.2 |
| **$M_t$1- $M_t$11=** | **13** | 33.3 | 33.3 | **$M_l$1- $F_l$1** | **4** | 6.8 | 26.7 | **$F_t$4- $M_l$1=** | **3** | 8.8 | 5.1 |
| **$M_t$5- $M_t$6=** | **18** | 47.4 | 36.0 | **$M_l$1- $F_l$2** | **17** | 28.8 | 51.5 | **$F_t$8- $M_l$1=** | **34** | 58.6 | 57.6 |
| **$M_t$5- $M_t$9=** | **22** | 57.9 | 19.1 | **$M_l$1- $F_l$3** | **6.5** | 11.0 | 92.9 | **$M_t$1- $M_l$2=** | **14** | 35.9 | 20.6 |
| **$M_t$5- $M_t$11=** | **5** | 13.2 | 12.8 | **$M_l$2- $F_l$2** | **11** | 16.2 | 33.3 | **$M_t$5- $M_l$2=** | **2** | 5.3 | 2.9 |
| **$M_t$6- $M_t$9=** | **28** | 56.0 | 24.3 | **$M_l$2- $F_l$3** | **6** | 8.8 | 85.7 | **$M_t$6- $M_l$2=** | **6** | 12.0 | 8.8 |
| **$M_t$6- $M_t$11=** | **10** | 20.0 | 25.6 | **$M_l$3- $F_l$1** | **2** | 18.2 | 13.3 | **$M_t$9- $M_l$2=** | **36** | 31.3 | 52.9 |
| **$M_t$9- $M_t$11=** | **28** | 24.3 | 71.8 | | | | | **$M_t$11- $M_l$2=** | **15** | 38.5 | 22.1 |
| **$F_t$2- $F_t$3=** | **3** | 9.1 | 7.1 | | | | | **$F_t$2- $M_l$2=** | **16** | 48.5 | 23.5 |
| **$F_t$2- Ft8=** | **12** | 36.4 | 20.7 | | | | | **$F_t$3- $M_l$2=** | **9** | 21.4 | 13.2 |
| **$M_t$1- $F_t$2=** | **15** | 38.5 | 45.5 | | | | | **$F_t$4- $M_l$2=** | **2** | 5.9 | 2.9 |
| **$M_t$1- $F_t$3=** | **7** | 17.9 | 16.7 | | | | | **$F_t$8- $M_l$2=** | **28** | 48.3 | 41.2 |
| **$M_t$1- Ft8=** | **8** | 20.5 | 13.8 | | | | | **$M_t$9- $M_l$3=** | **2** | 1.7 | 18.2 |
| **$M_t$5- $F_t$2=** | **2** | 5.3 | 6.1 | | | | | **$F_t$8- $M_l$3=** | **1** | 1.7 | 9.1 |
| **$M_t$5- $F_t$3=** | **9** | 23.7 | 21.4 | | | | | **$M_t$5 - $M_l$5=** | **1** | 2.6 | 4.5 |
| **$M_t$5- Ft4=** | **4.5** | 11.8 | 13.2 | | | | | **$F_t$4- $M_l$5=** | **5** | 14.7 | 22.7 |
| **$M_t$6- $F_t$2=** | **2** | 4.0 | 6.1 | | | | | **$M_t$9- $F_l$1=** | **3** | 2.6 | 20.0 |
| **$M_t$6- $F_t$3=** | **19** | 38.0 | 45.2 | | | | | **$F_t$2- $F_l$1=** | **2** | 6.1 | 13.3 |
| **$M_t$6- Ft4=** | **2.5** | 5.0 | 7.4 | | | | | **$F_t$8- $F_l$1=** | **3** | 5.2 | 20.0 |
| **$M_t$9- $F_t$2=** | **33** | 28.7 | 100.0 | | | | | **$M_t$9- $F_l$2=** | **2** | 1.7 | 6.1 |
| **$M_t$9- $F_t$3=** | **24** | 20.9 | 57.1 | | | | | **$F_t$4- $F_l$2=** | **1** | 2.9 | 3.0 |
| **$M_t$9- Ft4=** | **7** | 6.1 | 20.6 | | | | | **$F_t$8- $F_l$2=** | **11** | 19.0 | 33.3 |
| **$M_t$9- Ft8=** | **25** | 21.7 | 43.1 | | | | | **$F_t$8- $F_l$3=** | **2.5** | 4.3 | 35.7 |
| **$M_t$11- $F_t$2=** | **9** | 23.1 | 27.3 | | | | | | | | |
| **$M_t$11- $F_t$3=** | **12** | 30.8 | 28.6 | | | | | | | | |

**M= male, F=female**

**Table 5.4. Home range within species (median and quartile overlaps).**

| Species and sex | Home range overlaps | | |
|---|---|---|---|
| | Lower quartile (%) | Median (%) | Upper quartile (%) |
| **Male tigers Vs Male leopards** | 4.0 | 12.8 | 33.6 |
| **Female tigers Vs Female leopards** | 3.6 | 5.2 | 12.6 |
| **Males tigers Vs Female leopards** | NA | 2.2 | NA |
| **Male leopards Vs Male tigers** | 6.5 | 18.2 | 26.3 |
| **All tigers Vs All leopards** | 3.6 | 12.0 | 26.4 |
| **All leopards Vs All tigers** | 7.3 | 18.2 | 27.0 |

A home range overlap of > 50 % between tiger and leopard was recorded only for tiger F8 - leopard M1 and for tiger M9- leopard M2 (Table 5.3). But there was overlap between most individuals. Within species, median and quartile overlaps for males and females are presented in Table 5.4. Overall results showed a clear tendency of spatial separation between tiger and the leopard (Table 5.4).

