1

General Introduction

1.1 Introduction

1.1.1 Carnivore conservation worldwide

The evolution of cats (*Felidae*) started only relatively recently with several species diverging within a time span of c. 28.5 to 35 million years (Sunquist & Sunquist 2002). It has been estimated that the group of large 'roaring' cats, including tigers and leopards, have diverged around 2-3 million years ago (Turner, 1987).

Historically, the conservation of large cats has been motivated on a.o. aesthetic, symbolic, spiritual, ethical, utilitarian and ecological considerations (Loveridge et al., 2010). Nowadays, the threats for the conservation of tigers and leopards are generally grouped into five main categories: 1) habitat destruction, 2) poaching for illegal trade, 3) decline of prey populations, 4) retaliatory killing after conflicts with local communities, and 5) genetic isolation and inbreeding depression (Mills & Allendorf, 1996; Inskip & Zimmermann, 2009; Karanth & Chellam, 2009; Ripple et al., 2014; Nyhus, 2016).

As human populations are increasing, natural habitat continues to be exploited, leading to considerable alterations to the global landscape (Lambin & Meyfroidt, 2011). Tigers and leopards are now regarded as conservation dependent species because their habitat is facing increasing threats from human developmental activities (Thapa et al., 2017). Loss of highly suitable habitats is generally attributed to unauthorized resource extraction, coupled with natural processes such as flooding and forest succession (Wegge et al., 2009; Carter et al., 2012). Across much of the leopard range, land has been converted to agriculture for producing crops in order to support the growing human population (Jacobson et al., 2016).

Poaching and illegal trade of skin, bones and other body parts of large carnivores has also greatly contributed to their decline in certain areas

(Goodrich et al., 2008; Kolipaka et al., 2017). Tigers, more so than leopards, require large populations to persist and are susceptible to modest increases in mortality, and less likely to recover quickly after a population decline (Chapron et al., 2008). Knowledge on rates of decline and causes of mortality among tiger and leopard populations is crucial in order to understand their population dynamics and hence to formulate effective conservation measures (Caughley & Sinclair, 1994; Goodrich et al., 2008). When prey levels are very low, a minor increase in poaching could result in the local extinction of the tiger (Damania et al., 2003). Mortality rates of more than 15% of adult female tigers can lead to their extinction (Chapron et al., 2008). For Amur tigers (*Panthera tigris altaica*) poaching was regarded as the main cause of death in Silhote-Alin Biosphere Zapovednik of Russia (Goodrich et al., 2008). Goodrich et al. (2008) even found that all dispersing Amur tigers that had been collared were poached before they got a chance to settle or reproduce. The threat posed to tigers by the illegal trade in wildlife parts is considered to be greater in Asia than anywhere else (Nowell & Jackson, 2006).

In a study on the effects of humans poaching on prey species of carnivores in the Northern part of Bardia, Bhattarai et al. (2017) found that decreased prey numbers led to a decrease in tiger, leopard, fox (*Vulpes vulpes*) and jackal (*Canis aureus*) population. After the area was included under the buffer zone in 2010 and due to regular patrolling by armed forces, poaching in this area had however dropped drastically (Bhattarai et al., 2017), and as a consequence carnivore populations have recovered recently.

Retaliatory killing by humans in areas where livestock or occasionally even humans are attacked by large carnivores has increasingly contributed to large carnivore population declines over the past decades (Inskip et al., 2014). When in the early 1950s tigers were declared a pest in China, this quickly resulted in uncontrolled killing of tigers, especially in areas where they were causing problems (Seidensticker et al., 2009). But also leopards have long been persecuted as a retribution measure to real and perceived livestock losses (Ray et al., 2005; Shehzad et al., 2015). In the Annapurna Conservation Area in Nepal there have been records of snow leopards killed in retaliation to the killing of sheep (Oli et al., 1991). Numerous studies have reported this same threat to cause great declines in population numbers of tigers in Asia (Inskip et al., 2014; Lamichhane et al., 2017), lions in Africa and South West Asia, and mountain lion (*Puma concolor*) populations in North America (Nowell & Jackson, 1996).

Several studies have found inbreeding among isolated populations of large carnivores to negatively impact their long-term viability (Smith et al., 1998; Perez et al., 2006). Reduced genetic exchange rates between populations could compromise genetic variation and long-term viability of populations (Smith et al., 1998). Furthermore, as a consequence of high inbreeding rates, small population sizes and long-term population isolation, genetic variability could become alarmingly low, potentially leading to increased susceptibility to contagious lethal diseases (e.g. Arabian leopards in Israel; Perez et al., 2006). To maintain demographic and genetic viability of low density and wide-ranging species such as the tiger, it is essential to extend conservation actions beyond protected area boundaries, i.e. at the landscape level (Waltson et al., 2010). In addition, promoting protected area connectivity is suggested to positively influence the conservation status of wide ranging large carnivores (Mills & Allendorf, 1996, Wikramanayake et al., 2004).

