Pavel Kindlmann *Editor*

Snow Leopards in Nepal

Predator-Prey System on the Top of the World

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Preface

Snow leopard belongs to the genus *Panthera*, lives mainly in montane habitats in central Asia and is a flagship species of high altitude ecosystems. In order to survive there, it has evolved adaptations for living at low temperatures and hunting on steep slopes at high altitudes. Its prey consists mainly of ungulates, particularly blue sheep and Himalayan tahr. Many other predators, however, compete with snow leopard: wolf, brown bear, lynx, fox, and also vultures and various raptors, and at the periphery of its range, it competes with the slightly larger common leopard.

Snow leopard was listed as endangered in 1972, and international leopard trade was banned in 1975. Published estimates of its abundance range from 3000 to 8000 individuals, with over half of them in China. No more precise estimates exist because of lack of empirical data on its abundance, due to its cryptic behaviour and the inaccessibility of its habitats. For the same reason, there are no long-term studies of populations, lasting a decade or more, which are necessary for measuring its dynamics and/or birth and death rates. Recent research on snow leopards has been fragmentary and usually brief, lasting a few weeks or months. The first long-term study was that of Jackson et al. in 1982, who carried out a 3.5-year study in Nepal using radio telemetry. This research was followed by McCarthy's study in the 1990s and the South Gobi programme undertaken by the *Panthera* and Snow Leopard Trust, using GPS satellite collars, during 2008–2013. In recent years, camera traps have provided good data on population size and density of snow leopard. Despite all these efforts, however, we still have too little information for ensuring the future survival of snow leopard. With climate change, the situation may become even worse, as a considerable amount of snow leopard habitat may be lost due to an upward shift of the tree line and subsequent reduction in the alpine zone.

Given the attractiveness of snow leopard, it is not surprising that there are many books on this iconic animal. For example, a search for books in amazon.com gave over 4000 results for "snow leopard"! Most of these books are very popular, intended for children or present just photographs. A famous exception is Matthiessen's book (P. Matthiessen, 1978. The Snow Leopard, Viking Press, New York). Very recently, a comprehensive and purely scientific book covering all aspects of the life of snow leopard appeared, edited by McCarthy and Mallon (T. McCarthy and D. Mallon,

2016. Snow Leopards, Elsevier/Academic Press, Amsterdam, London, New York). The existence of this all-encompassing compendium might indicate that no more books on snow leopard are needed.

However, when thinking about publishing this book, we were influenced by the considerable amount of unpublished data collected by the co-author of most of the chapters, Bikram Shrestha, which might be useful for other researchers working on snow leopard. In addition, researchers might find it useful to have a key for determining the diet of snow leopard based on remnants of its food in its scats. Last, but not least, based on the difficulty we experienced trying to compare and combine different sets of results, we propose a general methodology for collecting data. Thus, this book is not an all-encompassing compendium, but is an attempt to fill some gaps in the literature and to show how to publish new data in a useful and workable way.

In the introductory chapter, we present facts about snow leopard: general description, ecology and typical habitats, followed by its distribution in the world. We then enumerate the main threats to the survival of this animal: conflicts with people, illegal trade and climate change. This chapter concludes with a description of possible ways of conserving this endangered species: changes in legislation, international cooperation, education and awareness and financial support for its conservation.

Nepal is widely acknowledged as the first country to effectively involve mountain communities in snow leopard conservation. The most important habitats for snow leopard in the world are in Nepal and studies on this predator began there much earlier than elsewhere, but the results are scattered in the literature. In contrast to Chap. 1, which concentrates on global aspects, Chap. 2 summarizes different aspects of snow leopard biology, ecology, threats to their survival and conservation with a particular emphasis on Nepal.

The secretive lifestyle of snow leopard makes it difficult to optimize conservation strategies, for which it is necessary to know its distribution within an area and relative abundance in different habitats. For those who wish to obtain such data, it is important to know which method is the most appropriate in his/her case. To facilitate this, we provide in Chap. 3 an account of the methods used for estimating snow leopard abundance. The most frequently used methods include searching for signs of their presence (usually scrapes), genetic analyses and now most often camera traps. No photograph of a wild snow leopard existed until 1980, but now camera traps are available and have replaced direct capturing of an animal, which is almost impossible because they are very rarely encountered.

On many occasions, it is important to know the diet of snow leopard in a region, as it helps us to understand its effect on its local wild and domestic species of prey. However, the secretive style of life of snow leopard makes observing their hunting and feeding behaviour difficult. It is possible, however, to determine its diet by identifying the hair in its scats. This is difficult for an unskilled person and no easy-to-use key for its identification existed. Chapter 4 introduces the reader to the methodology and provides a key for identifying the hair of their prey, which is not digested by snow leopard and is present in their scats.

There is a complete lack of predictive models of snow leopard population dynamics. In Chap. 5, a large set of previously unpublished empirical data is presented and used to highlight the serious problems encountered when attempting to use such data to model snow leopard population dynamics. Some rules are proposed at the end of this chapter, which should be followed in each project in order to prevent waste of time and money by collecting incompatible data, which cannot be used for such an analysis. Some common rules are outlined, which should be agreed on, in order to make the data compatible.

Habitat suitability models based on particular environmental variables are increasingly being used to predict the occurrence of species in wildlife management. A variety of techniques and statistical methods are used in species distribution modelling. In Chap. 6, we use MaxEnt and data on the distribution of snow leopard in Nepal based on a large set of occurrence data (camera traps, scats, monitoring of fresh pugmarks and scrapes), collected from a much wider range of areas than in previous studies. We show that altitude and annual mean temperature are important common factors contributing to snow leopard habitat suitability within the area studied. Some other possible factors include distance from roads and precipitation in the driest month. We conclude that according to habitat suitability models, the main danger for snow leopard survival may be climate change and human population pressure.

In Chap. 7, the distribution and population size of snow leopards are based on the genetic identification of their scats. Noninvasive genetic sampling and molecular scatology are emerging and promising scientific techniques for such studies. Their benefit is that the target species does not have to be directly observed or handled, as the most commonly used samples in genetic analyses are their hairs and scats. As collecting samples of scat of a focal species in the field is subject to a high degree of misidentification, it is important that DNA extracted from samples of scat must be genetically analysed.

Snow leopard is threatened particularly by habitat loss, reduction in the availability of prey, conflict with herders and poaching in connection with traditional Asian medicine. Understanding the dynamics of snow leopard–human conflicts and the perceptions of local people of the threats posed by snow leopards is important for gaining local support for mitigating the effects of conflicts. Chapter 8 therefore presents an assessment of the knowledge and perception of local people of livestock losses due to snow leopards in the Central and Northeastern Himalayas in Nepal. Based on an extensive data set, it is concluded that the snow leopard–human conflict still presents a major threat to the long-term survival of snow leopards and its natural prey in the areas studied. Mitigation measures identified during discussions with local people should be applied to create a win-win situation for both local people and the long-term survival of snow leopards.

Chapter 9 describes the areas used for monitoring of snow leopards and their prey and the snow leopard–human conflict study. They are as follows: Lower Mustang, Upper Mustang, Upper Manang, Tsum Valley (Chhekampar VDC) and Sagarmatha National Park. The first three are parts of the Annapurna Conservation Area (ACA), and Tsum Valley is a part of the Manaslu Conservation Area. In this chapter, each of these areas is described and the core areas for snow leopard within them defined.

Chapters 1 and 3 are adapted from Valentová KA (2017) Abundance and threats to the survival of the snow leopard—a review. Eur. J. Environ. Sci. 7: 73–93.

If this book results in improvements in the conservation management and survival of snow leopard, then the time devoted to writing it was well spent.

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Pavel Kindlmann

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Bikram Shrestha took the following photographs: Figs. 4.6–4.20, 5.1–5.12, 6.2–6.8 and 8.5 and Maan Rokaya those in Figs. 2.2– 2.4.

Contents

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Chapter 1
Distribution, Threats and Conservation of Snow Leopard Throughout the World

Kamila Anna Valentová, Bikram Shrestha, Maan B. Rokaya,
and Pavel Kindlmann

Abstract In this introductory chapter, we present facts about snow leopard. We start with a general description of snow leopard, its ecology and typical habitats in Sect. 1.1. Details on snow leopard distribution in the world follow in Sect. 1.2. We then enumerate the main threats to this animal, which include conflicts with people, illegal trade and climate change in Sect. 1.3. The last part, Sect. 1.4, is devoted to possible ways of conserving this endangered species: changes in legislation, international cooperation, education and awareness and financial support for its conservation. The chapter is adapted from Valentová KA (2017) Abundance and threats to the survival of the snow leopard—a review. Eur. J. Environ. Sci. 7: 73–93.

1.1 Introduction

1.1.1 Nomenclature, Description and Conservation Status

The main synonym of snow leopard, *Panthera uncia* Schreber is *Uncia uncia.* Basic information about this species is summarized in Box 1.1.

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Snow leopard is a member of the genus *Panthera* in the family Felidae and most closely related to tigers, *Panthera tigris* Linnaeus (Jackson et al. 2008). However, the phylogenetic analysis for *P. uncia* and other related species indicate that *P. uncia* and *Panthera leo* Linnaeus are sister species, which is different from previous findings. The structural characteristics of the *P. uncia* mitochondrial genome are similar to those of *Felis catus* Linnaeus, *Acinonyx jubatus* Schreber, *Neofelis nebulosi* Griffith (Wei et al. 2008).

Panthera uncia was first systematically described by Schreber (1775). Later, it was studied and described in detail by Hemmer (1972) in Sikkim, in the eastern Himalayan region under the name *U. uncia*, and different subspecies of snow leopard, *Panthera uncia uncia*, was described from Siberia (Stroganov 1962), *P. uncia uncioides* Horsfield 1855 from Nepal (Horsfield 1855), *P. uncia schneideri* from Sikkim, India (Zukowsky 1950) and *P. uncia baikalensis-romanii* Medvedev 2000 from Transbaikal, Russia (Medvedev 2000). All these descriptions are based on coat colour. However, recently three separate subspecies were confirmed using genetic analyses. They are *P. uncia uncioides*, which occurs in northern Qinghai, southern Qinghai, Himalayas (Bhutan, Nepal and Tibet), *P. uncia uncia* in western India, Pakistan, Tajikistan and Kyrgyzstan and *P. uncia irbis* in western and southern Mongolia (Janecka et al. 2017). According to Janecka et al. (2017), the species in Nepal is *P. uncia uncioides*.

The genus name, *Uncia*, is derived from the old French word *Once*, which was used for the European lynx. The snow leopard is still occasionally called Ounce. Origin of the name "*Panthera*" is unknown, but according to the Greek πάν pan ("all") and thēr (beast of prey) it means the animal that can hunt and kill all animals. This probably originates from the Sanskrit word "the yellowish" or "whitish-yellow animal".

Box 1.1 Basic Information

Scientific name: *Panthera uncia uncioides* Horsfield 1855.

Synonyms: *Felis uncia* Schreber, 1775; *Uncia uncia* Schreber, 1775.

Common name: Snow leopard.

Other names: Snow leopard, ounce (English), barfānī chītā" (Hindi, Urdu), bars or barys (Kazakh, Him Chituwa, Hiuchituwa (Nepali), him tendua (Sanskrit, Hindi), ilbirs (Kyrgyz), irves (Mongolian), Léopard des neiges, once, Panthère des neiges (French), palang-e barfi (Dari), Pantera de la Nieves (Spanish), shan (Ladakhi), wāwrīn pṛāng (Pashto), zigsa (Tibetan) and sněžný levhart (Czech).

Status: Vulnerable C1 Ver. 3.1 (2017), CITES Appendix I, National Parks and Wildlife Conservation Act 1973 in Nepal.

Size: 0.55–0.65 m tall, 0.9–1.15 m long from head to rump with a 0.78–1 m long tail, and weighs up to 39–74 kg, sometimes large males reach 75 kg and small females may be less than 25 kg.

Population: About 4000 individuals globally of which 2700–3400 are mature and 300–500 are in Nepal.

Life cycle: Mating season is between January and mid-March, when males and females are observed together for a few days for copulation. After that the females become pregnant, which lasts for 93–110 days, with the cubs born in June or July. Mother alone cares for the cubs, providing them with both food and shelter.

Life span: 10–20 years.

Distribution: Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan, Uzbekistan and northern Myanmar. They usually occur at altitudes between 500 and 5800 m. In the Himalayan region, they occur at altitudes between 3000 and 5800 m, whereas in Russia and Mongolia they occur at low altitudes. The occupied range is estimated to be about 2.8 million km^2.

Habit: They are shy, elusive and known for their solitary nature. They are active at dawn and dusk and most active during the mating period in winter.

Habitat: Snow leopards prefer terrains with cliffs, rocky outcrops and ravines. They travel along ridge lines and around the bases of cliffs and choose bedding sites with good views over the surrounding terrain. The climate in their habitat is generally cold and dry and most of the land is barren with sparse grass and small shrubs. The cubs become independent of their mothers 18–22 months after birth.

Sources: Oli (1997), Li et al. (2013a), McCarthy et al. (2016), Anonymous (2017), Janecka et al. (2017), McCarthy et al. (2017)

Snow leopard is whitish-grey (tinged with yellow), and patterned with dark grey rosettes and spots (McCarthy and Chapron 2003). Unlike other big cats, it has underdeveloped fibro-elastic tissue in its vocal apparatus (Rajput 2009), so it is not able to roar. In general, snow leopards live solitarily, though small groups of up to six snow leopards are reported (McCarthy and Chapron 2003).

In the 1972 IUCN's Red List of Threatened Animals it is listed as an "endangered" species (EN) due to its small population worldwide. In 2017, its categorization was changed to "vulnerable". This down-listing in the IUCN Red List is not a serious demotion, as it is still endangered and in need of wide-range population monitoring and conservation (Mallon and Jackson 2017). Snow leopard is also included in Appendix I of CITES (McCarthy et al. 2017).

1.1.2 Snow Leopard Reproduction and Diet

Mating occurs in winter and spring (January–April), during which they make loud noises, probably to attract each other (Jackson and Ahlborn 1988; Jackson 1996).

As previously reported in different parts of the world, 2–3 cubs (rarely less or more) are born in April-June after a pregnancy lasting 90–105 days (Rieger 1984).

Snow leopards are carnivores and depend on different kinds of animals, mostly wild but also domestic animals (Shehzad et al. 2012; Wegge et al. 2012; Lyngdoh et al. 2014; Chetri et al. 2017; Shrestha et al. 2018; Lu et al. 2019). One snow leopard can eat up to about 20–30 adult blue sheep annually (Jackson et al. 2008). Snow leopards are opportunistic nocturnal predators that are most active at dawn and dusk. Normally, they are not aggressive, but will become so, when they or their cubs are threatened. They are powerful hunters and a 20 kg snow leopard can kill a fully grown male bharal/nayur weighing over 55 kg (Jackson and Hillard 1986; Jackson and Ahlborn 1988). A study in Tajikistan shows that 10 snow leopards require a biomass equivalent of 57 ibex or 30 argali or mountain sheep (*Ovis ammon* Linnaeus) per year (Weiskopf et al. 2016). Unfortunately, for a large part of the distribution of snow leopards there are no accurate estimates of prey abundance (Schaller 1977; Oli et al. 1993). Thus, a quantitative analysis of snow leopard diet is needed, which will distinguish not only the species, but also the size and age of the prey eaten: calves, young animals, healthy or ill adults (Shrestha et al. 2018).

A detailed analysis of snow leopard diet in Nepal in terms of the species of prey preferred and seasonal variation in their diet is presented in Sect. 2.4.

1.2 Worldwide Distribution of Snow Leopard

1.2.1 Distribution in the World

Snow leopards are restricted to subalpine regions in South and Central Asia in 12 countries (Fig. 1.1): China, Bhutan, Nepal, India, Pakistan, Afghanistan, Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan, Russia and Mongolia (McCarthy and Chapron 2003).

The alternative range-wide model proposed by McCarthy and Chapron (2003) predicts that its area of distribution is potentially larger: 3,024,728 km^2. Its results are presented in Fig. 1.2. Blue coloured areas are “good” sites with more than 30-degree slopes outside areas subject to human disturbance. Grey coloured areas are “fair” sites of unknown slope or less than 30 degrees or inside areas subject to human disturbance. The 109 protected areas with a total size of 276,123 km^2, identified by Green and Zhimbiev (1997), are marked in red in Fig. 1.2. Population densities of snow leopard in “good” areas are greater because they are known to have strong preference for slopes in excess of 40° (McCarthy and Chapron 2003). However, this may be an overestimate, because the range-wide model only uses the geographic habitat and neglects other parameters such as competition, distribution of prey and grazing pressure (McCarthy and Chapron 2003).

The main habitat of snow leopard consists of alpine and sub-alpine regions (mostly 3000–5000 m) in the Himalayas. Their habitat is in terrain that is rugged and steep,

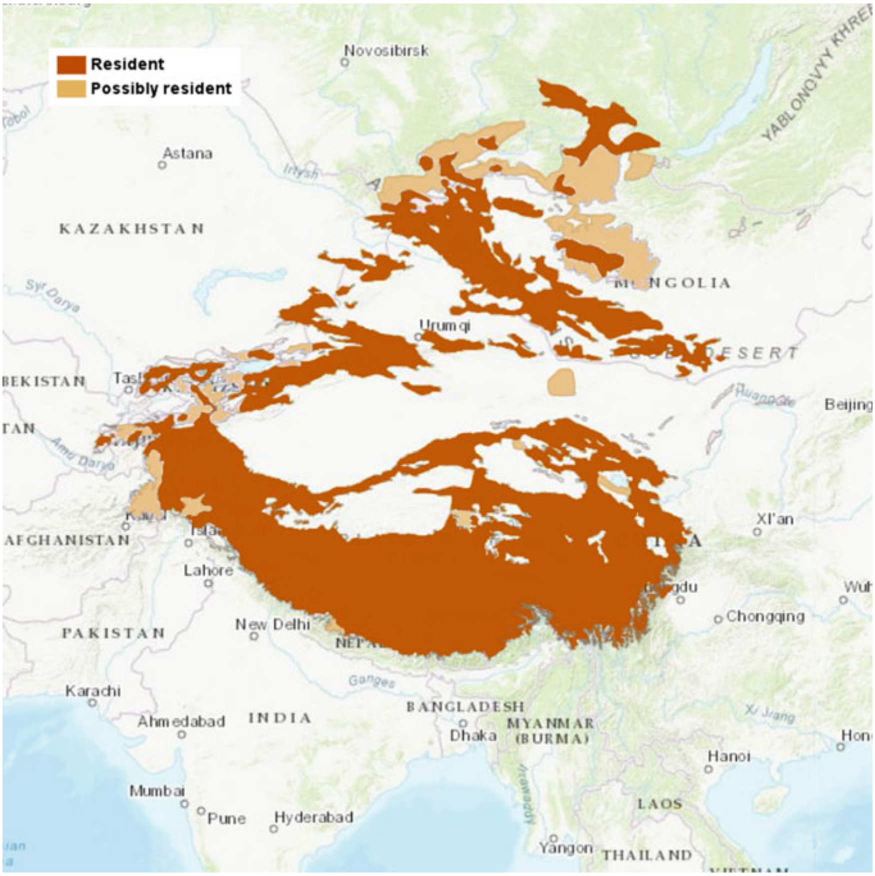

Fig. 1.1 Map showing the extent of the distribution of snow leopards. *Source* https://upload.wikimedia.org/wikipedia/commons/7/7b/SnowLeopard_distribution.jpg

separated by ridges, cliffs, rocky outcrops and gullies (Schaller 1977; Jackson and Ahlborn 1989; Ale et al. 2014)—see also Sect. 2.3.3 for its typical habitat in Nepal. Nevertheless, it occurs even on flat and rolling terrain in Tibet and Mongolia, wherever there is ample cover in which they can hide (McCarthy 2000; Jackson et al. 2008). Thus, at the northern limits of its range it occurs at much lower altitudes: 900–2500 m (McCarthy and Chapron 2003).

Estimated areas of snow leopard habitat in km^2 and estimated populations and densities per country are listed in Table 1.1. From this table it follows that the largest populations of snow leopard are in China, Mongolia, Nepal, Pakistan, Kyrgyzstan and India. The greatest population density of snow leopards is in Bhutan, Nepal, China and Kyrgyzstan. Although the area of snow leopard habitat in Bhutan is the lowest, nevertheless the population density of snow leopards there is the highest.

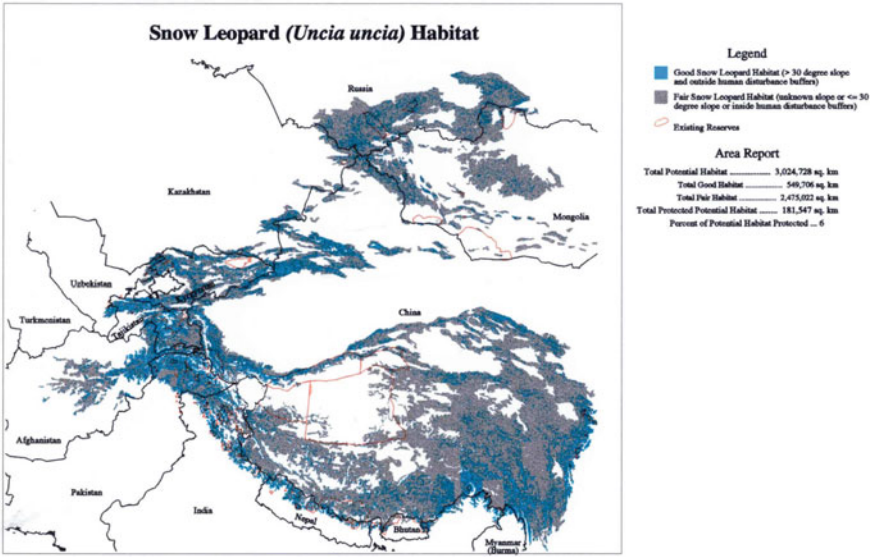

Fig. 1.2 Predicted potential extent of snow leopard habitat. *Source* McCarthy and Chapron 2003, https://globalsnowleopard.org/

Table 1.1 Area of habitat and estimates of abundance and population density of snow leopards listed by countries

Locality	Area of habitat (km^2)	Abundance	Population density (individuals/area)
China	1,100,000	2000–2500	1.4–3.29/100 km^2
Mongolia	103,000	500–1000	> 1–1.1/100 km^2
Nepal	13,000	301–400	1.5–3.2/100 km^2
India	100,000	400–700	0.21–1.03/100 km^2
Pakistan	80,000	300–420	1/250 km^2 $\doteq$ 0.4/100 km^2
Tajikistan	85,700	250–280	unknown
Kazakhstan	50,000	100–120	unknown
Kyrgyzstan	105,000	350–400	2.35/100 km^2
Russia	30,000	70–90	unknown
Bhutan	10,000	100–200	2.39–3.36/100 km^2
Afghanistan	52,000	50–200	unknown
Uzbekistan	10,000	80–120	unknown

Sources Fox (1994), McCarthy (2000), Hussain (2003), McCarthy and Chapron (2003), WWF-Nepal (2009), Biocontrol of Uzbekistan (2014), Snow Leopard Network (2014), McCarthy and Mallon (2016), WCNP and WWF (2016), Loginov and Loginova (2017), Liu et al. (2019)

There is an urgent need to determine the exact population density of snow leopards in Mongolia, Tajikistan, Kazakhstan, Russia, Afghanistan and Uzbekistan.

1.2.2 Distribution in Nepal, India and Bhutan

The population of snow leopards in **Nepal** is estimated to be 150–300 individuals (Jackson 1979; unpublished data). However, a computerized habitat suitability model (Jackson and Ahlborn 1990) predicts a population of about 350 to 500 animals in an area of approximately 30,000 km^2 (Jackson and Ahlborn 1990; unpublished data; McCarthy and Chapron 2003). The revised snow leopard population in 2009 is estimated as 301–400 individuals residing in ca. 13,000 km^2 (Table 1.1, WWF-Nepal 2009) and density is estimated at 1.5–3.2 animals/100 km^2 (Snow Leopard Network 2014). A comprehensive analysis of prey, habitat, distribution, home range and marks left by snow leopards in Nepal is presented in Chap. 2.

Estimated population size in **India** is about 400–700 individuals (Table 1.1, Snow Leopard Network 2014). However, the revised snow leopard population estimates are ca. 516 (238–1039) (McCarthy and Mallon 2016). Chundawat et al. (1988) and Fox et al. (1991) estimated 200–400. The snow leopard density for relatively poor and good quality habitats in Spiti were 0.21 snow leopard/100 km^2 and 1.03/100 km^2, respectively (Table 1.1).

Chundawat et al. (1988) suggest that Ladakh is a core area for snow leopards in India. Therefore, new parks and reserves are being established there (Fox et al. 1991). The only protected area where snow leopard density is known, is the Hemis National Park in the Ladakh region, located in the states of Jammu and Kashmir. Mallon and Bacha (1989) estimate that approximately 75–120 snow leopards live in an area of 1200 km^2. Jackson et al. (2006) report 66 and 49 capture events (capture success 8.9 and 5.6 per 100 trap-nights) in two consecutive years, 2003 and 2004, in the Hemis National Park.

Snow leopard may occur also in a number of other protected areas (Table 1.2), but its presence in many of them is uncertain (McCarthy and Chapron 2003). In the Khangchendzonga Biosphere Reserve in the eastern Himalayan region (Sikkim), where Sathyakumar et al. (2011) conducted the first survey to obtain basic information on abundance of mammals including snow leopard, they confirmed the presence of snow leopard based on photo capture, scat/dung, tracking and information from locals. Photo capture rate of snow leopard was lower than in the Hemis National Park (Sathyakumar et al. 2011). Sathyakumar et al. (2011) recommend that surveys are also carried out in other watersheds in the Khangchendzonga Biosphere Reserve. In India, it is necessary to search the whole area for signs and after that to conduct detailed studies.

In **Bhutan**, mainly along the northern high Himalayas and a small area in the east, camera trapping has confirmed the presence of about 100–200 snow leopards (Table 1.1, Snow Leopard Network 2014). The density of snow leopards is 2.39–3.36 individuals/100 km^2 in the Wangchuk Centennial Park (Table 1.1). The suitable

Table 1.2 Areas of habitat suitable for snow leopards in India

State	Protected areas where it is possible for snow leopard to occur in India
Himachal Pradesh state	Pin Valley National Park Khokhan Wildlife Sanctuary Rupi Bhaba Wildlife Sanctuary
Uttaranchal state	Nanda Devi National Park Yamunotri Wildlife Sanctuary
Arunachal Pradesh state	Dibang Valley
Sikkim state	Kanchenjunga National Park Dzongri Wildlife Sanctuary Tolung Wildlife Sanctuary
Jammu and Kashmir states	Hemis National Park Dachigam National Park Lungnag Wildlife Sanctuary and 9 others

habitats are above 3000 m in an area of about 15,000 km^2 (Fox 1994) and a more recent estimate is 10,000 km^2 (Snow Leopard Network 2014). Survey of signs suggests a lower occurrence of snow leopards in Jirgme Dorje National Park than in Shey Phoksundo National Park in Nepal, although there is a greater abundance of prey in the former (Jackson and Fox 1997; Jackson et al. 2000). Snow leopard presence has been confirmed in Toorsa Strict Nature Reserve, Jigme Dorje National Park and Wangchuk Centennial Park. Protected areas with potential habitats are Sakten Wildlife Sanctuary, Jigme Singye Wangchuk National Park and Bumdeling Wildlife Sanctuary.

1.2.3 Population and Distribution in China and the Former Soviet Union

In **China**, the largest country where snow leopard occurs, there is as much as 60% of its potential habitat (Fig. 1.2; Hunter and Jackson 1997; McCarthy and Chapron 2003). The total estimated area where snow leopards are present is 1,100,000 km^2 with approximately 2000–2500 individuals (Table 1.1, Fox 1994). According to the latest published data, the total potential habitat is 1,771,662 km^2 and population density fluctuation caused by the change in seasons ranges from 1.46 to 3.29/100 km^2 (Liu et al. 2019). Due to the patchy distribution of its prey, the mean density is comparable to that in other countries (Table 1.1, McCarthy and Chapron 2003).

Snow leopards occur in six provinces in China (Qinghai, Gansu, Sichuan, Yunnan, Xinjiang and Xizang or Tibet) and in the seventh (Inner Mongolia) it is nearly extinct (McCarthy and Chapron 2003). A review paper of literature published from 1950 to 2014 by Alexander et al. (2016a) cites a status survey based on a systematic sign survey, camera trapping and genetics at sites in Xinjiang, Sichuan, Xizang, Qinghai, Gansu and the Tien Shan mountains (Buzzard et al. 2017a, b). A metadata analysis of published and unpublished data from 1980 to 2018 (Liu et al. 2019) reports that there are density surveys for only a small fraction of snow leopard habitat (1.7%) in China. Areas with the highest priority for status surveys are the Nayainqentanglha, Taniantaweng and Ningjing Shan mountains in eastern and south-eastern Tibet, western Nepal, the mountains bordering Uttar Pradesh in India and the Nganlang Kangri mountains bordering Ladakh (McCarthy and Chapron 2003). Snow leopards are likely to occur on the northern slopes of the Himalayas close to the border with Nepal and on mountain ranges bisecting the Tibetan Plateau (McCarthy and Chapron 2003). Jackson et al. (1994) report up to 100 snow leopards in the Qomolangma Nature Preserve, a 33,910 km^2 area along the main Himalayan and Nepalese border, centred around Mt. Everest. In the area including the Sanjiangyuan National Nature Reserve (Qinghai Province), Qiangtang National Nature Reserve (TAR) and Nanshan area (Danghe, Gansu Province) 89 samples were identified as indicating snow leopard, which gives an estimate of the presence of 48 individuals there (Zhou et al. 2014).

In the Tomur National Nature Reserve (Fig. 1.3) in Xinjiang Autonomous Region there have been 20 SLIMS sign surveys (McCarthy et al. 2008). Based on counts of the prey of snow leopards, ibex and argali, the potential density was estimated to be 1.1 snow leopards/100 km^2 (McCarthy et. al. 2008). Photo-capture rates at Tomur were 2.37 photos/100 trap-nights. The photo capture-recapture method provides estimates of about 6 snow leopards occurring in Tomur, whereas genetic analyses indicate at least 9 individuals (McCarthy et al. 2008). Home range of snow leopard in the Qinghai Province is highly fragmented (Liao 1994). Zhang et al. (2009) report 11, 5 and 5 snow leopards, based on genetic analyses in Zongjia Township (ZJ) and Nuomuhong Township (NMH) in Dulan County, and Suojia Township (SJ) in Zhiduo County, respectively.

Apart from these areas, Schaller et al. (1988) report three "hotspots" in Qinghai Province: North Zadoi, South Zadoi and Yushe, where the population density of snow

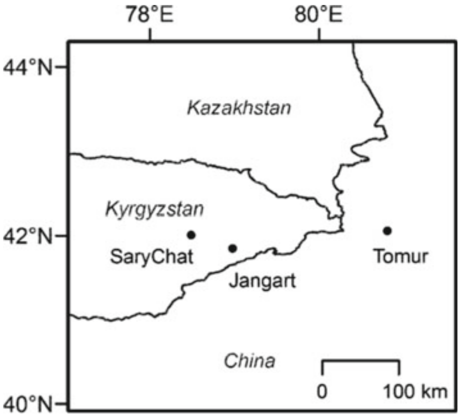

Fig. 1.3 Map of the area in the Tien Shan Mountains in Kyrgyzstan and China showing the locations of 3 snow leopard camera capture-recapture study sites in 2005: Sary Chat, Jangart and Tomur. *Source* McCarthy et al. (2008)

leopard is estimated to be 1 individual per 25–35 km^2. In adjacent Gansu Province northeast from Qinghai Province, 17–19 individuals were identified using the camera capture-recapture method. In total, 251 snow leopard captures were recorded over 7133 trap-days, which is higher than the average number of captures recorded in Tomur (China), Sary Char and Jangart in Kyrgystan (Alexander et al. 2016b).

The Gouli Region (Fig. 1.4), in Qinghai Province, is one of the core zones of snow leopard in China. Sign surveys conducted there along transects of total length of approximately 440 km, recorded 72 signs and 60 snow leopard scrapes (Xu et al. 2008). As mentioned before, there is no information on the abundance of snow leopards in China and the results of the few studies carried out there are not consistent with those for other countries.

Before the dissolution of the USSR (1990) the population of snow leopards there was between 1000 and 2000 individuals (Braden 1982; Bannikov 1984), most of which (75%) were in Kyrgyzstan and Tajikistan (Koshkarev and Vyrypaev 2000). According to these authors and Bannikov (1984), there were 150–200 snow leopards in the Russian Federation, 100 in Uzbekistan and 180–200 in Kazakhstan, making up about 2000 individuals. Koshkarev (1989) estimates the population in Tien Shan and Dzhungarsky Alatau to be about 400–500 individuals. After the dissolution of the USSR, populations in Kazachstan and Kyrgyzstan decreased by at least 50% due to poaching (McCarthy and Chapron 2003). The current legal and management status of many reserves is still unknown.

Fig. 1.4 Map showing the area surveyed in the Gouli Region in the East Burhanbuda Mountains and Kunlun Mountains, China, and the locations of leopard signs and camera traps. *Source* Xu et al. (2008)

Snow leopards are reported in **Russia** (Table 1.3; Fig. 1.1) in the Altai and Sayan ranges on the border with the People's Republic of Mongolia, and in southern Siberia, including the Tuvan and Buryat mountain ranges (Paltsyn et al. 2012). Genetic analysis of 67 samples of hair and faeces, revealed that only 12 belonged to snow leopard in the Tsagan_Shibetu, Mongun taiginskii raion, Tsagan_Shuvuut, Erzinskii and Tere_Khol'skii raions, Tyva regions of Russia and only four snow leopards were individually identified using genetic markers in Tsagan_Shibetu and Mongun taiginskii raion (Rozhnov et al. 2011). Seven or eight adult snow leopards are reported as constant inhabitants on the Tunkinskie Gol'tsy, Munku-Sardyk, and Bol'shoi Sayan mountain ridges (Karnaukhov et al. 2018). The mean population density in the Altai Mountains is estimated to be 0.75–1.5 individuals/100 km^2, with approximately 40 individuals in total (Sopin 1977). On the Chikhachev Ridge located in the Altai Republic, Tuva Republic and Mongolia, about 5–7 snow leopards occur, or 10–15

Table 1.3 Area of habitat and estimates of the abundance of snow leopards in Russia

Location	Area of habitat, km^2	Abundance	Notes
Chikhachev Ridge	1000	5–7	Total population of this transboundary group, including those in Mongolia, is 10–15 animals
Tsagan-Shibetu Ridge, southern Shapshalsky Ridge, western side of Western Tannu-Ola Ridge	2500	15–18	Total population of this transboundary group, including those in Mongolia, is 20–25 animals
Sayano-Shushensky Nature Reserve, its buffer zone, and adjacent parts of Khemchiksky and Kurturshubinsky Ridges	Not more than 200–500	9–10	
Sengelen Ridge	2000	7–10	
Okinsky and Tunkinsky Ridges, possibly	5000–6000	15–20	This area requires additional research
Total	6000 (possibly 11,000–12,000 if Okinsky and Tunkinsky Ridge populations are included)	36–45 (possibly 50–65 if Okinsky and Tunkinsky Ridge populations are included)	

Source Paltsyn et al. (2012)

if we include those in Mongolia. Snow leopard population size in the Sayan region is approximately double (Koshkarev 1996) than that in Sayano-Shushensky Nature Reserve in the Sayan region (Table 1.3). In southern Siberia, snow leopards possibly occur on the Okinsky and Tunkinsky Ridges (Table 1.3, Paltsyn et al. 2012). Smirnov et al. (1990) estimate that there are about 80 snow leopards in southern Siberia including those in Mongolia. As mentioned in Table 1.3, more research needs to be done in this area. In general, there is no detailed data for Russia and that which is available is out of date. Loginov and Loginova (2017) report that the latest rough estimates are no more than 70–90 individuals. In Russia, the suitable habitat of snow leopard occupies 16,500 km^2 with transient territories covering 32,800 km^2. Most of the area of suitable habitat is associated with the Altai Mountains, Western Sayan Mountains, Sangilen Plateau, Tsagan-Shibetu and Shapshal (Kalashnikova et al. 2019).

There is insufficient information on the distribution and status of wildlife in post-Soviet **Kyrgyzstan**, (McCarthy et al. 2010). On the other hand, the Government of the Kyrgyz Republic has increased the enforcement and development of protected areas (Dexel 2002; Chapron 2005). Snow leopards occur in the Talasskiy Alatau and Ferganskiy mountains and in Tien Shan bordering China and Kazakhstan (Fig. 1.1; Braden 1982; Koshkarev 1989). Koshkarev (1989) estimates a population of 113–157, with an average population density larger than in other post-soviet countries (Table 1.1). McCarthy et al. (2008) report snow leopard abundance at Jangart and Sary Chat Ertash in the Tien Shan Mountains in eastern Kyrgyzstan. Sixteen sign surveys in the Sary Chat with total transect length of 8.2 km and 13 surveys with 8.6 km transect length in the Jangart revealed 7 snow leopards in the Jangart. Based on photo capture-recapture, more individuals were identified at Sary Chat than Jangart. The potential density calculated based on counting snow leopard prey, ibex (*Capra* sp.) and argali (*O. ammon*), also predicts greater numbers of snow leopard at Sary Chat than Jangart. In Kyrgyzstan, snow leopard numbers have decreased at an alarming rate over the last few decades, with 650–800 individuals estimated in the 1990s, against 150–200 in 2000 (Koshkarev and Vyrypaev 2000). Latest estimates are around 300–400 individuals (McCarthy and Mallon 2016) in a territory of 89,000–105,000 km^2 (Loginov and Loginova 2017). Several studies based on genetic analyses and camera trapping estimated the snow leopard population size in the Sarychat-Ertash State Reserve (SESR) to be around 20 individuals between 2011 and 2015 (Koshkarev and Vyrypaev 2000; McCarthy et al. 2008; Jumabay-Uulu et al. 2014; McCarthy and Mallon 2016; Rode et al. 2020).

According to Hunter and Jackson (1997), the estimated area of potential snow leopard habitat in **Kazakhstan** is 71,079 km^2. The approximate population size is similar to that recorded in Russia, Bhutan, Tajikistan and Afghanistan (Annenkov 1990; Zhirjakov 1990). In the south of Kazakhstan, snow leopards occur on the Khigizskiy Range and Tasskiy Alatau bordering Kyrgystan, the Sarytau Mountains near Alma Ata and bordering China on the Dzungarsky Alatau. (McCarthy and Chapron 2003). According to Zhirjakov (1990) there are about 20 snow leopards at Zailiskiy Alatau and in northern Tien Shan. The presence of snow leopard in protected areas is confirmed for the Aksu Dzhabagliy State Reserve and Alma Atinskiy Nature

Table 1.4 Confirmed occurrence of snow leopard in protected areas in Tajikistan

Protected area
Great Pamir National Park
Ramit State Reserve
Dashti-Dzhumskiy Reserve
Iskanderskul'skiy lake Reserve
Muzkul'skiy Reserve
Pamisskiy Reserve
Sangvorskiy Zakazniki Reserve
Khokh Serkh SPA

Sources Sokov (1990), Hunter and Jackson (1997), McCarthy and Chapron (2003)

Reserve (McCarthy and Chapron 2003). Now in Kazakhstan there are not more than 100–120 snow leopards that live in a territory of at least 50,000 km^2 (Table 1.1, Loginov and Loginova 2017).