MALE TIGERS

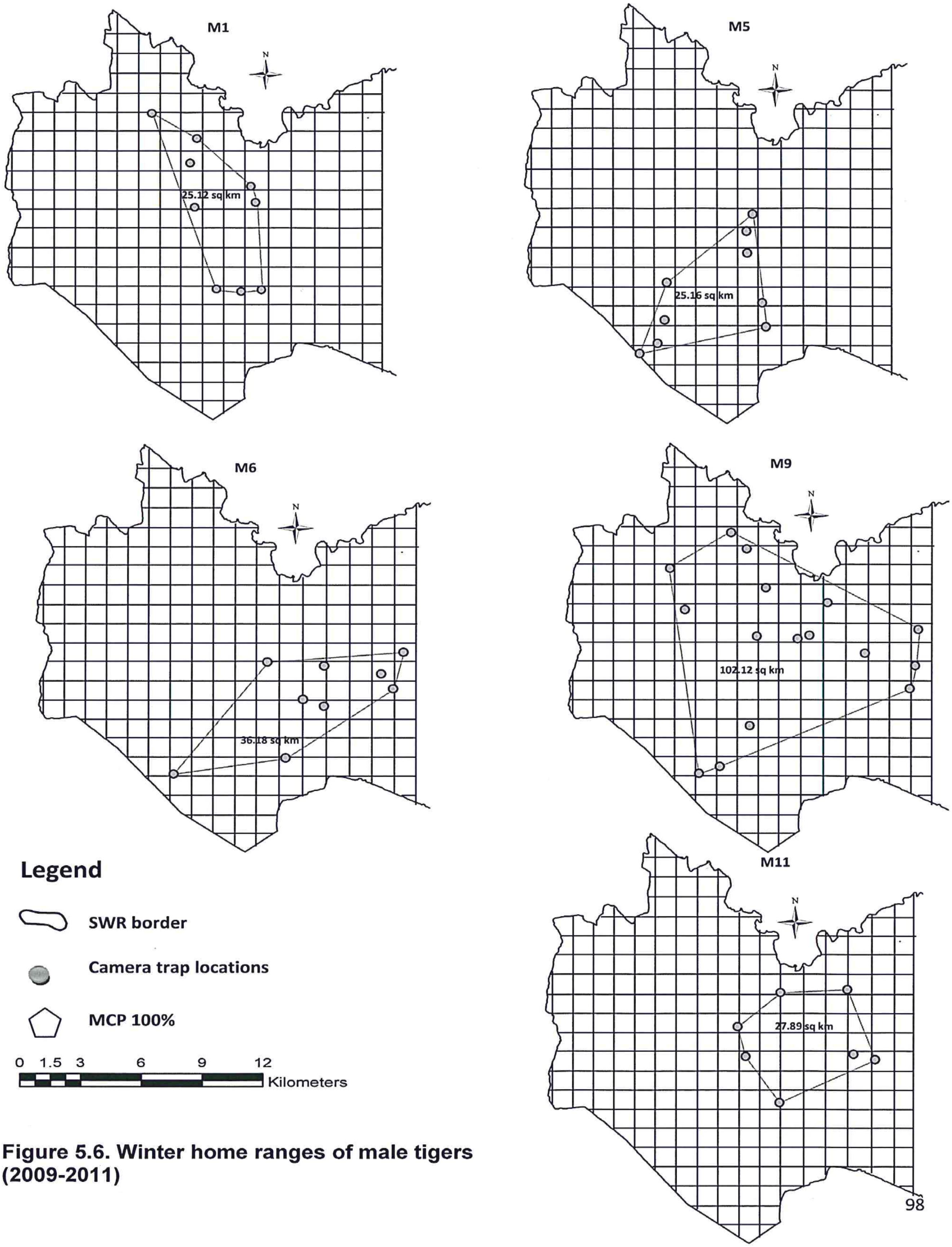

Figure 5.6. Winter home ranges of male tigers (2009-2011)