Morrison et al. (2007) compared the historical (1500 AD) range map of large mammals with their current distributions to determine which areas today retain complete assemblages of large mammals and reported that at the time of his assessment, leopards inhabited 65% of their historical range while tiger populations have shrunk to a mere 18% of their historical range. This indicates a significant global decline in distribution of these large carnivores. Since tiger and leopard densities are naturally limited by energetic constraints, their numbers could significantly impact the community structure of herbivores through resource facilitation and trophic cascades (Ripple et al., 2014).

1.1.2 Human-wildlife conflicts

While large cat species worldwide generally serve as an umbrella and flagship species for ecosystem conservation (Loveridge et al., 2010), the relationship between humans and wild felids has historically been a complex and often paradoxical one (Loveridge et al., 2010). In certain cultural beliefs wild cats have since long been considered as valuable assets, cultural icons or to carry a significant symbolic value (Bhattarai & Fischer, 2014; Kolipaka et al., 2015). In terms of their economic value, a clear shift has taken place over the past century or so, from being the main target as a valuable hunting trophy to generating income as a key tourist attraction (Mehta & Heinen, 2001; Bhattarai & Fischer, 2014).

But just like their larger carnivorous relatives around the world, large cats are also known to cause serious problems if their activities coincide with those of humans (Woodroffe et al., 2005; Treves et al., 2006; Inskip & Zimmerman, 2009). Due to a global increase in land resource use, numerous wildlife species have lost vital habitat and are forced to live in close proximity to humans, thereby competing for space and food (Inskip & Zimmerman, 2009). Conflicts arising from this competition could pose a serious threat on both the wildlife species involved, especially if it is considered threatened with extinction, and the people that are trying to defend themselves or their livestock (Saberwal et al., 1994). Particularly wide ranging species, such as leopards and tigers, could trigger a conflict situation at great distances from protected areas (Bhattarai & Fischer, 2014; Acharya et al., 2016). At the same time, retaliatory actions taken by local communities that suffered losses due to attacks by such predators could extend far into protected areas. Such species are therefore prone to being killed by people (Woodroffe et al., 2005; Kolipaka et al., 2017). The methods used by local inhabitants to kill large carnivores are numerous, and vary to a great extent including shooting, poisoning of livestock kills, electrocution, snaring and trapping (Karanth & Gopal, 2005). Local villagers around Chitwan National Park, Nepal have been reported to put out poisoned livestock carcasses to kill tigers (Sunquist, 1981).

But conflicts with large carnivores not only arise as a consequence of direct interactions with humans, expanding human habitation, loss of natural habitat, the local and international trade in wildlife parts and in some regions growing wildlife populations resulting from successful conservation programs are also important contributing factors (Saberwal et al., 1994; Treves & Karanth, 2003; Wang & Macdonald, 2006).

Inskip & Zimmerman (2009) define a human-wildlife conflict (HWC) as the situation that arises when behavior of a non-pest, wild animal species poses a direct and recurring threat to the livelihood or safety of a person or a community and in response, persecution of the species ensues. The use of the term 'human-wildlife conflict' is usually misleading as it portrays wildlife as an antagonist with conscious intent to interfere with people's lives and livelihoods, whereas the real conflict is between conservation and other human interests (Peterson et al., 2010; Redpath et al., 2015; Fisher, 2016). The phrase 'human-wildlife conflict' is now commonly used to describe a situation that involves any negative interactions between humans and wildlife (Messmer, 2009).

1.1.3 Tiger ecology

The tiger (*Panthera tigris,* Linnaeus, 1758) is one of the world's most iconic predator species. Unfortunately, it is also one of the most endangered species (Seidensticker, 2010). The tiger is regarded as a top predator and a flagship or umbrella species for their role in biodiversity conservation and maintaining a healthy ecosystem (Morrison et al., 2007; Ripple et al., 2014). According to the IUCN global Red list, the tiger is considered Endangered (IUCN, 2018).

In 2011 a Tiger Summit was organized in St. Petersburg, Russia, to discuss on a global action plan for tiger conservation (GTRP, 2011). In the St. Petersburg declaration which resulted from this meeting, the member states have recognized that in the past century, tiger numbers have plummeted from 100,000 to below 3,500, and are still declining (GTRP, 2011). While tigers were once widely distributed across Central, East and South Asia (Figure 1.1, Mazak, 1981) the declaration indicates that tiger numbers and habitat surface area had shrunk by 40 percent in the last decade alone, largely due to habitat loss, poaching, illegal wildlife trade, and human-tiger conflicts (GTRP, 2011). A study by Waltson (2010) has identified 42 tiger source sites representing 6 % of their existing range, and holding 70% of the tiger population.

There are nine sub-species of tigers identified of which four are already extinct (Seidensticker, 2010). Wilting et al. (2015) supports the recognition of two distinct evolutionary groups of sub-species of tiger: the Sunda tiger (*P. tigris sondaica*) and the continental tiger (*P. tigris tigris*) (Table 1.1).