There is no data on the current status and distribution of snow leopard in **Tajikistan**. They are said to occur in the central and western parts on the Zeravshanskiy, Gissarskiy, Karateginskiy and Petr Pervyi mountains, the Hazratishog and Darvaskiy Mountains and in the Gorno-Badahshansk area, including the Pamirs (McCarthy and Chapron 2003). Bykova et al. (2002) estimate a total of 180–220 and Muratov (2004) 200–220 snow leopards that occur there. Based on local camera trap studies and the availability of habitats, it is likely there are 250–280 snow leopards in Tajikistan (Table 1.1, McCarthy and Mallon 2016). In some protected areas, the presence of snow leopard is confirmed (Table 1.4). In 2003, Rodney Jackson conducted a survey in order to determine whether it was possible to promote wildlife conservation in Tajikistan. He trained local staff and herders to monitor snow leopards and Marco Polo sheep using surveys along transects (Jackson et al. 2004). The snow leopard has many habitats in Tajikistan, among which there are five key zones including Kuraminsky-West-Tien Shan, Vakhsh-Darvaz and Hissar-Alai with an estimated number of 250 individuals (Loginov and Loginova 2017).

Uzbekistan is at the western edge of the distribution of snow leopard. They occur in the Turkestanskiy, Chatkalskiy and Gissarskiy ranges bordering Tajikistan and Kyrgyzstan (Braden 1982), where the total population is estimated to be 50 animals (Sludskiy 1973, cited in Braden 1982). Kreuzberg-Mukhina et al. (2002) and Azimov (2009) report a population size of 30–50, which is small compared with that recorded. Recently, experts of Biocontrol of Uzbekistan (2014) estimated 80–120 individuals (Table 1.1). The population in West Tien Shan is 10–40 individuals and in the Pamir Alay 20–80 individuals, although it varies seasonally due to transboundary movements (McCarthy and Mallon 2016). As in Tajikistan, snow leopard presence is confirmed in protected areas, for instance in the Zaaminskiy State Reserve, Uzbek National Park, Gissarskiy State Reserve and Chatkal'skiy State Reserve (McCarthy and Chapron 2003).

1.2.4 Population and Distribution in Pakistan, Afghanistan and Mongolia

The potential snow leopard habitat in **Pakistan** covers 80,000 km^2 (Table 1.1, Fox 1994) with a population comparable to that estimated for Nepal (Schaller 1977; Hussain 2003). Based on the mean density (Table 1.1.), the total number of snow leopards is approximately 320 (McCarthy and Chapron 2003). It occurs in some areas, but its presence in many potential habitats has not been confirmed (Table 1.5, McCarthy and Chapron 2003). Hussain (2003) surveyed the Baltistan district between 1998 and 2001 and estimate that approximately 36–50 snow leopards live there. With respect to the availability of its prey and suitable habitat, he suggests 90–120 snow leopards occur in the whole of Baltistan. Its presence in Azad Kashmir Province remains unconfirmed (Roberts 1977).

The numbers of snow leopards in **Afghanistan** remain to be determined. The estimates of the area of potential habitat in Afghanistan differ considerably. Fox (1989) estimates 80,000 km^2 and subsequently 50,000 km^2 (Table 1.1, Fox 1994),

Table 1.5 Confirmed, to be confirmed and likely habitat areas of snow leopards in Pakistan

	Province	Area
Confirmed	North-West Frontier Province (Khyber Pakhtunkhwa)	Chitral Gol National Park Agram Basti Wildlife Sanctuary Goleen Gol Game Reserve Gahriat Gol Game Reserve
	Gilgit Baltistan	Baltistan Wildlife Sanctuary Kargah Wildlife Sanctuary Khunjerab National Park Nazbar Nallah Game Reserve
To be confirmed	Ghizar District	Sherquillah Game Reserve
	North-West Frontier Province (Khyber Pakhtunkhwa)	Parit Gol/Ghinar Gol Game Reserve
	Gilgit Baltistan	Kilik/Mintaka Game Reserve Nar/Ghoro Nallah Game Reserve Askor Nallah Game Reserve Astore Wildlife Sanctuary Chassi/Baushdar Game Reserve Danyor Nallah Game Reserve Pakora Game Reserve
	Azad Jammu and Kashmir	Machiara National Park Ghamot National Park
Likely	Gilgit Baltistan	Nanga Parbat Conservancy Area Gojal Conservancy Area
	North-West Frontier Province (Khyber Pakhtunkhwa)	Tirichmir and Qashqar Conservancy Area

Source McCarthy and Chapron (2003)

and Hunter and Jackson (1997) suggest 117,653 km^2. Snow leopard occurrence is confirmed in the Hindu Kush and Pamir mountains in north-eastern Afghanistan (Habibi 1977; Petocz 1978; Sayer 1980). Snow leopards occur at Zedak in the southern part of Badakhshan (McCarthy and Chapron 2003). Due to a long history of many wars in Afghanistan, wildlife laws are not enforced there (McCarthy and Chapron 2003). The actual status of snow leopards at many locations is unknown (McCarthy and Chapron 2003). The latest information on the occurrence of snow leopards in Wakhan District in Badakhshan is that of the Wildlife Conservation Society (WCS) and National Environmental protection Agency who installed remote camera traps in 2009 and recorded over 1300 images of snow leopard at 20 sites (Noras 2015a). Three individuals were captured and equipped with satellite collars in 2012. Thanks to the confirmation of the presence of snow leopards in that area, the whole of Wakhan Distict, with an area of 10,000 km^2, was declared a National park in 2014 (Noras 2015a).

Mongolia is a state with the second largest population of snow leopards (Green 1988) (Table 1.1; Fig. 1.1; Schaller et al. 1994; McCarthy 2000). It occurs in at least 10 protected areas (Table 1.6, McCarthy and Chapron 2003). The main populations occur in the Altay and Transaltay Gobi mountain ranges, with smaller populations in the Khangai, Hanhohiy Uul and Harkhyra Uul ranges (McCarthy and Chapron 2003). Bold and Dorzhunduy (1976) estimate that there are 170–230 snow leopards in the southern Gobi region in Mongolia. During 1994–1997 McCarthy et al. (2005) recorded snow leopard movements and activity based on year-round radio-monitoring in the Altai Mountains in south western Mongolia. Home ranges determined by standard telemetry techniques are at least of 11–141 km^2 (McCarthy et al. 2005).

In the area of Burhan Budai in the Altay, Schaller et al. (1994) found signs of at least 10 individuals within 200 km^2. This population density is one of the highest

Table 1.6 Confirmed occurrence of snow leopards in protected areas in Mongolia

Protected area
Transaltay Gobi SPA
Khokh Serkh SPA
Otgontenger SPA
Tsagaan Shuvuut SPA
Turgen Uul SPA
Gobi Gurvansaikhan NCP
Altai Tavaan Bogd NCP
The Burhan Buudai Nature Reserve
Alag Khairkhan Nature Reserve
Eej Uul National Monuments

Source McCarthy and Chapron (2003)
SPA stands for Strictly Protected Area, NCP for National Conservation Park

estimated in the whole of its habitat. From 2008, the Snow Leopard Trust (SLT) and Panthera, in co-operation with the Mongolian government, started a 10-year conservation program and captured and radio collared 20 individuals. To date, in the Altai Mountains there are conservation programs, which involve more than 400 families of herders (Noras 2015b).

1.3 Threats to Snow Leopard

The main threats to snow leopard include illegal trade, conflict with locals (human-snow leopard conflict), lack of conservation, awareness and policy and climate change (Jackson et al. 2008).

1.3.1 Human-Snow Leopard Conflict

Snow leopard home ranges often overlap extensive agro-pastoral land at high altitudes that are located inside and outside protected areas. Killing of livestock is rapidly increasing in these areas because of the decline in the abundance of wild prey. This is partially due to decreasing primary productivity and competition for forage with livestock (Bagchi and Mishra 2006; Jackson et al. 2008). The occurrence of livestock may have a negative effect on the occurrence of wild ungulate prey, resulting in intensification of human-snow leopard conflicts caused by livestock depredation (Rovero et al. 2020). Maybe even more importantly, however, this is because of the reduction in abundance of natural prey of snow leopard due to illegal hunting of ungulates for meat in the Commonwealth of Independent States and in western China, i.e., in Kyrgyzstan, Kazakhstan, Xinjiang province of China, Uzbekistan and Tajikistan (Jackson et al. 2008).

Livestock is an important source of food for snow leopards there; in some areas, it makes up to 58% of their food (Jackson et al. 2008). No wonder then that this leads to conflict with local people resulting in retaliatory killing (Jackson et al. 2008), such as in the Kanchenjunga Conservation Area (KCA) in Nepal (Ikeda 2004), and it is now the most significant threat to snow leopards (see Chap. 8 for a detailed analysis). However, killing of snow leopards in retaliation for their livestock killing and the reduction in the abundance of natural prey is inherently very challenging in the Himalayan region (India, Nepal, Bhutan, Tibetan Plateau and other southern China), Karakorum and Hindu Kush (southwest China, Pakistan and Afghanistan).

An example of a specific case of the human-snow leopard conflict in Nepal will be presented in Sect. 2.5.

1.3.2 Illegal Trade

Snow leopards are killed not just for killing livestock, but also for commercial purposes. It is estimated that over 400 snow leopards were poached annually globally since 2008 (Nowell et al. 2016). There is a big demand for snow leopard pelts, followed by their claws, meat, male organs and bones as substitutes for tiger bones in Chinese medicine (Theile 2003). Thus, illegal hunting for trade is also a serious threat to their survival.

Because of the strong Chinese economy, the illegal trade in snow leopard products increases, for instance with adjoining Mongolia (Wingard and Zahler 2006) and Afghanistan, where it is difficult to stop because of the current military situation there (Habibi 2004). With the fall of the Soviet Union in the 1900s, in Kyrgyzstan and other recently independent states, increased unemployment and corruption in mountainous regions led to a growth in black-market trading in wildlife products (McCarthy et al. 2010). For instance, in Kyrgyzstan people living in villages close to protected areas are poor and, in some cases, have to resort to poaching wildlife within the park boundaries (McCarthy et al. 2010). Nowadays, some of the former Soviet socialist republics continue to promote a sustainable developmental agenda (McCarthy et al. 2010). As a result, the level of poaching is lower, but it continues in many other former Soviet republics.

Information about specific problems on illegal trade in Nepal can be found in Chap. 2.6.

1.3.3 Lack of Awareness and Policy

The general lack of awareness, at both local and national levels, for the need to conserve wildlife, especially predators, further hinders conservation efforts (Jackson et al. 2008).

To estimate abundance of snow leopard in some cases, e.g. when genetic analyses are used, it is necessary to transport samples across countries. Difficulties in transporting samples between countries complicate such surveys, especially in areas adjacent to politically sensitive international borders. In the IUCN's research, lack of transboundary cooperation is challenging at almost every location, where snow leopards occur, such as the Himalayan region, Commonwealth of Independent States and western China (Jackson et al. 2008). For instance, in Nepal, there is only one laboratory in Kathmandu specializing in wildlife, which is insufficient. The majority of herders in Nepal complain about insufficient project management in terms of reliability and transparency (Ikeda 2004).

In some areas, e.g., in Kyrgyzstan, the legislative system is inadequate for protecting reserves. McCarthy et al. (2010) compare the composition of species in an unprotected area, which is used for hunting by foreign companies, with that in a strictly protected national park (Sary Chat) in the Tien Shan Mountains in eastern

Kyrgyzstan. Even though hunting is not permitted at Sary Chat, cases of poaching by rangers and local villagers are reported (Koshkarev and Vyrypaev 2000). On the other hand, after the breakup of the Soviet Union, Jangart was established as a foreign currency hunting reserve, hosting non-nationals who come to Kyrgyzstan to hunt ungulates (McCarthy et al. 2010). Unexpectedly, the numbers of photographs of ungulates recorded by camera traps in the unprotected area (Jangart) were higher than in the protected area for most species (McCarthy et al. 2010). A possible explanation is that Jangart is more isolated from local villages than Sary Chat, where rangers and their families have settled along the edges of the park (McCarthy et al. 2010).

This reflects a fundamental problem with the reserves in Kyrgyzstan, a deficiency in auxiliary enterprises for local people. The government replaced park staff and a nongovernmental organization (CBF—Community Business Forum), with the International Snow Leopard Trust involved, but nonetheless there is still evidence of poaching of some carnivores continuing in and around the reserve (McCarthy et al. 2010).

Ineffective enforcement of the law and institutional incapacity are problems mainly along the northern edge of the distribution of snow leopards (Russia, Mongolia, Tien Shan ranges and Altai in China), Karakorum and Hindu Kush (Afghanistan, southwest China and Pakistan) (Jackson et al. 2008).

Military conflict has also affected snow leopards, primarily by destroying their habitats (landmines), secondarily by encouraging trade in wildlife (Jackson et al. 2008). This is a serious problem in the Himalayan region and Commonwealth of Independent States and western China.

1.3.4 Climate Change

Climate change is a serious threat to biodiversity (McCarthy et al. 2001; Thomas et al. 2004; Beaumont et al. 2011). In general, climate change destabilizes systems and their management, such as the balance between resource use by locals and wildlife biodiversity (Comiso 2003; Mishra et al. 2004; Namgail et al. 2007; Sharma and Tsering 2009). The United Nations Intergovernmental Panel on Climate Change forecasts that the global temperatures will increase by something between 1.4 and 5.8 °C by 2100 (IPCC 2001; Locky and Mackey 2009). Most areas in snow leopard home ranges, such as high altitudes and cold deserts in the Trans-Himalayan region, are among the most vulnerable ecosystems in terms of the effects of climate change (Christensen and Heilmann-Clausen 2009; Dong et al. 2009; Sharma and Tsering 2009; Xu et al. 2009; Aryal et al. 2012).

There are two contradictory predictions of the changes in snow leopard distribution due to climate change. The ***first hypothesis*** (Aryal et al. 2013) claims that snow leopard is likely to move to lower altitudes, following the movement of its prey (mainly blue sheep) in the Trans-Himalayas, as grasses and many species of shrubs will no longer be found in sufficient abundance at high altitudes and consequently blue sheep will move to low altitudes. However, there the snow leopard is more likely to encounter and kill livestock (Table 1.7, Aryal et al. 2013). Table 1.7 shows the predicted effect of climate change on the livelihood of the people, blue sheep and snow leopard according to this hypothesis. In consequence, increased crop raiding by blue sheep and killing of livestock by snow leopards may adversely affect the livelihood of local people (Aryal et al. 2013).

The ***second hypothesis*** claims that the increase in temperature and precipitation due to climate change is likely to cause an upward shift in the tree line (Forrest et al. 2012). It moved 388 m upwards in the Indian Himalayas from 1970 to 2006, and 270 m in the south eastern Tibetan Plateau since 1920s (Baker and Moseley 2007; Singh et al. 2012). However, snow leopard is adapted to hunting in rocky terrain above the treeline and it rarely ventures into forested areas (Schaller 1977; Jackson and Ahlborn 1989), therefore this change could significantly reduce its hunting range.

Regarding the snow leopard's natural prey, such as blue sheep, argali and ibex, which are already threatened by habitat loss and hunting, the ***second hypothesis*** claims that climate change could contribute to further decline of these species. This

Table 1.7 Predicted effect of climate change on rangelands, livelihood of local people, blue sheep and snow leopard

Rangelands (%)	Livelihood (%)	Blue sheep (%)	Snow leopard (%)
Reduction in the availability of water (18)	Reduction in food and drier farmland (9)	Reduction in numbers (38)	Reduction in numbers and fewer sightings (41)
Reduction in the amount of grass (33)	Reduction in livestock (4)	Crop raiding (16)	Increase in attacks on livestock due to decrease in natural prey (24)
Drying out of land (12)	Health problems with new diseases (3)	Movement downwards towards farmland (14)	Approaching villages (13)
Reduction in snowfall (27)	Reduced availability of drinking water and fewer irrigation channels (36)	Sightings near villages (4)	Change in use of habitat and increase in their tendency to kill domestic livestock rather than natural prey (22)
Move towards desertification (10)	Changes in the timing and cultivation of agricultural crops (27) Increase in wind speed Economic crisis (7) Water seepage and damage to traditional houses (14)	Reduction in grazing land (20) Change in habitat use (8)	

Source interview with local people
Data are the percentages of the 221 respondents that agreed with a statement
Source Aryal et al. (2013)

will be due to the colonisation of grasslands by less nutritious grasses and avoiding livestock-grazed areas, and consequently the snow leopard prey may be competitively excluded from better habitats (Schaller 1977; Mishra et al. 2004; Namgail et al. 2007; Bhattacharya et al. 2020) and pushed closer to human settlements. E.g., blue sheep prefers alpine grasslands (moist and dry) and barren and snow-covered areas (Wegge 1979; Kala et al. 2002; Namgail et al. 2009; Johnsingh and Manjrekar 2015; Bhattacharya et al. 2020). Due to heavy snow and less productivity of grassland in winter, blue sheep tend to forage in areas covered by trees and shrubs in winter, where they feed on fallen leaves. These areas are at low altitudes and therefore close to human settlements. (Liu et al. 2007).

Warmer temperatures will also drive farmers to plant crops and graze their livestock at high altitudes, where now snow leopards live. There is also likely to be no more tourists or villagers present there during winter. As grazing will intensify and snow leopard's natural prey will decline, retribution killings due to conflict with humans are likely to accelerate as part of a climate-induced domino effect. In addition, common leopard is also beginning to move towards higher altitudes due to climate change, which will increase the competition with snow leopard for their common prey (see Chap. 5; Buzzard et al. 2017b).

1.4 Conservation Aspects of Snow Leopard

Conservation of snow leopard is a very complex problem because its habitat is very rugged, it has a large home range and frequently comes into conflict with humans (Li et al. 2013a). Below is a list of some possible ways of protecting it by means of legislation, international cooperation, financial support, education and awareness.

1.4.1 Legislation

Legislation relating to the conservation of snow leopards is based on the designation of nature reserves by governments and supporting programs led by nongovernmental organizations (McCarthy and Chapron 2003; Mishra et al. 2003). However, their power is limited (Li et al. 2013a). There is little information on the current management status of protected areas or their role in sustaining snow leopard populations (Fox 1994; Green and Zhimbiev 1997). To date, the area of snow leopard habitat inside nature reserves is just 0.3–27% in 11 out of 12 countries (Li et al. 2013a). The only exception is Bhutan with 57% of the snow leopard habitat protected (Hunter and Jackson 1997).

To reduce the threats to snow leopard, such as poaching and illegal trade, it is necessary to implement legislation and conservation policies and prevent the hunting, killing, possession, sale and trade in snow leopards, including all its body parts and derivatives, at local, regional and national levels (Theile 2003; Aryal et al. 2013). It would help if governments could be assisted and given advice on how to penalize people who break the law, and to consider implementing "whistle-blower" policies to provide incentives for reporting illegal activities (Theile 2003; Aryal et al. 2013). Theile (2003) also recommends the setting up of "anti-poaching" teams, which would monitor main markets and trade centres in order to obtain information on illegal killing. For a better understanding of the factors affecting the effectiveness of protected areas for the conservation of diversity, long-term and detailed research and the evaluation of the interactions between populations outside and inside protected areas are needed (Gaston et al. 2008). The Park requires a revision of the livestock grazing zone and increased law enforcement with emphasis on the creation and protection of livestock-free areas (Rovero et al. 2020). Conservation efforts should concomitantly target livestock practices by engaging herders in the process of developing new grazing plans, as elaborated in the Snow Leopard Survival Strategy (Snow Leopard Network 2014; Rovero et al. 2020).

For successful conservation, it is important to have the support of the government of each state. Four countries that already have national action plans are Nepal, Pakistan, Mongolia and Russia (McCarthy and Chapron 2003). The government of India initiated Project Snow Leopard (PSL), a national government program, on January 20, 2009. The goal of that project is to conserve snow leopards together with other species living at high altitudes in five states in the Himalayas: Jammu and Kashmir, Himachal Pradesh, Uttarakhan, Sikkim and Arunachal Pradesh (Rajput 2009). The PSL is a knowledge-based adaptive wildlife management policy aimed at enforcing the law, promoting awareness and educating the public about the need for wildlife conservation (Rajput 2009). The PSL resulted from a national conference at Ladakh in 2006 and collaboration with the International Snow Leopard Trust (ISLT), the Nature Conservation Foundation (NCF), the State Governments, the Ministry of Environment and Forests (Government of India), Wildlife Institute of India (WII), the Snow Leopard Network, local communities and certain NGOs (Rajput 2009).

1.4.2 International Cooperation

Snow leopard distribution spans across 12 countries in South and Central Asia. Therefore, the cooperation of all these countries is necessary to implement internationally valid acts, such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which regulates the export or import of animals or their body parts (Nowell et al. 2007). Protected areas are important in sustaining the overall snow leopard population, because the distribution of snow leopards includes areas that include international borders (McCarthy and Chapron 2003). The Snow Leopard Network (SLN, https://snowleopardnetwork.org/) unifies organizations such as the Snow Leopard Conservancy and International Snow Leopard Trust. The function of the SLN is to coordinate, cooperate and share information. International conferences can be used to identify locations for snow leopard conservation, name Snow Leopard Conservation Units and provide a framework for the development of national action plans (Jackson et al. 2008). Recently, e.g., an International Conference on Range-wide Conservation Planning for Snow Leopards was held in Beijing, China in March 2008. Another function of international societies, such as the World Wide Fund For Nature (WWF), is to secure with governments, such as that of Nepal, secure funding for compensatory programmes (Ikeda 2004).

On 22–23 October 2013, the 12 countries within the snow leopard range, together with other bodies, gathered at the Global Snow Leopard Conservation Forum in Bishkek, Kyrgyz Republic, with the shared goal of conserving snow leopards and their fragile habitats. They initiated the Global Snow Leopard and Ecosystem Protection Program (GSLEP), which operated until 2020. The countries within the distribution of snow leopards, with support from interested organizations, identified and secured at least 20 snow leopard landscapes by 2020, or—in brief—"Secure 20 by 2020" (Snow Leopard Working Secretariat 2013). Secure snow leopard landscapes are defined as those that contain at least 100 snow leopards of breeding-age, about which, with the involvement of local communities, it was agreed that they should be conserved with adequate and secure prey populations and connections with other snow leopard landscapes, some of which cross international boundaries.

Snow leopard is legally protected from hunting in most of the 12 countries in which it occurs (McCarthy and Chapron 2003). Afghanistan recently afforded snow leopard legal protection by listing it on the country's first Protected Species List in 2009. This act bans all hunting and trading of snow leopards within Afghanistan. Except for Tajikistan, the rest of the countries are also signatories of the CITES agreement (Snow Leopard Network 2014).

1.4.3 Education and Awareness

It is important to educate and increase the awareness of the need for conserving snow leopards among local communities, national governments and internationally (Jackson et al. 2008). The effectiveness of conservation is increased by using community-based programs that involve local people such as livestock herders, trekking guides, farmers, former hunters and students (Sathyakumar et al. 2011; Snow Leopard Network 2014). Various ways of supporting cultural, social and religious beliefs of locals exist such as education of the public by monks in monasteries or involving locals in some studies, e.g., measurement of changes in climate (Jackson et al. 2008).

The Snow Leopard Survival Strategy (McCarthy and Chapron 2003) may include the management of grazing in order to diminish its effect on native wildlife (e.g. large ungulates) and support for husbandry practices that reduce livestock vulnerability to snow leopard predation and improve efficiency and yield (Jackson et al. 2008). As mentioned above, herders of small and medium-sized livestock are notably vulnerable to losses of livestock, which can be reduced by corralling the livestock at night. Understanding what determines the carrying capacity (based on the distribution and population structure) of predators such as snow leopard will simplify the management of the human-wildlife conflict (Aryal et al. 2014), which is explored in detail in Chap. 8 of this book. One of the major issues is the protection of prey populations (e.g. blue sheep) as a resource for snow leopards in order to reduce their need to kill livestock and so inflame the human-predator conflict (Aryal et al. 2014). It is also appropriate to provide a legal mechanism, which enables herders to kill snow leopards that repeatedly kill their livestock (McCarthy and Chapron 2003). In prior studies, physical precautions, such as installation of predator-proof livestock corrals or guard dogs or formation of core areas, for snow leopard conservation are recommended (Jackson and Hunter 1996; McCarthy and Chapron 2003). Another objective is to decrease the suspicion of herders that snow leopard abundance will increase unduly in the future by proposing more adaptable conservation policies that provide a better compromise between livestock rearing and wildlife protection (Ikeda 2004).

One of the ways of protecting snow leopards is a monastery-based conservation. In the Sanjiangyuan region in China's Qinghai Province and Mustang in Nepal, Buddhist monasteries play an important role in snow leopard conservation (Li et al. 2013b; Ale et al. 2014). This method may prove very efficient and by establishing it in other Tibetan Buddhist regions, it could result in the extension of protection to about 80% of the snow leopard habitat (Li et al. 2013b). It should be possible to decrease the killing of snow leopards by adhering to Buddhist tenets such as respect, love and compassion for all living things. Thus, the 336 monasteries located in the Sanjiangyuan region could protect more snow leopard habitat (8342 km^2) through social norms and active patrols than the core zones of the nature reserves (Li et al. 2013b).

As mentioned above, climate change is another serious issue. It is important to implement strategies that mitigate and adapt conservation management at the local level in order to reduce the effect of climate change (Jackson et al. 2008). This strategy may include plantations on private land and in local areas, use of solar energy for cooking and heating, seeding native grasses, development of water holes in areas where long distances need to be covered, storage of rainwater for agriculture, construction of reservoirs for winter and times of water shortage, control of poaching and continued monitoring of the distribution of trees (Aryal et al. 2013). For conservation planning, bioclimatic models, used to predict the persistence of species populations and habitats resulting from climate change, are impractical because their reliability and scope are limited (Heikkinen et al. 2006). Therefore, the use of individual-species climate models as guidelines for climate-integrated conservation planning may be more appropriate as they are more reliable than community-based or assemblage models (Hannah et al. 2002; Pearson and Dawson 2003; Thuiller 2007).

1.4.4 Financial Support

For efficient conservation, it is essential to understand the economic situation of local herders and determine how to avoid conflicts between wildlife conservation and livestock rearing in countries where incomes are low (Ikeda 2004). It is necessary to obtain detailed ecological and socio-economic information in order to design a system which will function successfully (Mishra et al. 2003). Except for the Annapurna Conservation Area and the Spiti Region in Himachal Pradesh in India, where these surveys were conducted by Oli et al. (1994) and Mishra (1997), there is a lack of such data (Ikeda 2004).

One option for improving the compensation, is to involve herders in ecotourism (Schellhom and Simmons 2000; Hanson et al. 2018), as in Baltistan (Tibet) and Pakistan (Hussain 2000) and in Ladakh, India (Aishwarya and Sambandam 2019; Vannelli et al. 2019). This was not possible in the recent past in Nepal, because of the unstable situation in the country due to Maoists, which led to a decrease in the number of foreign trekkers (Hussain 2000). Fortunately, this is now over. A community-based homestay and snow leopard based eco-tourism program was recently launched in Jhong, Lower Mustang part of the Annapurna Conservation Area, Nepal. The above when incorporated in snow leopard conservation ensures the meaningful participation of villagers in snow leopard conservation (Shrestha and Vaidya 2020). Other alternative financial incentives recommended by the Snow Leopard Survival Strategy (McCarthy and Chapron 2003) and Jackson (2015) are the establishment of cottage industries, e.g., village-made handicrafts, construction of predator proof corrals, community-managed livestock insurance schemes, immunization of livestock against diseases or a well-structured ungulate trophy-hunting program (Mishra et al. 2003; Jackson et al. 2008; Kachel et al. 2017) similar to that already operating in Kyrgyzstan (Mishra et al 2003; McCarthy et al. 2010).

1.5 Conclusions

The largest populations of snow leopard are in China, Mongolia, Nepal and India, and the smallest in Russia, Bhutan, Kazakhstan, Afghanistan and Uzbekistan. The greatest population densities of snow leopard are in Bhutan, Nepal, China and Kyrgyzstan. Although the area of habitat suitable for snow leopard in Bhutan is one of the lowest, the population density there is very high. There is a need to determine the population density of snow leopards in Mongolia, Tajikistan, Kazakhstan, Russia, Afghanistan and Uzbekistan.

The main threats for snow leopard come from conflict with locals (human-snow leopard conflict), lack of a conservation policy, illegal trade, poor awareness and policy and climate change. Killing snow leopards in retaliation for killing livestock and the decline in the abundance of their natural prey is inherently challenging in the Himalayan region and Karakorum and Hindu Kush. The issue of military conflict is also a problem in the Himalayan region and Commonwealth of Independent States and western China.

In order to improve conservation aimed at increasing the likelihood of snow leopards surviving, it would be useful to obtain detailed information on current management and its role in sustaining snow leopard populations in protected areas, for which such information is currently unavailable.

Introduction of "anti-poaching" teams may decrease poaching and illegal trade of snow leopard products. To improve international cooperation, the signature of Tajikistan, the last non-signatory country, to the CITES agreement, is needed. Transboundary cooperation should be increased in areas where snow leopard occurs, in order to decrease logistic constraints, e.g. transport of samples for genetic analyses, or the building of more laboratories in each country. Currently, action plans only exist for Nepal, Pakistan, Mongolia and Russia. There is now an urgent need to create national action plans or governmental programs in the remaining countries.

The most successful conservation is that based on community-based programs involving local people, such as monastery-based conservation by protecting snow leopard by the adoption of social norms and active patrols. Therefore, it may be effective to encourage the use of this method in other Tibetan Buddhist regions. To improve the financial aspect of the conservation of snow leopards, it is important to understand the economic situation of local herders and estimate the monetary value of damage to livestock in order to determine the correct level of compensation. Up to now, this is only available for the Annapurna Conservation Area in Nepal and Spiti Region in Himachal Pradesh in India. It is also important to improve the procedure for verifying the damage to livestock caused by snow leopards. The compensatory system may involve, e.g., the development of ecotourism or cottage industries.

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Chapter 2
Snow Leopard in Nepal—A Case Study

Maan B. Rokaya, Binu Timsina, and Pavel Kindlmann

Abstract The most important habitats for snow leopard in the world are in Nepal and studies on this elusive predator began there much earlier than elsewhere, but the results are scattered in the literature. The review presented in this chapter therefore aims to compile the results of the Nepalese studies, which over the last four decades consist of several published and unpublished manuscripts, and to summarize different aspects of snow leopard biology, ecology, threats and conservation with a particular emphasis on Nepal (in contrast to Chap. 1, which concentrates on global aspects). It is expected that this review will serve as a baseline for future studies and the formulation of ways of managing and conserving snow leopard in Nepal.

2.1 Introduction

There is a continuous loss of faunal diversity globally, largely due to habitat loss caused by encroachments or climate change, forest fires, landslides, developmental projects and over-exploitation of natural resources (Hoffmann et al. 2010). Of all the species, large-bodied mammals are at the greatest risk (Cardillo et al. 2005). It is estimated that about 59% of the world's biggest mammalian carnivores are listed as threatened with extinction in the International Union for the Conservation of Nature (IUCN) Red List (Ripple et al. 2016). Like many big animals (for example:

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tigers, elephants, bears, musk deer, wolves, rhinoceros, spotted leopards, etc.), snow leopards are also threatened, including in the Himalayan region, where most of its important habitats occur (Chetri et al. 2017).

There are many studies on various aspects of snow leopard biology and ecology, such as taxonomy, behaviour, habitat requirements, diet, conflicts, trade, genetic diversity, seasonal movement and conservation issues (McCarthy et al. 2016). Despite an effort to bring all these studies together in a single publication (McCarthy et al. 2016), many studies are still widely scattered in various forms, such as research articles, books, reports, theses, popular articles in magazines, etc. Therefore, we attempt here to compile and summarize the results of the studies done on snow leopards in Nepal, a central Himalayan region with a rich biodiversity, in order to identify the strengths and weaknesses of these studies. It is intended that this review should serve as a baseline for future studies and for the formulation of management and conservation plans for snow leopards in Nepal (Adhikari 2004).

2.2 Data Sampling

2.2.1 Database

We reviewed scientific studies on snow leopards in Nepal published in journals, books, theses and reports. Different electronic databases were searched (ISI Web of Science, Science Direct, Scopus and Google Scholar) using specific search terms such as “Snow leopard”, *Panthera uncia*”, “*Uncia uncia*”*,* “*Felis uncia*”*,* “*Panthera uncia uncioides*”, “Nepal”, “Himalaya” “Himalayas” and “Himalayan region”. We also carried out a library search for hard copies.

2.2.2 Literature

We consulted 93 documents related to snow leopard in Nepal. They consisted of 49 journal articles, 20 reports, 6 books, 3 book chapters, 2 conference papers, 2 magazine articles and 1 conference proceeding. Snow leopard is the topic of research for 5 master degrees (Oli 1991; Adhikari 2004; Conradi 2006; Upadhyay 2010; Bhattarai 2015) and 5 Ph.D. degrees (Jackson 1996; Ale 2007; Aryal 2013; Hanson 2017; Chetri 2018) and also the topic of books based on expeditions (Matthiessen 1978; Hillard 1990). There was a significant increase ($p = 0.0003$, $R^2 = 0.3598$) in the number of documents on snow leopards published per year from the 1970s up to September 2020 (Fig. 2.1). Similar trends are also recorded for various fields of study worldwide (Laakso et al. 2011).

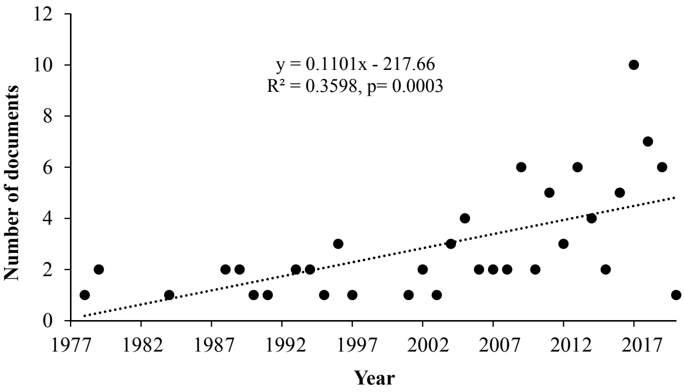

Fig. 2.1 The number of documents on snow leopards in Nepal published each year from 1978 to September 2020

Different methods are used to study snow leopards. The majority involves field surveys of their status, distribution, diet composition etc., and depends on the markings on snow leopards (e.g. Ahlborn and Jackson 1988; Wolf and Ale 2009; Shrestha et al. 2018) or the use of radio-collars to monitor them over long periods of time (Jackson and Ahlborn 1988; Oli 1994) or camera traps for relatively short periods of time (Ale et al. 2014; Lama et al. 2018). Some of the studies are also based on the literature and review different aspects, such as prey diversity (Lovari et al. 2013a; Lyngdoh et al. 2014; Valentová 2017), threats (Valentová 2017) or current knowledge and status of snow leopards in various parts of the world (McCarthy and Chapron 2003), or people's attitude towards snow leopard or the conservation of snow leopard (Khanal et al. 2018; Schutgens et al. 2018; Hanson et al. 2019a, b; Kusi et al. 2019).

Substantial numbers of studies are also based on questionnaires, informal discussions, focus group discussions, and key informant interviews on human-snow leopard conflict and attitudes of locals towards snow leopards. Genetic analyses are also used to identify density/population, gender, and the relationship between a population and other populations of snow leopards (Conradi 2006; Aryal et al. 2014a; Karmacharya et al. 2016; Chetri et al. 2017; Janecka et al. 2017).

There is even a discussion of the methods to be used for storing scats for genetic studies (Conradi 2006). A study of samples (48 sun-dried scats and 19 stored in ethanol) revealed that extraction and genotyping quality was much higher for ethanol than for the air-dried samples. Of the dry samples 25% were of sufficient quality to be genotyped, whereas it was 50% for the ethanol-preserved samples. In recent years, cameras have been used to record their status (Ale et al. 2014; Shrestha 2016; Shrestha et al. 2018), in particular, their presence and movements in a region were monitored this way.

2.2.3 Studies: Then and Now

Snow leopard first came to prominence after the publication of "The snow leopard" by Matthiessen (1978). This book was an outcome of a journey by Matthiessen and his fellow naturalist George Schaller through the Dolpo region in Nepal in 1973. Schaller's aim was to study wild blue mountain sheep and compare them with common sheep in the USA, while for Matthiessen the trip was more of a spiritual exploration. His next aim was to observe snow leopard, a predator of *bharal*, which had only been seen twice by westerners in the previous twenty-five years, and then to visit the Crystal Monastery in Tibet and the Buddhist lama there. Though they did not see any snow leopards during their journey, Matthiessen wrote "*…. it has pale frosty eyes and a coat of pale misty grey, with black rosettes that are clouded by the depth of the rich fur …*" and also "*… snow leopard is the most mysterious of the great cats; of its social system, there is nothing known. Almost always it is seen alone; it may meet over a kill, as tigers do, or it may be unsociable and solitary, like the true leopard.*" The publication of "The snow leopard" not only received a National book award in 1979, but also helped in the establishment of the Shey Phoksundo National Park that partly helped to preserve the native habitat of the snow leopard. Thus, in Nepal snow leopards were of great interest to many academicians and biologists much earlier than elsewhere in the world (Ale and Karky 2002). Following the publication of Matthiessen's book, the first scientific pioneering work was carried out by R. Jackson in the Dolphu region, in western Nepal. After Jackson, there has been a huge increase in research related to snow leopard and many publications have been emerging day by day (Chetri 2018; Schutgens et al. 2018; Shrestha et al. 2018).

2.3 Distribution of Snow Leopard in Nepal

Snow leopards occur in the northern part of Nepal. They occur in eight mountainous areas in Nepal that are protected: the Annapurna Conservation Area, Shey Phuksundo National Park, Kanchenjunga Conservation Area, Manaslu Conservation Area, Makalu Barun National Park, Dhorpatan Hunting Reserve, Sagarmatha (Everest) National Park and Langtang National Park. Snow leopards also occur in Humla, Jumla, Mugu and Shankhuwasawa regions (Jackson 1996; Lama et al. 2018). Snow leopards that were previously thought to have disappeared from the Everest region were observed there again in 2004 (Shrestha 2004, 2006; Ale and Boesi 2005). Their presence was confirmed by scats and pugmarks observed near Phortse, Namche and Ngozumpa glacier. They even suggest that there should be snow leopard in the area, as there are prey animals there, such as tahr and musk deer. Still a large part of northern Nepal is yet to be explored in detail.