**FEMALE TIGERS**

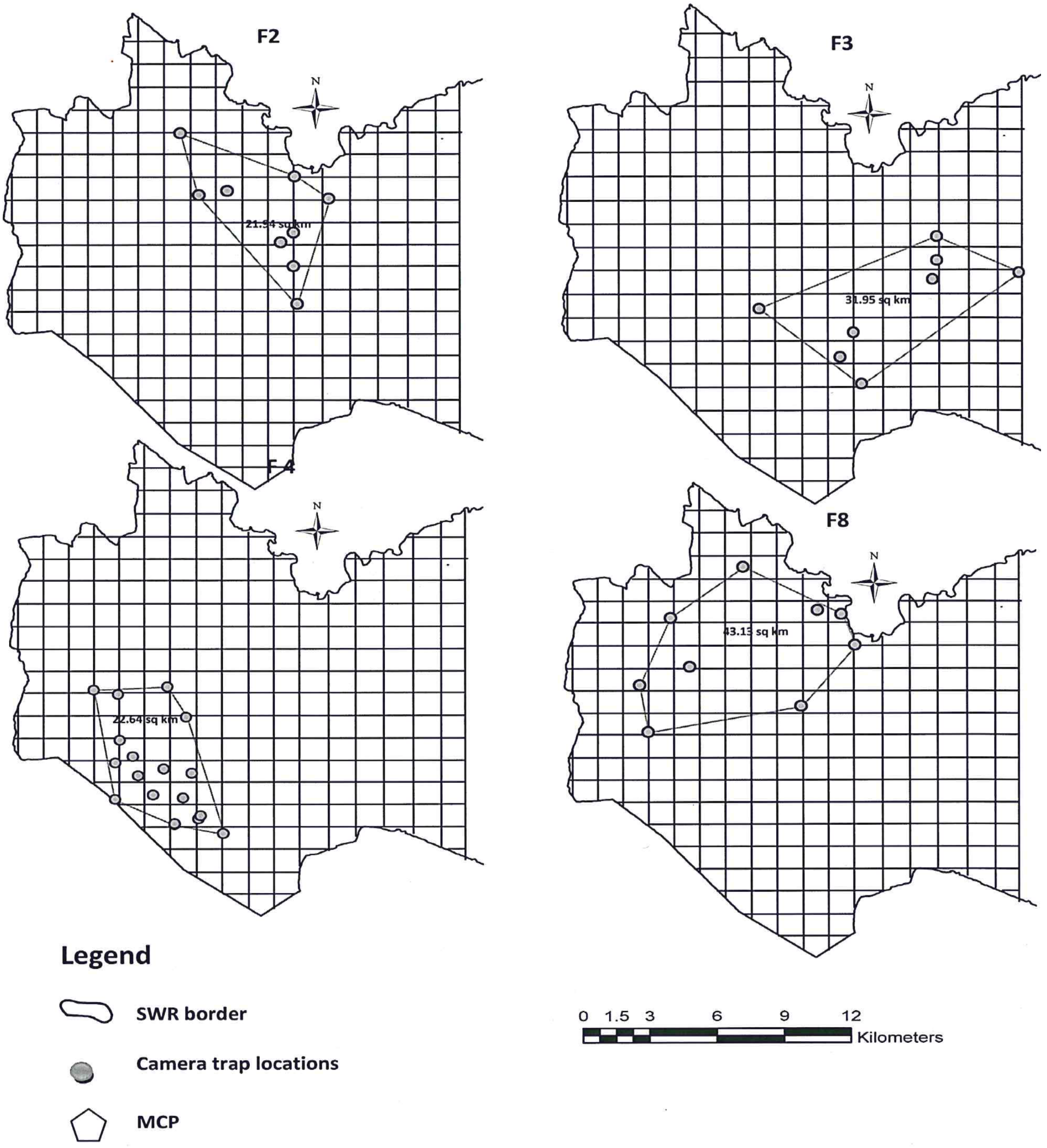

Figure 5.7. Winter home ranges of female tigers (2009-2011)

## MALE LEOPARDS

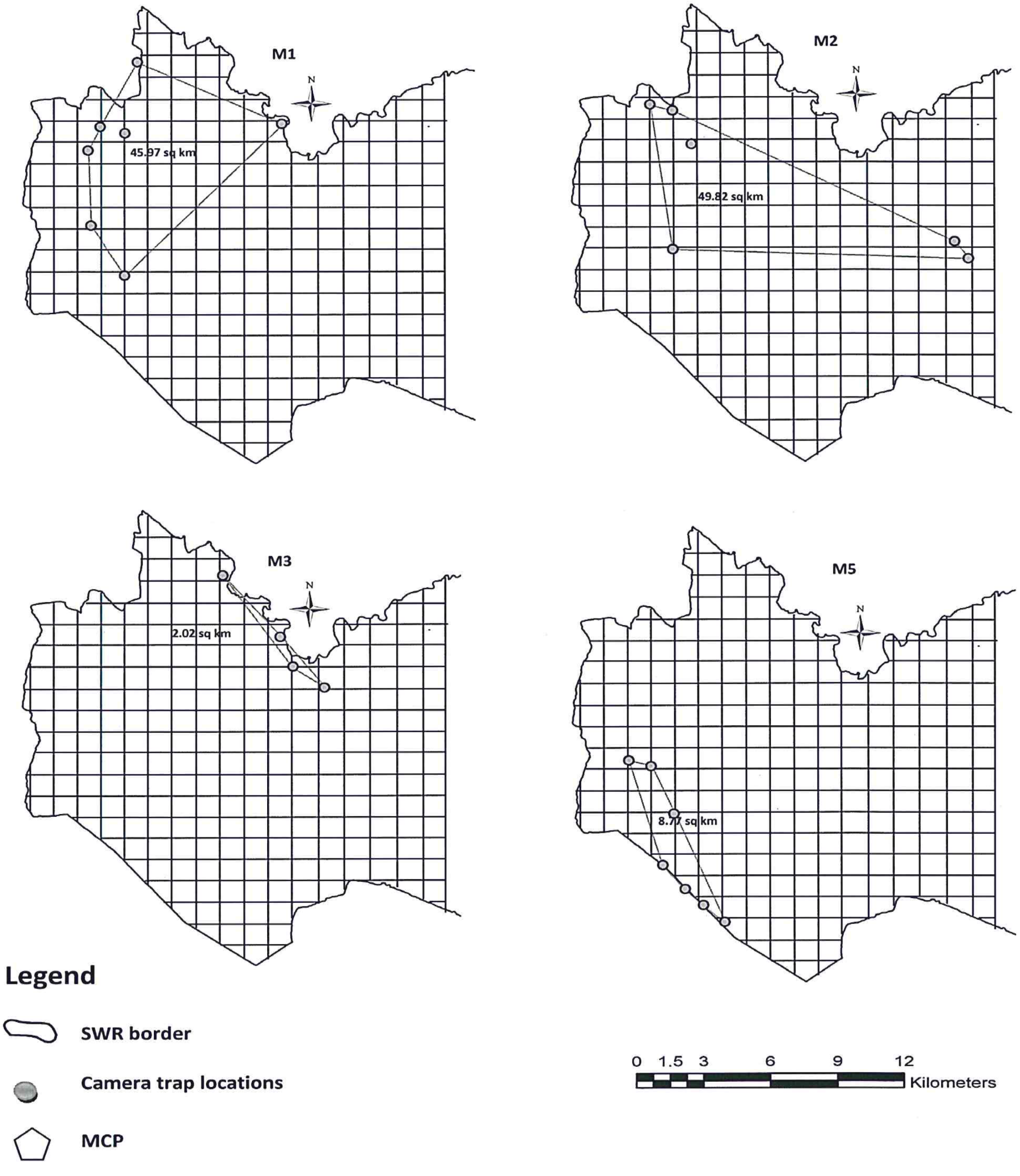

Figure 5.8. Winter home ranges of male leopards (2009-2011)