Table 1.1
Sub-species of tigers, with their distribution and status

	Sub-species	Common name	Distribution	Status
Sunda tiger	*P. tigris sondaica*	Javan tiger	Java island of Indonesia	Extinct since the early 1980s
	P. tigris balica	Bali tiger	Bali island of Indonesia	Extinct in the 1940s
	P. tigris sumatrae	Sumatran tiger	Sumatra island of Indonesia	Living
Continental tiger	*P. tigris tigris*	Bengal tiger	Nepal, Bhutan, Bangladesh, Burma and India	Living
	P. tigris altaica	Siberian tiger	North East China and Russian Far East	Living
	P. tigris amoyensis	South China tiger	South East China	Extinct since the 1990s
	P. tigris corbetti	Indochinese tiger	Cambodia, Laos, China, Burma, Thailand and Vietnam	Living
	P. tigris virgata	Caspian tiger	Caspian sea	Extinct since the 1970s
	P. tigris jacksoni	Malayan tiger	Malay peninsula	Living

(Reference: Seidensticker, 2010; Wilting et al., 2015)

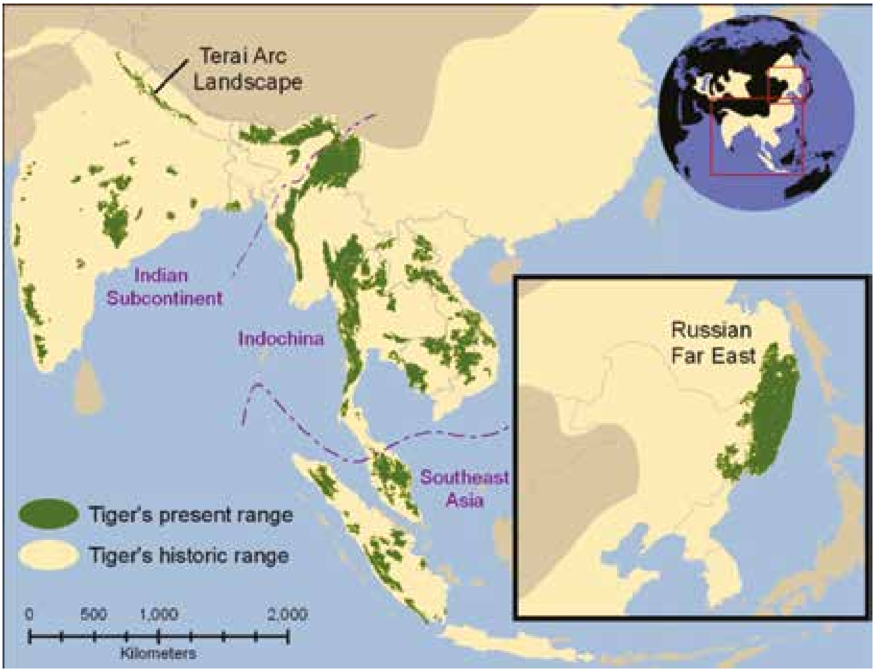

Figure 1.1
Recent (2007) and historic range of the tiger (Dinerstein et al., 2007).

Tigers maintain large home ranges and exhibit intra-sexual territoriality (Smith et al., 1989). A study carried out by Smith & McDougal (1991) in Chitwan National Park, Nepal on reproductive patterns in the local tiger population showed that the mean age of reproduction for female tigers was 3.4 years and for male tigers 4.8 years. Adult male tigers are about 1.3 to 1.6 times larger than female tigers (Seidensticker & McDougal, 1993). Tiger litter size varies from 2-5, with an average of 3 cubs, and a gestation period of 103 days (Sunquist, 1981; Smith & McDougal, 1991). Female tigers vocalize and scent mark extensively during the week prior to estrous. In response, male tigers could track an estrous female, possibly marking the onset of a period in which the male and female remain in close proximity and frequently mate (Smith & McDougal, 1991). Smith & McDougal (1991) suggested that on two occasions an estrous female was located near the territorial boundary of two males. This resulted in a fight between the two males and the winner successfully mated with the female while the other male left the area permanently (Smith & McDougal, 1991).

The size of a tiger's home range can vary from 20 to over 400 km^2 depending on the availability of prey (Smith, 1993; Seidensticker & McDougal, 1993). In

Chitwan National Park, tiger home ranges varied in size from 60-70 km^2 for adult males and from 16-20 km^2 for adult females, with the smallest home ranges recorded in the wet season, for both males and females (Sunquist, 1981). The distance a female tiger covers at night in this study area was estimated at 10-20 km/night (Sunquist, 1981). In general, dispersing tigers may travel over 100 km in search for a suitable new home range, with males dispersing three times more often than females (Smith, 1993). Female philopatry is frequently observed in tigers, with sub-adult females often inheriting a portion of their natal home range and males generally dispersing longer distances than females (Smith, 1993; Goodrich et al., 2010). Male and some female tigers leave their natal areas when they are 19-28 months old.