2.3.1 Estimating Snow Leopard Abundance

Snow leopards leave different kinds of marks (scrapes, spray, scat, pugmarks, hair, kills) in their territories. The marks are usually surveyed using transects, as described by 'The Snow Leopard Information Management System', known as SLIMS (Jackson and Hunter 1996) or by the incidental method (Ale et al. 2014). See Chap. 3 for details of the types of marks and methods of estimating abundance. Here, we concentrate on the specific conditions in Nepal: when and how snow leopard abundance is to be estimated.

The most suitable time for seeing marks left by snow leopards or snow leopards themselves is from June to September in the Langtang National Park (Adhikari 2004). However, in western Nepal, marks are recorded more frequently during January–March (Jackson and Ahlborn 1988). The marks are found on a wide range of substrates, vegetation, upright boulders, at the base of rocky outcrops and cliffs, on the top of promontories and knolls, in the open, at the base of pine trees, near the edges of riverine terraces/bluffs, on cliff ledges exposed on the crests of ridges, and even in landslides or on river gravel and sandbars (Ahlborn and Jackson 1988). The abundance of marks varies from place to place. Scrapes are the most common type of mark and are often repeated (Schaller 1977; Ahlborn and Jackson 1988). Scat is also important, as it is quite frequently deposited (Ale et al. 2014; Devkota et al. 2017; Chetri 2018; Table 2.1). Although marks eventually disappear, spray marks are sometimes still detectable after more than 60 days and can be 80–100 cm above the ground (Ahlborn and Jackson 1988; Fox 1989).

The distances surveyed varied from 4.023 to 139.3 km. Sometimes there are seasonal differences in the marks left by snow leopards. In the Sagarmatha (Everest) National Park more scats (66) were recorded in autumn than in summer (40) (Lovari et al. 2009). In Mustang, more marks were recorded in spring (112) than in autumn (66) and summer (41). There were more marks recorded in upper Mustang at high altitudes (121) than in lower Mustang at low altitudes (98) (Ale et al. 2014). The occurrence of the different marks also depends on population size, age/sex ratio and also on the type of habitat (Ahlborn and Jackson 1988).

2.3.2 Population Status

In 1972 Schaller estimated that there were three individuals near Lepche in the Bhote Koshi valley in east Nepal (Schaller 1973). Schaller, after surveying about 500 km^2 in 1973 at Shey gompa and Phoksundo lake in Dolpa, estimated that there were at least six snow leopards in this area, especially during winter months when they roam around searching for food (Schaller 1977). The first in-depth study was carried out in the Langu valley in western Nepal, where radiometry results were compared with the abundance of signs of their presence (Jackson 1979a; Jackson and Ahlborn 1988).

Table 2.1 Abundance of signs of snow leopard presence in different parts of Nepal

Place	Area surveyed using transects (km)/area	Total number of signs	Most frequent sign	Number of signs per km	Individual sign density (sign/km)	References
Langu valley, western Nepal	4.908	–	Scrapes	–	Single sign every 204 ± 71 m	Jackson and Ahlborn (1988)
Chhekampar VDC, Gorkha, central Nepal	8.12	29 (faeces 14, scrapes 8, pugmark 7)	Scrapes	3.57	0.99	Devkota et al. (2017)
Langtang region, central Nepal	–	90	–	2.4–11.75 at 4000–4810 m a.s.l. (7.74 signs) and at 3700–4000 m a.s.l. (6.21 signs)	2–9.14	Adhikari (2004)
Kanchenjunga conservation area, eastern Nepal	18.01	200	Scrapes	–	–	Khatiwada and Chalise (2006)
Everest region	13.9 km (2004), 5 km (2005)	193 signs and 252 incidental signs	Scrapes	4.5	3.2	Ale (2005, 2007)
Shey Phoksundo National Park, western Nepal	4.475	46 (25 scats, 10 scrapes, 10 pugmarks and 1 kill)	Scats	10.28	5.59	Poudel et al. (2008)

(continued)

Table 2.1 (continued)

Place	Area surveyed using transects (km)/area	Total number of signs	Most frequent sign	Number of signs per km	Individual sign density (sign/km)	References
Humla region, western Nepal	6.76	45 signs (32 scrapes, 11 faeces, 1 urine mark and 1 pugmark)	Scrapes	5.49–7.36	3.92–5.23 scrapes	Khatiwada and Ghimirey (2009)
Sagarmatha (Everest) National Park, eastern Nepal	–	223: scrape (131), followed by faeces (55), pugmark (23) and rubbing sites and also scent spray (7 each)	–	–	–	Wolf and Ale (2009)
Rolwaling	4.023	29 (9 scrapes, 13 scats, 2 pugmarks, 5 tufts of hairs)	Scrapes	3.2	2.2	Ale (2010)
Upper Mustang, central Nepal	18.47	204 (49 pugmarks, 93 scrapes, 49 faeces, 10 urine spray, 1 rock scent, 1 hair sample and 1 kill)	Scrapes	10.8	6.8	Upadhyay (2010)
Upper Mustang, central Nepal	49.6	292	Scrapes	5.89	2.63	Aryal (2011)
Mustang, central Nepal	19.4	296: faeces (70), pugmark (31), scrapes (188), spray (6), hair (1)	Scrapes	5.8	2.8	Ale et al. (2014)

(continued)

Table 2.1 (continued)

Place	Area surveyed using transects (km)/area	Total number of signs	Most frequent sign	Number of signs per km	Individual sign density (sign/km)	References
Upper Mustang, central Nepal	59.9	283	Scrapes	4.72	2.85	Aryal et al. (2014a)
Annapurna Conservation Area (ACA) and the Manaslu Conservation Area (MCA)	–	573	–	–	–	Chetri et al. (2019b)
Sagarmatha National Park and the Annapurna Conservation Area (Lower Mustang and Upper Manang)	139.3	268	–	–	–	Shrestha et al. (2018)

Dash (–) Data not available

In 1979, it was estimated that there were about 150–300 snow leopards in Nepal (Jackson 1979a) and the most recent estimate (WWF 2009) is that there are around 300–400.

The estimated density is 5–10 individuals/100 km^2 in western Nepal (Jackson and Ahlborn 1988), 4.8–6.7/100 km^2 in Manang (Oli 1994), 1–3 individuals/100 km^2 in the Everest region (Ale 2005, 2007), 9 of which were resident (it is likely that five of them constituted a family group with a resident male and female and three cubs, with the rest most likely roaming animals attracted to the valley during the mating season) in the Phu valley. A subsequent estimate for Manang is 10.4 individuals/100 km^2) (Conradi 2006). Similarly, there were 7 individuals/100 km^2 in the Everest region (Lovari et al. 2009), 5–6 individuals/100 km^2 in the northern part of Langtang National Park (Chalise 2011), 9 individuals/100 km^2 in the Shey Phoksundo National Park (Karmacharya et al. 2011), 10–12 individuals/100 km^2 in the Langu valley, 4.8–6.7 individuals/100 km^2 in Manang (Thapa 2011), 6 (four females and two males) in an area of about 125 km^2 in Phu valley (Wegge et al. 2012), at least 3 adults at Mustang (Ale et al. 2014), 5 individuals (3 males and 2 females) in an area of 264.7 km^2 with a population density of 1.9 individuals/100 km^2 in upper Mustang (Aryal et al. 2014a), 5 individuals in 2007 (10.9/100 km^2) and two in 2010 (4.3/100 km^2) in Sagarmatha (Everest) NP (Ferretti et al. 2014), 6 in lower Mustang in 2014 and 8 in upper Manang in 2016, based on records of camera traps (Shrestha 2016), and 34 individuals of which 20 were males and 14 were females in the Annapurna Conservation Area (ACA) and the Manaslu Conservation Area (MCA) (Chetri et al. 2019b). Likewise, the density in western Nepal was estimated to be 3.2 individuals/100 km^2, in Rolwaling 1.5 individuals/100 km^2, in Sagarmatha NP 1.8 individuals/100 km^2 and in Kanchenjunga 2.6 individuals/100 km^2 (WWF 2009). These figures show that the population status is not uniform throughout the country, it is changing with time and more studies are needed.

2.3.3 Habitat Ecology and Home Range

Snow leopards were generally found in the areas with low rainfall at between 3000 and 5000 m and sometimes recorded even up to 5600 or 6000 m in Nepal (Jackson and Ahlborn 1984; Jackson 1996; Upadhyay 2010; Aryal et al. 2014a). The widest altitudinal range was recorded in upper Mustang and that between 2900 and 6000 m (Aryal 2011). Most snow leopards occur at altitudinal ranges of between 4000 and 4500 m and rarely at lower altitudes (Aryal et al. 2014a).

In Nepal, snow leopards normally occupy rugged mountainous terrain (Jackson and Ahlborn 1988). Such terrain is characterized by rocky outcrops, ridges, cliffs, gorges, stream beds of gravel and sandbars, vegetation dominated by grasses and sedges, shrubs or trees, broken or very broken ruggedness, rolling and flat ruggedness, with grassland, shrub land and both grass and shrub land, mixed and barren habitats without any vegetation or less grazed areas, forest borders or open shrub land/alpine meadows, and sometimes cultivated fields and areas subject to landslides (Figs. 2.2,

Fig. 2.2 Snow leopard habitat in high mountains in Mustang district, Nepal. *Photo by* M. Rokaya

2.3 and 2.4) (Jackson and Ahlborn 1988; Adhikari 2004; Lovari et al. 2013a; Aryal et al. 2014a; Upadhaya 2017). However, snow leopards avoid agricultural areas, glaciers and human settlements, and instead use barren land and grassland in Mustang (Aryal et al. 2014a). Of all the different types of habitats, ridgelines, narrow valleys, trails and cliff-edges are most frequently used by snow leopards for moving about their home range (Jackson and Hunter 1996). Snow leopards are active during the night, bedding in different places each day unless searching for prey (Jackson and Ahlborn 1989; Jackson 1996).

Total range of snow leopards is about 30,000 km^2 in Nepal (Fox 1989) and the estimated potential range is 27,432 km^2, of which 26.7% is in protected areas (PA). However, snow leopards depend on an abundance of food, enough cover for shelter, availability of escape routes, enough food for reproduction and absence of hunting.

There are concerns that the current increase in temperature will result in a reduction in the area of suitable habitat. Habitat modelling of snow leopard in six countries (Bhutan, China, India, Myanmar, Pakistan and Nepal) indicate that about 30% of snow leopard habitat in the Himalayan region may be lost due to an upward shift in the tree line and consequent shrinking of the alpine zone, mostly along the southern edge of its range and in river valleys.

However, a considerable part of the snow leopard habitat and corridors are likely to be resilient to climate change, and it is these that should be protected (Forrest et al. 2012). Similarly, Aryal et al. (2016) predict the effect of climate change on the distribution of snow leopards in the Himalayas using previously and recently collected data on their distribution. This study indicates that 11.6% (17,190 km^2) of

Fig. 2.3 Snow leopard habitat in high mountains in Yak kharka in Manang, Nepal. *Photo by* M. Rokaya

Fig. 2.4 Snow leopard habitat in high mountains in Thorang La in Manang, Nepal. *Photo by* M. Rokaya

this area is currently suitable for snow leopards and will be reduced by 14.57% due to climate change by 2030 and by 21.5% by 2050. They suggest that conservation should concentrate on establishing new protected areas high up in the mountains in order to mitigate the possible effect of climate change (Aryal et al. 2016).

The home range of snow leopards in the Langu valley, western Nepal, varies from 12 to 39 km^2. The patterns of movement of males and females are different, with males moving an average distance of 1.16 km/day and females 0.64 km. Both take a zig-zag route, when moving in their home ranges (Jackson and Ahlborn 1988). The movement slightly differs when recorded using radio-collars and following their movement for 18 months. The daily movement distance of males ($n = 3$) is 1.3 km and 1.0 km of females ($n = 2$) (Jackson and Ahlborn 1989). Similarly, based on the movement of 3 radio-collared snow leopards (1 male and 2 females) at Manang, winter home ranges vary between 19.9 and 22.3 km^2, and home ranges overlap extensively within and between both sexes. The core habitat area is around 8.1 km^2 (Oli 1997). In upper Mustang, however, snow leopards patrol an area of 264.7 km^2 and females tend to roam more (59.3 km^2) than males (52.9 km^2) (Aryal et al. 2014a).

2.4 Diet of Snow Leopard in Nepal

Bharal/nayur (*Pseudois nayaur*), also called the blue sheep, is the most preferred prey in the Langu valley (Jackson and Ahlborn 1988), Mustang (Aryal 2011; Aryal et al. 2014a; Shrestha et al. 2018), Manang (Oli et al. 1993; Wegge et al. 2012; Shrestha et al. 2018), the Shey Phoksundo National Park (Devkota et al. 2013) and west Nepal (Shrestha et al. 2019). Himalayan tahr (*Hemitragus jemlahicus*) and musk deer (*Moschus chrysogaster*) are preferred prey animals in the Everest (Ale 2005; Lovari et al. 2009; Shrestha et al. 2018) and Langtang regions (Chalise 2011). However, small animals like pika (*Ochotona roylei*) are also reported as the most preferred prey in the Dhorpatan Hunting Reserve (Aryal 2009) and west Nepal (Shrestha et al. 2019). Different studies report a wide range of different species of prey (wild animals, domestic animals, birds and unidentified prey) in Nepal. There are also reports of vegetation or grass in scats (Table 2.2). The species of prey in the scats are identified by direct observation, questionnaires, interviews and analysing scats both microscopically (Oli et al. 1993; Shrestha et al. 2018) and genetically (Karmacharya et al. 2016; Chetri et al. 2017; Shrestha et al. 2018).

There is seasonal variation in the types of prey. In the Sagarmatha (Everest) National Park, Himalayan tahr is the main prey in summer (48%) and less so (37%) in autumn (Lovari et al. 2009). Wild ungulates are the most frequent prey in the cold season (78%) and less so in the warm season (33%) in the Manaslu Conservation Area. In contrast, small mammals/birds are more frequently caught in summer (74%) than in winter (22%) (Chetri et al. 2017). Likewise, in the Sagarmatha National Park (SNP), the most frequent species of prey is Himalayan tahr in both winter and summer, followed by cow and musk deer in winter, and cow and yak in summer; weasel sp. and dog are also consistently recorded in both seasons and some small prey occur

Table 2.2 List of the animals, birds, plants and unidentified items recorded in snow leopard diet

Wild	Common names	Regions and references
Alectoris chukar	Chukor Patridge	Upper Langtang National Park (Chalise 2011), Shey Phoksundo National Park (Devkota et al. 2013)
Cervus sp.	Deer	Nepal (Lovari et al. 2013a)
Equus kiang	Wild ass/Kiang	Upper Mustang (Aryal 2011), Manang and Mustang (Aryal et al. 2014a), Manaslu Conservation Area, Gorkha (Chetri et al. 2017)
Hemitragus jemlahicus	Himalayan tahr	Everest region (Ale 2005), Dhorpatan Hunting Reserve (Aryal 2009), Everest region (Shrestha 2008), Everest region (Lovari et al. 2013a), Upper Langtang National Park (Chalise 2011), Nepal (Lyngdoh et al. 2014), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Chhekampar VDC, Gorkha, Manaslu Conservation Area (Devkota et al. 2017), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Lepus oiostolus	Himalayan woolly hare	Manang and Mustang (Aryal et al. 2014a), Chhekampar VDC, Gorkha, Manaslu conservation area (Devkota et al. 2017), Manaslu, Gorkha (Chetri et al. 2017), Shey Phoksundo National Park (Devkota et al. 2013), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Lepus sp.	Hare	Everest region (Shrestha 2008), Nepal (Lovari et al. 2013a), west Nepal (Shrestha et al. 2019)
Marmot sp.	Marmot	Manang, central Nepal (Oli et al. 1993), upper Mustang (Aryal 2011), Nepal (Lovari et al. 2013a)
Marmota himalayana	Himalayan marmot	Samagaun, Manaslu Conservation Area (Bhattarai 2015), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Chhekampar VDC, Gorkha, Manaslu Conservation Area (Devkota et al. 2017), Shey Phoksundo National Park (Devkota et al. 2013)

(continued)

Table 2.2 (continued)

Wild	Common names	Regions and references
Martes foina	Marten	Manang and Mustang (Aryal et al. 2014a)
Moschus chrysogaster	Himalayan musk deer	Dhorpatan Hunting Reserve (Aryal 2009), Upper Langtang National Park (Chalise 2011), Everest region (Shrestha 2008; Lovari et al. 2009, 2013b), Chhekampar VDC, Gorkha, Manaslu Conservation Area (Devkota et al. 2017), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Moschus sp.	Musk deer	Manang and Mustang (Aryal et al. 2014a), Nepal (Lovari et al. 2013a)
Musela nivalis	Weasel	Manang and Mustang (Aryal et al. 2014a)
Myodes sp.	Voles	Everest region (Lovari et al. 2009), Phu valley, Manang (Wegge et al. 2012), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Nemorhaedus goral	Goral	Dhorpatan Hunting Reserve (Aryal 2009)
Ochotona roylei	Pika/Royle's pika	Dhorpatan Hunting Reserve (Aryal 2009), Everest region (Shrestha 2008), Upper Mustang (Aryal 2011), Shey Phoksundo National Park (Devkota et al. 2013), Manang and Mustang (Aryal et al. 2014a), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Chhekampar VDC, Gorkha, Manaslu Conservation Area (Devkota et al. 2017), west Nepal (Shrestha et al. 2019)
Ochotona sp.	Pika	Langu valley, west Nepal (Jackson and Ahlborn 1988), upper Langtang National Park (Chalise 2011), Phu valley, Manang (Wegge et al. 2012), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Ovis ammon hogs	Tibetan argali	Manang and Mustang (Aryal et al. 2014a), Manaslu Conservation Area, Gorkha (Chetri et al. 2017)

(continued)

Table 2.2 (continued)

Wild	Common names	Regions and references
Procapra picticaudata	Tibetan gazelle/Goa/Tibetan antelope	Upper Mustang (Aryal 2011), Manaslu Conservation Area, Gorkha (Chetri et al. 2017)
Pseudois nayaur	Bharal/Blue sheep	Dolphu region, Mugu (Poudel et al. 2008), Manang, central Nepal (Oli 1993), Dhorpatan Hunting Reserve (Aryal 2009), Upper Mustang (Aryal 2011), Phu valley, Manang (Wegge et al. 2012), Nepal (Lovari et al. 2013a), Mustang (Ale et al. 2014), Mustang (Aryal et al. 2014b), Manang and Mustang (Aryal et al. 2014a), Everest region (Ferretti et al. 2014), Nepal (Lyngdoh et al. 2014), Samagaun, Manaslu Conservation Area (Bhattarai 2015), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Chhekampar VDC, Gorkha, Manaslu Conservation Area (Devkota et al. 2017), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Rattus sp.	House rat	Everest region (Shrestha 2008)
Soriculus sp.	Shrew	Everest region (Shrestha 2008)
Sus scrofa	Wild boar	Dhorpatan Hunting Reserve (Aryal 2009)
Vulpes sp.	Fox	Upper Mustang (Aryal 2011), Nepal (Lovari et al. 2013a)
Vulpes vulpes	Red fox	Everest region (Shrestha 2008), Manang and Mustang (Aryal et al. 2014a), Samagaun, Manaslu Conservation Area (Bhattarai 2015)
Soriculus nigrescens	Himalayan Shrew	Chhekampar VDC, Gorkha, Manaslu Conservation Area (Devkota et al. 2017)
-	Rat spp.	Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
-	Mustelids	Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Unidentified wild	Small mammals	Nepal (Lovari et al. 2013a)

(continued)

Table 2.2 (continued)

Wild	Common names	Regions and references
	Small rodents	Langu valley, west Nepal (Jackson and Ahlborn 1988)
	Unidentified rodents	Manaslu Conservation Area, Gorkha (Chetri et al. 2017)

Domestic	Common names	Regions and references
Bos grunnens	Yak	Manang, central Nepal (Oli 1993), Everest region (Shrestha 2008; Lovari et al. 2013b), Upper Mustang (Aryal 2011), Phu valley, Manang (Wegge et al. 2012), Manang and Mustang (Aryal et al. 2014a), Samagaun, Manaslu Conservation Area (Bhattarai 2015), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Nepal (Lovari et al. 2013a), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018), west Nepal (Shrestha et al. 2019)
Bos sp.	Cow	Everest region (Shrestha 2008), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018), west Nepal (Shrestha et al. 2019)
Bos sp.	Yak	Everest region (Lovari et al. 2009)
Bos sp.	Bovine	Manang and Mustang (Aryal et al. 2014a)
Cannis familiaris	Dog	Everest region (Shrestha 2008), Everest region (Lovari et al. 2013b), Nepal (Lovari et al. 2013a), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Capra sp.	Goat	Dhorpatan hunting reserve (Aryal 2009), Everest region (Shrestha 2008), Upper Mustang (Aryal 2011), Phu valley, Manang (Wegge et al. 2012), Nepal (Lovari et al. 2013a), Manang and Mustang (Aryal et al. 2014a), Nepal (Lyngdoh et al. 2014), Samagaun, Manaslu Conservation Area (Bhattarai 2015), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018), west Nepal (Shrestha et al. 2019)
Equus asinus	Donkey	Nepal (Lovari et al. 2013a)
Equus caballus	Horse	Dhorpatan Hunting Reserve (Aryal 2009), Everest region (Shrestha 2008), Upper Mustang (Aryal 2011), Phu valley, Manang (Wegge et al. 2012), Nepal (Lovari et al. 2013a), Manang and Mustang (Aryal et al. 2014a), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)

(continued)

Table 2.2 (continued)

Domestic	Common names	Regions and references
Myodes regulus	Royal vole	Manang, central Nepal (Oli 1993)
Ovibos sp.	Ox	Manang, central Nepal (Oli 1993), Samagaun, Manaslu Conservation Area (Bhattarai 2015), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
Ovis sp.	Sheep	Manang, central Nepal (Oli 1993), Phu valley, Manang (Wegge et al. 2012), Nepal (Lovari et al. 2013a), Manang and Mustang (Aryal et al. 2014a), Manaslu Conservation Area, Gorkha (Chetri et al. 2017)
Taurus/indicus/Yak hybrid	Lulu cow	Manaslu Conservation Area, Gorkha (Chetri et al. 2017)

Birds	Common names	Regions and references
Lophophorus impejanus	Impheyan pheasant	Chhekampar VDC, Gorkha, Manaslu Conservation Area (Devkota et al. 2017)
Tetraogallus tibetanus	Tibetan snow cock	upper Langtang National Park (Chalise 2011), Shey Phoksundo National Park (Devkota et al. 2013)
	Game birds	Langu valley, west Nepal (Jackson and Ahlborn 1988)
	Birds – Galliformes	Everest region (Lovari et al. 2009)
	Phasianidae	Nepal (Lovari et al. 2013a)
	Birds	Manang, central Nepal (Oli 1993), Dhorpatan Hunting Reserve (Aryal 2009), Upper Mustang (Aryal 2011), Phu valley, Manang (Wegge et al. 2012), Manang and Mustang (Aryal et al. 2014a), Manaslu Conservation Area, Gorkha (Chetri et al. 2017), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)

Plant	Common names	Regions and references
Myricaria rosea	–	Everest region (Lovari et al. 2013b)
Myricaria sp.	Tamaricaceae spp.	Everest region (Lovari et al. 2013b)
	Grasses	Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)
	Vegetation	Dhorpatan Hunting Reserve (Aryal 2009), Lower Mustang, Upper Manang and Sagarmatha National Park (Shrestha et al. 2018)

Unknown	Common names	Regions and references
	Non-food items	Dhorpatan Hunting Reserve (Aryal 2009)

only in summer, whereas in the Annapurna Conservation Area, the main prey is blue sheep in winter and yak and goat in summer. Snow leopard prefers large prey and avoids small prey in summer, but not in winter. In Sagarmatha National Park, wild prey is eaten only in winter (Shrestha et al. 2018).

For snow leopards, medium-large prey weighs 51–75 kg and small prey 2–25 kg (Lovari et al. 2009). The relation between snow leopard and its main prey, blue sheep, in terms of weight was 1:113–181 in 1989–1990 (Oli 1991) and 1:114–159 in 1990–1991 (Oli 1994). In the upper Mustang region, there are 0.86 blue sheep per km^2 and a total biomass of approximately 38,925 kg. This could support nearly 19 snow leopards (1.6 snow leopards/100 km^2) (Aryal et al. 2014b). The density of blue sheep is much higher at Chhekampar VDC, Gorkha and Manaslu Conservation Areas (3.8 animals/km^2) and thus these areas could support more snow leopards (Devkota et al. 2017).

Livestock also makes up an important part of the diet of snow leopards. Domestic animals such as goat, yak and cows are reported as food for snow leopard (Shrestha et al. 2019). Figures have shown that 42% of snow leopard's diet consists of domestic animals in the Phu valley, Manang (Wegge et al. 2012) and 54.54% in the Sagarmatha (Everest) region (Shrestha 2008). Chetri et al. (2017) report that livestock are killed more frequently by male snow leopards (males: 47%, females: 21%) and wild ungulates more frequently by female snow leopards (males: 48%, females: 70%).

2.5 Human-Snow Leopard Conflict and Public Attitude to Conservation in Nepal

Killing of livestock by snow leopards is quite common in Nepal (Ikeda 2004; Shrestha et al. 2012; Wegge et al. 2012; Aryal 2013; Devkota et al. 2017). Generally, during alpine winter (December–April) livestock on pastures is the most vulnerable, especially young calves (1–3 years of age) (Ikeda 2004). They are also more at risk in areas, where there are bushes, forest, boulders, crevices and depressions (Khatiwada and Ghimirey 2009; Sherchan and Bhandari 2017). The losses vary from place to place. In the Lelep VDC, it increased from 17.2% in 2005 to 28% in 2014, whereas at Yampdhudin it decreased from 8.9% in 2005/06 to 6% in 2014/15. Both of these villages are located inside the Kanchenjunga Conservation Area (Sherchan and Bhandari 2017). Annual percentage losses due to depredation by snow leopards ranged from 1.29 to 63%, and the number of domestic animals killed ranged from 12 to 412. Although in the Annapurna Conservation Area (ACA) and the Manaslu Conservation Area (MCA) the predation percentage was low (0.9%), the snow leopard was responsible for more than a half of it (61.9%) (Chetri et al. 2019a; Table 2.3).

The killing of livestock by snow leopards is costly for the herders in Nepal, and most of them favour extermination of snow leopards as the best way to resolve this problem (Poudel et al. 2008; Khatiwada and Ghimirey 2009; Ale 2010). In Rowaling, people have a mixed response towards snow leopards, with over half of

Table 2.3 Animals killed by snow leopard in Nepal (1991–2017). Dash (–) Data not available

Regions	Total loss percentage	Animals killed by snow leopard	Reported by
Manang, Annapurna conservation area, central Nepal	2.6	72	Oli (1991)
Khangshar, Annapurna conservation area, central Nepal	63	200	Jackson (1996)
Chhekampar VDC, Gorkha, Manaslu conservation area	1.29	12	Devkota et al. (2017)
Langtang, central Nepal	31.8	273	Adhikari (2004)
Phu valley, Annapurna conservation area, central Nepal	3.87	–	Conradi (2006)
Sagarmatha National Park	54.4	18	Shrestha (2008)
Humla, West Nepal	–	16	Khatiwada and Ghimirey (2009)
Dolphu, Phoksundo, Vijer and Saldang, Shey Phoksundo National Park	47.33	257	Bhudhathapa (2011)
Phu valley, Annapurna Conservation Area, central Nepal	15.1	159	(Wegge et al. 2012)
Shey Phoksundo National Park, west Nepal	45.6	412	(Devkota et al. 2013)
Manang-Mustang, Annapurna Conservation Area, central Nepal	18.4	–	(Aryal et al. 2014a)
Lower Mustang (LM), Upper Manang (UM) and Sagarmatha National Park (SNP)	–	250 (LM-92, UM-93, SNP-65)	(Shrestha et al. 2018)
Annapurna Conservation Area (ACA) and the Manaslu conservation area (MCA)	61.9	–	(Chetri et al. 2019a)

the livestock owners (57%) with no specific desire to minimize livestock killing by snow leopards and 23% in favour of eradicating snow leopards. Only 10% of the herders favoured mitigation measures, while the rest (10%) believed it could be reduced by performing religious ceremonies (Ale 2010). In the Kanchenjunga Conservation Area, local herders think that if the killing of snow leopards is to be banned, then they should be compensated for their loses and management in terms of reliability, and transparency should be tested before the initiation of such a livestock insurance policy (Ikeda 2004).

Study in the Sagarmatha National Park carried out by Hanson et al. (2018) have examined how local communities that responded to the idea of translocation of the prey species—blue sheep into the Sagarmatha National Park in Nepal to reduce the predation of livestock by snow leopard. The result showed that herders were reluctant because they feared crops would be damaged and competition for pasture more than the loss of livestock.

In the Sagarmatha National Park and the Annapurna Conservation Area, Hanson et al. (2019b) found a high percentage of local people had positive (60.5%) attitudes towards snow leopard, 19.0% were neutral, 16.5% were negative and 4.1% were very negative. Positive attitudes because of cultural and religious values were the most common and negative reasons because of the challenges of coexisting with a predatory species and its real or perceived danger to livestock. Kusi et al. (2019) conducted a survey of people's perception of snow leopard conservation in upper Humla, upper Dolpa, and Kanchenjunga Conservation Area in Nepal. They found that overall attitudes were more positive towards snow leopard than the Himalayan wolf *Canis* sp., which commonly attacks livestock.

In the past, herders often killed snow leopards at Manang (Oli et al. 1993, 1994) and in the Langu valley (Jackson 1979a). However, after the establishment of the Annapurna Conservation Area, the residents at Mustang and Manang became more reluctant to hunt snow leopards for fear of being reported or fined by the government and instead of killing them they chased them away (Jackson et al. 1996). In other places in Nepal, such as in the Langtang National Park (Adhikari 2004) and at Humla (Khatiwada and Ghimirey 2009), retaliatory killing and poaching of snow leopards continues.

Despite the existence of people-snow leopard conflicts, there are also reports of a positive attitude towards snow leopards in the Manaslu Conservation Area, Gorkha (Ale et al. 2014; Devkota et al. 2017). This is because most of the people in this area are Buddhist. They believe that snow leopards are ambassadors of god and that the presence of snow leopards in their area is a matter of dignity. Traditionally, killing and hunting is strictly forbidden in the restricted zone. If anyone uses violence against snow leopards, this goes against their social norms, and must be punished by Lamas (local priests).

Recently, Schutgens et al. (2018) surveyed willingness to pay for conservation of snow leopard in the Annapurna Conservation Area, Nepal. Out of 406 foreign tourists, it was found that 49% of visitors stated that they would pay additional fees for conservation of snow leopard. However, the majority of visitors were unwilling to pay additional fees, as they thought that the fee paid to the Conservation Area was already expensive. Similarly, tourists also expressed their views in supporting snow leopard conservation in Annapurna Conservation Area, Nepal. This shows that wildlife tourism could be employed as an important tool to conserve snow leopard (Hanson et al. 2019a).

2.6 Threat and Trade in Nepal

The threats in the Dolphu region and Shey Phoksundo National Park are due to weak enforcement of the law, unregulated livestock grazing and human pressure. Moreover, there is a great human pressure on snow leopard habitat, especially during the collection of *Ophiocordyceps sinensis* (formerly known as *Cordyceps sinensis*) *or yartsa gunbu* (Poudel et al. 2008). Decrease in natural prey and increase in the use of alpine pastures by humans and their livestock in the Langu valley also threatens the survival of snow leopards (Jackson 1979a). Livestock and wild ungulates spatial overlap and grazing competition are responsible for habitat degradation (Shrestha 2006; Shrestha et al. 2012). Depletion of its prey population (such as blue sheep, Himalayan tahr, Himalayan musk deer) is the main reason for the decrease in the abundance of snow leopards (Kyes and Chalise 2005; Chalise 2011; Ferretti et al. 2014). Deforestation, habitat fragmentation, unmanaged use of pastures and tourists (Adhikari 2004; Upadhyay 2010), along with hunting and killing snow leopards for their pelts and bones, which can be sold for high prices (Jackson 1979b; Jackson and Ale 2009), are the main threats to snow leopard survival. In addition to this, Khanal et al. (2018) found that human disturbance and habitat degradation associated with extraction of non-timber forest products, livestock grazing and poaching are major threats to snow leopards in the Api Nampa Conservation Area (Khanal et al. 2018).

There is no formal record of snow leopards' skin and bones trade in Nepal that was mainly carried out by Kashmiri traders in Kathmandu until 1980. Despite the increase in the publicity directed at conserving snow leopards, this trade continues, but surreptitiously. Currently, there is a trade of body parts of snow leopards and tiger bones with Tibet, but no evidence of a trade of live animals (Dexel and Deutschland 2002). Recently, during a monitoring of data for snow leopard from 2003 to 2014, Maheshwari and Niraj (2018) showed that in Nepal there were five cases of trade of snow leopard parts. Of the 5 cases, 3 were recorded in the literature and 2 were based on questionnaire surveys.

2.7 Conservation Measures in Nepal

In Nepal, snow leopards are legally protected under the National Parks and Wildlife Conservation Act 2029 (HMGN 1973). The fourth amendment of this Act 2049 (HMGN 1993) defined the penalties for poaching snow leopards, or acquiring, buying and selling their pelts (Kharel et al. 2001). The penalty is either a fine of Rs. 50,000–100,000 or a prison sentence of 5–15 years, or both. There are also meetings between governmental and non-governmental agencies with an interest in or jurisdictional responsibilities for wild life legalization in this country, which have also boosted interest in conservation (Heinen et al. 1995). The holistic integrated programs launched by the Department of National Parks and Wildlife Conservation (DNPWC), The National Trust for Nature Conservation (NTNC) (previously the King Mahendra National Trust for Nature Conservation, KMTNC), World Wide Fund For Nature in Nepal (WWF Nepal), International Centre for Integrated Mountain Development (ICIMOD), Snow Leopard Conservation Committees (SLCC), etc. have also contributed to the conservation of snow leopards in Nepal (Ale and Karky 2002). It is also proposed that prey, such as blue sheep, should be translocated (Aryal et al. 2013), and corridors between different national parks (for example, Makalu Barun and Sagarmatha) maintained (Ale 2010) in order to protect snow leopards. The Government of Nepal has outlined snow leopard conservation plans (2005–2015 and 2011–2021) aimed at consolidating ongoing initiatives and addressing contemporary issues and challenges of snow leopard and their habitats conservation (GoN/DNPWC and WWF Nepal 2013; GoN/DNPWC 2017).

The first community-based Livestock Insurance Scheme (LIS) was initiated in KCA with the support of WWF Nepal in order to mitigate human-snow leopard conflict in 2006 (GoN/DNPWC 2017). This policy aims to compensate affected households for the loss of their livestock caused by snow leopards (Anonymous 2017) and is regulated by the Snow Leopard Conservation Committees (SLCC) in the area. The intention is to enable people to cope with the situation and so reduce the retaliatory killings of snow leopards (Anonymous 2017; WWF Nepal 2007). The government of Nepal has also formulated the 13th plan (2013/14–2015/16) covering the agriculture/livestock development policies, which formalizes the provision of insurance for loses of livestock and agriculture produce (Pradhanang et al. 2015). It is thus necessary to expand LIS to all the places where human-snow leopard conflicts occur.

2.8 Future Perspectives

In Nepal, snow leopards are well established in the northern part of the country in an area of 30,000 km^2 at altitudes between 2900 and 6000 m. Despite the remoteness and inaccessibility of the habitats of snow leopards they are relatively well studied in Nepal. The first studies were of their home ranges and movements. The objectives of the studies gradually changed with the advent of camera traps and genetic analysis. However, there is a constant need for development of new and improved methods, as those available today are often not able to determine the gender of snow leopards (Conradi 2006). A considerable number of studies highlight that the killing of livestock by snow leopards results in herders often having a negative attitude towards snow leopards, which leads to retaliatory killing and contributes to the decline in their abundance. The livestock insurance policy, which was initiated in the Kanchenjunga Conservation Area in eastern Nepal, is a milestone in the increase of awareness and development of positive attitudes towards snow leopards, which will ultimately protect them. As most effective conservation measures involve community-based participation, it would be a great achievement if local people could be trained to record marks and store scat or hairs in local repositories prior to making them available to ecologists. This new, but not yet practiced approach could be an important part of public awareness programs.

Studies on snow leopard diet reveal that it feeds on relatively few animals and depends on the availability of small mammals, birds or even livestock. Thus, it is important to protect those areas where the natural prey of snow leopards occurs. Local community-based programs that result in people not killing animals, as at Gorkha (Devkota et al. 2017), is one method of improving the conservation of snow leopards. Other community-based programs, which could help in their conservation, are field patrols, provision of livestock insurance, construction of predator-proof night time corrals and other means of protecting livestock, managed livestock grazing and establishment of a conservation-based tourism program to bring additional income to local communities.

Recording of reproduction, diseases and real time movements of snow leopard using satellite based global positioning system (GPS) are yet to be explored in Nepal. Illegal killing and poaching for trade are important issues yet to be addressed. Competition with other animals for food and habitat (Lovari et al. 2013a), or a simple comparison of the past and present abundance of snow leopards or their prey are also lacking in Nepal (Ghoshal et al. 2017). As emphasized above it is also important to take into account in-situ conservation and minimize conflict while promoting a positive attitude towards snow leopard (Lama et al. 2020).

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Chapter 3
Methods of Estimating Snow Leopard Abundance

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Abstract To optimize the conservation strategies of snow leopard, it is necessary to know its distribution within an area and relative abundance in different habitats (Sheng et al. Biodivers Conserv 19:3195–3206, 2010). Its secretive lifestyle makes this quite difficult. Estimation methods of snow leopard abundance include search for signs of their presence, capture-recapture, predator-prey biomass ratios, photographic-capture rate and genetic analyses (McCarthy et al. in J Wildl Manage 72:1826–1833, 2008). There was no photograph of a snow leopard taken in the wild until 1980 (Schaller in Stones of silence: journeys in the Himalaya. Viking Press, New York, 1980). A huge step forward came with the availability of camera traps, which have replaced live-capture (direct capture of an animal), which is almost impossible because of the very low rate of a face-to-face encounter: about 3/1000 trap-nights (McCarthy et al. in J Wildl Manage 72:1826–1833, 2008). Thus, for those who wish to obtain data on snow leopard population dynamics, or at least on its distribution in an area, it is important to know, which method is the most appropriate in his/her case. To help people in this decision, we give an account of the methods used for estimating snow leopard abundance. The chapter is adapted from Valentová (Eur J Environ Sci 7: 73–93, 2017).

3.1 Sign Surveys (SLIMS)

Snow Leopard Information Management System (SLIMS) has been developed just recently to monitor the abundance of snow leopard and its prey (Jackson and Hunter

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1996). This system is based on standardized sign surveys, which are used regularly. Sign surveys result in indices of relative abundance of snow leopards, which can be used to compare areas with similar topographies (Ale et al. 2014). This method is being used to monitor trends in abundance in the same area over a longer period of time. However, it needs to be complemented by additional methods, for example by genetic analyses (e.g., Janecka et al. 2008) or remote cameras (e.g., McCarthy et al. 2008). SLIMS is not expensive and it minimally affects studied species, which makes it the most commonly used method for monitoring snow leopards (Schaller 1977, 1998; Wilson and Delahay 2001; Wolf and Ale 2009). Most of ecological problems can be tackled only with the help of indices of density, and therefore the usage of absolute estimates of density is not really necessary (Caughley 1977). Therefore, SLIMS may be sufficient enough in most of the cases.