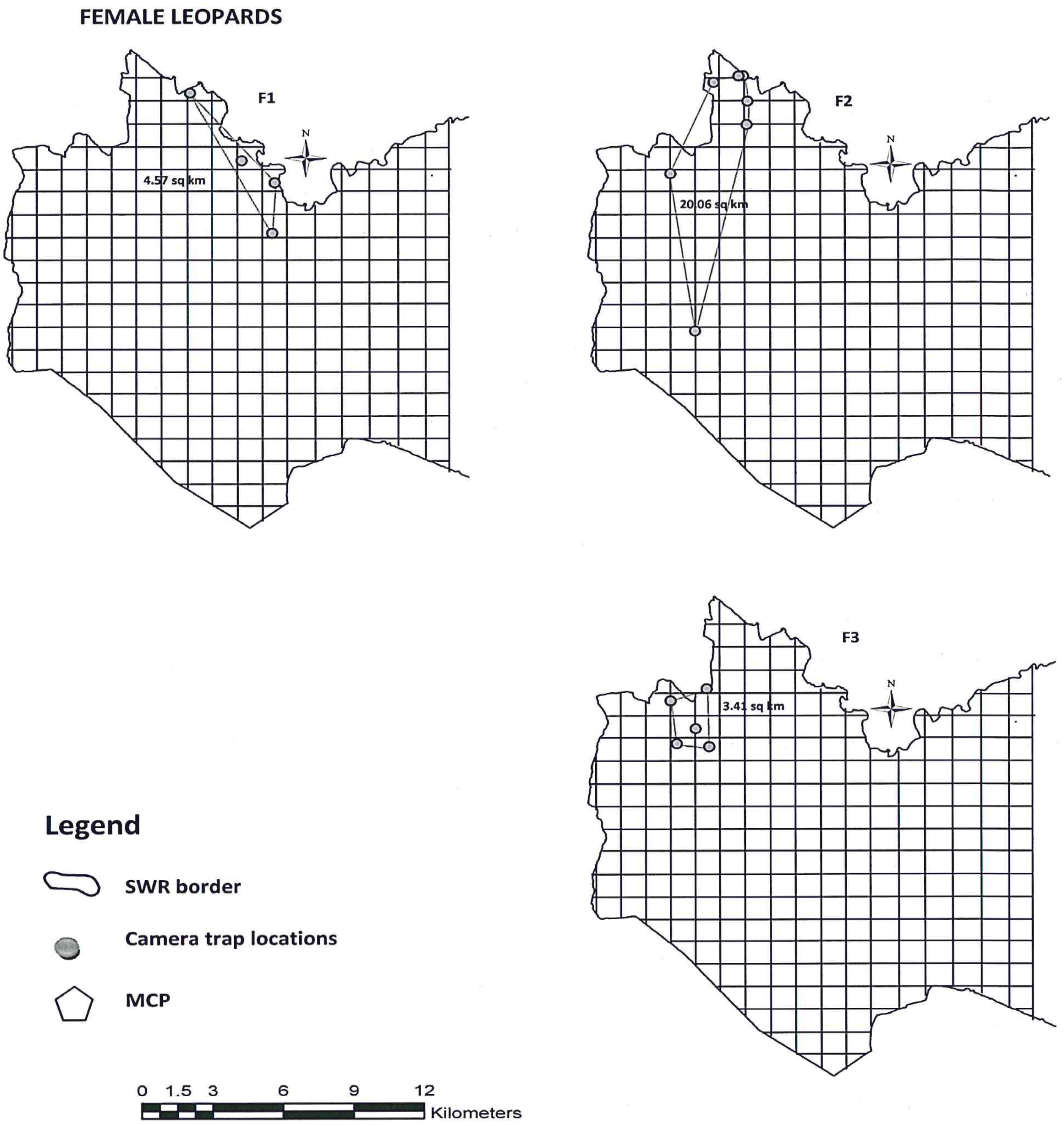

Figure 5.9. Winter home ranges of female leopards (2009-2011)

## 5.4. DISCUSSION:

### *5.4.1. Number and density of tigers and leopards*

The results of the camera trapping survey clearly showed that populations of tigers and leopards have increased slightly from the preceeding three years. However, the number of tigers was much lower compared to an estimate from camera trapping (20 individuals) about a decade ago (Regmi 2000). Population estimates for leopards are not available from previous years. The data here provided a baseline. The dramatic decline in number of tigers from SWR might be poaching (Karki *et al.* 2008). Another cause could be habitat encroachment, as can observed in the eastern part of the reserve. The abundances of the sympatric tigers and leopards can be recovered by controlling poaching and stopping illegal human activities (encroachment and illegal grazing) inside the reserve.

The sex ratio of tigers was found to be 1male:1female, taking the third year as an example, with a similar ratio found for leopards. This ratio appeared to be different from that found elsewhere. In an intensive telemetry study in Chitwan National Park (Smith *et al.* 1987) the sex ratio of sexually active tigers as 1 male: 2.25 females. From the same area, Sunquist (1981) concluded that the total ratio was 1 male: 3-4 female tigers. In Bardia, the sex ratio was found to be 1 male: 2.25 females in 1998/99 and 1 male: 1.4 females in 2000/01 (Wegge *et al.* 2009). Karanth (1995) captured four adult male tigers and three adult females within a 15 km$^2$ area in Nagarahole National Park in India, which is also a very different ratio from what is expected in a natural, healthy population. However, in concordance with the findings of this study, a 1:1 sex ratio was estimated in the Bardia population in 2001/2002 (Wegge 2004, Pokheral 2002). Alternatively the high proportion of males recorded by camera trapping during the study could be due to the trapping method itself, and could also be due to the "insular, isolation effect" which restricts natal dispersal of males. Males are expected to encounter traps more frequently than females because they move over larger areas. Conversely, females with new born cubs may move within a very restricted area, which may not be covered by a trapping station.

Genetic analysis may become an invaluable tool for the conservation and management of endangered wildlife (Moritz 1994, Avise 1996, Smith and Wayne 1996, Ashley 1999). Over the last decade, molecular methods have become widespread in the field of conservation biology as tools for informing the development of strategies for conserving genetic diversity in both ex-situ and in-situ populations. Non-invasive techniques such as scat sampling are also especially useful for animals that are elusive, nocturnal, rare or difficult to detect directly. Though in this study camera trapping identified more individuals than molecular analysis of scats, genetic analysis nonetheless allowed the identification of species from the scat sample in most cases (66 to 70%). Success rates were lower from the molecular identification of individual genotypes (20 to 32%) and sex (21 to 37%) from scat samples. These low rates may be due to a storage problem of fresh samples immediately after collection in the field. When sample sizes are adequate and storage issues are resolved, however, molecular techniques promise to provide useful additional information on presence and identify of individuals of cryptic species such as tigers and leopards. Camera trapping provided a great deal of information above and beyond the images themselves. However, this technique requires a large number of camera traps and human resources to cover the entire study area, which may prove more expensive than analyzing for DNA from scat samples.