The tiger is the largest of all living felids. Its morphology reflects adaptations for killing large and potentially dangerous prey either by concealment, stealth or by sudden attack (Seidensticker & McDougal, 1993; Karanth & Sunquist, 2000). Prey is killed using throat bites, leading to strangulation in 70% of the kills, followed by a neck twist in 14% of the kills, resulting in a cerebral fracture (Karanth & Sunquist, 2000). A tigress requires 5-6 kg of meat per day as a maintenance diet to fulfill her metabolic requirements (Sunquist, 1981). Tiger densities are positively correlated to prey densities, and under optimal conditions 10% of the available prey within a tiger territory will be annually consumed (Karanth et al., 2004). The density of tigers in Chitwan National Park has been estimated at 3.8 tigers/100 km^2 through camera trap studies (Dhakal et al., 2014). This is higher than the tiger densities found in other protected areas, such as Bardia (3.3 tigers/100 km^2) and Suklaphanta (3.4 tigers/100 km^2) (Dhakal et al., 2014). Wegge & Storaas (2009) reported that the tigers' main prey species in Bardia were chital *Axis axis*, hog deer *Axis porcinus* and wild pig *Sus scrofa*, supplemented by fewer barking deer *Muntiacus muntjac*, barasingha *Cervus duvauceli* and nilgai antelope *Boselaphus tragocamelus*. Tigers in Chitwan National Park were found to prey heavily on medium- to large-sized large cervids (Kapfer et al., 2011).

In Nepal, three distinct populations of tigers have been identified: the Chitwan population, the Bardia population and the Suklaphanta population (Smith et al., 1998). In a recent study carried out on the status of the tiger's prey base in Nepal, it was estimated that the tiger population had increased by 63% over a 5-year period, with an annual growth rate of 12.7% (Dhakal et al., 2014). In Bardia, the tiger population was estimated at 18 individuals in 2008/2009 (Karki et al., 2009), growing to an estimated 87 tigers in 2018 (unpublished results).

1.1.4 Leopard ecology

The leopard (*Panthera pardus,* Linnaeus, 1758) is the most widely distributed wild felid, with a distribution ranging from sub-Saharan Africa, the Middle-East, the Far-East, extending northwards to Siberia and southwards to Sri Lanka and Malaysia (Figure 1.2, Nowell & Jackson, 1996). According to the IUCN Red list, the leopard is considered Vulnerable (IUCN, 2018). The Indian leopard (*P. p. fusca*), with its distributional range restricted to the Indian subcontinent, is listed as near-threatened (IUCN, 2018). The leopard is a habitat generalist, ranging from tropical rainforest to arid savanna and from Alpine mountains to the edges of urban settlements (Nowell & Jackson, 1996; Dutta et al., 2013). In India and Southeast Asia, leopards are found in all forest types, from tropical rainforest to temperate deciduous and alpine coniferous forest (up to 5,200 m in the Himalaya), as well as in dry scrub and grasslands (Nowell & Jackson, 1996). Their ability to inhabit such a variety of landscape types is largely due to their highly adaptable foraging strategy (Balme et al., 2007).

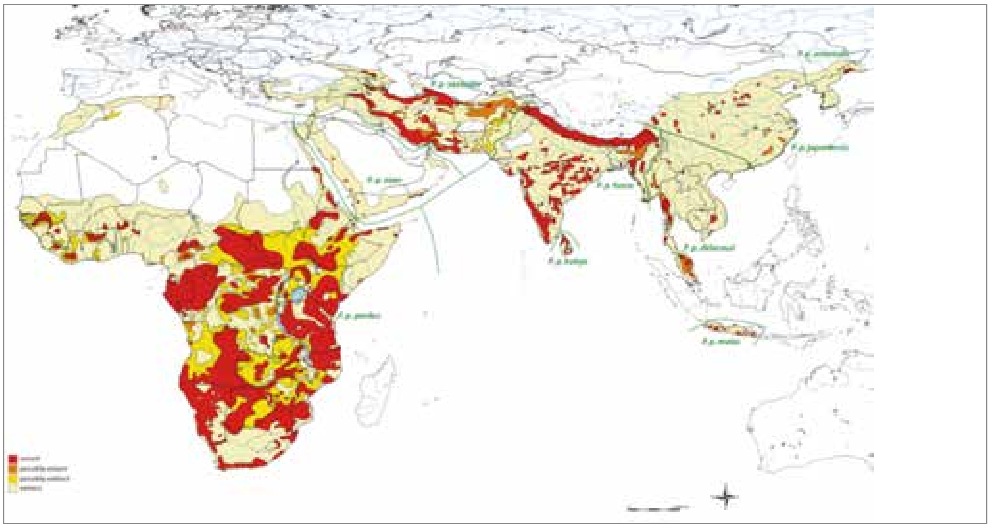

Figure 1.2
Present and historic range of the leopard in Africa and Eurasia [Source: Peter Gerngross, IUCN (2016)].

The leopard now occupies 25-37% of its historic range, but there are differences between different sub-species (Jacobson et al., 2016). There are nine sub-species of leopard known (Table 1.2) of which three (*P. pardus pardus*, *P.p. fusca*, and *P.p. saxicolor*) account for 97% of the leopard's entire distributional range, while another three (*P. pardus orientalis*, *nimr*, and *P.p. japonensis*) have each lost 98% of their historical range (Jacobson et al., 2016).