The estimated number of snow leopards based on sign abundance follows Jackson and Hunter (1996): 20 signs per kilometre indicates 10 individuals per 100 km^2—a crude method which is quick and easy-to-use, and which has been therefore useful particularly in conservation planning in countries with low resources (Ale et al. 2014). An adult snow leopard female is assumed to have a minimum home range of 25 km^2, which also represents the appropriate minimal space out for the camera installation—1 camera per 25 km^2 (Jackson and Hunter 1996; Ale et al. 2014).

To identify transect locations for the sign survey, it is inevitable to hike through the region and detect all sites with suitable snow leopard habitat, and terrain and locations where its prey occurs. As Ale et al. (2014) did in Nepal, it is important to identify narrow valleys, trails, ridgelines and cliff-edges which are often being used by snow leopards to move around its territory (Jackson and Hunter 1996). For location of these sites, it is helpful to use 1:50,000 topographic maps, as used by Ale et al. (2014) or the 1:100,000 topographic maps used by McCarthy et al. (2008) in Kyrgyzstan and China.

After locating transects (sites with high probability of snow leopard occurrence), the transects are searched for signs of snow leopards. In addition, to provide useful information for comparison with that gathered along sign transects, it is possible to record signs between transect lines (McCarthy et al. 2008). Snow leopard presence signs include pugmarks (footprints), scent (or spray) marks, faeces, scrapes and rocks or boulders that are used by snow leopards to deposit their scent or cheek-rub (Ale et al. 2014). Even though scrapes and scent marks may give us more biological and ecological information than faeces and pugmarks, they are also more expensive to detect (Schaller 1977, 1998). The monitoring of scats may be strongly biased, because genetic analyses reveal that more than 50% of the scats collected, which looked like snow leopard scats, in fact belonged to other carnivores, such as red fox etc. (Janecka et al. 2008; Shrestha et al. 2018). Similarly, footprints are hardly visible when the trail is dry and hard, and are difficult to detect during heavy rainfall (see Chap. 4).

Following information gathered through surveys conducted in the Mustang District of Nepal's Annapurna Conservation Area (Table 1.2), most frequently are detected scats and scrapes, and scent sprays and pugmarks are detected less often. According to Ale et al. (2014), the highest probability of finding signs is in spring

(10.2 signs/km) and the lowest is in summer (2.1 signs/km), which may be due to snow leopard and its prey, blue sheep, moving to higher locations, which are less accessible to observers (Jackson and Hunter 1996; Oli and Rogers 1996). Another possible explanation is presence of livestock in summer, which leads to obliteration of snow leopard signs (Ale et al. 2014). To better compare the effectiveness of sign surveys in different seasons, sign surveys during summer and spring should be conducted in other countries as well. In case such surveys show that the probability of finding signs is consistently higher in spring, then it might be sufficient to conduct just spring surveys.

For estimates of predator numbers using SLIMS, a standard methodology should be used, e.g., for comparison of sign transects between various areas, unit transect lengths should be compared (Ale et al. 2014). Reduction of observation bias is also necessary. One of the options to achieve that is to allow all observers to obtain the same training. This avoids disagreements over what constitutes a snow leopard scrape, as differences in the determination of scrapes by different observers can lead to erroneous results (McCarthy et al. 2008). Environmental conditions of the surrounding (e.g. snow cover) and accessibility of the terrain can also have an effect on the results. With respect to the latter, in Qinghai (China), snow leopards mark the bases of hills flanking broad valleys, where their travel routes cannot be easily accessed (Schaller et al. 1988; Ale et al. 2014). Also in the Himalayas, where wide U-shaped valleys and broad ridges are common, it is difficult to find signs of snow leopard (Jackson and Hunter 1996). Therefore, to avoid observation bias, sign surveys are only useful for comparison of the abundance index over a long period in the same place.

3.2 Predator-Prey Biomass Ratio

Predator-prey models of population dynamics predict a negative feedback between prey and predator biomass (Fuller and Sievert 2001; Carbone and Gittleman 2002). An observation at Sary Chat in Kyrgyzstan indirectly supports this, as there is a decrease of snow leopard abundance, followed by an increase of abundance of ungulates (McCarthy et al. 2008). This provides a basis for another method—estimation of the size of snow leopard populations, the predator-prey biomass ratio, from which the abundance of snow leopard can be estimated if one knows the biomass of prey (Fuller and Sievert 2001; Carbone and Gittleman 2002), which is estimated using SLIMS (Jackson and Hunter 1996).

To measure the number of snow leopard prey, it is vital to select an advantageous point at each site, from which the animals will not be disturbed and from which it will be possible to effectively localise and determine group size, and age and sex of each individual (McCarthy et al. 2008). Binoculars and spotting scopes are appropriate equipment for the observations. Following the observation, the total biomass of prey is calculated by multiplying the number of animals observed by the average weight of the prey (Fedosenko and Blank 2001). Ungulate biomass per 100 km^2 can then be recalculated to leopard biomass by a simplified conversion factor of 10,000 kg prey for 90 kg of predator (Carbone and Gittleman 2002), which can be converted to numbers using an average weight for snow leopard of 50 kg (McCarthy et al. 2008). However, competition for food with other predator species (for example wolves) can bias the predator-prey ratio (McCarthy et al. 2008).

A more sophisticated method proposed by Aryal et al. (2014) is that of the maximum number of snow leopards that can be supported by the prey available (its carrying capacity, K), which is calculated as

$$K = \frac{A}{ESSR \times AHRS}$$

with:

$$ESSR = \frac{PBY}{PD \times SUF \times BD \times EHD}$$

where:

A	area;
AHRS	average home range size (about 22.6 km^2/individual);
ESSR	ecological sustainable stocking rate;
PBY	prey biomass/snow leopard/year (~548 kg/year, 1.5 kg/day-Schaller 1977);
PD	total prey biomass/km^2;
SUF	safe use factor—the total biomass production of the ecological site that is available for use by animals with the remaining biomass available for ecological sustainability (Alberta Sustainable Resource Development 2004; Aryal et al. 2014); in Nepal, Aryal et al. (2014) used 25% for SUF due to the presence of other predators (lynx, red fox, jackal, wolf); it means that snow leopards can consume just 25% of the total sheep population and the rest is available to other predators;
BD	birth:death, for instance for blue sheep in Nepal it is presumed to be 2:1, based on the estimate that 50% of blue sheep die between birth and 2 years of age in the Dhorpatan Hunting Reserve (Schaller 1977; Wegge 1979);
EHD	environment and human disturbance factors in the habitat (poaching, livestock grazing) where the grassland is that sustains the prey: predator population; e.g., the Upper Mustang in Nepal has a lower young-to-old male ratio than Lower Mustang due to its lower productivity (Ale et al. 2014); productive grasslands are expected to have a higher proportion of young males while the opposite would be the case for ungulate populations on degraded grasslands (Ale et al. 2014).

3.3 Genetic Analyses

For estimation of snow leopard abundance, there is a promising method of genetic analysis of faecal DNA (McCarthy et al. 2008) and with a better-developed format for scat collection we could achieve a better understanding of territoriality or marking behaviour. Genetic analyses represent the only available method providing an information about genetic relationships, including the source of dispersers (Gese 2001; McCarthy et al. 2008). The fact that they are based on using specialized equipment and prior training is another advantage, which helps us to avoid situations where estimates are subject to observer bias (McCarthy et al. 2008). Genotyping of faeces may generate a higher number of known individuals than visual discrimination based on photographs, and simultaneously provide minimum population estimates. For instance, for Sary Chat, Jangart, and Tomur the estimates based on photographs were 3, 5 and 9 individuals respectively, while those based on genotypes were 9, 9 and 17 (McCarthy et al. 2008).

However, these methods have a significant disadvantage, which is their price (about US $50–225 for one sample), and also logistics of transporting faecal material between countries can be complicated (McCarthy et al. 2008). A possible solution to the high costs would be processing the genetic data in laboratories located within the country of sample collection. Shrestha, one of the authors of this chapter, not only conducts field studies in Nepal, but he also processes collected samples in a local laboratory in Kathmandu and later works on a further analysis with his colleagues in Prague. Nevertheless, it would be surely more effective if it were possible to send the samples to other countries.

In any case, in order to use genetic analysis to monitor the snow leopard, it is necessary to collect samples first. For example, McCarthy et al. (2008) while studying snow leopards in China and Kyrgyzstan received their samples of suspected snow leopard faeces from SLIMS determined study areas. Another way to develop a more accurate method of sampling is to use scent pads or hair samples from cheek rubbing (Weaver et al. 2005). It is important to minimize samples, which do not belong to snow leopard by selecting them according to their shape, location and size. Following McCarthy et al. (2008) contamination can be avoided by collecting faecal samples using plastic spoons, and then storing them in individual 5-ml transport tubes containing 4 ml of 90% ethanol. This process should be also done wearing latex gloves. In general, to prevent errors in scat collection, it is appropriate to obtain samples of scrapes to increase certainty that it is a snow leopard sign. After sample collection, DNA extraction is carried out in a laboratory and the polymerase chain reaction (PCR) is set for a low-quantity of DNA in the samples. For DNA extraction, it is possible to use stool kits, e.g., the Qiagen stool kit (Qiagen Inc., Valencia, CA) and protocols inclusive of negative controls to monitor for contamination. After PCR, the sample of an approximately 160–base-pair section of the cytochrome B gene of the mitochondrial DNA control region is sequenced (McCarthy et al. 2008). Stated primers and formerly published methods are used to identify which species deposited each faecal sample, (Farrell et al. 2000; Onorato et al. 2006). To distinguish individual snow leopards, it is important to use as many primers (polymorphic microsatellite loci) as possible. McCarthy et al. (2008) used 10 polymorphic microsatellite loci to identify individual snow leopards.

3.4 Camera Traps

Camera trapping has been widely used in studies on birds and mammals (Cutler and Swann 1999). It is used to estimate presence/absence (Foster and Humphrey 1995; Whitefield 1998), population characteristics (Karanth 1995; Karanth and Nichols 1998), daily activity patterns (Pei 1998; Azlan and Sharma 2006; Sathyakumar et al. 2011) and abundance (Carbone et al. 2001; O'Brien et al. 2003; Rowcliffe et al. 2008) of animals. Camera trapping is a non-invasive method (Mace et al. 1994; Karanth 1995; Karanth and Nichols 1998; Carbone et al. 2001; Mackenzie and Royle 2005) for monitoring cryptically living animals, such as snow leopard, and population studies of those species whose individuals can be recognized by their markings (Karanth 1995; Carbone et al. 2001; Sathyakumar et al. 2011). It is more dependable than other methods when sample sizes are small and species are scarce (Carbone et al. 2001; Sathyakumar et al. 2011). Karanth et al. (2002) and Henschel and Ray (2003) provide detailed methods for camera trapping in the case of estimating the densities of tigers (*Panthera tigris*) and leopards (*Panthera pardus*). Camera trapping also shows better sustainability for local teams, including protected areas staff, for carrying out surveys independently and sustainably over a longer period of time (Alexander et al. 2015).

Nevertheless, there are also limitations. Camera traps are difficult to use in areas with dense vegetation, steepness or located at great distances (Sathyakumar et al. 2011). For instance, Sathyakumar et al. (2011) used infrared sensor camera units with high sensitivity which resulted in capturing wind-caused movement of vegetation, which led to many photographs of vegetation. Even in bad weather, such as heavy rain or extremely low temperatures, camera traps sometimes fail.

A "photo event" is defined as any photo or set of photographs of a snow leopard at a photo-trap site, even if it is not possible to identify the individual (McCarthy et al. 2008). Wilson and Anderson (1985) define photographic rate as an index of relative abundance (RAI), calculated as the number of photographs of a species divided by the number of trap-days per site (in most cases 100 trap-nights). To ensure more accurate results, individuals captured more than once within one hour by the same camera trap should be counted as one photograph (Bowkett et al. 2007; Sathyakumar et al. 2011). The number of trap-nights depends on the number of cameras and on the number of days they are operated. For instance, McCarthy et al. (2008) conducted a survey spanning 1078–1180 trap-nights in each area. In most cases, cameras are oriented towards the south or north to minimize the effect of sunlight. In general, the first choice for camera trapping are marking sites along suspected snow leopard trails, e.g., along high, well-defined and narrow ridgelines or valley bottoms, or immediately adjacent to frequently scent-sprayed rocks and scrapes (Jackson et al. 2006; Ale et al.

2014). Camera sites are then usually arranged about 2 km from each other in a circular pattern, 45–50 cm above the ground, with a 90-s delay between photographs, as in McCarthy et al. (2008). An infrared sensor is an advantage (Sathyakumar et al. 2011). Distinct patterns of spots on the photographed snow leopards' fur helps to identify individuals (Jackson et al. 2006; Ale et al. 2014).

3.5 Capture-Recapture Method

The camera capture-recapture method is considered to be a feasible way of estimating densities of individually recognizable animals with large home ranges and low densities, so it is especially suitable for snow leopard (Silver et al. 2004; McCarthy et al. 2008). The data are analysed using individual capture histories to estimate abundance and area sampled (Sharma et al. 2014; Alexander et al. 2015). However, very low densities can cause this method to be vulnerable to logistical constraints (McCarthy et al. 2008). There are two analytical methods for estimating density of snow leopards: (i) buffering capture locations to obtain size of effectively sampled area and (ii) spatial explicit capture-recapture method.

3.5.1 Buffering Capture Locations to Obtain Size of Area Effectively Sampled

There are several methods on how to create a spatial buffer of potential capture locations to cover the effective area sampled (Fig. 3.1, McCarthy et al. 2008). One of them is the mean-maximum-distance-between-recaptures, formulated based on capture-recapture of small mammal populations (Wilson and Anderson 1985). This theory is often criticised in the literature (McCarthy et al. 2008), because its dependability is thought to decrease with decline in trap rate and increase in the size of the home range (Wilson and Anderson 1985). Another method is to use maximum distance between recaptures for creating the buffer (O'Brien et al. 2003).

A third method is the use of the average minimum reported home-range size or average home-range size of the species (Otis et al. 1978). It is rather difficult to estimate the size of the home range, because it depends on the accessible food biomass. Standard home range size is about 22.6 km^2/individual. Another limitation is that in some areas the data of snow leopard occurrence are not available. As a good example serve the Tien Shan Mountains (McCarthy et al. 2008).

Home range size of carnivores is often inversely correlated with prey biomass (Fuller and Sievert 2001). Due to this fact, we should take into account ungulate densities (Table 1.1) and fit the data by linear regression. McCarthy et al. (2008) calculate the effective study area according to the methods described above (Fig. 3.1): mean maximum distance moved between recaptures, half mean maximum distance moved

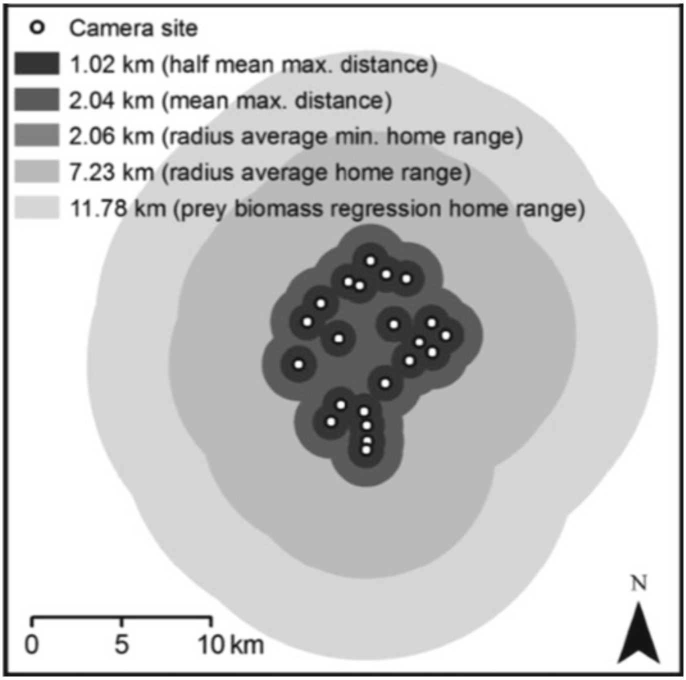

Fig. 3.1 Effective study-area buffers for snow leopard around camera-trap sites in the Jangart Hunting Reserve, Kyrgyzstan, 2005. *Source* McCarthy et al. (2008)

by recaptured animals, radius of the average minimum home range or average home range, and radius of the estimated home range from ungulate densities (McCarthy et al. 2008).

By choosing one of these methods, the density estimates can be considerably altered (McCarthy et al. 2008). Total area covered by cameras and size of the effective area of buffer circles are used for density calculations (McCarthy et al. 2008). However, the drawback of this method is overestimation of density when the effective sampled area is small. There may also be methodological issues when the study areas are very small relative to the size of the home range of the animal (Suryawanshi et al. 2019). These disadvantages are demonstrated both statistically (Efford 2004; Efford et al. 2009) and empirically (Soisalo and Cavalcanti 2006; Sharma et al. 2010).

3.5.2 Spatial Explicit Capture-Recapture Method (SECR)

SECR models were developed relatively recently (Efford 2004; Borchers and Efford 2008; Royle and Young 2008; Borchers 2011) and are currently widely used for the analysis of capture-recapture data, especially of those based on camera trapping, DNA methods and other recently used technologies (Royle et al. 2015). SECR are used to analyse encounter location data to study spatial aspects of animal populations. It is a unified framework for inference about density and probability of using a pixel (space usage) relative to a mean altitude pixel (Borchers and Efford 2008; Royle et al. 2009, 2013).

3.6 Biotelemetry (Global Positioning System, Collaring and Radio Collaring)

Biotelemetry is used to obtain detailed information about animals that are not easily observed (Jackson et al. 2004). Biotelemetry helps us to better understand the patterns of movement and factors affecting the distributions of animals, their home range, patterns of habitat utilization, social organization and habitat preferences (Jackson 1996; Schofield et al. 2007). This information is important for behavioural ecology and management, and conservation of protected areas (Schofield et al. 2007). For snow leopard, we use tracking, radio and satellite transmitters (Global Positioning System, GPS). Both methods are based on receiving data or signals from the transmitter attached to a collar around the animal's neck.

Both these methods are considered to be invasive due to the fact that for fitting the collar, the animal must be firstly trapped, which requires special skills and can sometimes be even dangerous for the animal (Jackson 1996; Jackson et al. 2004). According to Jackson (1996), the most effective trapping locations are places where vegetation, boulders and other physical structures constrain the movement of snow leopards to a natural trail less than 0.5 m wide and where an abundance of fresh snow leopard scrapes and related signs indicate recent visits and ongoing marking activity. The immobilized animals are usually weighed, measured, tattooed inside one ear with an identifying number and fitted with a radio-collar (Jackson 1996).

Telemetry is about one order of magnitude more costly than camera trapping due to the labour and equipment needed (Jackson et al. 2004). Their use is often forbidden along national borders and in other politically sensitive areas, which include a large proportion of the snow leopard's range (Schofield et al. 2007).

Radio tracking is based on the transmission of pulses of radio frequency by radar systems and measuring the time that they take to be reflected back (McEwan 1995). This time is a measure of the distance from the radar unit to the reflecting objects (McEwan 1995). Highly directional antennas allow such transmissions and signal reflections back to be narrowly focused, so that the direction of such reflective objects can also be estimated (McEwan 1995). There are several places where radio telemetry has been used, such as in Nepal (Oli et al. 1994), India (Chundawat 1990, 1992; Chundawat et al. 1988) and Mongolia (Schaller et al. 1994). However, there are also limitations in produced results of these studies due to small sample size (1–3 individuals) or short monitoring periods that are never longer than 3 months (Jackson et al. 2004). First in-depth study using radio telemetry was conducted by Rodney

Jackson in Nepal in the1980s. During 1994–1997, McCarthy et al. (2005) surveyed snow leopard movements and activities based on year-round radio-monitoring in the Altai Mountains in south-western Mongolia. Home ranges were determined to be at least of 11–13 km^2 in size (McCarthy et al. 2005). However, using this method in an environment typical for mountainous, rocky terrain brings also some disadvantages and complications as such environment may affect the propagation of radio-waves and the range of reception due to radio-wave attenuation, signal bounce and deflection (Amlaner and MacDonald 1980; Jackson 1996).

Currently, the GPS method is preferred over the radio telemetry due to its greater accuracy. By matching the animal's GPS coordinates with a habitat map using satellite images or aerial photographs and ground-truthing, the researcher is able to determine habitat features or conditions that are most important for feeding, resting or breeding (Jackson et al. 2004). Along with data on average home range size and prey densities, scientists are able to better estimate snow leopard population size and density (Jackson et al. 2004). In 2013, in Mongolia, for the first time a mother snow leopard and her cubs were located using GPS collars and remote camera traps (Noras 2015). The Snow Leopard Trust team collared a female snow leopard and its sub-adult offspring and was able to monitor the movement of the mother and cub, and observe when and how the young cat became independent (Noras 2015).

3.7 Comparison of the Methods Used for Estimating the Population Density of Snow Leopards

For a rigorous comparison of the abundance of snow leopards, it is necessary to gather data for all of its habitats, as currently there is no such data available. Studies conducted in different snow leopard habitats are not methodologically consistent. The reasons may be objective, e.g., differences between habitats can cause difficulties in collecting data, or the same method might not be feasible due to the differences in snow leopard densities. At high densities (4–8 individuals/100 km^2), lower standard errors and an area that can be studied for a long period of time make it feasible to use the camera capture-recapture method, as in Hemis National Park, India (Jackson et al. 2006; McCarthy et al. 2008).

In areas with very low densities and little prior knowledge of snow leopard behaviour, a short period of time (usually about the 7-weeks) might not be sufficient enough to obtain necessary data for a viable capture-recapture modelling (Karanth et al. 2002; McCarthy et al. 2008). This leads us to the suggestion that the camera capture-recapture method is unreliable, when used where home ranges fluctuate in size and the capture rate is very low (McCarthy et al. 2008). Biotelemetry represents another valuable method for gathering of detailed information on the spatial dynamics of individuals. Currently, it is more common to use GPS collars over the radio collars, due to their higher reliability. However, great issues come with subsequent GPS tracking and to it related significant costs and logistic challenges. From this point of view, use of this method is only possible in countries with a high per capita income or with external support from international organizations.

In cases where determination of the densities does not play such a vital role, it is possible to use sign surveys or photo rates. According to McCarthy et al. (2008), these two methods provide a valid index of snow leopard abundance, because the results are similar to the genetic results. On the contrary, the estimates resulting from predator-prey biomass ratios and capture-recapture are not in accordance with other estimates of abundance.

As already mentioned above, non-invasive genetic analyses provide us with accurate estimates of densities, therefore they are more appropriate to use. Their results are not subject to observer bias, as are other methods, for instance erroneous identification of scats. For example, in the genetic study of Janecka et al. (2008) in Mongolia, up to 60% of all scats that were attributed to snow leopard in fact belonged to red fox (*Vulpes vulpes*).

From our point of view, the best way of estimating snow leopard abundance depends on the aims of the study and available resources (budget and labour). For example, sign survey might be appropriate for designing a short-term (ad hoc) conservation plan using occupancy modelling. To determine the trend in population density or population dynamics for a long-term term conservation plan, a rigorous database is necessary, which can be obtained by camera trapping or genetic analysis using SECR analysis.

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Chapter 4
A Key for Identifying the Prey of Snow Leopard in Nepal Using Features of the Structure of the Hair of Their Prey Present in Their Faeces

Bikram Shrestha, Soňa Vařachová, and Pavel Kindlmann

Abstract Large carnivores like snow leopard are solitary and elusive species, which makes observing their hunting and feeding behaviour difficult. In addition, small prey are completely consumed and it is not easy to determine where they were killed (Oli et al. in J Zool Lond 231:365–370, 1993). However, as the hair of prey is not damaged during mastication and digestion and is passed in the faeces of predators, it could be a reliable way of identifying their prey. Since the end of the nineteenth century there have been a number of publications on the microstructure of the hair of mammals. However, there are only a few such publications (Oli et al. in J Zool Lond 231:365–370, 1993; Khatoon, Diet selection of snow leopard (Uncia uncia) in Chitral area, Arid Agriculture University Rawalpindi Pakistan, M. Phil, 2010; Anwar et al. in Pak J Zool 44:737–743, 2012) that are on the prey of snow leopard, and therefore there is a lack of detailed information. The aim of this chapter is to provide details of the microstructure and measurements of hair of Himalayan mammals collected in snow leopard habitats in Nepal, and digital photographs of the medulla, cuticle (scales) and cross-sections of the guard hairs that can be used to identify the prey of this predator.

4.1 Introduction

The first reference to the identification of hair is that of Brewster (1837), who describes the microscopic structure of the hair of moles and Quekett (1844) that of bats. This was followed by Browne (1860: in Brothwell and Spearman 1963) and

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Pruner-Bey (1877) who examined the hair of mummies, and McMurtrie's (1886) scientific paper on mammalian hair. Thereafter, there were many publications on the microstructure of animal hairs (Hausman 1920, 1924, 1930; DeBoom and Dreyer 1953; Day 1966; Dreyer 1966; Brunner and Coman 1974; Koppikar and Sabnis 1975; Stuart 1976; Perrin and Campbell 1979; Keogh 1983; Teerink 2003; Debelica and Thies 2009; Cornally and Lawton 2016) in wildlife, veterinary, forensic and medical studies on taxonomy, carnivore food habits, epidemiology etc. However, there are only a few publications (Oli et al. 1993; Khatoon 2010; Anwar et al. 2012) on the microstructure of the hair of prey of snow leopard and no detailed information on the measurements of its microscopic characteristics.

This information could elucidate population dynamics in terms of trophic ecology. Predator hunting behaviour and prey selection affect the population dynamics of their prey, which in turn affects the population dynamics of these large carnivores. Therefore, our understanding of their trophic ecology and foraging strategies is important for predicting their population dynamics and consequently for developing effective conservation programs (Shrestha et al. 2018). However, large carnivores like snow leopard are solitary and elusive species, which makes it difficult to observe their hunting and feeding behaviour. Moreover, small prey is completely consumed, and it is not easy to detect their kill sites (Oli et al. 1993). Only hair remains undamaged after mastication and digestion because of its high content of cysteine-containing keratin and dead keratinocytes. These components make the hairs resistant to post-mortem changes and chemical decomposition (Harkey 1993; Knecht 2012), which means the hairs can be identified (Oli et al. 1993).

Each hair consists of a hair root located below the surface and a shaft above the surface of the skin. The hair root is embedded in the dermis of the skin in a hair bulb. The bulb surrounds the hair papilla and contains blood vessels and nerves that nourish and maintain the root, which adds new cells to the shaft of the hair which extends above the skin. The cells in the shaft become keratinized, hard and soon die, so that the hair protruding above the skin is a dead structure. Typically, the hair shaft consists of three layers: an external cuticle made up of overlapping microscopic scales, cortex containing shrivelled cells and pigments, and inner medulla consisting of many shrunken and variously arranged or a lattice of cells (web or mesh like structure). The mammalian coat is composed of guard hairs, which are long, stiff and also determine the normal texture of the body, and fur that is thin, soft and usually undulating in appearance and also has a smaller taxonomic value (Debelica and Thies 2009; Chakraborty and De 2010).

This chapter provides details of the microstructure and measurements of parts of the hair shaft (medulla and cuticle) of Himalayan mammals collected in snow leopard habitats in Nepal. In addition to the digital photographs of the medulla, cuticle (scales) and cross-sections of guard hairs and the description of the characteristics of hair, a key for identifying hair is provided.

4.2 Hair Collection, Preparation and Identification

The identification of hair is based on a reference collection of hair, microscopical preparations of hair and an identification key.

4.2.1 Reference Collection

Samples of hair (guard hairs) were collected from all of the potential mammalian prey (wild and domestic) of snow leopard in three areas, mainly in the Sagarmatha National Park and Annapurna Conservation Area (Lower Mustang and Upper Mustang), during a field study of the diet of snow leopard in 2006 and 2007 (Shrestha 2008; Shrestha et al. 2012), and during 2014–2016 (Shrestha et al. 2018). Entire tufts of hair from different parts of the body of live animals and carcasses were collected at hunting sites. Reference hairs for 15 species of prey were collected, among which 10 were wild species: Himalayan tahr (*Hemitragus jemlahicus*), blue sheep (*Pseudois nayaur*), musk deer (*Moschus chrysogaster*), snow leopard (*Panthera uncia*), red fox (*Vulpes vulpes*), woolly hare (*Lepus* sp.), Mountain weasel (*Mustela* sp.), shrew (*Soricidae*), rat (*Rattus* sp.), and pika (*Ochotona*) and 5 domestic animals: yak (*Bos grunniens*), dog (*Canis lupus*), cow (*Bos* sp.), horse (*Equus* sp.), mountain goat (*Capra* sp.).

4.2.2 Microscopical Preparation

Each sample of hair was washed in tap water several times to remove dirt and then dried on a clean watch glass. After that the samples were examined macroscopically and the colour and texture recorded. Each sample was placed in 30% hydrogen peroxide overnight prior to microscopic examination. The hairs were examined following the methods of Brunner and Coman (1974), Keogh (1983), Oli et al. (1993), Rijal et al. (2004) and Shrestha et al. (2012), which provided: (A) impressions (imprint) of the cuticle, (B) whole-mounts (a part of or whole hair placed directly onto a microscope slide) and (C) cross-sections of the medulla.

(A) ***Impression (imprint) of cuticle***: A thin layer of nitrocellulose lacquer (transparent nail polish) was applied to the surface of microscope slides on which samples of hair were placed horizontally (parallel to the edge of slide). As the lacquer dried, the surface of each hair formed an imprint that remained when the hair was peeled off prior to observation under a microscope. The characteristics of the cuticular scales along the shaft from the base to the tip of each hair were recorded. As the characteristics of scales varies along the length of the hair, the details of the hair imprint were recorded for the base,

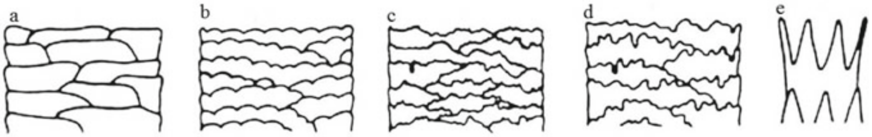

Fig. 4.1 Diagrams depicting the margins of scales: **a** smooth; **b** scalloped; **c** crenate; **d** ripple; **e** dentate. Adapted from https://www.landcareresearch.co.nz/tools-and-resources/identification/hair-sample-identification-and-factsheets/hair-features/, original source: Brunner and Coman (1974)

middle and tip of each hair. The cuticular characteristics of the scales were recorded in terms of three parameters: margin, width and pattern.

(i) ***Margins***

a. smooth margin: margin of the scales is smooth without waves, saw-like appearance or indentations (a deep recess or notch on the edge or surface) (Fig. 4.1a).
b. scalloped margin: having a series of curves on the margin with rounded peaks and pointed troughs (Fig. 4.1b).
c. crenate margin: having a scalloped edge with shallow and pointed indentations (Fig. 4.1c).
d. ripple margin: having a small wave or series of waves and the indentations are rounded and relatively deeper in comparison with the crenate pattern (Fig. 4.1d).
e. dentate margin: having tooth-like projections or serrated edge (Fig. 4.1e).

(ii) ***Width***

The widths of the scales were visualized based on diagrams and categorized as broad, narrow or thin (Fig. 4.2).

(iii) ***Pattern*** (Fig. 4.3)

a. regular: height and length of the overlapping scales similar.
b. irregular: heights and lengths of the scales irregular.
c. diamond: scales diamond shaped.
d. narrow diamond: scales with a narrow diamond shape in which the length is considerably longer than the width.

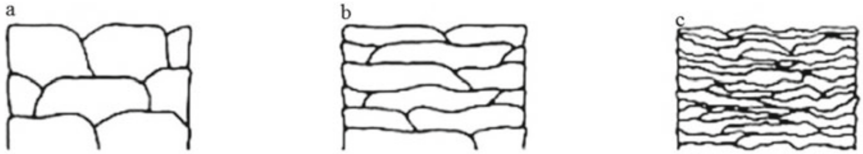

Fig. 4.2 Diagram showing the vertical widths of the scales: **a** broad; **b** narrow; **c** thin. Adapted from https://www.landcareresearch.co.nz/tools-and-resources/identification/hair-sample-identification-and-factsheets/hair-features/, original source: Brunner and Coman (1974)

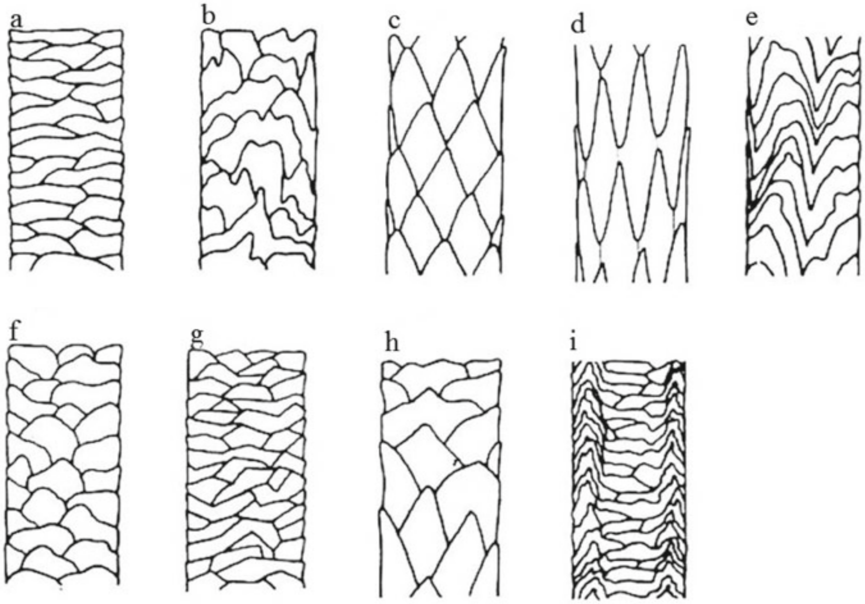

Fig. 4.3 Pattern of scales: **a** regular; **b** irregular; **c** diamond; **d** narrow diamond; **e** chevron; **f** broad; **g** flattened irregular; **h** transitional; **i** streaked. Adapted from https://www.landcareresearch.co.nz/tools-and-resources/identification/hair-sample-identification-and-factsheets/hair-features/, original source: Brunner and Coman (1974)

e. chevron: scales do not overlap and have a narrow V-shape.
f. broad: scales overlap and are broader vertically and irregular in size and shape.
g. flattened irregular: scales of dissimilar sizes and shapes, but wider than deep.
h. transitional: the scale pattern changes from the base to the tip of the hair, transitional refers to a specific point where one pattern changes into another.
i. streaked: irregular pattern interrupted at regular intervals by vertical running columns of scales with steep margins.

(B) ***Whole-mounts and examination of the medulla***: each bleached hair was chopped into pieces about the length of a microscope slide and dipped in xylene for 3–4 h. Then the hair was wet-mounted in D.P.X and its cortex and medulla viewed under a microscope and the details recorded. The measurements of both the cortex and medulla were recorded at ten intervals along the shaft of each hair. These measurements were then converted to millimetres and the mean calculated. The average diameter of the medulla was similarly determined. In addition, medullar indices and their averages were calculated. The above calculations were made only for hairs with a medulla. The medullary

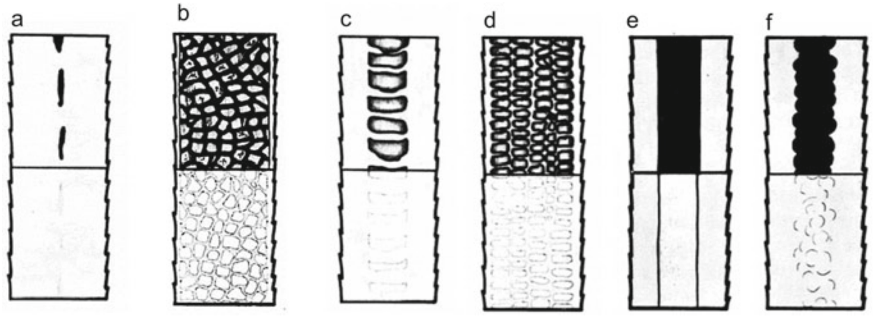

Fig. 4.4 Type of medulla: **a** fragmented; **b** wide with lattice; **c** uniserial ladder; **d** multiserial ladder; **e** simple; **f** scalloped or globular margin. Adapted from https://www.landcareresearch.co.nz/tools-and-resources/identification/hair-sample-identification-and-factsheets/hair-features/, original source: Brunner and Coman (1974)

index (MI) was calculated using the following formula:

$$\mathrm{MI} = \frac{\text{Width of medulla}}{\text{Width of cortex}}$$

The characteristics of the different types of medulla were classified as follows (Fig. 4.4):

a. fragmented: medulla is interrupted along the length of the hair by short sections of cortical material.
b. continuous: medulla unfragmented (Fig. 4.4b–f).
c. wide medulla with lattice: medulla is wide with a web or mesh like structure; each cell of lattice is pentagonal or hexagonal in shape.
d. uniserial ladder: medulla has a single row of air spaces along its length that are either round, cup, angular or flat in shape.
e. multiserial ladder: medulla with two or more distinct rows of mostly uniform air spaces along its length.
f. simple: medulla has no specific pattern and an amorphous appearance.
g. scalloped: the edge of the medulla has a series of semicircles along its length.

(C) ***Cross-section***: a tuft of hairs was inserted into a straw and then molten wax was sucked into the straw. Once the wax had solidified, the straw was cut open and a bundle of hair embedded in wax was removed. This was cut transversally several times with a razor blade. The sections were treated with xylene to remove the wax and observed under a microscope. The cross-sections of hairs were then classified based on the shape of the medulla (circular, oval, oblong, biconcave, dumb-bell) and its width (wide or large, medium, narrow) (Fig. 4.5). The medulla of the hair of blue sheep and musk deer is porous (Figs. 4.6 and 4.7).