### *5.4.2. Home ranges*

This study provides baseline data regarding the winter season home ranges of tigers and leopards in SWR of Nepal. However, perhaps the home ranges reported here were probably underestimated due to low number of capture locations. As expected, the results indicate that tiger home range size is larger than those of leopards, and that males of both species have large home ranges than females. These sex-related differences in home range size are attributable to two main drivers: both predators are dimorphic, with males being larger in size than females, and both have a polygynous breeding system (Skinner & Smithers 1990). Male home range size is therefore not only determined by nutritional requirements, but also by the distribution of females in the area. Other studies have also shown home ranges of male felids to be larger than those of females (e.g. tiger: Smith 1984, leopard: Odden & Wegge 2005), so that they can acquire enough resources for subsistence and maximizing breeding opportunities (Sandell 1989). For example, among leopards, Odden & Wegge (2005) reported that the average size of the male home range was 2.8 times larger than the home range of females.

Interestingly, the average home range of tigers in this study was larger in both sexes than reported elsewhere within their range (Table 5), except for the female tigers of Kanha (Schaller 1967), USSR (Matjushkin *et al.* 1977) and Sikhote-Alin (Goodrich *et al.* 2005), and male tigers of Chitwan (McDougal 1977) and USSR (Matjushkin *et al*. 1977). Goodrich *et al.* (2010) suggested that the home ranges of male Amur (Siberian) tigers (*Panthera tigris altaica*) are 3.6 times larger than those of females, whereas the data recorded in this study indicates that male home ranges are 1.4 times larger than those of females, on average. Smaller home ranges of female tigers are associated with breeding and raising of young (Sunquist 1981). Early radio telemetry studies in Chitwan National Park showed that both male and female tigers maintain largely exclusive home ranges where prey densities are high (Smith *et al*. 1987, Sunquist 1981). Likewise, the prey selection chapter in this thesis clearly demonstrated that prey density is high also in SWR, this could reflect the HRs of tigers.

**Table: 5.5. Home range sizes in the studies of tigers and leopards in spatial ecology**

| Species | Home range (HR) size (km2) | | Methods of Home range estimation | Location | Source |
|---|---|---|---|---|---|
| | M (n) | F (n) | | Country | Reference |
| **Tiger** | 43.3 (5) | 29.9 (4) | CT- 95% MCP | Shuklaphanta, Nepal | Present study |
| | | 9.3 | MCP | Chitwan, Nepal | Seidensticker et al. (1976) |
| | 60-72 | 16-20 (3) | RT (MCP) | Chitwan, Nepal | Sunquist (1981) |
| | | 20.7 (7) | RT (100 % MCP) | Chitwan, Nepal | Smith et al. (1987) |
| | 90-105 | 26-39 | - | Chitwan, Nepal | McDougal (1977) |
| | | 12.3 (2) | GPS (95% MCP) | Sundarbans, Bangladesh | Barlow ACD et al. (2011) |
| | 78 | 65 | - | Kanha, India | Schaller (1967) |
| | 30-50 | 10-20 | - | Kanha, India | Panwar (1979) |
| | 38-50 | 12-42 | - | Palamau, India | Sinha (1979) |
| | | 27 (1) | RT (MCP) | Panna, India | Chundawat et al. (1987) |
| | | 16.5 (1) | RT (95%MCP) | Nagarahole, India | Karanth & Sunquist (2000) |
| | | 402(14) | RT (95%MCP) | Sikhote-Alin, Russia | Goodrich et al. (2005) |
| | 800-1000 | 100-400 | - | USSR | Matjushkin et.al. (1977) |
| **Leopard** | | | | | |
| | 26.6 (4) | 9.3 (3) | CT- 95% MCP | Shuklaphanta, Nepal | Present study |
| | | 8 (1) | MCP | Chitwan, Nepal | Seidensticker et al. (1976) |
| | | 8.7 (3) | RT (95%MCP) | Chitwan, Nepal | Seidensticker et al. (1990) |
| | 35.3 (2) | 17.1 (1) | MCP | Bardia, Nepal | Odden & Wegge. (2005) |
| | 9-10 | 8-10 | - | Sri Lanka | Eisenberg and Lockhart (1972) |
| | 21.7 (2) | | RT (95%MCP) | India | Karanth & Sunquist (2000) |
| | 27.0 (1) | 11.4 (1) | RT (95%MCP) | Thailand | Rabinowitz (1989) |
| | 17.7 (2) | 8.8 (1) | RT (95%MCP) | Thailand | Grassman (1999) |
| | 37.2 (2) | 20.2 (6) | RT (95%MCP) | Thailand | Simcharoen et. al. (2008) |
| | 229.0 (3) | 179.0 (4) | RT (95%MCP) | North central Namibia | Marker & Dickman (2005) |
| | 1137 (3) | 290 (5) | MCP | South Africa | Bothma et al (1997) |
| | | 40-60 | - | Serengeti | Schaller (1972) |
| | 9-63 | 29 | - | Tsavo | Hamilton (1976) |
| | 10-19 | 10-19 | - | Rhodesia | Smith R.M. (1978) |

The home ranges of all male tigers overlapped each other at least partially and almost completely in some cases. The ratio of males and females in this study was 1:1, which is not normal for size-dimorphic, polygnous carnivores (Gittleman 1986). Such a high proportion of males probably limited some males from access to females, creating a high degree of competition between males in the area. One likely reason for the overlap between male home ranges is the good prey population in the study area (see Chapter –Prey selection). The variation in home range size was also different between sexes. A 100% overlap in home ranges was recorded in the case of the male tigers M1 and M9. However, M1 was only recorded in the area during the first winter, with the area most likely then taken over by M9, which was captured frequently by the camera traps in the following winters.

Home ranges of male tigers have been previously shown to overlap with more than one female's range (Sunquist 1981). My results from SWR are in agreement with this. In Kanha National Park, India, up to three female tigers have previously been observed to share the same area, with almost complete home range overlap (Schaller 1967). Goodrich *et al.* (2010) observed similar patterns of overlap in Amur tigers in Russia Far East, where male home ranges overlapped extensively with those of one to five females.