Table 1.2
Sub-species of leopards with their distribution

Sub-species of leopard	Common name	Distribution
P. pardus pardus	African leopard	African subcontinent
P. pardus fusca	Indian leopard	Indian subcontinent: Pakistan, India, Nepal, Bhutan and Bangladesh
P. pardus saxicolor	Persian leopard	Iran, Iraq, Georgia, Armenia, Azerbaijan, Turkmenistan, Afghanistan, Turkey and North Caucasus
P. pardus orientalis	Amur leopard	Russian Far East and Northern China
P. pardus nimr	Arabian leopard	Arabian peninsula: Saudi Arabia, Oman, Yemen, Kuwait, United Arab Emirates, Israel, Jordan, Lebanon and Syria
P. pardus japonensis	North Chinese leopard	North China
P. pardus melas	Javan leopard	Java island of Indonesia
P. pardus kotyia	Sri Lankan leopard	Sri Lanka
P. pardus delacouri	Indochinese leopard	Mainland Southeast Asia: Myanmar, Thailand, Malaysia, Cambodia, Laos, Vietnam and South China.

(References: Miththapala et al., 1996; Upriyanka et al., 2001; Jacobson et al., 2016).

Leopards are considered as a catholic predator, generally preying on over a hundred prey species with an average weight of 10 to 40 kg (peaking at 23 kg; Hayward et al., 2006). A leopard weighs 38 kg (females) to 58 kg (males) (Bailey, 1993; Nowell & Jackson, 1996). The average food intake for a male leopard is 4.3 kg/day and for a female 4.9 kg/day (Odden & Wegge, 2009). Leopards are nocturnal hunters, relying heavily on their good vision and to a lesser extent on hearing to detect their prey (Sunquist & Sunquist, 2002). Leopards kill most of their prey (90%) using throat bites, with the nape bite or a nape-and-throat bite often being used to kill medium-sized prey, such as barking deer (*Muntiacus muntjac*) or chital fawns (Karanth & Sunquist, 2000).

Young leopards disperse from their mother when they are 12-18 months old, becoming reproductively active at the age of 2-3 years (Sunquist, 1983) and only acquiring a home range when they start breeding (Sunquist & Sunquist, 2002).

In India, leopard densities are highest inside protected areas, e.g. with a density estimate of 14.99 leopards/100 km^2 in the Chilla range of Rajaji National Park (Harihar et al., 2009) and of 23.5 leopards/100 km^2 in the Sariska Tiger Reserve (Chauhan et al., 2005).

Leopard home range sizes vary greatly throughout their distributional range and depend mostly on prey availability (Simcharoen et al., 2008; Odden et al., 2010). In sub-Saharan Africa, home range sizes of 15-16 km^2 have been reported in prey rich areas but could cover up to 2,182 km^2 in areas with very low prey densities (Bailey, 1993; Bothma & Le Riche, 1984). The home ranges of three leopards in subtropical forest of Bardia National Park was estimated using radio-telemetry techniques and was found to be 47.4 km^2 for two males and 16.9 km^2 for one female (Odden & Wegge, 2005). Home range size also depends on the reproductive status of the female. The smallest home ranges have been reported for female leopards having cubs of less than 6 months old (Odden & Wegge, 2005).

1.1.5 Tiger-leopard interactions

Tigers and leopards are sympatric, normally inhabiting the same habitat with a substantial overlap in the prey species they catch (Seidensticker, 1976; Lovari et al., 2015). Tigers prefer habitats with more grassland and higher landscape connectivity compared to leopards (Carter et al., 2012). The size of the prey they kill, does differ however, (Seidensticker, 1976), with leopards generally focusing their foraging efforts on the prey items that are too small for tigers (Odden et al., 2010). Tigers are mostly ground-dwelling while leopards also frequently use trees as a resting, feeding or venturing point (Seidensticker, 1976). Interspecies competition between tigers and leopards where they occupy the same habitat, can lead to the displacement of leopards (Odden & Wegge, 2005; Harihar, et al., 2011; Mondal et al., 2012). Leopards are generally less active when tigers are around, both during the day and night (Sunquist, 1981). Tigers are more susceptible to heat than leopards and tend to be more active during early mornings, when it is cooler. Leopards do not avoid activity during the day, but generally become more active after sunset (Seidensticker, 1976). When there is sufficient prey to sustain both tigers and leopards in a certain area, they can co-exist, provided that competitive interactions are limited through spatial and/or temporal partitioning (Lovari et al., 2015). Although there are several studies covering interactions between sympatric tigers and leopards, only few study cover the impact of such interactions on human-wildlife conflicts (Bhattarai & Kindlmann, 2012). In general, tigers prefer less disturbed areas located further away from human settlements, while leopards seem to be more resilient to disturbances; in some areas (e.g. Maharashtra in India) leopards are surviving despite spending a considerable part of their daily activities inside or around human settlements (Athreya et al., 2013).

Nevertheless, whenever both species are ranging in close proximity to local human communities and their livestock the risks of conflicts arising from this are higher (Harihar et al., 2011). Such inter-species dynamics thus not only influence population numbers of the interacting species, they could alsoplay a significant role in the onset of conflicts with humans.