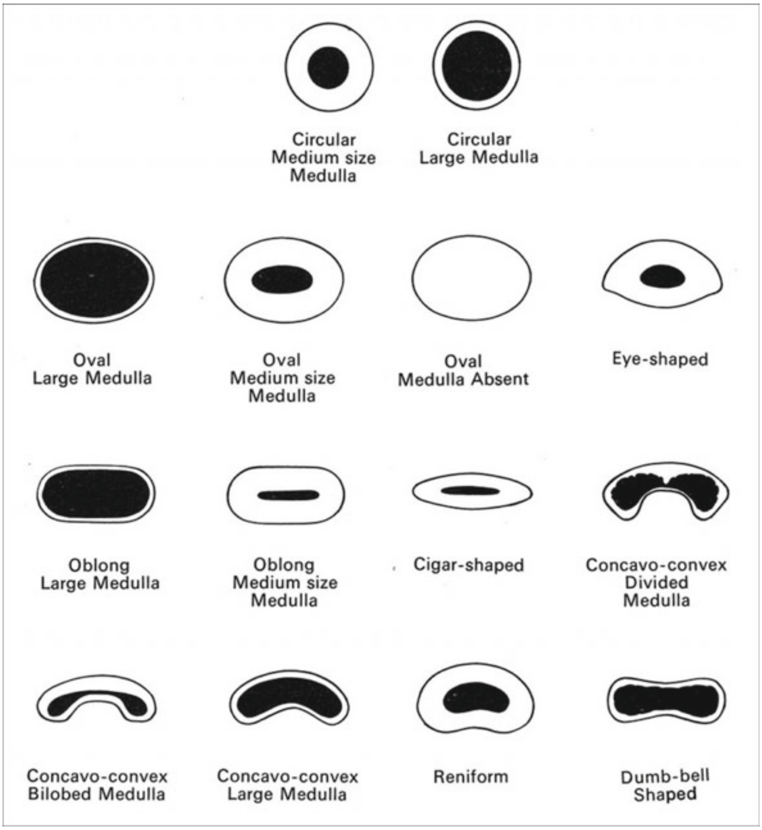

Fig. 4.5 Diagrams of cross-sections of different types of guard hairs. Adapted from https://www.landcareresearch.co.nz/tools-and-resources/identification/hair-sample-identification-and-factsheets/hair-features/, original source: Brunner and Coman (1974)

4.2.3 *Hair Identification*

First, the hairs were observed using a microscope. Then microphotographs of the medulla and cross-sections along the length of the hairs of each species were taken at 200× and 400× magnification using a light microscope and the photographing program BEL Eurisko™. Several photographs were taken from the base towards the tip of the hair so that the changes in the cuticle along the hair are clearly visible. Afterwards, detailed characteristics recorded in the microphotographs were also noted.

4.2.4 Identification of Unknow Hairs of Prey in Snow Leopard Scat

Each sample of scat (faeces) was soaked overnight in liquid Dettol mixed with water and then washed carefully over a 1 mm mesh sieve. Microscope slides of sample hairs found in the scats were used to identify the species of prey by using the identification key and the microphotographs of samples of hair.

4.2.5 Macroscopic Observation

Overall thickness, colour and shaft length of the hairs are presented in Table 4.1. Overall shaft thickness and length of hair can be used to separate large and small species of prey as the large species have thicker and longer hairs. Colour patterns and texture of hair are also important for distinguishing species.

4.2.6 Microscopic Measurements

Measurements of guard hairs of all the potential mammalian species of prey of snow leopard inhabiting Sagarmatha National Park and Annapurna Conservation Area (Lower Mustang and Upper Manang) are presented in Table 4.2.

4.2.7 Microscopic Characteristics

Microscopic characteristics of the guard hairs of the prey of snow leopard in Nepal are described at the end of this chapter, in Box 4.1—Appendix, Figs. 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19 and 4.20. Terminology of the characteristics is as in 4.2.2.

4.3 Key for Identifying the Hair of the Prey of Snow Leopard

1. Macroscopic observation

    1.1 Thick (30 μ to 335 μ) and long (3–30 cm) ………..……………… ……………..... 2

Table 4.1 Macroscopic characteristics of hair

Species	Macroscopic characteristics	Shaft length (cm)
Himalayan tahr	Thick shaft, proximal part: white; middle: grey/copper; distal: grey/black, straight or wavy	5.5–11.1
Blue sheep	Thick shaft, white, black and grey, brittle and wavy	3–7.5
Musk deer	Thick shaft, proximal part: white; middle: black; distal: yellow; tip: black; the white part of the hair is almost straight, and the rest is wavy and brittle	1.7–6.2
Snow leopard	Thin shaft, black and white, mostly wavy, white and straight	5–11.5
Red fox	Moderately thick shaft, most hairs from proximal to distal part are white, red/dark brown, white/light brown and black; few are proximally white and distally black	5.5–6.9
Yak	Thick shaft, black: thick, mostly wavy and few straight; pale gold: relatively thin and wavy	10–30
Dog	Moderately thick shaft, black, white, curved, wavy	4–6.5
Cow	Moderately thick shaft, black, straight	3.8–5.1
Horse	Thin shaft, black, white or red brown, straight with a slight curve	3–8
Goat	Thick shaft, mostly white, and few are brown and slightly wavy	5.8–9
Woolly hare	Very thin shaft, proximal to middle: light black and extremely thin; middle: black and moderately thick; distal: white and thick, tip: black	2.8–3.6
Mountain weasel	Moderately thick shaft, proximal: dark grey and white; tip: yellowish to light brown	2
Shrew	Very thin shaft, proximal and distal parts are yellow and middle part is grey, slightly wavy	0.8
Rat	Thin shaft, black, mostly straight with a few curves	1.9–2.8
Pika	Very thin shaft, root: dark grey; middle: white; tip: black, slightly curved	1.5–2

(Proximal end of a guard hair is its root or the end closest to the body, distal end of a guard hair is its tip or the end furthest from the body)

1.2 Thin (10 μ to 110 μ) and short (0.8–3.6 cm) ……………………………………….... 8

2. Scale margins

2.2 Smooth ………………………………………………………….… 3
2.3 Smooth or slightly crenate …………………………………… 4
2.4 Crenate, rippled or scalloped ………………………………… 5
2.5 Dentate ………………………………………………………….… 6

Table 4.2 Measurements of cortex and medulla, and the medullary index of the guard hairs of the prey of snow leopard in Nepal

Species	Cortex diameter (μ)	Medulla diameter (μ)	Medullary index (average)
Himalayan tahr	65–175	30–155	0.717
Blue sheep	220–250	110–240	0.789
Musk deer	150–335	140–325	0.943
Red fox	60–85	40–70	0.788
Snow leopard	40–70	15–30	0.406
Yak	70–110	5–20	0.119
Dog	25–75	5–25	0.319
Cow	45–60	15–60	0.431
Horse	30–55	10–30	0.531
Goat	150–215	85–175	0.722
Woolly hare	25–65	15–65	0.763
Mountain weasel	50–87	36.5–60	0.735
Shrew	12.5–22.5	12.5–17.5	0.802
Rat	40–110	30–100	0.871
Pika	10–55	5–52.5	0.88

3. Medulla wide[1] with lattice
   - 3.1 Pattern of scales is broad petal and cross section is oval or circular with wide[1] medulla ………………………………………………………….... **Blue sheep**
   - 3.2 Scale pattern is flattened irregular mosaic and cross section is circular with wide[1] and large porous medulla ……………………………………………………. **Musk deer**
4. Scale pattern a regular or irregular wave and medulla continuous
   - 4.1 Medulla is straight or with a very slightly scalloped margin, cross-section is circular, wide[1] and porous (MI = 0.717)..…….. **Himalayan tahr**
   - 4.2 Medulla is a simple or uniserial ladder and cross-section is circular of medium size[2] (MI = 0.319) ……………………………………………………...………. **Dog**
   - 4.3 Medulla has a straight margin, cross-section is circular or oval of medium size[2] (MI = 0.431)

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[1] it extends as far as to the cuticle, see Fig. 4.4

[2] medulla reaches to half of cortex, see Fig. 4.5

………..…………………………………………………..……..…….. **Cow**

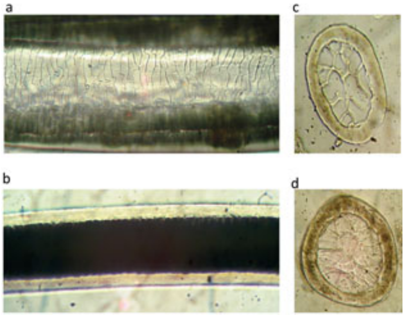
5. Scale pattern a regular or irregular wave and continuous medulla
   - 5.1 Medulla margin slightly scalloped, cross-section circular medium size^2 …………………………………………………………..…………………..…… **Snow leopard**
   - 5.2 Medulla fragmented, thin (MI = 0.119) and heavily pigmented, in cross-section absent, oval or narrow ………………………………………………………….…**Yak**
   - 5.3 Medulla margin straight, cross-section oval and of medium size^2 ……………………………………………………………….…..…**Horse**
   - 5.4 Medulla margin fringed, in cross-section wide^2, circular or oval (MI = 0.722) ……………………………………..………………...……...…… **Domestic goat**

6. Scale pattern diamond shaped, medulla margin regularly fissured or fringed, cross-section circular or oval ……………………..………………………………**Red fox**
8. Scale margins
   - 8.1 Dentate ……………………………………………………… 9
   - 8.2 Rippled ………………..…………………………….……………… 10
   - 8.3 Dentate (proximally) and smooth (distally) ……………….……………………. 11

9. Scales broad (far apart), scale pattern regular wave or chevron like, margin of medulla scalloped and in cross-section wide^2, oval or biconcave …………….**Woolly hare**
10. Scales narrow, scale pattern is an irregular wave, medulla unbroken vacuolated, irregular uniserial ladder, scalloped margin and in cross-section wide^2, circular or oval …………………………………………………………….………... **Mountain weasel**
11. Pattern of scales diamond or petal shaped and transitional
    - 11.1 Scales broad, medulla an elongated uniserial ladder and in cross-section wide^2, circular or biconcave …………………..……………………………………….. **Shrew**
    - 11.2 Scales narrow, medulla irregularly stacked, double bands or ladders and in cross-section wide^2 and circular …………………………...………………….……**Pika**
    - 11.3 Scales narrow, medulla lattice, scalloped margin and in cross-section wide^2, circular or biconcave …………………………………….……………………**Rat**

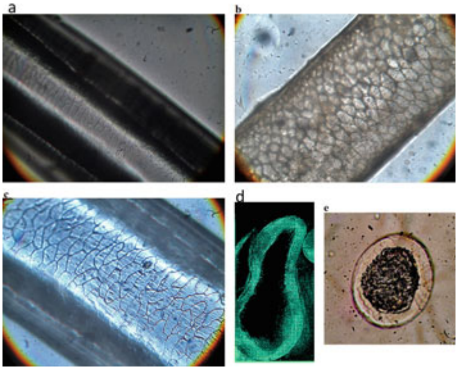
4.4 Summary

The hair of prey in the faeces of predators can be reliably used for identifying their prey. This study reveals that microscopic photographs of the hair of potential prey and a key to species of prey based on the microscopic features of the cuticular scales, medulla (medullary index) and thickness of the cortex etc., are a suitable for identifying the prey of carnivores. Compared to direct observations the above proved a more convenient and an easier way of identifying the prey of snow leopard.



Scale margin	Scales	Scale pattern	Medulla	Cross-section
Smooth or slightly crenate	Broad	Regular wave	Continuous, with simple straight or very slightly scalloped margin	Circular, wide and porous medulla

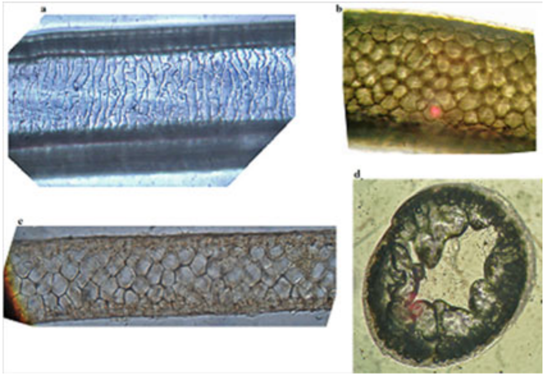
Fig. 4.6 Microphotographs (all 400×) of a guard hair of **Himalayan tahr**: **a** pattern of scales on hair; **b** longitudinal section; **c**, **d** cross-sections



Scale margin	Scales	Scale pattern	Medulla	Cross-section
Smooth	Broad	Broad petal	Wide medulla with lattice	Oval or circular, wide medulla

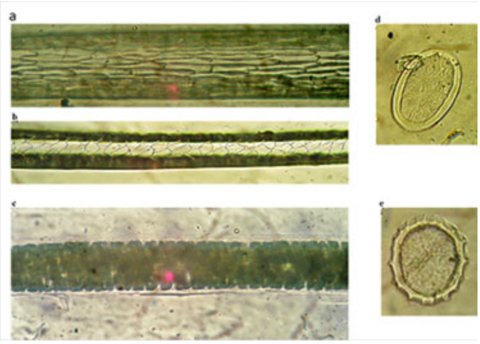
Fig. 4.7 Microphotographs (all 400×) of guard hairs of **blue sheep**: **a** scales on tip; **b** whole-mount; **c** main scale pattern; **d**, **e** cross-sections

Box 4.1—Appendix



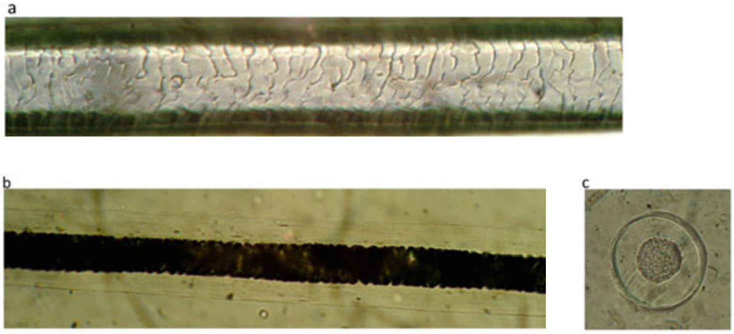
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Smooth	Broad	Flattened irregular mosaic	Wide with lattice	Medulla circular, wide, large and porous

Fig. 4.8 Microphotographs (all 400×) of guard hairs of **musk deer**: **a** main scale pattern; **b**, **c** whole-mount; **d** cross-section



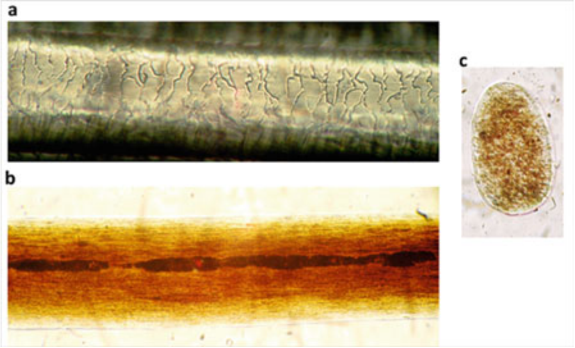
Scale margin	Scale	Scale pattern	Medulla	Cross-section
Dentate	Broad	Diamond petal	Continuous, regularly fissured or fringed (the inner edge of the cuticula with a series of inward pointing peaks)	Medulla circular or oval and wide

Fig. 4.9 Microphotographs (**b** 200×; all other 400×) of guard hairs of **red fox**: **a** pattern of scales on proximal part; **b** pattern of scales on the middle part; **c** whole-mount; **d**, **e** cross-sections



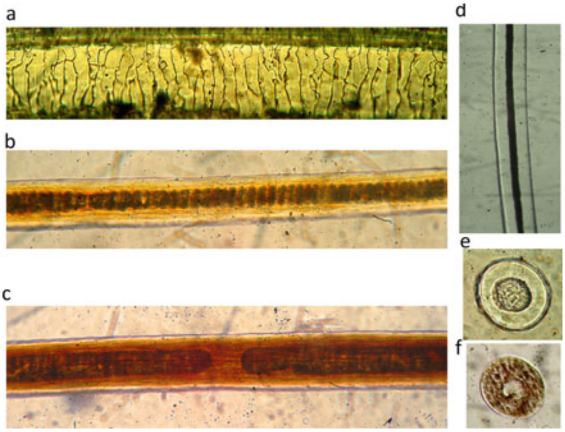
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Rippled or crenate	Narrow	Irregular wave	Continuous, simple, slightly scalloped margin	Medulla circular and medium sized

Fig. 4.10 Microphotographs (all 400×) of guard hairs of **snow leopard**: **a** main pattern of scales; **b** whole-mount; **c** cross-section



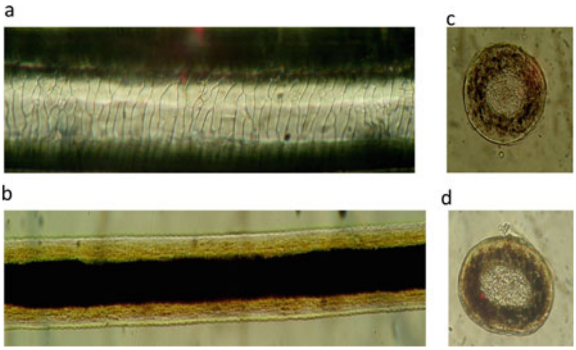
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Crenate or rippled	Narrow	Irregular wave	Fragmented, thin, heavily pigmented	Medulla absent or narrow oval

Fig. 4.11 Microphotographs (all 400×) of guard hairs of **yak**: **a** main pattern of scales; **b** whole-mount; **c** cross-section



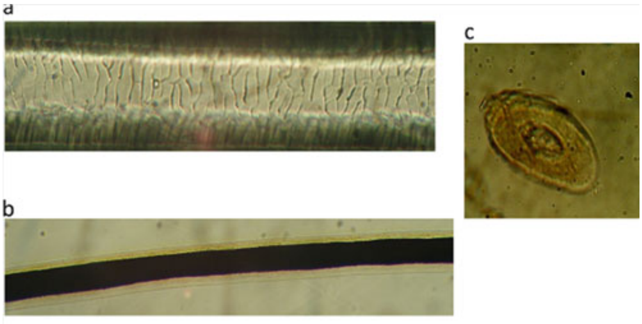
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Smooth or slightly crenate	Broad	Regular wave	Continuous, simple or uniserial ladder	Medulla circular and of medium size

Fig. 4.12 Microphotographs (all 400×) of guard hairs of **dog**: **a** main pattern of scales; **b**, **c** whole-mount of a hair Tibetan black dog; **d** whole-mount of a small white dog; **e**, **f** cross-sections



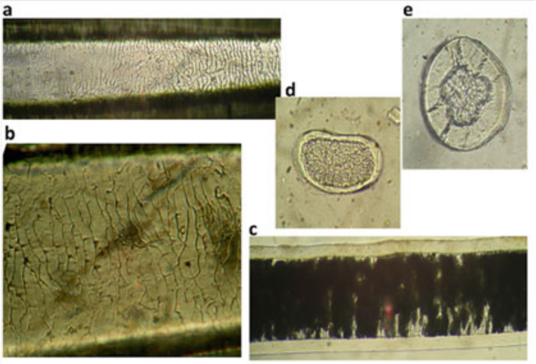
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Smooth or slightly crenate	Broad	Regular or irregular wave	Continuous, simple, straight margin	Medulla circular or oval, of medium size

Fig. 4.13 Microphotographs (all 400×) of guard hairs of **cow/ox**: **a** main pattern of scales pattern; **b** predominant whole-mount; **c**, **d** cross-sections



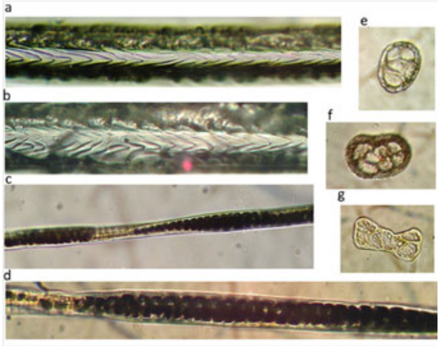
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Crenate	Narrow	Regular or irregular wave	Continuous, simple, straight margin	Medulla oval of medium size

Fig. 4.14 Microphotographs (all 400×) of guard hairs of **horse**: **a** main pattern of scales; **b** whole-mount; **c** cross-section



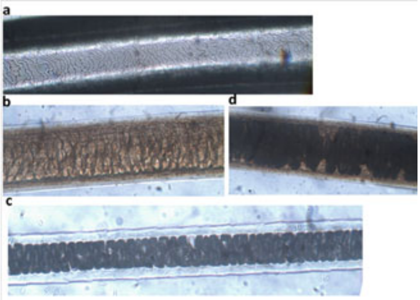
Scale margin	Scale distance	Scale pattern	Medulla type	Cross-section
Rippled and Crenate	Close	Irregular wave	Continuous and simple or slightly fringed	Circular or oval, wide medulla

Fig. 4.15 Microphotographs (**a** 200×; all other 400×) of guard hairs of **domestic goat**: **a**, **b** pattern of scales; **c** whole-mount; **d**, **e** cross-sections



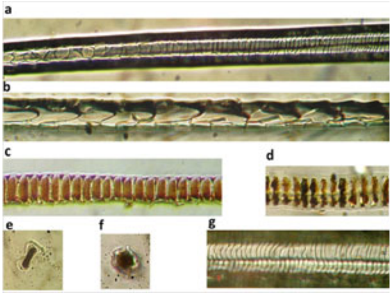
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Dentate	Broad	Regular wave, chevrons	Continuous, scalloped margin	Medulla wide oval or biconcave

Fig. 4.16 Microphotographs (**a** 200×; all other 400×) of guard hairs of **woolly hare**: **a**, **b** main pattern of scales; **c** whole-mount; **d**, **e** cross-sections



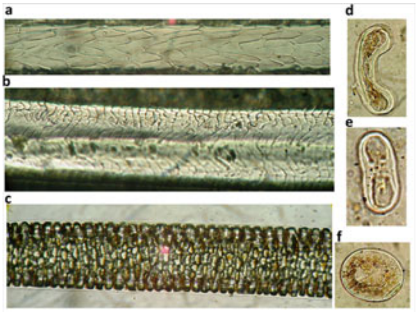
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Rippled	Narrow	Irregular wave	Unbroken vacuolated in middle of shaft, irregular uniserial ladder and scalloped margin distally	Medulla wide, circular or oval

Fig. 4.17 Microphotographs (all 400×) of guard hairs of **mountain weasel**: **a** main pattern of scales; **b**, **d** whole-mount; **c** whole-mount of distal end



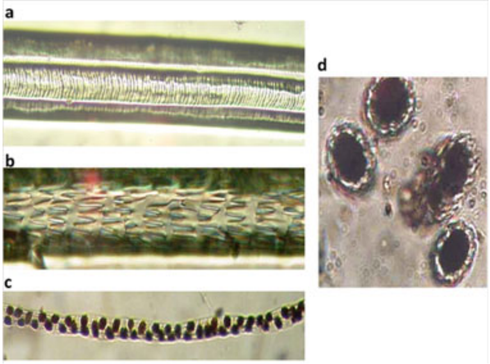
Scale margin	Scales	Scale pattern	Medulla	Cross-section
Smooth and dentate	Broad	Diamond petal and transitional	Elongated uniserial ladder	Medulla wide, circular or biconcave

Fig. 4.18 Microphotographs (**a**, **b**, **e**, **f**, **g** 400×; **c**, **d** 200×) of guard hairs of **shrew**: **a** transitional pattern of scales; **b** scale pattern on proximal part; **c**, **d** whole-mount; **e**, **f** cross-sections; **g** scale pattern on distal part



Scale margin	Scales	Scale pattern	Medulla type	Cross-section
Dentate and slightly crenate	Narrow	Diamond petal and Irregular wave	Wide medulla lattice, elongated fringed, scalloped margin	Medulla circular, concave–convex or dumb-bell shaped

Fig. 4.19 Microphotographs (**a** 200×; all other 400×) of guard hairs of **rat**: **a** main pattern of scales on proximal end; **b** scale pattern on distal part; **c** whole-mount; **d**–**f** cross-sections



Scale margin	Scales	Scale pattern	Medulla	Cross-section
Dentate and smooth	Narrow	Narrow diamond petal and regular wave, slightly streaked	Irregularly stacked, irregular double bands or ladders	Medulla wide and circular

Fig. 4.20 Microphotographs (**a**, **c** 200×; **b**, **d** 400×) of guard hairs of **pika**: **a** pattern of scales on distal part; **b** pattern of scales on proximal part; **c** whole-mount; **d** cross-sections

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Chapter 5
Abundance of Snow Leopards and Their Prey in the Annapurna and Everest Regions of Nepal

Zdenka Křenová, Pavel Kindlmann, Bikram Shrestha, and Iva Traxmandlová

Abstract This chapter focuses on changes in the numbers of snow leopard and their prey over time. We present a large set of empirical data collected by Bikram Shrestha during several grant-funded projects. This data is valuable considering the lack of detailed data on snow leopards and might be used in various contexts in the future. Although it is a large and probably world unique set of metadata, it has proved very difficult to combine data from different sources for use in an analysis. The problems that made a more rigorous analysis very difficult or even impossible are highlighted. Finally, some rules are proposed, which should be followed in order to prevent waste of time and money in a disorganised collection of incompatible data, which cannot be analysed and some rules outlined that need to be followed to make the data compatible.

5.1 Introduction

Modelling population dynamics of endangered species provides a good way of managing their conservation. In the case of snow leopard, there are very few, if any, long-term predictive population dynamic models, although there is a lot of data

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on the numbers of individuals. Snow leopards are reported in the Annapurna Conservation Area (ACA) in several studies, not only in Lower Mustang and Upper Manang (Oli 1994; Ale et al. 2014), but also in other areas (Wegge et al. 2012; Aryal et al. 2014). However, a detailed knowledge of their population dynamics is lacking. We know virtually nothing about the likely long-term survival of this species.

There are several reasons for the absence of such models for snow leopard. One is the duration of most research projects used to collect the data, which usually only last for about 3 years. This is a period too short for making any rigorous analyses, let alone predictive models of the population dynamics of a long-lived species. Therefore, we badly need long-term monitoring of the distribution of snow leopards and demographic parameters, such as abundance, survival and recruitment.

Other problems are: (i) snow leopard's highly cryptic behaviour, (ii) its territories are in rugged landscapes and (iii) the limited resources and lack of work force necessary for collecting such data. Therefore, data available on snow leopard biology are scant, biased and outdated, and generally of poor quality (Fox et al. 1991; Jackson and Hunter 1996; Jackson et al. 2006). Until recently, the analyses performed were based on indirect observations, such as monitoring of scrapes. During the last few years, a good and efficient method was increasingly used to monitor rare and shy wildlife: camera trapping. See Chap. 3 for detailed description of the methods used for estimating the abundance of snow leopard.

The short-term length of the data might potentially be overcome by lumping different datasets together. An important point we address in this chapter is exploration of the possibilities and limitations of this lumping. The thing is that by lumping different datasets together we encounter other limitations: mutual incompatibility of the data. In different projects, the data are usually collected in different ways. For example, when monitoring scrapes or using camera traps, different transects are often used in different projects in the same region and this may make a rigorous analysis very difficult, if not impossible. This is what we will illustrate based on different sets of data.

The same situation exists for the main species of prey of snow leopard, Himalayan tahr (*Hemitragus jemlahicus*) and blue sheep (*Pseudois naur*). For example, many data on the abundance of Himalayan tahr are available for the period 1989–2010 (Shrestha 2004, 2006; Ale 2007; Lovari et al. 2009; Ferretti et al. 2014). However, data on the mortality rates of the different sexes and age classes of Himalayan tahr, and a good understanding of the relationships between snow leopard density and reproductive rates of Himalayan tahr are still missing, which is essential for a rigorous analysis of the population dynamics of these two species.

Thus, in this chapter, we first present unpublished observations, made as stated above, by Bikram Shrestha over many years. In addition, other published data on the numbers of snow leopard and that of the two above-named species of prey are presented in the hope that they may be used in future analyses. Such analyses might facilitate the development of more effective snow leopard management strategies.

The other aim of this chapter is a methodological one: we discuss the problems associated with lumping different datasets together for a more comprehensive analysis, as mentioned above. We then conclude with suggestions on what should be done in order to overcome these problems.

5.2 Study Area

The areas studied in this chapter are located in three different snow leopard habitats in Nepal. Two of them are within the Annapurna Conservation Area (ACA): Lower Mustang (LM) and Upper Manang (UM), and the third in the Sagarmatha National Park (SNP). Details about these areas can be found in Chap. 9, and corresponding maps are in Figs. 9.1, 9.2, 9.3, 9.4, 9.6 and 9.7.

5.3 Methodology

5.3.1 Locations of the Transects Monitored

As stated above, the funding for collecting the data used in this chapter came from several different sources, which is reflected in the choice of locations of the transects monitored. The Snow Leopard Information Management System (SLIMS; Jackson and Hunter 1996) was used to establish the transects. Using 1:50,000 topographic maps, the transects were laid along ridgelines, narrow valleys, trails and cliff-edges, along which snow leopards are likely to move between areas and leave signs (Fox et al. 1991; Mallon 1991; Jackson 1996). Transects covered most of the typical biotopes of snow leopard.

The transect parameters are described in Table 5.1 and the values for their altitude, slope, distance to nearest cliff and several topographic parameters are shown in Appendix—Box 5.1. The lengths of the transects varied not only because they were established for different projects, but also because they were limited by local conditions. Sometimes it was not possible to establish a sufficiently long transect, because long transects are more likely to cross habitats or landform boundaries, making the data more difficult to interpret and assign to a particular type of terrain.

Transect monitoring occurred mainly during the dry season (September–March), but transects in LM and UM were also monitored during the wet season (June–August) 2016. The actual timing was dependent on weather. We always walked along transects in SNP, but in 2007 and 2009, some parts of the transects (4 in 2007 and 7 in 2009) were not visited, because no snow leopard signs were recorded there in 2006, and even local people confirmed that their livestock was not killed by snow leopard in this area. Therefore, Bikram Shrestha decided not to monitor areas for which there were reports that snow leopards were not present, based on the SLIMS (Snow Leopard Information Management System, see Chap. 3). In contrast, in 2015,

Table 5.1 Descriptions of transects

	Parameter	Abbreviation/name in table	Explanation
Study area	Lower Mustang	LM	Name of the study area
	Upper Manang	UM	
	Sagarmatha NP	SNP	
Year			Year of monitoring
Period		Dry/Wet	Dry or wet season of the year
Transect	Code of transect	LM14_01 etc.	
Length (km)			Length of transect
Topography (TPG)	Cliff	CLF	Terrain is very precipitous (slope > 50°)
	Ridge	RID	Narrow crest sloping down on either side
	Hill-slope	HS	Side or slope of a hill
	Scree/boulders	BOL	Accumulation of rocks and pebbles at the base of a steep slope
Landform ruggedness (RUGG)	Broken	BK	Terrain of irregular slopes, rocky outcrops and gullies
	Very broken	VB	Terrain of rocky outcrops, ravines and gullies
	Rolling	ROL	Terrain of a smooth land surface (e.g., rolling hills or alluvial fan)
Habitat (HAB)	Barren	B	Less than 10% of the ground is covered with vegetation
	Grassland	G	Dominant vegetation is grassland
	Low growing bushes	SC	Dominant vegetation consists of low growing bushes
	Tall shrubs	S	Dominant vegetation consists of tall shrubs
	Forest	F	Tree cover exceeds 30%
	Open forest	OF	Vegetation consisting of scattered trees growing in grassland

(continued)

Table 5.1 (continued)

	Parameter	Abbreviation/name in table	Explanation
Cliff distance (CLD) (m)			Distance to the nearest cliff
Slope (SLP) (°)			Slope of transect
Aspect (ASP)	North	N	Predominant cardinal points of exposure of the transect
	East	E	
	South	S	
	West	W	
	South–west	SW	
	South–east	SE	
Trail	Herder trail	HT	Trail used infrequently only by herders
	Main trail	MT	Main trail regularly used by locals and tourists
	No trail	NT	Transect does not follow a regular trail
Altitude (m a.s.l.)			Altitude of the transect
Avg. altitude (m a.s.l.)			Average altitude of the transects

some herders grazed their livestock in this area at high altitudes in late autumn and winter (see Chap. 8 in detail for livestock herding practices) and claimed that snow leopard had killed their livestock. Therefore, these transects were monitored again. In UM and LM, transects differed between years because most of the landscape there was covered by snow in 2014, which limited its accessibility. This presence/absence of monitoring in certain years makes the analysis difficult—gaps in the data should be avoided in the future. This is one of the messages of this chapter.

The lengths of the transects were 7–7.4 km/100 km^2 in LM, 9.5–14.3 km/100 km^2 in UM and 17.81 km/100 km^2 in SNP (Appendix—Box 5.1). In LM and UM in ACA, there are many broad ridges and hills flanking wide U-shaped valleys, where the travel routes of snow leopards are less well defined, thus making it difficult to locate their signs along transects. In contrast, SNP has sharp ridges and deep V-shaped rugged valleys, where the routes taken by snow leopards were better observable. In some of the analyses, we used the data collected by Ale (2007), but for this data we lack exact descriptions of the transects.

5.3.2 Snow Leopard Abundance Based on Sign Surveys

Snow leopard signs include scrapes, scent (or spray), scats and pugmarks. Among them, ***sign encounter rates*** (signs/km) of scrapes are considered to be the most reliable for estimating snow leopard abundance (see Sect. 5.3.1 for a comprehensive description of this method). Monitoring of scats may be strongly biased, because genetic analyses show that more than 50% of the scats collected, which looked like snow leopard scats, in fact belonged to other carnivores, such as red fox etc. (Janecka et al. 2008; Shrestha et al. 2018, Sect. 3.1 here). Similarly, footprints are hardly visible when the trail is dry and hard and are difficult to detect during heavy rainfall. Therefore, we analysed only data for scrapes.

5.3.3 Snow Leopard Abundance Based on Camera Trapping

The estimates of relative abundances, population size and density of snow leopard were also obtained using camera-trapping (see Sect. 5.3.4 for description of this method) in consecutive periods in 2014–2016. For that, we used remotely triggered camera-traps (Bushnell HD camera, passive infrared detector Trophy Camera; Fig. 5.1) positioned along well-defined narrow ridgelines or valleys, or immediately adjacent to frequently scent-sprayed rocks and scrapes. Areas studied were divided into 4 × 4 km grids, which corresponds to the average home range size of female snow leopards (Jackson 1996; Oli 1997). Depending on the complexity of the terrain, one or two cameras were located in each grid cell with one or two camera-traps per station deployed at 2–3 m from the anticipated path of animals.

Fig. 5.1 Photograph of Bikram Shrestha installing a camera trap for monitoring in Manang, ACA

These camera-traps were checked, and batteries changed approximately every 7–10 days. We used 32–48 camera traps (depending on the number available) during two trapping sessions at each site (LM, UM, SNP), during the dry (October–January) and wet seasons (April–August). The number of camera traps differed between sites and seasons, but there were 4567 trap-nights altogether.

We identified individual snow leopards by their unique patterns of spots (Figs. 5.2 and 5.3), and created photo-capture histories based on the timing of individual captures. We categorized the photographs of snow leopard into full images (whole body visible) and partial images (only part of the body visible). Pictures taken one hour or more later were considered to be independent sightings (capture events). Pictures taken at shorter intervals than one hour were compared in terms of the colour pattern or other distinctive marks of the animals in order to determine, whether they were of different individuals. False images include blank photographs, whereas non-target images include those of all other animals except snow leopard, such as livestock, birds, wolves, red foxes, humans etc. For each camera trap, after the correction for false images, we calculated the ***relative index of abundance*** (***RAI***), defined as the number of capture events per 100 trap-nights.

We used the program CAPTURE to estimate snow leopard abundance and capture probabilities (Otis et al. 1978; Rexstad and Burnham 1991). The modelling of capture probabilities was done using four models: Mo (null model), which assumes no variation between individuals or over time, Mh (heterogeneity model), which assumes that the capture probability differs among individuals due to sex, age, activity, ranging patterns, etc., and Mb (behaviour model), which assumes capture probability is affected by their response to camera traps e.g., trap-happy or trap-shy animals, and

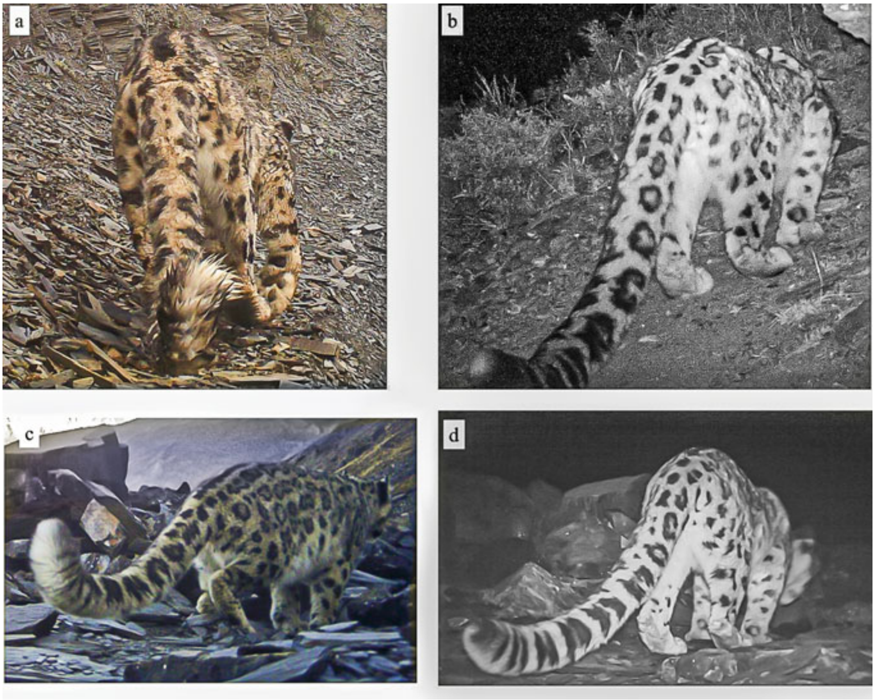


Fig. 5.2 Photographs of four different snow leopards identified by the pattern of marks on the fur on the dorsal surface of the tail captured by camera traps in Lower Mustang and Upper Manang in the Annapurna Conservation Area (2014–2016). Photographs: **a** and **b**—two different individuals in Upper Manang; **c** and **d**—two different individuals at the same place in Lower Mustang

Mbh (heterogeneity and behaviour model) is a combination of the Mh and Mb models. We used the results of the 5-day samples in Otis et al. (1978) and followed Jackson et al. (2006) recommendations that the capture probabilities should be > 0.10 (preferably > 0.20) and sample sizes > 5. The program CAPTURE calculates population size, its standard error and 95% confidence interval.

To estimate population density, we divided total population size obtained using CAPTURE by sizes of the areas studied. Sizes of each of the areas studied (LM, UM and SNP) were obtained from the total number of grid cells used for placing camera traps. The areas surveyed were identical with those surveyed in previous studies. Therefore, our results were unbiased, as far as geographic location and size of the areas studied are concerned, and suitable for comparing the status and trends in snow leopard population size over the years.