The home range of leopards in SWR was found to be similar to those in some studies (Table 5), though elsewhere larger home ranges have been recorded, for example in Bardia, Nepal (Odden & Wegge 2005), Thailand (Simcharoen *et al.* 2008), Namibia (Marker & Dickman 2005), Serengeti (Schaller 1972) and South Africa (Bothma *et al.* 1997) (Table 5). Previous studies of leopards using radio telemetry have also shown variation in home range size between locations. For example, home ranges were estimated to be 8 km$^2$ in Chitwan, Nepal (Seidensticker & Tamang 1974 & Seidensticker *et al* 1990) and greater than 1100 Km$^2$ (males) and 290 Km$^2$ (females) in South Africa (Bothma *et al.* 1997). This range in home range size is likely to be related to prey dispersion patterns, i.e. their accessibility, density and movement (Schaller 1972, Malcolm & Van Lawick 1975, Frame *et al.* 1979, Bailey 1993).

Telemetry studies in Thailand (Rabinowitz 1989, Grassman 1999, and Simcharoen *et al.* 2008) also suggest that male leopards may increase their home range in the wet season compared to the dry season. Other research has suggested that rainfall is not a controlling factor for the home range size of either male or female leopards (Marker & Dickman 2005), but that it may affect prey abundance and therefore indirectly affect home range size. Unfortunately, here could not examine seasonal patterns, as heavy monsoon rain and flooding in SWR hindered data collection during the rainy season.

Patterns of home range size variation may also differ between sexes: Odden & Wegge (2005) reported that the home range of a female leopard became smaller (5.2 and 6.6 km$^2$) during the cubs rearing season, especially when the cubs were not more than six months old. This could possibly be the reason why the female home range size was smaller than that of males in SWR (on average 9.3 km$^2$). In contrast however, Simcharoen *et al.* (2008) found that adult female leopards in Huai Kha Khaeng Wildlife Sanctuary in Thailand did not have significantly different home range sizes in the dry and wet season.

Leopards in SWR showed a gradient of range overlap (2 to 24 km$^2$) between both members of the same and opposite sexes. This shows that there might be moderate competition among the males, and perhaps females. The results support previous research on the home ranges of leopards, where the home range of a single male overlaps multiple females (Muckenhirn & Eisenberg 1973, Bailey 1993 and Mizutani & Jewell 1998). Similarly, Seidensticker (1976) found that the home range of a one male leopard encircled the home range of several females in Chitwan National Park. The home range overlaps were similar to those reported from Bardia (Odden & Wegge 2005). Studies from Kenya have shown that leopards maintain exclusive home ranges, suggesting territoriality among members of the same sex (Mizutani & Jewell 1998). Nevertheless, other studies have revealed considerable intra-sexual home range overlap for both sexes (Norton & Henley 1987, Bailey 1993, Marker & Dickman 2005).

The results from SWR show that even though there was between 12 and 18 % median overlap among tiger and leopard home ranges, there was a clear tendency for spatial separation between them. The leopards were more restricted to the peripheral areas of the reserve, while tigers were most abundant in the least disturbed areas of the core of the reserve. This spatial pattern may be a combination of tiger avoidance by leopards, and avoidance of disturbed areas by tigers. Similar distributions of the two species were also observed in Chitwan National Park from radio-tagged leopards and tigers (Seidensticker 1976, McDougal 1988), and also from Bardia National Park, Nepal (Odden *et al.* 2010).

The result of this study show that leopards and tigers are able to coexist, probably due to a combination of distribution and availability of prey species of varying sizes (Karanth and Sunquist 1995). The estimated population size of tigers was low compared to an estimate made about 10 years earlier (Regmi 2000). Because of the insurgency in the country within that period could be one of the reasons of decline the tiger number from the area. Conservation was not deliberate as a priority agenda and perhaps poaching and encroachment bloomed at that time. If habitats and prey base in the eastern part of the reserve area can be improved, there is great possibility of increasing the number of tigers. Shuklaphanta Wildlife Reserve may therefore be able to contribute to the achievement of the commitment made by the government of doubling the tiger number (250) in the country by 2022.

Genetic analysis (DNA scatology) provided useful insight into the species of carnivores addressed in this study, especially for the identification of species, and has great potential for monitoring. But challenges remain for improving the success rates off genotyping and sexing of individuals using scat samples. The camera trapping technique was nonetheless able to provide easily comparable information on home range sizes and landscape use patterns of large carnivores. Harmsen *et al.* (2009) suggested that camera traps had advantages over radiotelemetry in their potential to deliver data on the complete array of individuals within an area. But DNA scatology provides samples for diet analysis, individual identification, relatedness etc, and is probably less expensive than camera trapping in long run.

In SWR, both tigers and leopards were territorial in behavior with a wide range of distribution. Interestingly, the populations of tiger and leopard were rather similar in size and spatially spatial separated during the dry seasons. Because of this, another opportunity raised for further investigation on predator-prey relationship is to understand the seasonal patterns of coexistence in small populations and highly human-influenced habitat. Increased support will also be necessary for management authorities to develop species-specific conservation strategies to ensure long-term survival of these small and largely isolated populations.

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# Chapter: 6

## CONSERVATION AND MANAGEMENT

# Chapter: 6

## CONSERVATION AND MANAGEMENT

### 6.1. CONCLUSIONS

This research provides the first set of data from a study of tigers, leopards and their prey in Shukalphanta Wildlife Reserve, Nepal during the dry seasons. The study indicates that the densities of the main prey species is higher in SWR than in other lowland protected areas in Nepal, except from the southwest part of Bardia National Park (Wegge *et al*. 2009). On average, 131-175 individual prey animals were estimated to occur per km$^2$ during the study period. Wild prey comprised more than 60 percent whereas domestic prey, mostly nomadic within the reserve, comprised ca. 38 percent of the prey base. The most abundant wild prey were swamp deer and chital. The large grassland in the core area of the SWR supported a large herd of this sub-species of swamp deer. Chital was uniformly distributed and contributed a high proportion to the diet of tigers and leopards. Medium-sized prey was most important in the diet of the tiger and small sized prey in the case of leopards. Tiger consumed more larger prey than the leopards did. A large proportion of the diets consisted of wild ungulates (77% and 51 % for tigers and leopards, respectively). A substantial part of the diet of both predators was found to consist of domestic species. Niche overlap values indicated a great dietary overlap between tiger and leopard.