In a study carried out over a period of four years in the Chilla range of Rajaji National Park, India, increasing numbers of tigers (from 3.31 per 100 km^2 to 5.81 per 100 km^2; Harihar et al., 2011) not only caused the leopard population to decrease (from 9.76 per 100 km^2 to 2.07 per 100 km^2), it also initiated a shift in diet of leopards towards more domestic prey (from 6.8% to 31.8%) and towards smaller prey (from 9% to 36%) (Harihar et al., 2011).

Figure 1.3 shows different types of interactions in a protected area of a human dominated landscape. In order to better understand the extent to which interactions between tigers and leopards are causing conflict situations, we will be taking a broad set of independent factors into consideration.

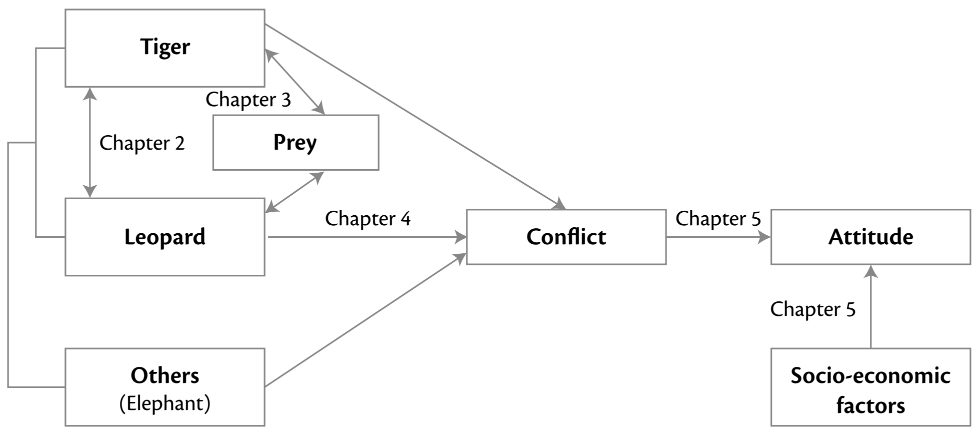

Figure 1.3
Conceptual research framework describing the conflict situation in Bardia National Park.

1.2 Research aims and objectives

1.2.1 Research aims

The overall aim of my research is to investigate and analyze to what extent interactions between sympatric tigers and leopards contribute to conflicts with humans. I chose the Bardia National Park and its surroundings as my study area, since preliminary results there suggest that tiger numbers are increasing as a result of recent conservation efforts (Dhakal et al., 2014). With respect to interactions with humans I expect to find similar results as in Chitwan National Park, where conflicts increased in response to a rise in tiger numbers.

1.2.2 Objectives

The specific objectives are:

1. To determine the spatial and temporal overlap in the activity of tigers and leopards.
2. To assess the diet composition and prey preferences of tigers and leopards.
3. To assess spatial and temporal patterns in conflict incidences around Bardia National Park.
4. To examine the perception and attitudes of local communities towards conservation in general and towards big wild cats in particular, and the implications thereof for the long-term conservation of tigers and leopards.

1.2.3 Research Questions

This study seeks to answer the following questions:

1. To what extent do activity patterns of tigers and leopards overlap in space and time?
2. What type of prey do tigers and leopards prefer, and is this related to conflicts with humans?
3. Do human-wildlife interactions around Bardia National Park change in space and time?
   - **a** What wildlife species are causing conflicts?
   - **b** How much money is spent on compensation schemes (compensation paid on real price)?
   - **c** What is the perception of local communities on how to manage the conflict situation?
4. How can risks of predatory attacks around protected areas be defined and what are the implications for their conservation status?

1.3 Study area

1.3.1 Nepal

Nepal is a landlocked country that lies between 80°4’ to 88°12’ East longitude and 26°22’ to 30°27’ North latitude, surrounded by the two most densely populated countries of the world: India (along the Eastern, Western and Southern border) and China (along the Northern border). Covering 147,181 km^2, Nepal is located in the central Himalayan region. It extends roughly 885 km from East to West and between 145-241 km from North to South. The climate varies with topography and altitude to include tropical, mesothermal, microthermal, taiga and tundra types of climate. The extensive altitudinal range (70-8,848m) is the main contributing factor to the great variety of habitats and the very rich biodiversity, all within a relatively short horizontal range of about 200 km (Acharya et al., 2016). Nepal includes twenty protected areas, largely situated in the Terai region and high Himalayas (Figure 1.4).

Figure 1.4
Protected areas of Nepal (DNPWC, 2017).