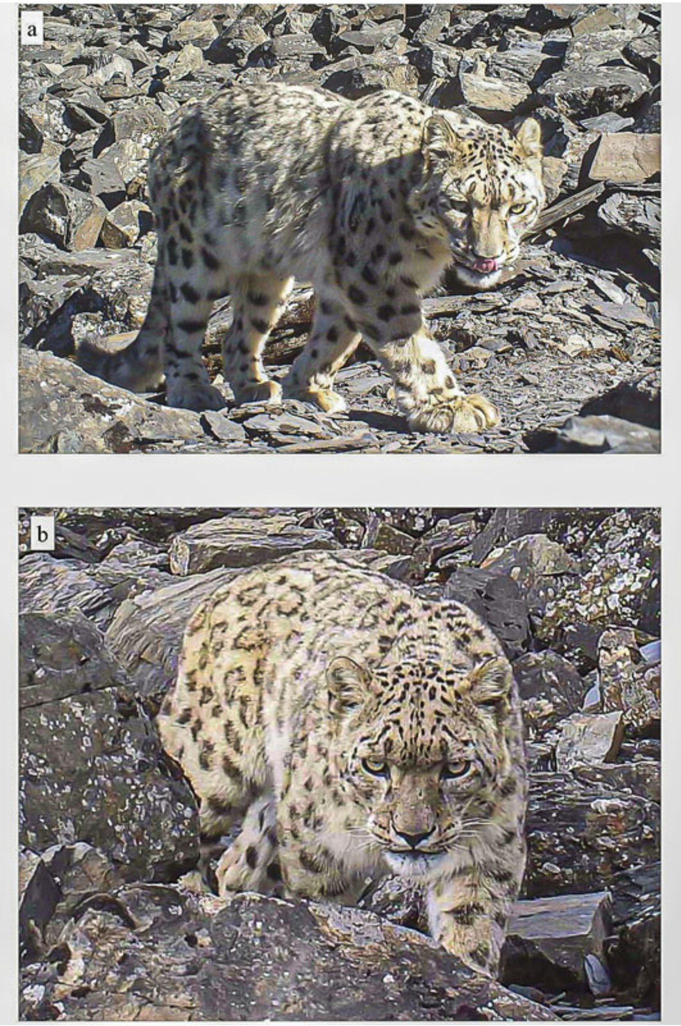


Fig. 5.3 Photographs of two different snow leopards at the same place taken by a camera trap, which are distinguished by the different patterns of marks on their forehead and body surface

5.3.4 Prey Survey (Blue Sheep in ACA and Himalayan Tahr in SNP)

We located and counted the main local prey (blue sheep in ACA: LM and UM, and Himalayan tahr in SNP) for snow leopards from as many suitable vantage points as possible, using a 8 × 21 binoculars and 15–45× spotting scopes (Schaller 1977; Jackson and Hunter 1996). In each of the three areas (LM, UM, SNP), we walked all the valleys in the area and searched for prey within each valley, divided into

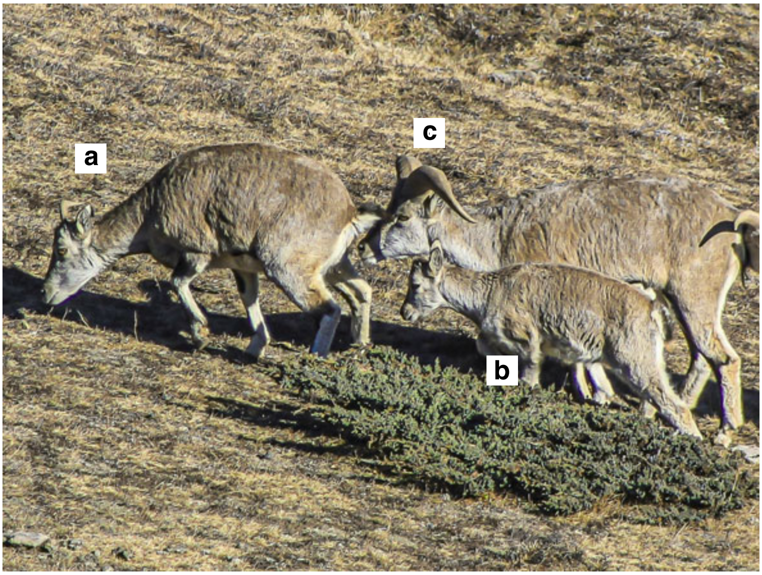


Fig. 5.4 Photograph of blue sheep in the dry season (November): **a** adult female, **b** young (kid), **c** sub-adult male

several survey polygons based on physical barriers such as a river, deep gorge or high mountain, prior to the monitoring. All individuals of blue sheep (in LM and UM) or Himalayan tahr (in SNP) were counted, classified in terms of sex and age when possible and their position marked on the map. Each polygon was scanned again during the monitoring walk and all prey individuals were recorded in the same way. We repeated these monitoring walks several times during each season, in order to avoid the bias caused by the prey moving from one site to another one. During each monitoring walk, each valley was scanned within 1–3 days to avoid overlapping with previously recorded herds of tahr and so provide more accurate total numbers of prey. Tahr and blue sheep, classified in terms of sex and age, were recorded repeatedly during each monitoring walk and the maximum numbers in each class of tahr recorded in all the monitoring walks were taken as the final tally. In this way, we recorded all the herds of animals in each valley.

In LM, we monitored blue sheep in four valleys: Thini (Vrapsa and Namu), Lupra, Muktinath and Jhong, and in UM in five valleys: Proper Manang, Yak Kharka, Khangsar, Thorang Phedi and Tilicho. These are the same valleys as those, where the transects for monitoring snow leopards were located. Note that these valleys were chosen based on the local terrain at each site (LM, UM, SNP) and are not the same as the Village Development Committees, which may overlap with some of them. We categorized blue sheep as either young (less than a year), yearling (1–2 years) or adult female and male (over 2 years). We further categorized male blue sheep as young (2–4 years), sub adult (4–7 years) and adult (> 7 years) (Figs. 5.4, 5.5 and

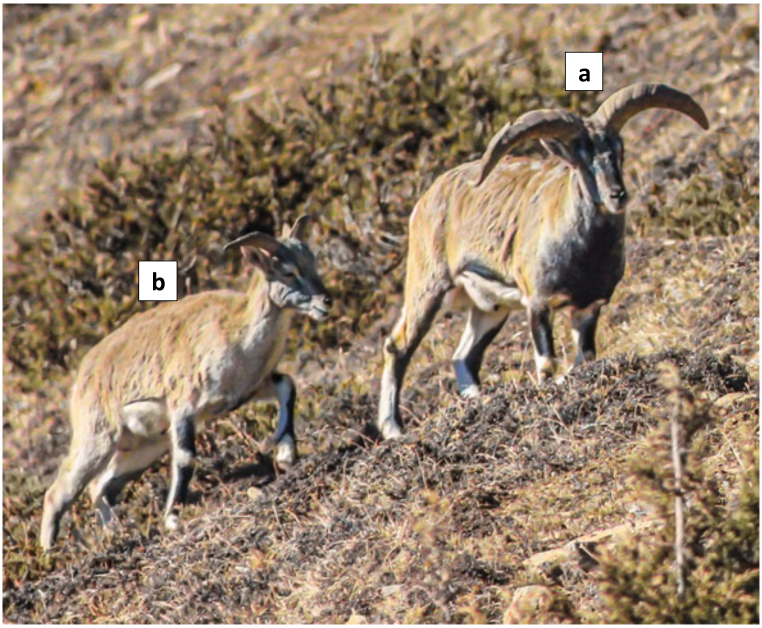


Fig. 5.5 Photograph of blue sheep in the dry season (November): **a** adult male, **b** young male

5.6). We monitored blue sheep in LM (101 km^2) and UM (105 km^2) at the same time as the camera trap surveys were carried out.

In SNP, we monitored prey in four valleys: Gokyo, Namche, Phortse and Thame covering 100 km^2. We categorized Himalayan tahr as either kids (< 1 year old), yearlings (1–2 years), adult females (> 2 years) or adult males. The adult males were further categorized as either in class I (2–3 years), II (3–4 years), III (4–7 years, dark brown), IV (7–9 years, pale brown) or V (> 9 years, golden or blond), based on the length/colour of their mane, horn length/shape and body size (Figs. 5.7, 5.8, 5.9, 5.10, 5.11 and 5.12).

The life cycle of Himalayan tahr can be described as of Leslie-type, which is graphically illustrated in Fig. 5.13. During July and August, when most of the kids are being born, females often temporarily leave the herd. During these wet months, clouds often reduce visibility, which makes monitoring difficult and therefore it is better to count new kids for the first time in September. At the same time, last year’s kids are transferred in the life tables to the category “yearlings”, last year’s yearlings to the female or male category class I, last year’s kids and yearlings are transferred to a higher demographic category (or die), but males can go to a higher demographic category or stay in the same category (or die), as indicated in the scheme depicted in Fig. 5.13.

The surveys of Himalayan tahr in SNP were carried out in 2004 (June–July), 2006 (Spring: May–June; Autumn: September–October), 2007 (Spring: April–June; Summer: July–September; Autumn: October–December), 2009 (Spring: March–April; Autumn: October–December) and 2015 (at the same time as the camera

Fig. 5.6 Photograph of a herd of blue sheep in the dry season (November) in Upper Manang in the Annapurna Conservation Area

Fig. 5.7 Photograph of an adult female Himalayan tahr in the dry season (December)

Fig. 5.8 Photograph of a young (kid) and yearling Himalayan tahr in the dry season (May)

trap survey). The total counts reveal the sizes (the minimum number alive) and demographic structure of the populations.

In principle, one could attempt to estimate the mortality rates of both blue sheep and Himalayan tahr based on the Leslie matrix model illustrated in Fig. 5.13. However, when we attempted to make these calculations, we encountered serious difficulties when comparing data from subsequent monitoring events. It became evident from the data analysed that there are problems with the exact determination of the age class, which made the datasets unusable. Therefore, we do not present the results of these analyses. This is another methodological message of this chapter: even if seductive, it is often impossible to develop age-structured models of population dynamics of these animals, simply because their age categories are difficult (if not impossible) to recognize in the field.

5.4 Results

5.4.1 Comparison of the Transects

Most transects were monitored during the dry seasons (SNP in years 2006, 2007, 2009, 2015; LM and UM in 2014), and only two transects during the wet season in 2016 (LM and UM; for more details see Appendix—Box 5.1). We repeatedly monitored the same transects in SNP, but not in LM and UM. This was because we had to establish transects at a lower altitude in LM and UM during the dry season

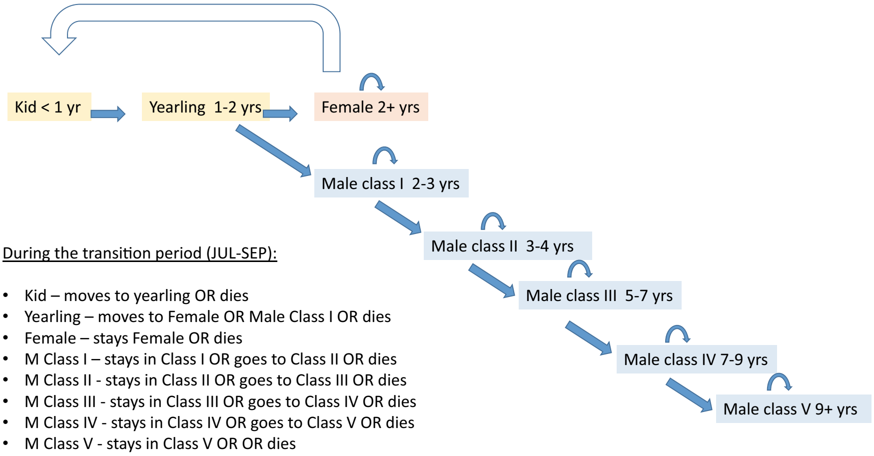
Fig. 5.9 Photographs of **a** a class I male Himalayan tahr and **b** a class II male Himalayan tahr in the dry season (December)

in 2014 due to deep snow and we were not able to use these transects again during the wet season 2016, when snow leopards and their prey live at higher altitudes. Therefore, new transects had to be established. To avoid the possibility that the results of our monitoring were due to variation in biotope quality in different years (dry vs. wet season), we tested whether transects studied in different years differed in habitat quality. We also tested for differences in the transects in SNP, LM and UM in

Fig. 5.10 Photograph of a dark brown (Class III male) Himalayan tahr in the dry season (December)

Fig. 5.11 Photograph of a pale brown (class IV male) Himalayan tahr in the dry season (December)

Fig. 5.12 Photograph of a golden or blonde (class V male) Himalayan tahr in the dry season (December)



During the transition period (JUL-SEP):

- Kid – moves to yearling OR dies
- Yearling – moves to Female OR Male Class I OR dies
- Female – stays Female OR dies
- M Class I – stays in Class I OR goes to Class II OR dies
- M Class II - stays in Class II OR goes to Class III OR dies
- M Class III - stays in Class III OR goes to Class IV OR dies
- M Class IV - stays in Class IV OR goes to Class V OR dies
- M Class V - stays in Class V OR OR dies

Fig. 5.13 Life cycle of Himalayan tahr. Main demographic categories and possible transitions

ACA in order to compare transects in areas where different species of prey of snow leopard occurred.

There were significant differences in the lengths of transects, their altitudes and distances to cliffs and slopes ($P < 0.05$). Transects in SNP were shorter (Fig. 5.14a) and located at lower altitudes than transects in LM and UM (avg. altitude 3898 m a.s.l. in SNP vs. 4186 m a.s.l. in LM and UM). The distances in SNP from the nearest cliffs were significantly greater (Fig. 5.14b, Appendix—Box 5.1). SNP transects were not as steep as those in UM and LM (Fig. 5.14c, Appendix—Box 5.1). Differences among transects monitored in SNP, LM and UM in ACA reflected differences in the geomorphology in the areas studied. There were no significant differences between these parameters among transects in SNP, LM and UM, when we analysed only 9 LM transects and 17 UM transects monitored during the dry season in 2014, and SNP transects, which were all studied during dry seasons.

When we compared dry season transects in SNP with those in LM and UM, we found differences in the percentages of different types of topography (Fig. 5.15a), habitats (Fig. 5.15b) and ruggedness (Fig. 5.15c). Slopes of hills (topography type HS) was the most common type of topography in all SNP transects. It covered about 75% of transects in SNP, but only 21.6% in dry season transects in LM, and 42.7% in dry season transects in UM. Ridges (topography type RID) were more common in LM and UM than in SNP and cliffs (topography type CLF) were frequent in LM and UM and almost absent in SNP transects. Tall shrubs (vegetation type S) were the most common type of vegetation occurring in most dry season transects. This type of vegetation covered more than 55% of transects in SNP, 50% in UM, but only 35% in LM. Open forests (vegetation type OF), the second most common type of vegetation in SNP, covered only 10% of dry season transects in LM and was missing in UM. Low growing bushes (vegetation type SC) were recorded only in LM transects (Fig. 5.15b). Rolling terrain (ruggedness type ROL) was recorded in more than 50% of the transects in SNP. The same type of ruggedness covered nearly 70% of dry season transects in UM, but only 35% in LM. Very broken terrain (ruggedness type VB) was missing or very rare in SNP transects, but covered more than 20% of transects in LM and over 10% in UM (Fig. 5.15c).

We planned to compare the behaviour of snow leopard and its prey during the dry and wet seasons, and therefore wanted to make sure that the differences were not affected by transect parameters, and so differences were tested for between transects monitored in LM and UM during the dry season 2014 and the wet season in 2016 (Fig. 5.16). We found no significant differences in types of topography between dry and wet season transects in LM, but there were differences between dry and wet season transects in UM. Cliffs (topography type CLF) were present in more than 17% of the dry season transects in UM and not present in transects monitored in UM during the wet season 2016 (Fig. 5.16a). Whilst the types of topography recorded during the dry and wet seasons in LM were very similar to each other, transects significantly differed in types of vegetation (Fig. 5.16b). Tall shrubs (vegetation type S) covering more than 35% of the dry season transects in LM were not present in transects monitored during the wet season in LM. In addition, percentages of other types of vegetation were different (Fig. 5.16b). Similarly, broken terrain (ruggedness type BK) covering more than 40% of the dry season transects in LM was not present in wet season transects monitored in LM. Percentages of three types of ruggedness differed slightly for the transects during the wet and dry season in UM (Fig. 5.16c).

In SNP, transects were located in four valleys that significantly differ in their main topographic parameters (One-way ANOVA, $P < 0.05$; Fig. 5.17). They also differed in types of habitat and ruggedness. Transects located in different valleys in UM and LM did not differ significantly in their topographic parameters. Only

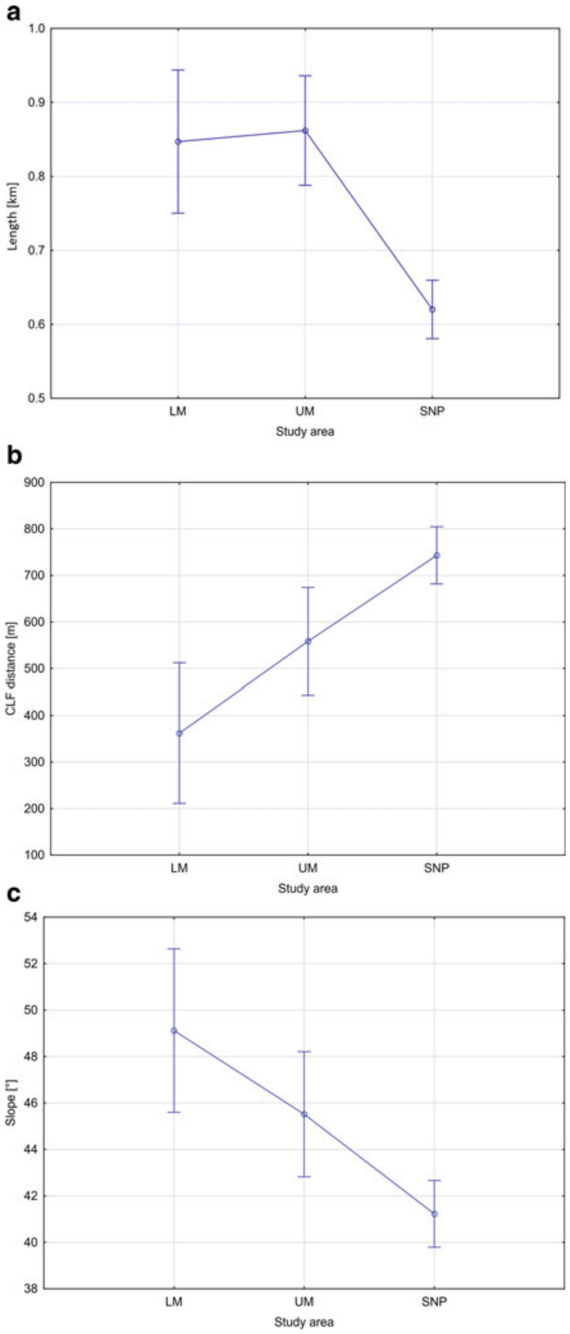


Fig. 5.14 Topographic parameters of the transects in the three areas studied (LM—Lower Mustang, UM—Upper Manang, SNP—Sagarmatha National Park) during dry seasons; **a** the lengths of the transects: transects in SNP were significantly shorter than transects in LM and UM; **b** distance of transects from the nearest cliff: transects in LM were closest to cliffs, whilst transects in SNP were located at the greatest distances from cliffs; **c** slope of transects: transects in LM were the steepest and those in SNP were moderately steep. Vertical bars denote 95% confidence intervals

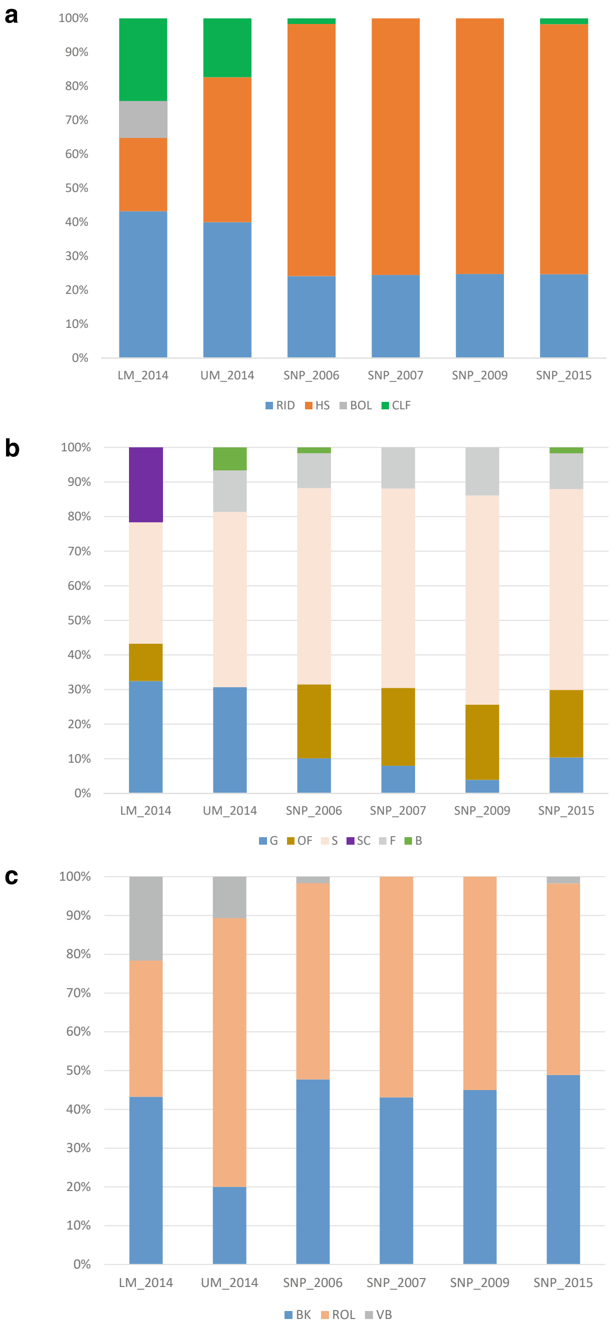


Fig. 5.15 Percentages of: **a** types of topography, **b** habitats and **c** landform ruggedness of the transects (i.e. ruggedness of terrain, where transects were situated), in the three areas studied (LM—Lower Mustang, UM—Upper Manang, SNP—Sagarmatha National Park) during dry seasons. See Table 5.1 for description of parameters

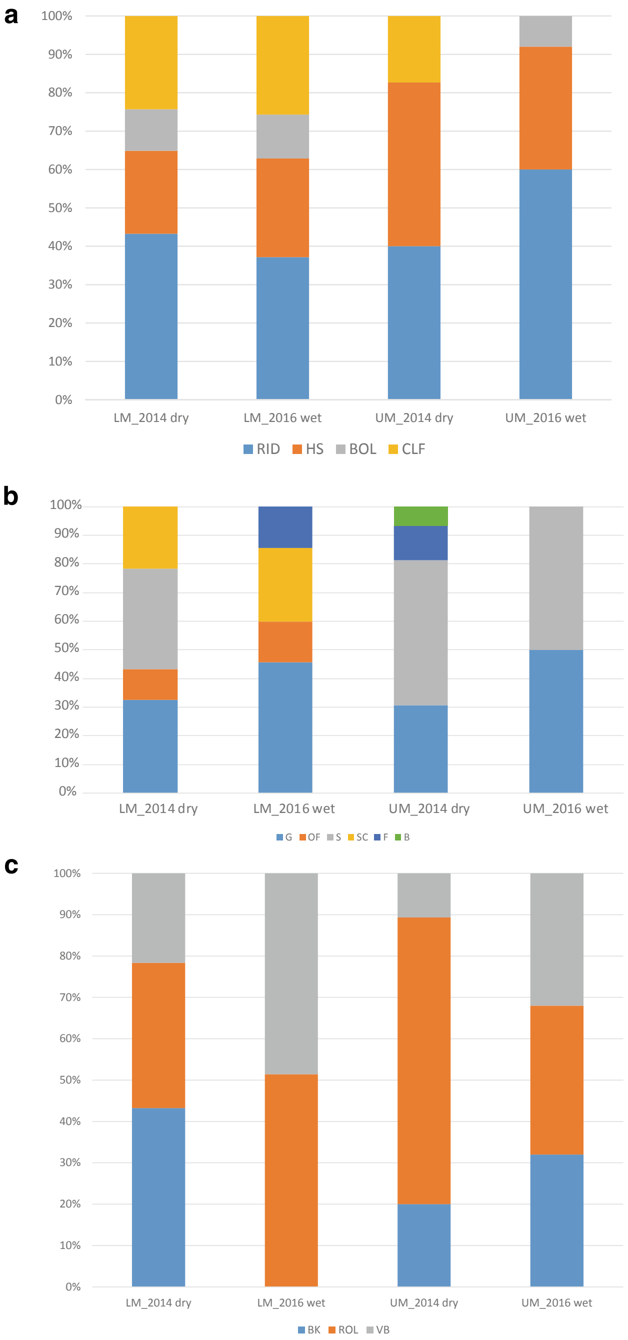


Fig. 5.16 Percentages of: **a** types of topography, **b** habitats and **c** landform ruggedness (i.e. ruggedness of terrain, where transects were situated) in transects in Lower Mustang (LM) and Upper Manang (UM) during dry and wet seasons. See Table 5.1 for description of parameters

transects in Lupra valley (LM, wet season 2016) were slightly longer and those in Jhong valley (LM, both dry season 2014 and wet season 2016) were steeper and closer to cliffs. Nevertheless, none of these differences was statistically significant (One-way ANOVA, $P > 0.05$).

To summarize: the transects differed significantly in many of their features when data for all transects and for transects monitored during dry seasons were included. There were no significant differences in their lengths, altitude and slopes in SNP, LM and UM when only transects monitored during the dry seasons in 2014 (LM and UM) and 2015 (SNP) were considered. In addition, other parameters differed only slightly and there were no statistically significant differences in the data recorded during the dry season in 2014 and 2015.

5.4.2 Non-target Animals in the Areas Studied

By using camera traps and DNA tests on faeces, we recorded five other large mammalian predators: common leopard (*Panthera pardus*), Himalayan wolf (*Canis lupus*), Eurasian lynx (*Lynx lynx*), golden jackal (*Canis aureus*) and red fox (*Vulpes vulpes*). Blue sheep (*Pseudois nayaur*), Himalayan tahr (*Hemitragus jemlahicus*) and musk deer (*Moschus chrysogaster*) were the only wild ungulates in the areas studied. Of small mammals, we recorded Royle's pika (*Ochotona roylei*), least weasel (*Mustela nivalis*), stone marten (*Martes foina*), Sikkim vole (*Alticola sikkimensis*), Pallas's cat (*Otocolobus manul*), jungle cat (*Felis chaus*) and leopard cat (*Prionailurus bengalensis*), all of which are potential prey of snow leopard.

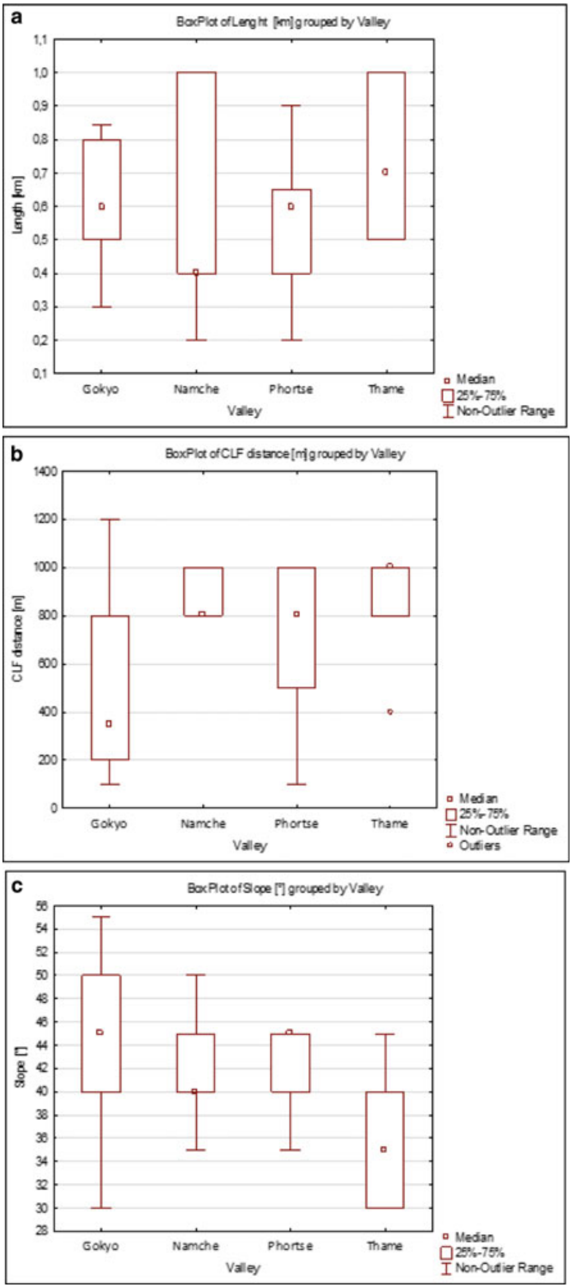
5.4.3 Indicators of Snow Leopard Abundance and Population Size

We considered two main indicators of snow leopard abundance: sign encounter rates (number of scrapes/km in this paper) and relative abundance indices (RAI—number of capture events per 100 trap-nights)—see Methods for formulas for their calculation.

The ***sign encounter rates*** within ACA were higher in UM than in LM. For example, in summer 2016, it was 5 scrapes/km in UM, but only 2.5 scrapes/km in LM (Fig. 5.18). However, this difference was not statistically significant (Table 5.2). Number of scrapes recorded during the dry period in 2014 was significantly higher than that recorded during the wet period in 2016. However, the transects where scrapes were monitored in 2014 were not identical with those monitored in 2016. Their altitude and other parameters differed (for more details see 5.4.1).

The **sign encounter rates** were higher in ACA than in SNP when all the data for 2014–2016 were considered (t-test, $t = 5.512$, $P < 10^{-7}$; Fig. 5.18). In SNP, the snow leopard sign encounter rates gradually decreased from 2006 to 2009 ($R^2 = 0.385$, P

Fig. 5.17 Differences in main topographic features of transects located in four valleys in the Sagarmatha National Park; **a** length of transects, **b** distance of transects from the nearest cliff, **c** slope of transects



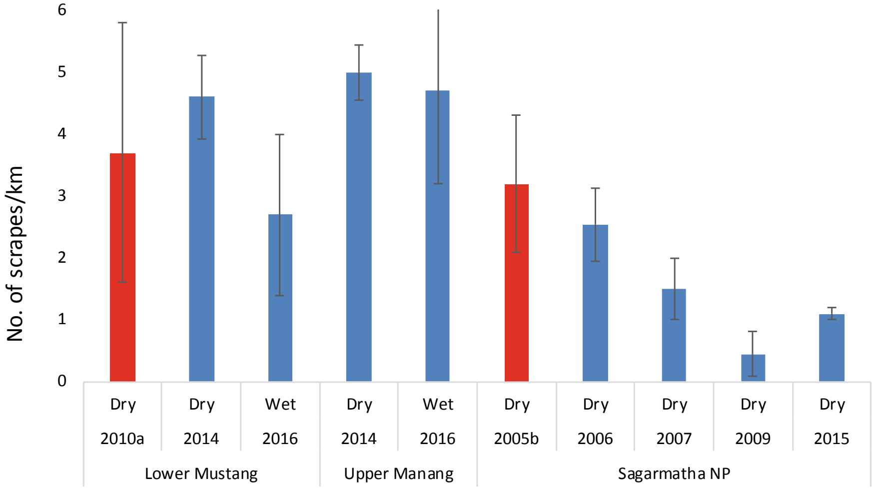


Fig. 5.18 Sign encounter rates (numbers of scrapes/km) recorded in three regions from 2005 to 2016. Red columns indicate the data were not collected in this study and the sources were: **a** Ale and Shrestha et al. (2014), **b** Ale (2007); blue columns are for data collected in this study. Dry = dry season, Wet = wet season. The vertical lines above the columns indicate standard errors

Table 5.2 Results of the ANOVA of the number of scrapes/km recorded in two areas (LM—Lower Mustang, UM—Upper Manang) during dry and wet periods (2014 and 2016 respectively)

Effect	SS	DF	MS	F	*p*
Area	24.43	1	24.43	2.384	0.130
Period	43.05	1	43.05	4.202	0.047*
Area*period	15.07	1	15.07	1.470	0.232

Significant *p*-value is marked by *

< 0.0003), and then increased in 2015, when data for 2009 and 2015 were compared. (t-test, t = −2.32, $P < 0.05$).

In all valleys in the areas studied, signs of snow leopards were recorded during the study periods, except in Thame valley in SNP and Lupra valley in LM, where the last signs were recorded in 2010. Of the four valleys in SNP, no snow leopard signs were recorded in Thame in both seasons in 2015 and the encounter rate monotonously decreased from 2005 to 2009 in this area. There were significant differences between the four valleys, years and valley*year interactions in the number of recorded scrapes (Table 5.3, Fig. 5.19).

Table 5.3 Results of an ANOVA of the number of scrapes/km recorded in four valleys in SNP in years 2006, 2007, 2009 and two periods in 2015

Effect	SS	DF	MS	F	*p*
Year	55.49	4	13.87	4.037	0.004*
Valley	45.34	3	15.11	4.398	0.006*
Year*valley	91.18	12	7.60	2.211	0.016*

Significant *p*-values are marked by *

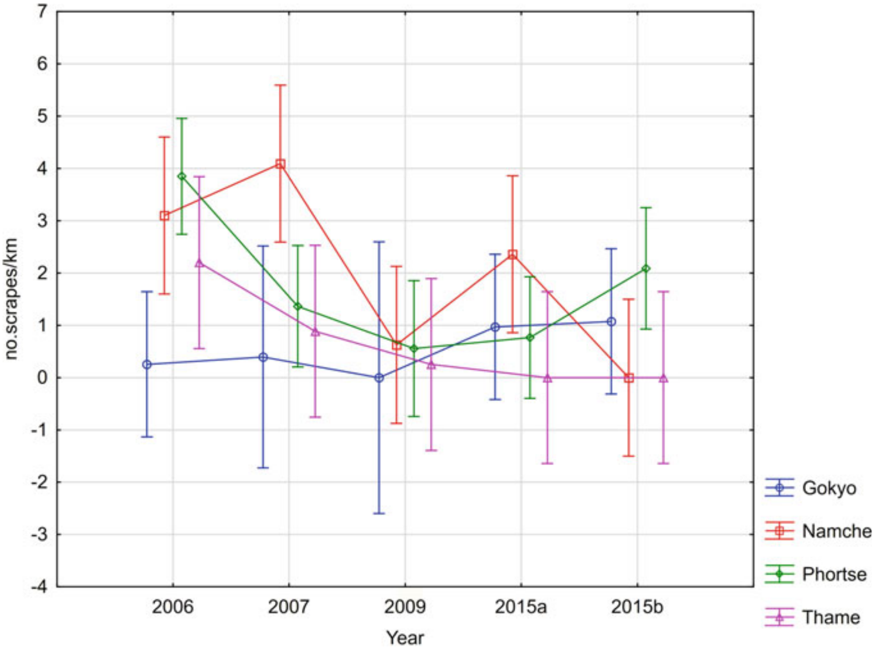


Fig. 5.19 Number of scrapes/km recorded in four valleys in the Sagarmatha National Park during the five monitored periods. Interaction year * valley are shown. Letters a/b next to the year 2015 indicate: a spring dry season 2015, b autumn dry season 2015. Vertical bars denote 95% confidence intervals

5.4.4 Numbers of Snow Leopards Recorded Using Camera Traps

Snow leopard ***relative abundance indices*** (RAI) were obtained from camera trap data (Table 5.4). The largest RAI was recorded in LM in winter of 2014 and in UM in autumn 2014 (5.3 and 4.7, respectively). However, RAI was lower in LM than in UM in the summer of 2016. Thus, RAI was not consistently lower in UM. Note also the drastic decrease in RAI in LM from winter 2014 to summer 2016. RAI was consistently lower in SNP, compared to LM and UM. Snow leopards were not

Table 5.4 Results for camera traps in the three areas studied in 2014, 2015 and 2016

Detail	Lower Mustang		Upper Manang		SNP	
	2014 Dry season	2016 Wet season	2014 Dry season	2016 Wet season	2015 Dry spring	2015 Dry autumn
Trapping effort (trap nights)	414	1020	321	1000	557	1215
Full images (SL)	132	34	43	53	25	27
Partial images (SL)	122	29	43	53	26	24
Total images (SL)	254	63	86	102	51	51
Capture events	22	12	15	24	12	14
False images	7130	2610	13,154	2632	13,510	19,022
Non-target images (non-target)	2439	4100	1619	2373	2462	10,816
Percentage of SL captures	2.6	0.9	0.6	2.0	0.3	0.2
No. of captures/100 nights (RAI)	5.3	1.2	4.7	2.4	2.2	1.15
Number of individuals	6	3	8	6	3	2

recorded in Thame valley in SNP in either of the seasons in 2015, or in Lupra in LM in both seasons in 2014 and 2016. This corresponds with the lack of any signs of presence of snow leopard (scrapes) during this period in the Thame and Lupra valleys.

There were many ***non-target images***. They included livestock, humans, birds, common leopard, Himalayan wolf, red fox, golden jackal, Eurasian lynx, jungle cat, leopard cat, pika, stone marten and Himalayan weasel. Common leopards were recorded (3 capture events) in alpine grassland at 4300 m a.s.l. in LM and in scrubland above the tree line in SNP (8 capture events). In lots of captures, no animals were visible (***false images***). This was because the camera was triggered by moving grass and clouds, by changes in the orientation of the sun and sunrays, etc. As a result, the percentage of snow leopard captures in the total capture was notably very low (0.2–2.6%).

In LM, six adult snow leopards were recorded using cameras in 2014: two adult males, two adult females (one of the females had one cub), one sub-adult snow leopard and two adults of unknown sex. Three individuals, which were recorded in 2010 (Ale et al. 2014), were also rerecorded in 2014. In 2016, only one adult male recorded in 2014 was rerecorded along with two different adults, of which one was male and the other was unidentified, but the three individuals recorded in 2010 and 2014 were not rerecorded in 2016. Thus, a total of eight individuals were recorded in 2014 and 2016.

In 2014, eight adults plus two cubs were recorded in UM: one adult male, one adult female with two cubs, and six adults of unidentified sex. In 2016, only six individuals were rerecorded (one adult female and one adult male, and the other individuals were of unknown sex) and no different individuals. Thus, eight individuals were recorded in UM during the monitoring in 2014 and 2016. In SNP, we identified three adults of unknown sex in spring 2015, of which two were rerecorded; no different individuals were recorded in autumn 2015. Thus, three individuals were recorded in SNP during 2015.

Based on the capture—recapture method (Otis et al. 1978), in LM three models (Mo, Mh, Mb) indicate similar abundances of snow leopards with capture probabilities of 0.5–0.67 (Table 5.5). In the case of UM, models Mo and Mh weakly fitted the data (capture probabilities of 0.1–0.13 with large variation in the 95% confidence intervals), while the Mb model fitted the data closely with a capture probability of 0.5 and small variation in the 95% confidence interval. In the case of SNP, two models (Mo and Mb) were the best fit with a capture probability 0.3, while the Mh model fitted the data weakly (capture probability 0.09). In the Mbh model, capture probability was not computed for all three areas (Table 5.6). Based on the best-fitting model, the calculated population sizes in LM, UM and SNP were 6, 8 and 3, respectively.

5.4.5 Population Density per 100 km^2 Based on Sign Encounter Rate and RAI

Snow leopard density increased slightly in UM from 1991 to 2014–2016, decreased in LM from 2014 to 2016, and decreased in SNP from 2006 to 2010–2015 (see Table 5.6).