A analyses of camera trapping data showed that both tigers and leopards were photo captured more frequently at night than during the day, thus indicating that both have nocturnal activity. However, tigers were found to have more diurnal activity than leopards. Leopards were photo-captured more frequently from the border area of the reserve than tigers. Variances in time use, temporally or spatially, have been recognized as behavioural characteristics that may motivate coexistence. In general, when comparing the activity pattern of tigers with leopards, leopards were more passive between 11AM- 5PM than tiger. There were partial, but not complete, overlap in observations between 02:00hrs and 05:00hr, with periods of peak activity during the hours of dawn and dusk. Concentration within certain areas and limited diurnal activity of leopards indicate the existence of temporal niche separation between the two cat species.

Comparing camera trap results from a decade ago (20 individuals, Regmi 2000) with the present results (8 individuals) reveals a serious decline in number of tigers. Population estimates for leopards are not available from previous years. The data (density 2.6/100km$^2$) from this study provide a baseline. Comparing the results between the camera trapping (photographs) and genetic analysis using scat samples showed that the camera trapping technique identified more individuals (tigers and leopards) than the genetic analysis. Genetic analysis, nonetheless, allowed the identification of species from the scat samples in most cases (66 to 70%). Success rates were lower from molecular identification of individual genotypes (20 to 32%) and sex (21 to 37%) from scat samples.

Camera trapping provided baseline data regarding the home range sizes of tiger and leopards. As expected, the results indicated that tiger home range size is larger than that of leopards, and the males of both species had large home ranges than females. The home ranges of all male tigers overlapped with each other at least partially and almost completely in some cases, whereas the ranges of leopards showed a gradient of range overlap (2 to 24 km2) between both members of the same and opposite sexes. There was a clear tendency for spatial separation between the home ranges of tigers and leopards. The leopards were more restricted to the peripheral part of the reserve, while tigers were most abundant in the least disturbed core area of the reserve. This spatial pattern may be a combination of tiger avoidance by leopards, and avoidance of disturbed areas by tigers.

## 6.2. RECOMMENDATIONS

This study showed that domestic amimals were a substantial proportion of the diet of both predators. Hence, there is large contact between livestock and wildlife, which may create a serious problem in the long term: i) transmission of disease and ii) human-predator conflicts:-

i) Searching the present scenario, massive illegal livestock grazing within the reserve could be a serious problem next to poaching, because the possibility of disease spreading between wildlife and livestock. The huge decline (more 60%) of tiger numbers in SWR since 1999 data presented by Regmi (2000), may have been due to disease in addition to poaching. Disease outbreaks can reduce population sizes (of carnivores or tigers etc) by more than 35% (Fosbrooke 1963, Roelke-Parker et al. 1996, Sillero-Zubiri et al. 1996). Wildlife disease study is lacking in our protected areas. Therefore, there is an urgent need of wildlife disease studies, particularly focused on carnivores, for the long term survival of these species.

ii) Despite the fact that, the study area is abundant in wild prey species, the results from the diet study showed that both tigers and leopards were considerably dependent on domestic animals. Killing of domestic animals by the large carnivores has escalated the human-wildlife conflict across their range and hinders the conservation of such endangered species, ultimately creating greater challenges for management authorities (Mishra 1997, Tamang 2000). Nowell & Jackson (1996) suggested that persecution by humans in response to livestock depredation in historical times has eliminated several carnivores, including the tiger, lion *Panthera leo*, and puma *Felis concolor*, from large parts of their former ranges. The conflict is likely to escalate unless the problem of depredation and illegal grazing inside the reserve is addressed.

*Management of the extension area*: The chital proportion was high in the diet of both predators. The density of chital and other prey species can be enhanced in the extension area of SWR to support more numbers of predators, but this requires effective protection from illegal grazing, encroachment and poaching. The extension area of the reserve under human pressure is ca.100 km$^2$. Further research is needed in this area to evaluate human-disturbance on both predators and prey, which will provide needed information for conservation management actions.

SWR is one of the potential sites of Terai Arc Landcsape for further long term research on predator-prey relationships with the inclusion of a transboundary wildlife corridor, by using advance technology (GPS satellite telemetry). This area is connected with the Lagga Bagga protected area in the south (Indian border), and the rest of the reserve boundary is highly dominated by the human settlements. Thus, a landscape study using advance GPS telemetry will aid in the understanding of how these two large predators use the wildlife trans-border corridor and their spatial coexistence pattern throughout the whole year.