1.3.2 Bardia National Park

Bardia National Park (IUCN, Category II) is located in the South-western part of Nepal (N: 28.2630 to 28.6711; E: 80.1360 to 81.7645), in Province 5. It is the largest park in the lowland Terai, covering an area of 968 km^2. The park was originally established as a hunting reserve in 1969. In 1976 an area of 368 km^2 was officially named the Royal Karnali Wildlife Reserve and renamed in 1982 as Bardia Wildlife Reserve. In 1984 the park was expanded to the current size with the inclusion of Babai valley. Finally, the park was upgraded to the status of National Park in 1998 (Brown, 1998). The park consists of two distinct units: the Karnali flood plain and the Babai valley. The Karnali flood plain covers the western side of the park and is rich in biodiversity, whereas Babai valley is a wilderness zone comprised of alluvial grassland and forests, covering more than 50% of the park (Chanchani et al., 2014). The Bardia National Park is part of the Terai Arc Landscape (TAL), one of the most important landscapes for tiger conservation, and was recognized as such in 2001 when it was designated as the number one tiger conservation unit by the Government of Nepal and WWF Nepal (Wikramanayake et al., 2004). The park was however identified as a poaching hot spot, when DNA forensic analysis from seized tiger parts revealed that six out of fifteen tiger parts originated from the Bardia tiger population (Karmacharya et al., 2018).

Bardia National Park is home to several flagship species, including tiger and leopard but also Asian elephant and Indian rhinoceros. It has been estimated that the tiger population of Bardia has increased from 18 in 2009 to 87 in 2018. The current prey base of Bardia is suggested to be sufficiently large to support a population of 100 tigers, assuming 10% removal per year (Karki et al., 2016). The current estimated population of 87 tigers in Bardia is therefore expected to grow, provided that other conditions for their survival remain optimal. Although information on leopard population dynamics for Bardia are lacking, other studies in similar habitat suggest that leopards occur at densities of approximately 14.99 individuals/km^2 (Harihar et al., 2009). Studies in other protected areas also showed that when both tigers and leopards share the same habitat, leopards are often displaced to the fringe of the protected area (Harihar et al., 2011; Mondal et al., 2012). Whether this is also the case for Bardia National Park, where prey is generally abundant, is part of the main objectives of the present research. I have chosen Bardia National Park for this study because the numbers of tigers are increasing as a result of implementation of better management practices.

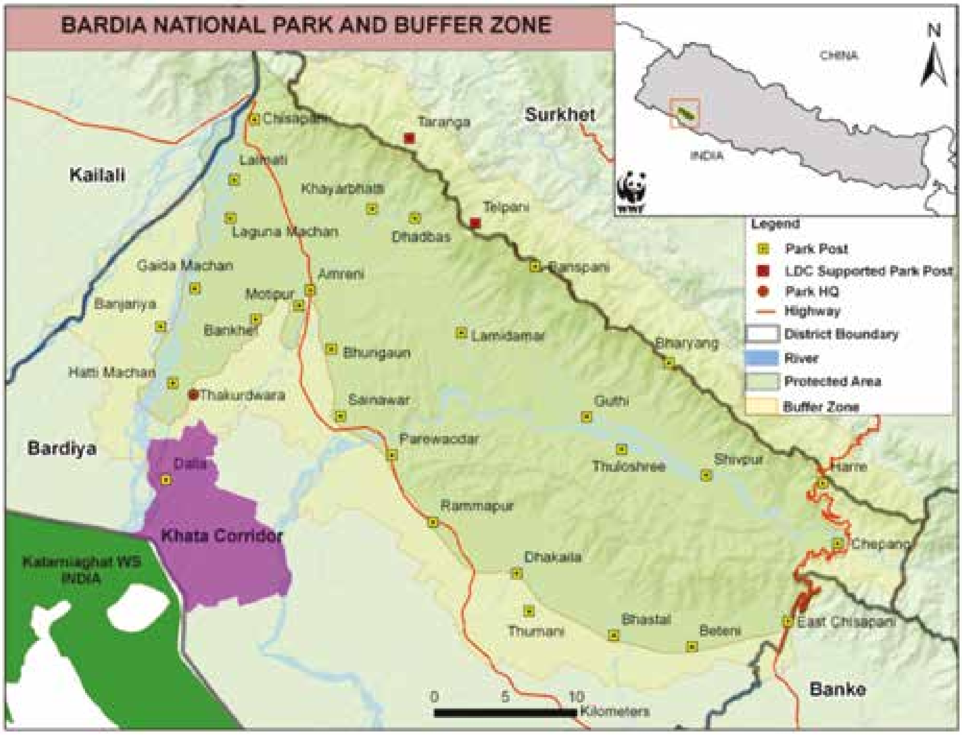

Figure 1.5
Bardia National Park showing the buffer zone and the Khata corridor (source: wwfnepal.org).

1.3.3 Geomorphology and climate

The park consists of three ecological zones, on the southern flank of the Himalayas: *siwalik* hills, *bhabhar* zone and the Terai plains (Shrestha, 2004). The *siwalik* hills are an uplifted ridge system formed from the debris brought down from the main Himalayas and runs along the base of the Himalayas. It is composed of coarsely bedded stone, crystalline rocks, clays and conglomerates. The soils are young and very shallow and exposed to greater erosion levels (Bhattarai, 2009). The *bhabar* is formed by the deposit of coarse material brought down by the Himalayan rivers along the foothills of Siwalik. The *bhabar* is characterized by a low ground water table because the deposits are primarily boulders which make them porous. This zone is not suitable for agriculture and is characterized by large tracts of forests (Bhattarai, 2009). The *Terai* plains, which are situated South of bhabar, hold a river basin and consists of fine alluvial soil with a high ground water table (Shrestha, 2004).