There was a significant positive correlation ($R^2 = 0.85$) between sign encounter rates (No. of scrapes/km) and estimated density of snow leopard per 100 km^2 (Fig. 5.20). Likewise, there was a significant positive correlation ($R^2 = 0.66$) between the relative index of abundance (RAI) and density of snow leopards per 100 km^2 (Fig. 5.21). The close correlations indicate that both the No. of scrapes/km and the No. of captures/100 nights are good approximations of the actual density of snow leopard.

5.4.6 Abundance of Blue Sheep in Lower Mustang and Upper Manang

Numbers of blue sheep in LM are shown in Fig. 5.22 and those in UM in Fig. 5.23, together with their density per km^2. Numbers of individuals differed in the four valleys of LM during the dry season in 2014 and wet season in 2016 (Table 5.7). There were also significant differences in the numbers found in the three valleys in UM during the dry season in 2014 and the wet season in 2016, but the total numbers in UM were not significantly different in these two seasons. The numbers in the wet season in 2016 were only 10% lower than those in the dry season in 2014 (Table 5.7). The strongest decrease was recorded in Proper Manang Valley, where there were 128 in the dry season in 2014 and only 49 in the wet season in 2016. On the contrary,

Table 5.5 Estimated abundances and capture probabilities of snow leopards sampled using the method of Otis et al. 1978 in Lower Mustang (LM), Upper Manang (UM) and Sagarmatha National Park (SNP) in 2014–2015

	Test for closure	Based on Mo (Null)		Based on Mh (Heterogeneity)		Based on Mb (Trap response)		Mbh (Heterogeneity and trap response)	
Study area	Capture	Capture probability	Abundance ± SE 95% CI	Capture probability	Abundance ± SE 95% CI	Capture probability	Abundance ± SE 95% CI	Capture probability	Abundance ± SE 95% CI
LM	$z = -0.026$	0.5	6 ± 0.32	0.50	6 ± 0.50	**0.67**	**6 ± 0.09**	Not computed	6 ± 0.09
	$P = 0.489$		(6–6)		(6–6)		**(6–6)**		(6–6)
UM	$z = -0.894$	0.1	25 ± 19.45	0.13	17 ± 5.0	**0.50**	**8 ± 1.1**	Not computed	8 ± 1.1
	$P = 0.1855$		(11–110)		(12–33)		**(8–8)**		(8–8)
SNP	$z = -0.488$	**0.3**	**3 ± 0.89**	0.09	9 ± 3.7	0.29	3 ± 1.2	Not computed	Not computed
	$P = 0.312$		**(3–3)**		(5–21)		(3–3)		

The bold numbers indicate the best fitting of three models (Mo, Mh, Mb), SE is the standard error. The values in parentheses just below the abundances are 95% confidence intervals (CI)

Table 5.6 Population size and density of snow leopard in LM and UM and SNP in different years

Location	Year	Population size	Density of snow leopard per 100 km^2
UM	1991[a]	5	4.8–6.7
	2014	8	7.6
	2016	6	5.7
LM	2014	6	6
	2016	3	3
SNP	2005[b]	6	6
	2010[c]	2	2
	2015	3	3

Indicators next to the year: [a]Oli (1994), [b]Lovari et al. (2009), [c]Ferreti et al. (2014), without—this study

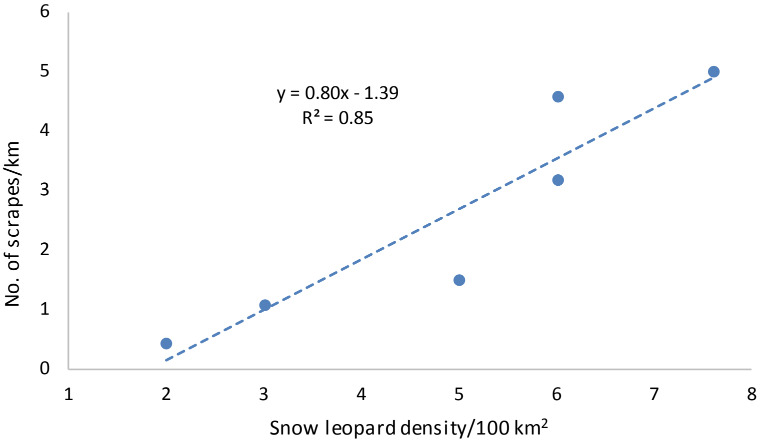


Fig. 5.20 Correlation between sign encounter rate (No. of scrapes/km) and snow leopard density per 100 km^2 recorded in LM, UM and SNP from 2014 to 2015

numbers recorded in Yak Kharka valley increased from 288 in the dry season in 2014 to 411 in the wet season in 2016.

Linear regression of the dependence of the population density of blue sheep and time (not depicted) yielded the following equations: $y = -0.23x + 2.2$ with $R^2 = 0.21$ for LM and $y = 6.83$ with $R^2 = 0.00$ for UM; neither of the R^2 values are significant ($P < 0.001$). Thus, the lack of significant correlation between the population density and time indicates that there was no significant trend in the population density of blue sheep either in LM or in UM (see also Figs. 5.22 and 5.23).

In LM, the sex ratios were 1.1:1 and 0.62:1 in 2014 and 2016 respectively, whilst in UM they were 0.94:1 and 1.1:1 in 2014 and 2016 respectively. In 1990–1991, the mortality rate of blue sheep from autumn to winter in UM was the highest for yearlings (0.46), followed by young males (0.41), adult males (0.40), sub adult males (0.35) and females (0.10) (Oli 1991). In LM, the kid to female ratio (reproductive

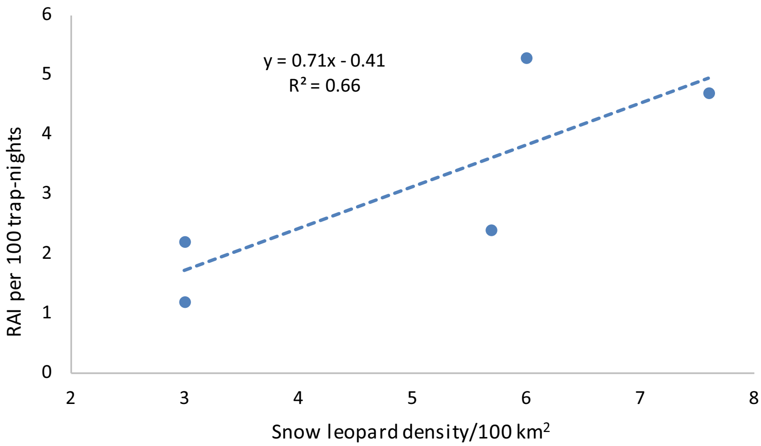


Fig. 5.21 Correlation between the relative index of abundance (RAI = No. of captures/100 nights) and snow leopard density per 100 km^2 recorded in LM, UM and SNP from 2014 to 2015

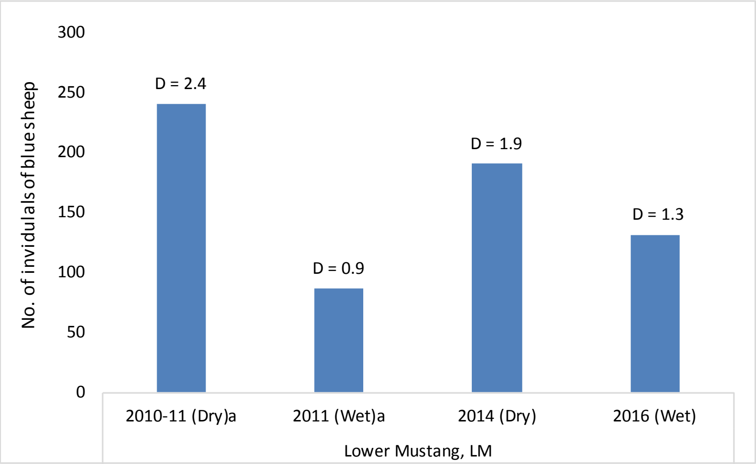


Fig. 5.22 Total number of blue sheep in Lower Mustang. Season indicated as “Dry” or “Wet”. D (above the columns) = density, No. of individuals/km^2. Letters next to the year: a Ale et al. (2014), no letter—this study

rate) was 0.54 during the dry seasons in 2010 and 2011 ($n = 29$, $SE = 0.11$), 0.55 during the wet season in 2011 ($n = 5$, $SE = 0.16$), 0.5 during the dry season in 2014 ($n = 28$, $SE = 0.07$) and 0.6 during the wet season in 2016 ($n = 7$, $SE = 0.06$), which indicates a stable population growth. There is no correlation between population size of blue sheep and time in LM (Fig. 5.22).

In UM, the kid to female ratio was 0.7 during the dry season in 1990 ($n = 38$) (Oli 1991), 0.66 during the dry season in 2014 ($n = 70$, $SE = 0.042$) and 0.65 during the

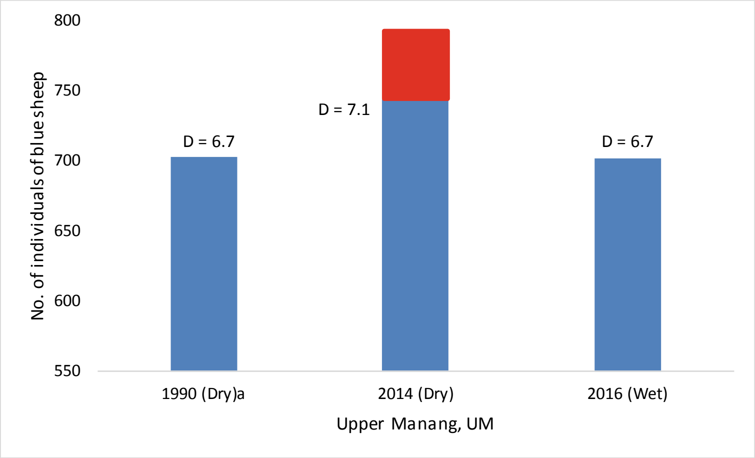


Fig. 5.23 Total number of blue sheep in Upper Manang. Season indicated as "Dry" or "Wet". D (above the columns) = density, number of individuals per km^2. Letters next to the year: a Oli (1991), no letter—this study. The red bar on top of the column 2014 indicates the 50 blue sheep killed by a heavy snowfall, which occurred during the monitoring period (see the main text for explanation)

Table 5.7 Numbers of blue sheep recorded in four valleys in Lower Mustang (LM) and three valleys in Upper Manang (UM) during the dry season in 2014 and the wet season in 2016

LM	Valley	Jhong	Lupra	Muktinath	Thini	Total
	Dry season 2014	16	32	16	127	191
	Wet season 2016	45	5	65	17	132

UM	Valley	Proper Manang	Yak Kharka	Khangsar	Total
	Dry season 2014	128	288	328	744
	Wet season 2016	49	411	242	702

wet season in 2016 (n = 25, SE = 0.03), which indicates that the population increased slightly over the years. However, in fact, the population density has been more or less constant in UM (Fig. 5.23). This discrepancy may be due to high mortality, for example during the monitoring period in 2014 when heavy snowfalls and avalanches killed ~ 50 adult male blue sheep in UM (Fig. 5.23).

5.4.7 *Abundance of Himalayan Tahr in the Sagarmatha National Park*

The total population size of Himalayan tahr recorded during the dry period in autumn decreased from about 350 individuals in 1989 to about 134 individuals in 2009, and after that the population increased to about 223 individuals in 2015 (Fig. 5.24). There

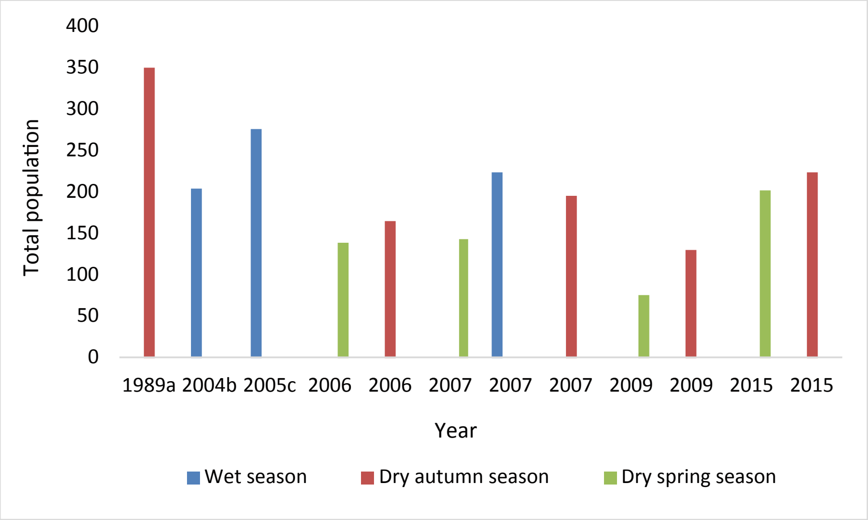


Fig. 5.24 Abundance of Himalayan tahr in different years and seasons. Letters next to the year indicate the source of data: a Lovari (1992) and Lovari et al. (2009), b Shrestha (2006), c Ale (2007), years not followed by a letter are data from this study. During this study, one, two or three monitoring sessions were carried out during the wet season, dry autumn season and dry spring season. When there were multiple sessions, the final number was the highest number recorded in each tahr demographic category (see Appendix—Box 5.1 and Fig. 5.27 for multiple monitoring sessions in each season)

is a similar trend in the population densities (Fig. 5.25). The sex ratios were 0.88, 0.71, 0.53 and 0.70 in spring of 2006, 2007, 2009 and 2015, respectively.

Himalayan tahr populations recorded in four valleys in SNP in years 2006–2015 differed significantly in their sizes (One-way ANOVA, $P < 0.001$; Table 5.8). The largest population was recorded in Phortse valley, where almost 100 individuals were recorded. The smallest population of only about 20 tahr was recorded in Thame valley.

In all four valleys, the lowest number of tahr was recorded in 2009, but different trends in abundance were recorded in individual valleys. The small population in Thame valley was more or less stable. Numbers decreased from 20 animals in 2006 to 15 in 2009 and increased again to 24 in 2015 (Table 5.8). A similar trend, but with bigger fluctuations between years was recorded in Namche valley. Numbers decreased from 53 in 2006 to only 40 in 2009, and almost doubled to 70 in 2015. In Thame and Namche valleys, numbers increased during the period studied and signs indicating the presence of snow leopards decreased and were absent in 2015 (Table 5.8 and Fig. 5.19). In Gokyo valley, numbers decreased from 30 individuals recorded during the dry season in 2007 to only 13 and 15 during the dry seasons in 2009 and 2015, respectively. Then this population grew only slightly to 15 in spring 2015 and 16 in autumn 2015. It is assumed that the numbers decreased in Gokyo, whereas signs of the presence of snow leopard increased. In the Phortse valley, the numbers decreased from 2007 to 2009 and increased from 2009 to 2015, whereas

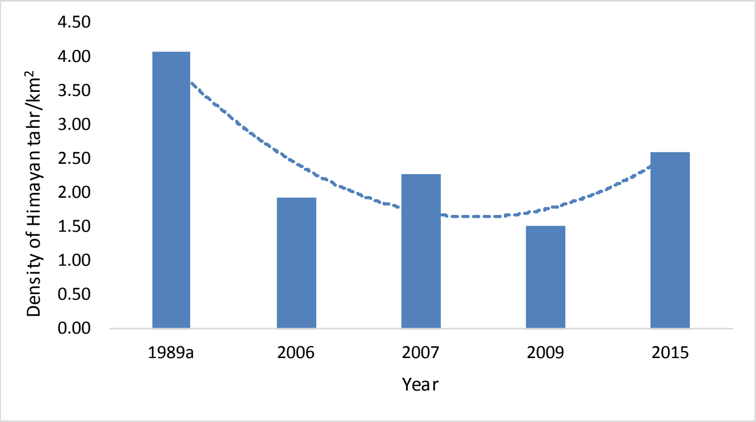


Fig. 5.25 Himalayan tahr density per km^2 in dry seasons of different years from 1989 to 2015 in SNP. Letter “a” next to the year indicates data from Lovari 1992 and no letter data from this study

Table 5.8 Numbers of Himalayan tahr recorded in four valleys in SNP in years 2006–2015

Valley	Gokyo	Namche	Phortse	Thame	Total
Dry season 2006	25	53	84	20	182
Dry season 2007	30	64	101	21	216
Dry season 2009	13	40	66	15	134
Dry spring season 2015	15	70	96	22	203
Dry autumn season 2015	16	86	97	24	223

the signs of the presence of snow leopard decreased from 2006 to 2009 and started to increase from 2009 to 2015 (Table 5.8 and Fig. 5.19). Tahr population density rapidly decreased in 2009, probably due to the high number of predators in the previous years, which was indicated by the signs of their presence (Fig. 5.19, Table 5.6).

The reproductive rate of Himalayan tahr was negatively correlated with the density of snow leopards (Fig. 5.26). In 1990, no snow leopards were recorded in SNP, but six individuals were recorded in the area in 2004–2005 (Table 5.6), when the ratio of kid to female decreased. During 2009–2015, the numbers of snow leopards decreased, whereas the kid to female ratio increased.

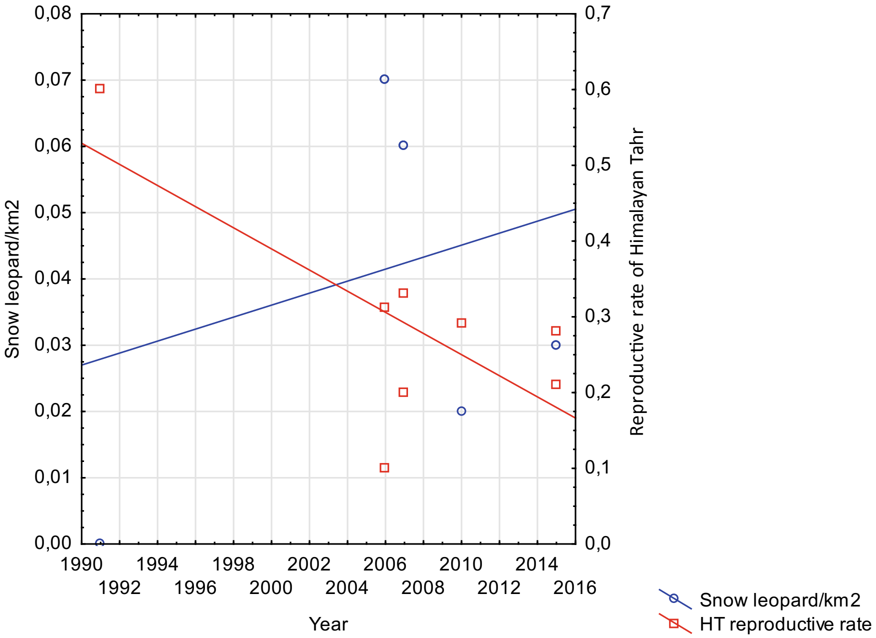


Fig. 5.26 Relation between snow leopard density and reproductive rate of tahr from 1990 to 2016

5.5 Discussion

5.5.1 Monitored Transects

When we compared all the transects in SNP, LM and UM, both in dry and wet seasons, significant differences in many of the transects' parameters were found. However, when we analysed only transects monitored during the dry seasons there were no significant differences. Dry season transects in SNP, and in LM and UM in ACA partly differed only in proportion of different habitats, topography and ruggedness. This reflected differences in vegetation cover and geomorphology of the two areas studied. Transects in SNP, where there are V-shaped rugged valleys are also shorter, located at lower altitudes and their distances to the nearest cliff are significantly greater than those of the transects in LM and UM, where there are wide U-shaped valleys. Because of the V-shaped valleys, transects in SNP were located at lower altitudes than transects in LM and UM and their distances to the nearest cliff were significantly greater.

In UM and LM, the exposure of valleys determines the natural vegetation. It is a transition zone between the moist southern Himalayan slopes and the high deserts of Tibet (Ale et al. 2014; Shrestha et al. 2018, 2020). The cooler north-facing slopes are densely forested with Himalayan pine (*Pinus wallichiana*), Himalayan fir (*Abies* *spectabilis*) and Himalayan birch (*Betula utilis*), while dwarf juniper (*Juniperus squamata*), *Caragana* sp., *Berberis* sp., and some grasses thrive on the drier south-facing slopes, which have higher evaporation rates. Patches of *Pinus excelsa, Betula utilis* and *Juniperus indica* occur along the riverbanks. These alpine valleys are in the rain-shadow of the Annapurna Mountain Range and have a dry and cold climate. In SNP, the dominant trees are *Pinus wallichiana, Abies spectabilis* and *Juniperus recurve* at 3000–3600 m a.s.l., followed by *Betula utilis, Abies spectabilis*, *Rhododendron barbatum* and *R. arboreum* at 3600–3800 m a.s.l., *Juniperus* sp. and *Rhododendron* sp. at 3800–4500 m a.s.l. and birch-rhododendron forests at 3600–4200 m a.s.l., mostly on colder, north facing slopes. Shrubland (*J. squamata*, *Berberis* sp., *Cotoneaster microphyllus, R. anthopogon, R. lepidotum, R. setosum and R. nivale*) and grass dominate the upper alpine landscape at 3500–5000 m a.s.l. (Buffa et al. 1998; Garbarino et al. 2014). Above 3000 m a.s.l., in rain shadow areas in LM and UM the average rainfall is less than 260 mm/year (NTNC 2008a, b), while in SNP it is 1166 mm/year at 3450 m a.s.l. (Bhattarai and Upadhyay 2013). Therefore, the rangelands in SNP are more productive in terms of grass and shrubs.

Snow leopard and its prey live and behave similarly in all these habitats. Snow leopard occurs in rocky and broken terrain, river bluffs, well defined ridgelines, cliffs, gorges, stream beds of gravel and sandbars, vegetation dominated by grasses, shrubs or trees, broken or very broken ruggedness, rolling and flat ruggedness, barren habitats without any vegetation or infrequently grazed areas, forest borders or open shrub land/alpine meadows and sometimes cultivated fields and areas subject to landslides, and strongly prefers slopes in excess of 40° (Jackson and Ahlborn 1988; Jackson 1996; Fox and Chundawat 1997). Our transects were placed in these typical snow leopard habitats.

5.5.2 Snow Leopard Abundance, Population Size and Density

In summary, in LM and UM, the numbers of scrapes recorded during the dry period in 2014 were lower than the numbers of scrapes recorded during the wet period in 2016. However, the 2014 and 2016 transects were not identical. Therefore, without additional data for wet and dry seasons, it is not possible to say, whether the increase in the numbers of scrapes from 2014 to 2016 is a real temporal trend (i.e. the SL population increased) or just a difference between wet and dry seasons.

Data from repeatedly monitored transects in SNP deliver a more comprehensive picture of the SL population in this area. Unfortunately, even in this case, observations for some years and valleys are missing. In addition, more information about changes in habitat conditions or grazing management in valleys during this time is needed for a rigorous explanation of the recorded changes in the SL population in SNP.

Our study showed that the No. of scrapes/km is positively correlated with snow leopard density recorded using camera trapping. The abundance of scrapes, as well as tracks and scats, may provide a rough index of relative numbers, but counts of scrapes may vary from area to area, because of:

Table 5.9 The ratio of scrapes/km to the number of individuals recorded using camera trapping

Location	Scrapes /km	Individuals /100 km^2	Ratio	Source
Ladak (India)	2.1	1		Fox et al. (1991)
Upper Indus valley	2.5	~ 3	0.83	Fox and Chundawat (1997)
Langu valley, west Nepal	11	8–10	1.1–1.37	Ahlborn and Jackson (1988)
LM, UM 2014	4.5–5	6–8	0.56–0.83	This study
SNP 2005–2006	2.5–3	6	0.31–0.5	This study
SNP 2015	0.5–1	3	0.17–0.33	This study

(i) different patterns in the terrain and topography,
(ii) local livestock density, which may play a role, because livestock may disturb the scrapes and make then invisible,
(iii) bad weather (rain etc.) can destroy the signs,
(iv) snow leopard itself may behave differentially from place to place (Jackson 1996; Fox and Chundawat 1997; McCarthy 2000) and
(v) density of transects (different total length of transects per 100 km^2).

The ratio of scrapes/km to the number of individuals recorded using camera trapping or other methods differs markedly between studies (Table 5.9). Therefore, counts of scrapes as a measure of abundance must consider factors (i)–(v) above. Number of scrapes recorded during the dry period in 2014 was significantly higher than that recorded during the wet period in 2016, but this result must be treated with caution if one considers the above factors.

The number of scrapes recorded was higher in the dry season than in the wet season in LM and UM and there are three possible reasons for this:

(i) The transects in dry and wet seasons significantly differed in many of their parameters. During the dry season in 2014, transects were established at lower altitudes than those monitored during the wet season in 2016, because in 2014 deep snow cover strongly limited mobility of animals and observers at high altitudes.
(ii) The likelihood of finding signs of the presence of snow leopards is greater during the dry season than during the wet season, when snow leopards probably move to higher altitudes, where the sites are more rugged and rainfall greater, and therefore are inaccessible for humans in summer. Thus, pressures from livestock grazing and human presence are stronger at lower altitudes. Lower abundance of the signs of snow leopard presence in summer than in autumn may be because they are destroyed by livestock in summer at lower altitudes (Ale et al. 2014).
(iii) Snow leopard population sizes were different in the two periods monitored in each study area (Table 5.5).

In LM and UM, the number of camera captures of snow leopard per 100 trap-nights (RAI) reflects the high inter-annual differences (dry season 2014 and wet season 2016) in snow leopard population size.

In SNP, the snow leopard population decreased from 2006 to 2015 and increased slightly in UM from 1990 to 2014 or 2016. During the two years of our study, neither signs, nor photographs of snow leopard were recorded in Lupra in LM and Thame in SNP. However, snow leopards were recorded earlier in Lupra in 2010 and 2011 (Ale et al. 2014), and in Thame in 2009 (Appendix—Box 5.1). In Lupra valley, this may be because of competition from common leopard, which was detected here three times even at an altitude as high as 4300 m a.s.l. Alternatively, increasing presence of local people collecting yarsagumba (*Cordyceps sinensis*—a well-known medicinal species) in Lupra valley during the wet season may have caused its prey (blue sheep) to go elsewhere.

In Thame valley, the reason may be the decrease in the numbers of its other prey, Himalayan tahr, from 2006 to 2009 (Table 5.9), or human-snow leopard conflict followed by retaliatory killing. In SNP, 8 camera captures of common leopard in forest and scrubland near to forest were recorded, which may indicate that interspecific competition might have resulted in a reduction in the abundance of snow leopards (Creel 2001).

The density of snow leopard slightly increased in UM from 1991 to 2014–2016, and the blue sheep population was stable during this time (above 6.7 individuals/km^2) and seemed to provide sufficient food for the recorded numbers of snow leopards (6–8 individuals in the area) to thrive. In contrast, the snow leopard density decreased in SNP from 2006 to 2010–2015 and the tahr population there decreased by 61% from 1989 to 2009. In both LM and UM, the snow leopard density decreased from 2014 to 2016. In 2014, it was due to a hard winter season and heavy snowfalls. Males and females were recorded mating and the habitats were not disturbed by humans. Therefore, camera traps might have captured more snow leopard individuals during winter. In contrast, in 2016, in summer and the wet season, when the habitats were disturbed due to *Cordyceps sinensis* collection by local people and grazing by herds of yaks at high altitudes, which might have displaced the blue sheep to other areas. This might be the reason, why fewer snow leopards were recorded by cameras in 2016. Because of small sample sizes and animals possibly moving outside the areas studied, the estimates for LM and UM should be viewed with caution.

5.5.3 *Abundance of Blue Sheep in Lower Mustang and Upper Manang*

There was more blue sheep in UM than LM, due to the more overgrazed and degraded land in LM. Based on our field experience and NTNC (2008a, b), LM is a more barren and unproductive area than UM. Moreover, livestock pressure is also low in UM.

The reproductive rate of blue sheep (0.67) indicates that the population is increasing. However, in UM, the number was more or less constant from 1990 to 2016 (Fig. 4.5). Plausible reasons for the lack of changes in population size in this area could be:

(i) slight increase in the number of snow leopards, with one or two more individuals than recorded in 1990;
(ii) environmental stochasticity, as heavy snowfalls and avalanches in 2014 and 2015, killed ~ 50 adult male blue sheep in UM.

Differences in the management of valley pastures may also explain the high inter-valley differences in UM: in Proper Manang, yak herds grazed these pastures during the wet season, but not in Yak Kharka.

In LM, the number of blue sheep was 30% lower in the wet season in 2016 than in the dry season in 2014, although the predator pressure was lower because there were fewer snow leopards there in 2016. The reasons for the lower number of blue sheep in 2016 might be:

(i) *Cordyceps sinensis* collection by local people and grazing by herds of yaks in the wet seasons at high altitudes might cause the blue sheep to go elsewhere;
(ii) possibility that some adult male blue sheep were missed during the counting because they leave the female herds in the wet season and wander widely at high altitudes, which could make finding them difficult in foggy weather.

5.5.4 Abundance of Himalayan Tahr in the Sagarmatha National Park

Himalayan tahr population decreased by 63% between 1989 and 2009 (from 350 to 134 individuals, Fig. 5.24) after which it increased by about 70% to 223 individuals in 2015. This is, however, still less than the 350 reported in 1989 by Lovari (1992). Unlike blue sheep, the numbers of which differed in the dry and wet seasons in the valleys, tahr numbers were more or less the same in all valleys in both seasons in 2007. Namche and Phortse valleys are separated by the deep gorges of two rivers, which can be a barrier for tahr moving between valleys. People do not collect *Cordyceps* in SNP during the wet seasons.

The results indicate an inverse relationship between the numbers of Himalayan tahr and signs of the presence of snow leopards in the four valleys in SNP. For example, in Namche and Thame there was a high number of Himalayan tahr and a low incidence of signs of the presence of snow leopards. A similar finding is reported by Fox and Jackson (2002) for snow leopards and blue sheep in trans-Himalayan Nepal (blue sheep 2–4/km^2 and 2.8 snow leopard signs/100 km) and in Bhutan (blue sheep 4–6/km^2 and 1.2 snow leopard signs/100 km). However, *Capra ibex* density does not appear to be a good predictor of snow leopard abundance in Mongolia (McCarthy 2000; Ale 2005). Thus, the common understanding (e.g., Ale 2005) is that that there is a better predictor of predator abundance than density of prey, which is a combination of:

(i) biomass of all available prey, including livestock and small mammals;
(ii) human-snow leopard conflict level (e.g., retaliatory killing);
(iii) disturbance factors associated with human activity (roads, trekking, sound, light, etc.).

The recent study by Shrestha et al. (2018) reports that Himalayan tahr is the most important prey of snow leopard in SNP. Our study revealed that the reproductive rate of Himalayan tahr is negatively correlated with the abundance of snow leopards (Fig. 5.26). In 2004–2006, i.e., when six snow leopards were recorded in the area again, the predation rate on Himalayan tahr was probably high, because the tahr there had no previous experience of predators. Therefore, the mortality rate of tahr was high in 2007 and probably continued into 2008. Therefore, the abundance of Himalayan tahr was low in 2009, and subsequently the number of snow leopards decreased to only two individuals in 2010. On the other hand, tahr moves down to forested areas during winter (January–February) and camera traps placed near such areas captured common leopard in Namche and Phortse. Therefore, in winter, the effect of predators on tahr could be high, as two species of predator were present. In addition, diseases, e.g. brucellosis, or other infections may affect the fertility of females and neonatal-juvenile mortality in ruminants, but Lovari et al. (2009) did not find any pathogens in the samples of blood collected from Himalayan tahr.

The competition for forage between tahr and livestock could cause a decrease in the abundance of tahr. Shrestha et al. (2012) report a large overlap in the diets of tahr and livestock, based on the Morisita index ($C_H = 0.83$). However, this study was carried out in the monsoon season, when the net primary productivity is high and forage quality is very good. During summer, tahrs are more agile than livestock and are able to reach vegetation growing in steep and rocky areas and therefore they are spatially separated from livestock (Shrestha et al. 2012). Hence, a strong competition for food is unlikely during summer. However, forage quality is very low in winter, when herders bring their livestock down to villages near to forest. Similarly, tahrs move down to forested areas during January–February. In shrub and forest areas, both yaks and tahrs must eat unpalatable forage, including shrubs and tree bark, and their dietary overlap might be 100% (Shrestha et al. 2012). In Namche, people no longer follow the traditional seasonal rotation in livestock grazing and they let their livestock graze freely throughout the year. Therefore, in winter livestock and tahr could compete for food in SNP. Most livestock remove large amounts of forage from pastures (Bagchi et al. 2004), which otherwise would be available to native prey.

5.5.5 Take-Home Message of This Chapter

The data presented provides information on the numbers of snow leopards and its two main species of prey in the area studied over a particular period of time and of the background changes occurring in the region that are also likely to affect these species. However, it is not a clear picture of the patterns and processes that are occurring in the snow leopard—prey system. This is because the data were lumped together from various sources, which are to a large extent incompatible. The differences between transects monitored even within the same area prevent pooling the data to obtain a longer time series and the production of a model of the population dynamics of the system. In addition, differences between transects and the regions studied make inter-regional comparisons of the population dynamics of snow leopard and its prey very difficult.

This is a great pity, because the collection of this large dataset has cost a large amount of money and manpower. Unfortunately, this is not unique. The same has happened in all the countries where snow leopards occur, which has resulted in large amounts of data, which are mutually incompatible. What does this indicate and what should be done in the future?

Although we have a very large data set, which was difficult to collect and the collection process took many years, there are still many aspects of the story, such as the details of the life history strategies of the snow leopard and its prey, which need to be resolved. It seems that the more research we do the more questions and possible interpretations arise. Snow leopard, the mysterious ghost of high mountains, protects its secrets very well.

Scientists and conservationists already recognise that better knowledge of the life history strategy of snow leopard is essential for the successful conservation of this iconic species. Time is running out and there is a risk that we will reveal the most important facts too late to ensure the survival of snow leopards. To avoid this, extensive and effective cooperation is needed. Maybe the IUCN or some other international authority could coordinate this.

The international community of scientists working on snow leopards should agree on some common rules on how data should be collected and shared. This needs specific recommendations for each region, target transects should be designed based on the current knowledge of the areas, where snow leopard occurs, including the data presented in this book. This common methodology should be based on discussions between scientists working on snow leopards and statisticians who will advise on how the data should be collected so that it is statistically tractable. This chapter provides instructive examples of this. For example, in some cases the data were not collected in particular years, because the scientists involved in the project considered they were unlikely to record snow leopards in a particular region. However, for the statistical analysis of the data, one should at least check that snow leopard is really absent in particular regions.

Appendix—Box 5.1

Tables of transects, main parameters and scrapes/km (Sc/km) in the three areas studied: Upper Manang (UM), Lower Mustang (LM) and Sagarmatha NP. Abbreviations and explanation of parameters are described in Table 5.1.