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# APPENDIX-1

Species, individual and sex detection of tigers and leopards in SWR

| Scat sample | Species identification (mtDNA cytochrome *b*) | Genotype (nine microsatellite loci) | Sex determination (ZFXY genes) | Year/month | |
|---|---|---|---|---|---|
| 1 | Tiger | low reliability | low reliability | 2009 | Jan |
| 2 | Tiger | # 1 | **FEMALE** | 2009 | Jan |
| 3 | Tiger | low reliability | low reliability | 2009 | Jan |
| 4 | Tiger | low reliability | low reliability | 2009 | Mar |
| 5 | Tiger | low reliability | low reliability | 2009 | Oct |
| 6 | Tiger | low reliability | low reliability | 2009 | Dec |
| 7 | Tiger | low reliability | low reliability | 2009 | Dec |
| 8 | Tiger | low reliability | low reliability | 2009 | Dec |
| 9 | Tiger | low reliability | low reliability | 2010 | Jan |
| 10 | Tiger | low reliability | low reliability | 2010 | Jan |
| 11 | Tiger | low reliability | low reliability | 2010 | Jan |
| 12 | Tiger | # 2 | **FEMALE** | 2010 | Feb |
| 13 | Tiger | low reliability | low reliability | 2010 | Mar |
| 14 | Tiger | low reliability | low reliability | 2010 | Mar |
| 15 | Tiger | low reliability | low reliability | 2010 | Mar |
| 16 | Leopard | low reliability | **FEMALE** | 2010 | Mar |
| 17 | Tiger | # 7 | **MALE** | 2010 | Oct |
| 18 | Leopard | # 6 | **FEMALE** | 2010 | Oct |
| 19 | Tiger | # 3 | **FEMALE** | 2010 | Oct |
| 20 | Tiger | # 1 | **FEMALE** | 2010 | Oct |
| 21 | Tiger | # 4 | **MALE** | 2010 | Oct |
| 22 | Tiger | low reliability | low reliability | 2010 | Nov |
| 23 | Tiger | low reliability | low reliability | 2010 | Nov |
| 24 | Tiger | # 2 | **FEMALE** | 2010 | Dec |
| 25 | Leopard | # 5 | **FEMALE** | 2010 | Dec |
| 26 | Tiger | # 1 | **FEMALE** | 2010 | Dec |
| 27 | Tiger | # 1 | **FEMALE** | 2010 | Dec |
| 28 | Tiger | low reliability | low reliability | 2010 | Dec |
| 29 | Tiger | # 2 | **FEMALE** | 2010 | Dec |
| 30 | Leopard | # 5 | **FEMALE (**low reli.**)** | 2011 | Jan |
| 31 | Tiger | # 3 | **FEMALE (**low reli.**)** | 2011 | Jan |
| 32 | Leopard | low reliability | low reliability | 2011 | Jan |
| 33 | Tiger | # 7 | **MALE** | 2011 | Jan |
| 34 | Tiger | low reliability | low reliability | 2011 | Jan |
| 35 | Tiger | low reliability | low reliability | 2011 | Jan |
| 36 | Tiger | # 7 | **MALE** | 2011 | Jan |
| 37 | Tiger | # 2 | **FEMALE** | 2011 | Feb |
| 38 | Leopard | # 8 | **FEMALE** | 2011 | Feb |
| 39 | - | low reliability | **FEMALE** | 2011 | Feb |
| 40 | Tiger | # 2 | **FEMALE** | 2011 | Feb |
| 41 | Tiger | low reliability | low reliability | 2011 | Feb |
| 42 | Tiger | # 1 | **FEMALE** | 2011 | Mar |
| 43 | Tiger | low reliability | low reliability | 2011 | Mar |
| 44 | Tiger | low reliability | low reliability | 2011 | Mar |
| 45 | Tiger | low reliability | **MALE** | 2011 | Mar |
| 46 | Tiger | # 2 | **FEMALE** | 2011 | Mar |
| 47 | Tiger | # 2 | **FEMALE** | 2011 | Mar |
| 48 | Leopard | low reliability | low reliability | 2011 | Apri |
| 49 | Tiger | low reliability | low reliability | 2011 | Apri |
| 50 | Tiger | # 4 | **MALE** | 2011 | Apri |
| 51 | Leopard | # 9 | **FEMALE** | 2011 | Apri |
| 52 | Tiger | # 7 | **MALE** | 2011 | Apri |
| 53 | Tiger | # 2 | **FEMALE** | 2011 | Apri |
| 54 | - | low reliability | **FEMALE** | 2011 | Apri |
| 55 | Tiger | low reliability | low reliability | 2011 | Apri |
| 56 | Tiger | # 7 | **MALE** | 2011 | Apri |

**#, individual**

# APPENDIX-2

Species, individual and sex detection of the tiger in Bardia National Park

| Scat sample | Species identification (mtDNA cytochrome *b*) | Genotype (nine microsatellite loci) | Sex determination (ZFXY genes) | Year/month |
|---|---|---|---|---|
| 1 | Tiger | low reliability | low reliability | 2009 Dec |
| 2 | Tiger | low reliability | low reliability | 2009 Dec |
| 3 | Tiger | low reliability | **MALE** | 2009 Dec |
| 4 | Tiger | low reliability | low reliability | 2010 Jan |
| 5 | Tiger | **# 1** | **MALE** | 2010 Jan |
| 6 | Tiger | low reliability | low reliability | 2010 Jan |
| 7 | Tiger | low reliability | **MALE** | 2010 Jan |
| 8 | Tiger | low reliability | **MALE** | 2010 Feb |
| 9 | Tiger | **# 2** | **MALE** | 2011 Jan |
| 10 | Tiger | low reliability | low reliability | 2011 Feb |
| 11 | Tiger | low reliability | low reliability | 2011 Feb |
| 12 | Tiger | low reliability | **MALE** | 2011 Feb |
| 13 | Tiger | low reliability | low reliability | 2011 Feb |
| 14 | Tiger | low reliability | low reliability | 2011 Feb |
| 15 | Tiger | low reliability | low reliability | 2011 Feb |
| 16 | Tiger | **# 1** | **FEMALE ( it could be drop out)** | 2011 Feb |
| 17 | Tiger | low reliability | low reliability | 2011 Feb |
| 18 | Tiger | **# 4** | **FEMALE** | 2011 Feb |
| 19 | Tiger | low reliability | low reliability | 2011 Feb |
| 20 | Tiger | low reliability | low reliability | 2011 Feb |
| 21 | Tiger | low reliability | low reliability | 2011 Feb |
| 22 | Tiger | low reliability | low reliability | 2011 Feb |
| 23 | Tiger | low reliability | low reliability | 2011 Feb |
| 24 | Tiger | low reliability | **FEMALE** | 2011 Feb |
| 25 | Tiger | low reliability | low reliability | 2011 Feb |
| 26 | Tiger | low reliability | low reliability | 2011 Mar |
| 27 | Tiger | low reliability | low reliability | 2011 Mar |
| 28 | Tiger | **# 1** | low reliability | 2011 Mar |
| 29 | Tiger | **# 7** | **FEMALE** | 2011 Mar |
| 30 | Tiger | low reliability | low reliability | 2011 Mar |
| 31 | Tiger | low reliability | low reliability | 2011 Mar |
| 32 | Tiger | **# 1** | low reliability | 2011 Mar |
| 33 | Tiger | **# 5** | **FEMALE** | 2011 Mar |
| 34 | Tiger | **# 1** | low reliability | 2011 Mar |
| 35 | Tiger | low reliability | low reliability | 2011 Mar |
| 36 | Tiger | **# 1** | **MALE** | 2011 Mar |
| 37 | Tiger | **# 6** | low reliability | 2011 Mar |
| 38 | Tiger | low reliability | low reliability | 2011 Mar |
| 39 | Tiger | low reliability | low reliability | 2011 Mar |
| 40 | Tiger | **# 1** | low reliability | 2011 Mar |
| 41 | Tiger | low reliability | low reliability | 2011 Mar |
| 42 | Tiger | low reliability | **MALE** | 2011 Mar |
| 43 | Tiger | low reliability | low reliability | 2011 Mar |

**#, individual**

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