The climate of Bardia National Park is subtropical monsoonal, with rain from June to early October, a cool dry season from late October to late February and a hot and dry season from March to mid- June. The temperature ranges from 10°C in January to 41°C in May, with an average rainfall of 1500mm (Dinerstein, 1979). The altitude of the park ranges from 152m to 1441m above sea level (Dinerstein, 1979).

1.3.4 Flora and fauna of Bardia

Seven major vegetation types have been identified in Bardia National Park, four of which are forests and three are grasslands. The forest vegetation types include: Sal forest, Khair-Sisso forest, Riverine forest and Hardwood forest (Dinerstein, 1979). The grasslands include: Wooded grassland, *Phanta* and Tall floodplain grassland (Dinerstein, 1979). The *Phanta* (grassland) of Bardia includes: Baghaura, Khauraha, Lamkauli, Sanoshree, Thuloshree, Chepang and Guthi (Chanchani et al., 2014). About 70% of the forest consists of Sal forest, with a mixture of riverine forest and grassland (DNPWC, 2018).

More than 30 different mammals and 230 species of birds have been recorded in the park (DNPWC, 2018), among which are the iconic, endangered tiger, Asian elephant, Indian rhinoceros, swamp deer and black buck (*Antilope cervicarpa*). Species that have been identified in the park as major prey species for tigers and leopards include chital (*Axis axis*) which is the most abundant medium-sized prey, followed by hog deer (*Axis pornicus*), muntjac (*Muntaicus muntjak*) and wild boar (*Sus scrofa*) (Wegge et al., 2009). The larger species of prey ungulates include barasingha (*Cervus duvauceli*), nilgai (*Boselaphus tragocamelus*) and sambar (*Cervus unicolor*) which are present in lower densities (Wegge et al., 2009). The tiger prey base density in Bardia National Park was estimated at 92.6 animals/km^2, which is the highest in Nepal as compared to other national parks (Dhakal et al., 2014).

1.3.5 The buffer zone of Bardia National Park

The buffer zone of Bardia National Park was established in 1996 with an area of 327 km^2, which was later on extended by adding 180 km^2 of the Surkhet district, finally expanding its surface area to 507 km^2 in 2010. It now includes forest patches, agricultural land, river and water bodies, settlements, a cultural heritage village and other forms of land use (Budathoki, 2003). The buffer zone provides benefits to both villagers and wildlife: villagers harvest forest products from the buffer zone community forests and wildlife uses it as extended habitat, as a refuge, and as a movement corridor (Budathoki, 2004). The buffer zone encompasses three districts: Bardia, Banke and Surkhet (DNPWC, 2018). Approximately 30 to 50% of the revenue generated by the protected area is invested in local communities residing in the buffer zone (Baral & Heinen, 2007). These investments are intended to support conservation and alternative livelihood activities, and are based on the priorities that have been established through an approved management plan (Heinen & Mehta, 2000; Baral & Heinen, 2007).

1.4 Structure of the thesis

This PhD dissertation is based on articles and is divided into six chapters. The individual chapters two to five are either published or in the process of publication in scientific journals. References of all the chapters are grouped together and presented at the end of the thesis.

Chapter one mainly focuses on the theoretical background of my study, stressing the need to fill theoretical gaps. The literature review in the introduction provides a basis for the description of the aim of my study and my research questions, which are followed by a description of the study area.

Chapter two mainly focuses on spatial and temporal interactions between leopards and tigers. Camera trap data from 2013 and 2016 are used to study the level of interaction between the two species. The 'overlap' package is used to determine temporal overlap between the two species. This article is currently under review in the Journal of Tropical Ecology.

Chapter three describes the diet and prey preference of male and female tigers. DNA analyses were performed to confirm the individual's species and sex. Microscopic hair analysis of prey species was done to determine the prey species that had been consumed. This study has been published as journal article in Tropical Conservation Science, 2018, Vol 11, DOI: 10.1177/1940082918799476.

Chapter four describes the spatial and temporal patterns of human-wildlife conflicts in Bardia National Park over a period of five years. We looked at variations in conflict incidence over time and in relation to moon phase. We also studied spatial patterns of conflict in different sub-regions of the buffer zone. This article is submitted to the Journal of Wildlife Management.

Chapter five provides an overview of the probabilities of livestock loss using a general linear model. The perceptions and attitudes of people living in the different sectors of the buffer zone of Bardia National Park are investigated by means of a questionnaire survey. This article is accepted for publication in the journal Oryx (13 November, 2018).

Chapter six covers the synthesis and integrates all chapters of this study. It also formulates strategies and suggestions for the successful management of co-existing tigers and leopards, and general recommendations for managing the human-wildlife conflict in the region as a whole, and for Bardia National Park specifically.