Upper Manang

	Length (km)	SC/km	TFG	RUGG	HAB	CLD (m)	SLP (°)	ASP	Elevation (m)	Trail
UM, 2014 (Dry)										
UM14_01	0.8	3.1	RID	VB	S	200	55	S	3800–4047	HT
UM14_02	0.8	2.5	HS	VB	G	800	40	S	4609–4730	HT
UM14_03	0.8	6.3	HS	ROL	G	500	40	SE	4207–4350	HT
UM14_04	0.8	6.3	RID	ROL	S	800	45	N	3571	HT
UM14_05	0.8	2.8	RID	ROL	S	50	45	SE	3817	HT
UM14_06	1	6.0	RID	ROL	F	600	45	SE	3701–3809	HT
UM14_07	0.8	5.0	RID	ROL	S	200	50	SE	4232	HT
UM14_08	0.8	6.3	HS	ROL	S	500	40	SW	4207	HT
UM14_09	1.2	5.8	HS	ROL	S	500	35	SW	4265	HT
UM14_10	0.8	5.0	RID	ROL	G	800	40	SW	4350	HT
UM14_11	1	7.0	HS	B	S	400	40	SW	4287	HT
UM14_12	1	1.0	HS	ROL	S	520	50	SW	4300–4434	HT
UM14_13	1.2	6.7	RID	B	G	500	30	NE	4053	HT
UM14_14	0.8	5.0	RID	B	G	800	45	S	4347	HT
UM14_15	0.8	4.4	HS	ROL	S	600	40	SE	4324	HT
UM14_16	0.8	3.8	HS	ROL	S	800	40	S	4116	HT
UM14_17	0.8	7.5	HS	ROL	G	800	40	S	4461	HT
UM, 2016 (Wet)										
UM16_01	1	1.5	RID	ROL	G	1,000	40	SE	4709	HT
UM16_02	0.8	0.6	RID	ROL	S	800	40	SE	4409	HT
UM16_03	0.8	2.5	HS	ROL	S	800	45	NE	4362	HT
UM16_04	0.8	5.0	HS	B	G	800	40	SE	4444	HT
UM16_05	1	20.0	RID	ROL	S	800	45	N	3571	HT
UM16_06	0.8	7.5	RID	VB	S	200	55	S	4200	HT
UM16_07	0.8	2.5	RID	VB	G	50	55	S	4730	NT
UM16_08	0.8	1.9	RID	B	G	500	45	SW	4574	HT
UM16_09	0.8	5.0	RID	VB	G	200	50	SE	4716	HT
UM16_10	0.8	1.3	HS	B	S	200	50	S	4543	HT
UM16_11	0.8	0.6	HS	B	G	1,000	50	N	4601	HT
UM16_12	0.8	1.3	BOL	VB	S	100	50	N	4478	HT

Lower Mustang

	Length (km)	SC/km	TFG	RUGG	HAB	CLD (m)	SLP (°)	ASP	Elevation (m)	Trail
LM, 2014 (Dry)										
LM14_01	0.8	5.0	RID	B	SC	500	45	SW	3351	HT
LM14_02	0.8	7.5	CLF	VB	SC	50	55	S	3761–3811	HT
LM14_03	0.8	7.5	RID	B	S	300	50	S	3957–4007	HT
LM14_04	0.8	6.3	CLF	B	S	100	40	S	3399–4125	HT
LM14_05	0.8	3.8	BOL	VB	G	200	35	NW	4252	HT
LM14_06	0.8	2.5	RID	B	G	100	50	SW	4480	HT
LM14_07	0.8	2.5	HS	ROL	OF	800	40	S	3705	HT
LM14_08	1	3.0	HS	ROL	S	800	40	S	4041	HT
LM14_09	0.8	3.7	RID	ROL	G	800	45	S	3618	HT
LM, 2016 (Wet)										
LM16_01	0.8	3.1	CLF	VB	SC	50	55	S	3761–3811	HT
LM16_02	1	5.0	CLF	VB	SC	50	100	S	4238–4394	HT
LM16_03	1	1.5	RID	ROL	OF	500	45	W	3934	HT
LM16_04	0.8	0.0	HS	ROL	G	100	55	N	4300	HT
LM16_05	1	0.5	HS	ROL	F	1000	45	N	3885	HT
LM16_06	0.8	0.0	BOL	VB	G	200	35	NW	4252	HT
LM16_07	0.8	0.0	RID	ROL	G	500	50	W	4450	HT
LM16_08	0.8	1.3	RID	VB	G	100	50	SW	4329	HT

Sagarmatha National Park

TRANSECT	Length (km)	Sc/km Dry 2006	Sc/km Dry 2007	Sc/km Dry 2009	Sc/km Dry-spring 2015	Sc/km Dry-autumn 2015	TFG
SNP_01	0.85	1.78	1.18	0.00	0.39	1.18	HS
SNP_02	0.50	0.00	0.00	0.00	0.00	2.00	HS
SNP_03	0.80	0.00	–	–	0.83	1.25	HS
SNP_04	0.30	0.00	–	–	3.33	0.00	CLF
SNP_05	0.60	0.00	–	–	0.00	0.00	RID
SNP_06	0.60	0.00	–	–	2.22	1.67	HS
SNP_07	0.70	0.00	0.00	–	0.00	1.43	HS
SNP_08	1.00	2.50	1.50	0.83	5.50	0.00	HS
SNP_09	0.40	5.00	7.50	0.00	0.00	0.00	RID
SNP_10	0.49	4.10	2.05	0.83	6.15	0.00	HS
SNP_11	0.40	3.75	5.00	0.83	0.00	0.00	HS
SNP_12	1.00	2.00	1.00	–	0.00	0.00	HS
SNP_13	0.40	1.25	7.50	0.00	2.50	0.00	RID

(continued)

(continued)

TRANSECT	Length (km)	Sc/km Dry 2006	Sc/km Dry 2007	Sc/km Dry 2009	Sc/km Dry-spring 2015	Sc/km Dry-autumn 2015	TFG
SNP_14	0.20	10.00	7.50	1.25	1.00	5.00	HS
SNP_15	0.60	8.33	0.56	1.25	0.00	1.67	HS
SNP_16	0.90	4.44	0.00	0.50	1.48	1.11	RID
SNP_17	0.65	6.15	1.54	0.63	2.46	1.54	HS
SNP_18	0.63	2.40	0.00	0.00	0.32	1.60	HS
SNP_19	0.40	0.00	0.00	–	0.00	0.00	HS
SNP_20	0.50	10.00	1.00	1.25	0.40	2.00	HS
SNP_21	0.50	1.00	0.00	–	2.00	2.00	RID
SNP_22	0.90	0.00	0.56	0.00	0.00	2.22	HS
SNP_23	0.40	0.00	2.50	0.83	0.00	3.75	HS
SNP_24	0.41	0.00	–	0	–	–	HS
SNP_25	0.50	3.00	1.00	0.00	0.00	0.00	RID
SNP_26	0.70	5.00	1.43	0.00	0.00	0.00	HS
SNP_27	0.50	2.00	2.00	0.63	0.00	0.00	HS
SNP_28	1.00	0.50	0.00	0.63	0.00	0.00	RID
SNP_29	1.00	0.50	0.00	0.00	0.00	0.00	HS

TRANSECT	RUGG	HAB	CLD (m)	SLP (°)	ASP	Elevation (m)	Trail
SNP_01	B	S	200	50	S	4293	MT
SNP_02	B	G	200	45	S	4365	MT
SNP_03	B	S	800	45	SW	4302	MT
SNP_04	VB	B	100	55	S	4844	NT
SNP_05	B	G	1200	40	S	4531	HT
SNP_06	B	S	500	45	SW	4534	HT
SNP_07	B	G	800	30	W	4575	MT
SNP_08	ROL	F	1000	40	S	3324	HT
SNP_09	HS	S	1000	40	S	3691	HT
SNP_10	B	S	800	45	S	3385	HT
SNP_11	ROL	OF	800	40	s	3350	HT
SNP_12	ROL	OF	1000	40	S	3500	MT
SNP_13	B	F	800	50	S	3486	HT
SNP_14	ROL	S	800	35	S	3868	HT
SNP_15	ROL	OF	1000	45	SW	3636	MT
SNP_16	B	S	100	45	S	3527	HT
SNP_17	B	S	500	40	S	3977	MT
SNP_18	B	S	400	45	S	3975	MT

(continued)

(continued)

TRANSECT	RUGG	HAB	CLD (m)	SLP (°)	ASP	Elevation (m)	Trail
SNP_19	ROL	S	1000	40	S	3881	MT
SNP_20	ROL	OF	800	45	S	4007	HT
SNP_21	ROL	S	1000	45	S	3963	HT
SNP_22	ROL	OF	1000	40	S	3861	HT
SNP_23	ROL	F	800	35	S	3684	HT
SNP_24	ROL	F	1000	35	S	3900	MT
SNP_25	ROL	S	1000	35	SE	3699	NT
SNP_26	ROL	S	1000	30	S	3552	HT
SNP_27	ROL	S	1000	30	S	3550	HT
SNP_28	ROL	S	800	40	E	3829	HT
SNP_29	B	S	400	45	SW	3953	HT

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Chapter 6
Assessment of the Suitability of Particular Areas in Nepal for Snow Leopard Based on MaxEnt Modelling

Bikram Shrestha and Pavel Kindlmann

Abstract Habitat suitability models based on particular environmental variables are increasingly being used to predict occurrence of species for wildlife management issues. A variety of techniques and statistical methods are used in species distribution modelling. In this case we use MaxEnt and data on the distribution of snow leopard in Nepal based on a large set of occurrence data collected from a much wider range of areas (9 districts) than in the previous studies. We used camera traps, scat collections and monitoring of fresh pugmarks and scrapes. All our data based on scats were consistently genotyped to avoid misidentification of the species that produced them. All fresh pugmarks and scrapes were verified whether they originate from snow leopard by using movement pattern of snow leopard from camera trap data. Altitude and annual mean temperature are important common factors contributing to snow leopard habitat suitability within the area studied, indicated by both the percentage contribution of environmental variables and jackknife test from MaxEnt model. Some other uncommon factors also seem to play a role as they were important in at least one of the analyses. These were: distance from roads and precipitation of the driest month; however, their importance has to be considered with caution. To conclude: the habitat suitability models indicate that the main danger for snow leopard survival may be climate change and human expansion. Both these phenomena will push the lower limit of its distribution upwards to higher elevations, which will entail two negative effects.

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6.1 Introduction

Habitats can be defined as regions in environmental space (Aarts et al. 2008; Hirzel and Lay 2008) that are composed of biotic or abiotic environmental variables related directly (e.g. forage biomass and quality) or indirectly (e.g. altitude) to the use of a location by an animal (Beyer et al. 2010). Habitat suitability is defined in terms of a habitat's potential to support particular species, and habitat suitability index is a numerical index, which ranges from a completely unsuitable to an optimal habitat (Kellner et al. 1992). This reflects spatial variability in the probability of species occurrence (Bacon et al. 2017). Habitat suitability models are used to predict species occurrence based on particular environmental variables and are increasingly used for wildlife management (Ottaviani et al 2004; Elith et al. 2006; Hirzel et al. 2006). Spatial structure and configuration of landscapes may have profound effects on population distribution of a species (Collinge 2010), and habitat-based conservation measures help to keep populations at viable sizes for a longer period.

During the last few decades, species distribution models have been widely used to quantify animal-habitat relationships, describe and predict differential space used by animals, identify habitat that is important for an animal (Shrestha 2006; Beyer et al. 2010), and for estimating the effect of climate change on species distribution (Bakkenes et al. 2006; Lavergne et al. 2010). This is essential for effective conservation and management (Kie et al. 2010). Species endangerment, species extinction and biodiversity loss are associated with habitat loss or small geographical range size, and low population density (Purvis et al. 2000). Therefore, information on habitat particularly important to a species is crucial to ensure that it is properly managed, and for determining the priorities for its protection.

A variety of techniques and statistical methods have been used for modelling the distributions of species (Corsi et al. 2000; Guisan and Zimmerman 2000; Scott et al. 2002; Elith et al. 2006; Franklin 2009). They are based on the resource selection function (Boyce and McDonald 1999; Manly et al. 2002), generalized linear models (McCullagh and Nelder 1989), algorithmic modelling based on machine learning (Ripley 1996), and a maximum entropy model called MaxEnt (Phillips et al. 2006). Currently, the most often used method among them is MaxEnt, because of its efficiency in handling complex interactions between response and predictor variables and the possibility of integrating it with GIS techniques (Elith et al. 2006; Yi et al. 2016).

Here we use MaxEnt to model the distribution of snow leopard in Nepal and adjacent parts of Tibet. Although there are some studies on habitat suitability (Fox 1994; Hunter and Jackson 1997; McCarthy et al. 2016; Holt et al. 2018; Kalashnikova et al. 2019; Watts et al. 2019; Atzeni et al. 2020) and the distribution of snow leopards (Li et al. 2016), there are only few on the fragile ecosystems in Nepal.

The first study on the suitability of habitats for snow leopard in Nepal was done by Hunter and Jackson (1997). It was based on a polygon digitized expert-based model. Another was based on the occurrence of scats, pugmarks and scrapes, and a model based on a resource selection factor available using GIS techniques (WWF-Nepal

2009). However, molecular analyses revealed that as much as 50% of the scats, which look like those of snow leopard, in fact belonged to other carnivores, such as wolf, common leopard, red fox and golden jackal (Shrestha et al. 2018). The third study was done by Aryal et al. (2016), who estimated suitability using MaxEnt and 364 occurrences for a few areas.

The suitability of areas and spatial pattern proposed by these studies differ greatly. For example, in the Sagarmatha National Park, the northern part, high mountains and deep river gorges are reported as unsuitable by WWF-Nepal (2009), but the whole Sagarmatha National Park, including large areas outside the park, are reported as suitable by Aryal et al. (2016). Generally, one has to be very cautious in determining suitability, as even small areas of unsuitable habitat (high mountain peaks, deep gorges etc.) in otherwise suitable area can negatively affect the movement of snow leopard between suitable patches of habitat.

Because of these discrepancies, the area suitable for snow leopard in Nepal has still to be determined and refined. Therefore, we used the MaxEnt model and a large set of occurrence data (450 observations) collected from a much wider range of areas (9 districts) across the whole of Nepal. The occurrences were based on camera trap results, scat collections, and monitoring of fresh pugmarks and scrapes. All the data on scats were consistently genotyped to avoid misidentification of the species that produced them. All fresh pugmarks and scrapes were verified based on the patterns in the movement of snow leopards recorded by cameras.

6.2 Study Area

Suitability of areas for snow leopard was estimated for its entire distribution in the northern Himalayan range in Nepal. Camera traps and genetic analysis of scats were used to record the occurrence in Lower Mustang and Upper Mustang of the Annapurna Conservation Area and Sagarmatha National Park (see Chaps. 5 And 9 for further details).

6.3 Methodology

6.3.1 Snow Leopard Occurrence Data and Modelling

Data on occurrences were obtained by monitoring snow leopard signs along transects and camera trapping, and GPS locations of genotyped scat as described in Chaps. 5 and 7.

There were 450 records of occurrence in nine different districts (Fig. 6.1) collected from 2004 to 2016, mostly in the Sagarmatha National Park (Fig. 6.2) and Annapurna Conservation Area (particularly Upper Manang and Lower Mustang) (Figs. 6.3 and

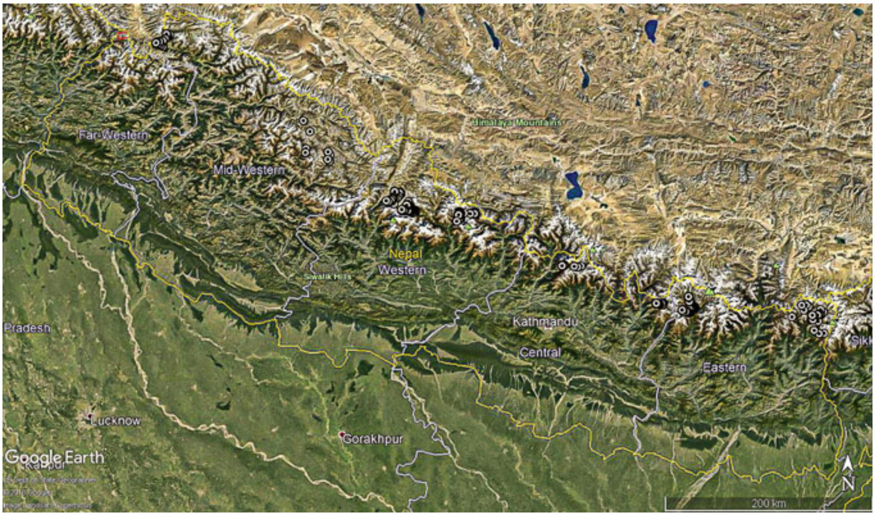


Fig. 6.1 Map of the area showing locations where we samples were collected; exact locations are indicated by circles

Fig. 6.2 Photograph of Bikram Shrestha recording a sample of snow leopard scat in SNP

6.4). Some literature data were also used, like that of Khatiwada and Ghimirey (2008), Shrestha (2008), WWF-Nepal (2009) and CMDN (2010). For descriptions of the environmental conditions and preparation of the habitat suitability model, we used habitat variables related to terrain (topography), 19 bio-climatic variables, habitat (land cover) and effect of human activity or disturbance (distance to nearest roads and buildings) (Table 6.1), which are likely to affect snow leopard presence/absence.

Fig. 6.3 Photograph of snow leopard and blue sheep habitat in Upper Manang, ACA

Fig. 6.4 Photograph of snow leopard and blue sheep habitat in Lower Mustang, ACA

For example, the typical habitat of snow leopard is the rugged terrain depicted in Figs. 6.5 and 6.6, with the upper limit at the snow line (Figs. 6.7 and 6.8).

In Table 6.1 is the total number of variables that were initially used.

Table 6.1 Environmental variables used in the study of the potential distribution of snow leopard. The codes used for variables are in parentheses

	Variable	Source
Topography	Altitude (Alt) Ruggedness index (Ruggedness) Vertical heterogeneity (Ver_het) Slope	SRTM (© CGIAR-CSI, 2004)
Climate	Annual mean temperature (Bio1) Mean diurnal range (Bio2) Isothermality (Bio3) Temperature seasonality (Bio4) Temperature July (Bio5) Temperature January (Bio6) Temperature, annual range (Bio7) Mean temperature in the wettest quarter (Bio8) Mean temperature in the driest quarter (Bio9) Mean temperature in the warmest quarter (Bio11) Annual precipitation (Bio12) Precipitation in the wettest month (Bio13) Precipitation in the driest month (Bio14) Precipitation seasonality (Bio15) (Coefficient of variation) Precipitation in the wettest quarter (Bio16) Precipitation in the driest quarter (Bio17) Precipitation in the warmest quarter (Bio18) Precipitation in the coldest quarter (Bio19)	WorldClim 2.0 (Fick and Hijmans 2017)
Habitat	Main land cover	FAO Global Land Cover Network (http://www.fao.org/geospatial-/projects/detail/en/c/1035672/)
Effect of human activity	Distance to roads (Dist_roads) Distance to buildings (Dist_builings)	Open Street Maps (2017) (www.openstreetmap.org)

The raster digital altitude model (DEM) with a 1-s resolution (approx. 30 m), was obtained from SRTM (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1). It also generated rasters for slope and altitude. The bioclimatic variables were obtained from the WorldClim database with a 30-s resolution (approx. 1 km^2). Land cover was obtained in vector format (polygons) from FAO Global Land Cover Network. The default 33 categories were merged into 9 main classes of land cover. Distance from roads in Euclidean spatial raster with a 30-m resolution was

Fig. 6.5 Photograph of the habitat of snow leopard and Himalayan tahr in SNP

Fig. 6.6 Photograph of Gokyo valley taken from Renjo La pass (5400 m a.s.l.) with Mt. Everest in the background. This is typical snow leopard habitat

generated from the line elements in the Open Street Map database. Distance from human settlements in Euclidean spatial raster with a 30-m resolution was generated from polygonal elements in the Open Street Map database. All these layers of environmental variables were prepared in ArcMap 10.6.1. All data were converted into a uniform raster with a 100-m spatial resolution in ASCII format.

Fig. 6.7 Photograph taken after a heavy snowfall in winter 2014 in Lower Mustang – ACA. The snow line can be as low as ~ 4000 m a.s.l. during winter

Fig. 6.8 Photograph of grassland in summer at Upper Manang, ACA, when the snow line can be above 5500 m a.s.l

ENM Tools version 1.3 was used (Warren et al. 2010) to test for multi-collinearity between 19 bio-climatic variables. ENM Tools output matrix of Pearson correlation coefficients (r) (Table 6.2) was used to exclude variables with |r| ≥ 0.75. Of the correlated variables, only those with a higher percentage contribution and training gain were selected (Tsiftsis et al. in press). After removing 13 highly correlated variables (|r| ≥ 0.75), the remaining six bio-climatic variables were used for producing the final habitat suitability map, which also includes the other important variables: altitude, ruggedness, vertical heterogeneity, slope, main land cover, distance to roads and distance to buildings.

Models of habitat suitability indicate both the actual and potential occurrence of a focal species (Elith et al. 2006). Habitat analyses and potential distribution modelling were run using MaxEnt tool 3.4.1 (Phillips et al. 2018), and 25% of the occurrence data was used to verify the model. Ten (10) models were run with MaxEnt using the auto-features mode and default settings suggested by Phillips and Dudík (2008), bootstrapping was used as a form of replication (test samples chosen randomly by sampling with replacement). Model performance was assessed using the Akaike information criterion (AICc) as it greatly outperforms BIC and AUC based methods. Models were selected using the ENMTools package (Warren et al. 2010) and by selecting that with the lowest AICc value (the model with the lowest AICc value is considered to be the best).

6.4 Results

6.4.1 MaxEnt Model Performance

The receiver operating characteristic (ROC) results (Fig. 6.9) of the best model indicate that the AUC value was high for the MaxEnt model of the training data (0.983) and that the predictions were excellent and potentially useful. The average training AUC for the 10 replicate runs is 0.983 and the standard deviation is 0.001. The low AUC standard deviation (0.001) indicates there was no overfitting around the presence data.

6.4.2 Distribution of Suitable Habitat for Snow Leopard with Predictor Variables

The percentage contribution of environmental variables (Table 6.3) revealed the four main factors contributing to snow leopard habitat suitability within the area studied. They are distance from roads (Dist_roads; 25.8%), annual mean temperature (Bio1; 23.2%), distance from buildings (Dist_buildings; 22.4%) and altitude (Altitude; 13.4%). The permutation importance in the MaxEnt model prediction

Table 6.2 Pearson correlation coefficients of 19 bio-climatic variables used for modelling snow leopard habitat suitability in Nepal

Variable	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
bio1	0.00	–0.34	0.66	−0.72	*0.98*	*0.99*	−0.68	*0.92*	*0.92*	*0.99*	*0.99*	*0.81*	*0.86*	0.04	*0.76*	*0.85*	0.29	0.67	–0.23
bio2	0.00	0.00	0.01	0.56	–0.21	−0.43	*0.76*	–0.38	–0.28	–0.28	–0.37	–0.64	–0.57	–0.57	–0.24	–0.57	–0.57	–0.66	–0.37
bio3	0.00	0.00	0.00	*−0.80*	0.61	0.69	−0.63	0.52	0.52	0.61	0.70	0.47	0.47	0.01	0.32	0.48	0.19	0.39	–0.36
bio4	0.00	0.00	0.00	0.00	–0.61	*−0.80*	*0.96*	–0.63	–0.56	–0.65	–*0.79*	–0.72	–0.69	–0.34	–0.38	–0.70	–0.47	–0.68	0.11
bio5	0.00	0.00	0.00	0.00	0.00	*0.95*	−0.55	*0.91*	*0.93*	*1.00*	*0.97*	0.74	*0.81*	–0.06	*0.78*	*0.81*	0.20	0.59	–0.28
bio6	0.00	0.00	0.00	0.00	0.00	0.00	*−0.77*	*0.91*	*0.90*	*0.97*	*1.00*	*0.84*	*0.88*	0.12	0.73	*0.87*	0.36	0.71	–0.19
bio7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–0.62	–0.54	–0.60	–0.74	–*0.78*	–0.72	–0.45	–0.38	–0.73	–0.56	–0.74	–0.06
bio8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.79*	*0.92*	*0.91*	*0.78*	*0.83*	0.12	*0.82*	*0.82*	0.30	0.67	–0.23
bio9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.93*	*0.91*	0.71	*0.77*	–0.04	0.64	*0.76*	0.24	0.54	–0.09
bio10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.98*	*0.78*	*0.84*	–0.01	*0.78*	*0.83*	0.25	0.63	–0.24
bio11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.82*	*0.86*	0.08	*0.73*	*0.86*	0.33	0.69	–0.22
bio12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.98*	0.32	0.65	*0.99*	0.45	*0.95*	0.00

(continued)

Table 6.2 (continued)

Variable	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
bio13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	*0.75*	*1.00*	0.38	*0.92*	–0.08
bio14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–0.14	0.21	*0.85*	0.33	0.64
bio15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.01	0.57	–0.34
bio16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	*0.93*	–0.09
bio17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.71
bio18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–0.05
bio19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

r ≥ |0.75| are highlighted in italics
Codes for variables are explained in Table 6.1 and in the text

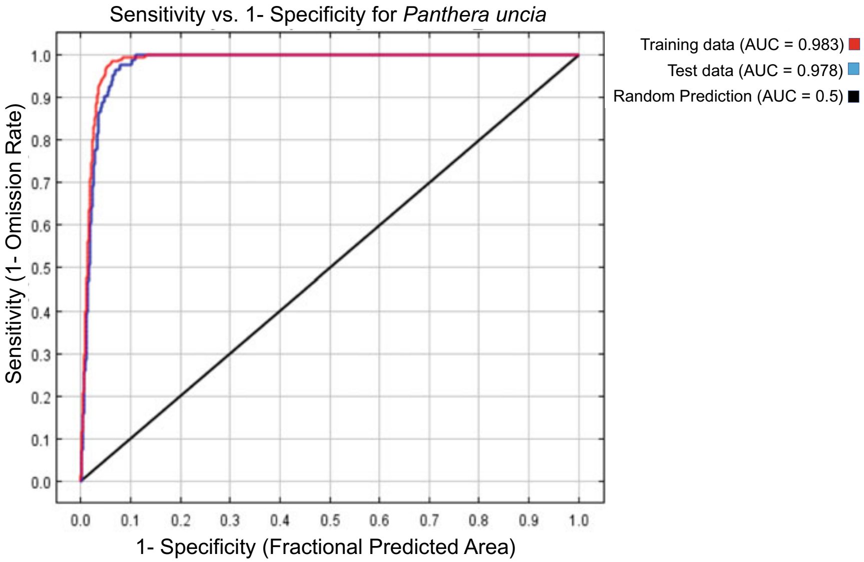


Fig. 6.9 ROC verification of the distribution of suitable habitat for snow leopard

Table 6.3 Percentage contribution and permutation importance values of environmental variables (four most important factors in bold)

Variable	Percent contribution	Permutation importance
Bio1	**23.2**	**66.4**
Bio2	1.7	1.7
Bio3	2	0.2
Bio14	4.8	**7.8**
Bio18	2.6	4.4
Bio19	0.8	1.9
Dist_roads	**25.8**	**8.4**
Dist_buildings	**22.4**	**8.3**
Altitude	**13.4**	0.2
Land cover main	2.8	0.2
Vert_het	0.4	0.3
Ruggedness	0.1	0.1
Slope	0	0.1

(Table 6.3) indicate that annual mean temperature (Bio1; 66.4%), distance from roads (Dist_roads; 8.4%), distance from buildings (Dist_buildings; 8.3%), and precipitation in the driest month (Bio14; 7.8%) were the four main factors affecting the suitability of snow leopard habitats.

The jackknife test of the environmental variables in training data produced by MaxEnt is presented in Fig. 6.10. It indicates that the five main factors contributing to snow leopard habitat suitability within the area studied are altitude (Altitude), annual mean temperature (Bio1), distance from buildings (Dist_buildings), distance from roads (Dist_roads) and precipitation in the driest month (Bio14). The environmental variable with the highest gain when used in isolation is altitude, which therefore appears to be the most useful. The environmental variable that decreases the gain most, when omitted, is distance from roads (Dist_roads), which therefore appears to indicate it includes important information that is not present in the other variables. If MaxEnt includes only the ruggedness index, it achieves almost no gain, so this variable is not (by itself) useful for estimating the distribution of snow leopard (Fig. 6.10).

In conclusion, the common factors indicated by both the percentage contribution of environmental variables in Table 6.3 and jackknife test in Fig. 6.3 are Altitude, Bio1, Dist_road, Dist_buildings and Bio14.

The response curves, which indicate the influence of each factor on the distribution of snow leopard habitat are shown in Fig. 6.11. The altitude in areas suitable for snow leopard was between 3000 m and 5000 m a.s.l, however, the spatial distribution of the most suitable habitat is a relatively narrow and compact belt at altitudes between ca 3500 and 4500 m a.s.l. based on suitability indices of more than 50% (Fig. 6.11b). Patches of the most suitable habitat are typically southern slopes at an altitude of around 4000 m a.s.l. with a relatively cold and dry climate, slope between 20° and 50°, with shrubs, rocks and open grassland (Fig. 6.11).

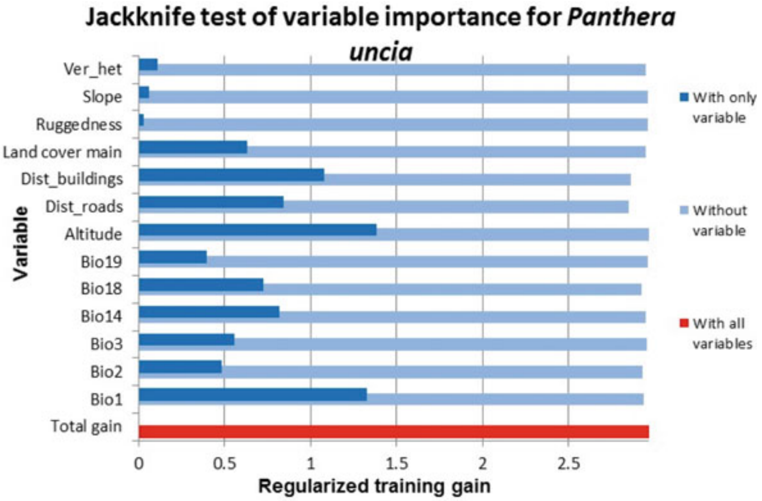
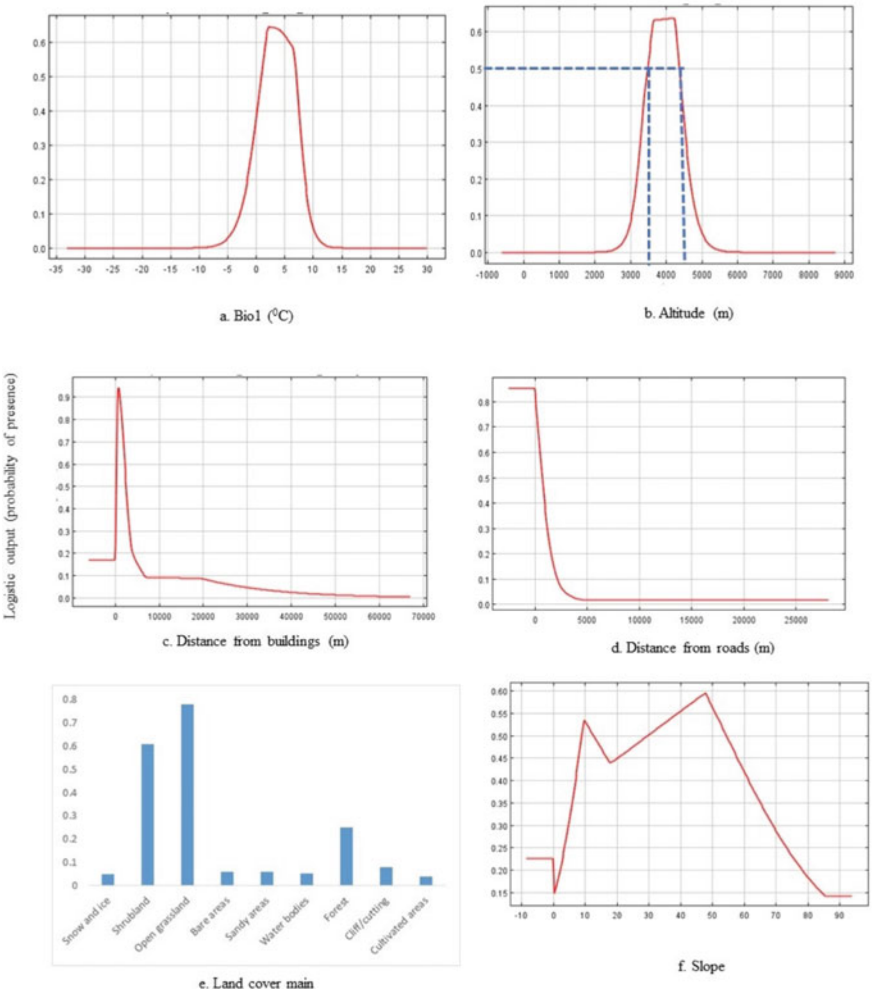


Fig. 6.10 Jackknife test of the importance of the environmental variables in the training data for the MaxEnt modelling



a. Bio1 (^{0}C)

b. Altitude (m)

c. Distance from buildings (m)

d. Distance from roads (m)

e. Land cover main

f. Slope

Fig. 6.11 Response curves of selected variables in terms of their importance in determining the distribution of suitable habitat for snow leopard in Nepal

The map of habitat suitability is presented in Fig. 6.12. The areas are reclassified as either unsuitable, of low suitability or highly suitable, and indicated by yellow, red and blue colours, respectively. The belt of suitable area is the widest in regions in western and central Nepal (e.g. in Annapurna and Dolpa—see Fig. 6.12). However, most of the area in eastern Nepal is rather narrow (Fig. 6.12), and therefore vulnerable to fragmentation.

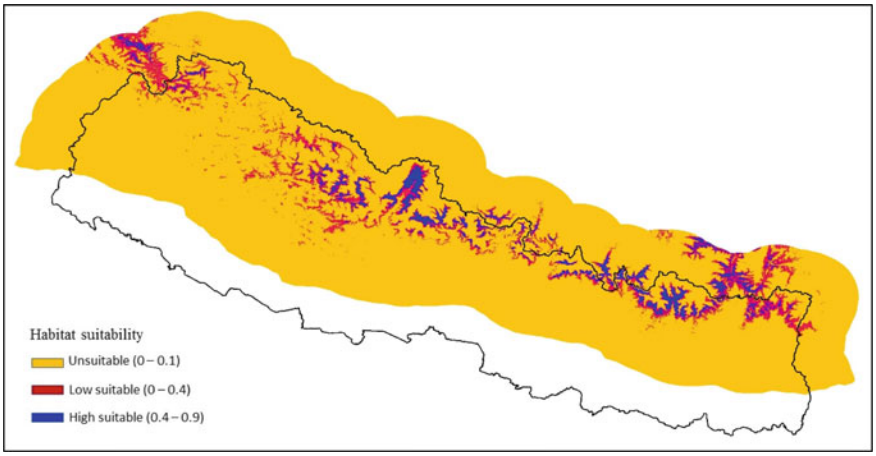


Fig. 6.12 Map of Nepal showing the distribution of suitable habitat for snow leopard predicted by the model. The black line is the Nepalese border. The overlaid map does not exactly coincide with the area of Nepal, as adjacent parts of Tibet were also considered. Different colours indicate the probability of occurrence of snow leopard (see inset). The most suitable areas are represented by the blue colour

6.5 Discussion

The results indicate that annual mean temperature and altitude are the two main factors influencing habitat suitability for snow leopard in Nepal. As these two factors are strongly correlated, it is highly likely the main factor determining the presence of snow leopard is just one of them, the biologically most meaningful—altitude. The response curves of the different predictor variables revealed that the probability of snow leopard presence in Nepal was the highest in areas at an altitude of around 4000 m a.s.l. with a relatively cold and dry climate, shrubs, rocks and open grassland.

Other factors also seem to play a role, as they were important in at least one of the analyses. These were: distance from roads, distance from buildings, land covered with grassland and shrubland, precipitation in the driest month and precipitation in the warmest quarter. What are the conclusions of other studies on the factors influencing snow leopard habitat suitability in Nepal?

Bai et al. (2018) suggest five main factors (the driest quarter, ruggedness, altitude, maximum temperature in the warmest month, and annual mean temperature) for the Qomolangma National Nature Reserve, Li (2013) reports two main factors: annual mean temperature and ruggedness for Sanjiangyuan National Nature Reserve, Watts et al. (2019) two main factors: altitude and ruggedness, and Aryal et al. (2016) only one factor: annual mean temperature. Atzeni et al. (2020) report that the landscape associated with suitable snow leopard habitat consists of that with a positive association with annual mean temperature and medium/large extent of grassy and herbaceous vegetation on ridges and uplands. These studies also indicate that climatic factors (e.g. annual mean temperature) and altitude are the main determinants. A contrasting result, however, is ruggedness, the presence of which is also considered to be important in providing a means of escape and shelter (Jackson 1996).

Based on the ***resource selection function*** (statistical method), ruggedness, bases of cliffs and stream beds in Xinjiang China (Xu et al. 2012), terrain and distance to trail and settlements in Sagarmatha National Park (Wolf and Ale 2009), cliffs, grassland and shrubland at high altitudes (3000–5000 m a.s.l.) in Upper Mustang, Nepal (Aryal et al. 2014), and distribution of prey in Spiti Valley, India (Sharma et al. 2015) appear to be the main factors determining the spatial distribution of snow leopard. Similarly, altitude is the most strongly associated with occurrence, whereas that with presence of prey and distance to roads is relatively weak (Alexander et al. 2016).

Based on ***radio-collar monitoring***, McCarthy et al. (2005) report steep and rugged terrain, areas rich in ungulate prey, and an affinity for the edges of habitats are the main predictors of the distribution of snow leopard.

The most often suggested factor determining the distribution of snow leopard in the above studies is, as we reported, annual mean temperature. A broad array of both abiotic (altitude, rugged terrain and annual mean temperature) and biotic factors (prey availability and human activity) are also suggested, which indicates that these factors may differ between areas. It was evident that temperature is very important in determining habitat selection in snow leopard in most of the regions studied, which indicates that climate change might affect snow leopard distribution in the future (Li et al. 2016). Disturbance by humans may further affect the living conditions of snow leopard, as with human expansion the lower altitudinal limit of snow leopard distribution may shift upwards in the future, which will further restrict its area of suitable habitat.

With regard to human activity, the incidence of snow leopard sign is usually positively related to distance from trails and settlements, which indicates they are less active in the vicinity of humans (Wolf and Ale 2009). Unlike the present study, Atzeni et al. (2020) report a few snow leopards occurring along roads and close to human settlements. The few sightings of snow leopards in the wild indicate that these animals tend to avoid humans (Schaller 1977; Jackson 1996; Wolf and Ale 2009), and they match the reports that human activity affects habitat use by other large predators such as grizzly bears, wolves and tigers (Whittington et al. 2005; Johnson et al. 2006; Linkie et al. 2006; Ciarniello et al. 2007; Wolf and Ale 2009). Generally, predators avoid large or well frequented roads and trails, especially in areas where hunting or harassment is common (James and Stuart-Smith 2000; Kaartinen et al. 2005; Whittington et al. 2005; Linkie et al. 2006; Wolf and Ale 2009). Thus, humans may be a substantial determinant of where snow leopards are active, which accords with the results of our study.

To conclude: the habitat suitability models indicate that the main threats to snow leopard survival are likely to be climate change and humans. Both of these will result in the lower limit of its distribution shifting upwards to higher altitudes. This in turn will result in a decline of suitable habitats for snow leopard in the area, which may result in a further decline in its metapopulation size, and that of each of the local populations, together with the negative effects associated with small populations. In addition, it is also likely to result in less movement between individual populations as they become more isolated from one another as the altitudinal lower limit of suitable habitat shifts upwards.

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Chapter 7
Non-invasive Genetic Sampling of Snow Leopards and Other Mammalian Predators in the Annapurna and Sagarmatha Regions of Nepal

Bikram Shrestha, Adarsh Man Sherchan, Jyoti Joshi, Dibesh Karmacharya, and Pavel Kindlmann

Abstract Snow leopard is threatened particularly by habitat loss, reduction in the availability of prey, conflict with herders, and poaching in connection with traditional Asian medicine. Therefore, an effective conservation strategy for snow leopard is needed. For this, however, we need estimates of its abundance and map of its spatial distribution. The problem is that because of the rugged and practically inaccessible terrain inhabited by snow leopards, its elusive nature and low population densities, there is very little information on its distribution and population status. Thus, in order to supplement conventional techniques, like surveying for signs of its presence, a more effective method is needed to ensure the long-term survival of this endangered felid. Non-invasive genetic sampling and molecular scatology are emerging and promising scientific techniques for sampling mammals. Their benefit is that the target species never has to be directly observed or handled, as the most commonly samples are their hairs and scats. However, the collecting of scat samples of a focal species in the field is subject to a high degree of misidentification as they can often belong to other species. Therefore, genetic analysis of DNA extracted from scat samples must be used. Here we study the distribution and population size of snow leopards based on the genetic identification of scat.

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7.1 Introduction

Snow leopard (*Panthera uncia*) is an umbrella species for the Himalayas and vulnerable throughout its range, which includes 12 countries in Asia (McCarthy et al. 2017). In Nepal, they are threatened particularly as a result of habitat loss, low availability of prey, conflict with herders and poaching in connection with their use in traditional Asian medicine. Although snow leopards in Nepal are protected under Schedule 1 of the National Parks and Wildlife Conservation Act, 1973, and they are a priority species for conservation, their numbers are declining dramatically. Thus, there is an urgent need to develop an effective conservation strategy in order to prevent the extinction of snow leopards (DNPWC 2017). Other carnivores such as wolf (*Canis lupus*), Eurasian lynx (*Lynx lynx*), red fox (*Vulpes vulpes*) and golden jackal (*Canis aureus*) co-occur across the snow leopard's range. Common leopard (*Panthera pardus*) also partly overlaps the snow leopard's range near the timber line. Understanding the interactions between these sympatric species is crucial for understanding snow leopard population dynamics. Before any effective conservation plans can be developed and implemented, it is important to obtain reasonable estimates of the current abundance and distribution of snow leopards and its co-predators, and to produce maps of its spatial distribution.

However, because of the rugged and practically inaccessible terrain inhabited by snow leopards, its elusive nature and low population density, very little information is available on its distribution and population status (Jackson et al. 2006). Thus, an effective, scientific and standardized method is needed to supplement conventional techniques like surveys of signs of their presence, and so ensure the long-term survival of this endangered felid. Promising scientific techniques such as non-invasive genetic sampling and molecular scatology may yield realistic population estimates of snow leopards when complemented with information obtained using conventional techniques (Waits and Paetkau 2005; Broquet et al. 2007; Waits et al. 2007; Janecka et al. 2008). The benefit of noninvasive sampling is that the target species never has to be directly observed or handled, as the most common samples used in this case are hairs and scats (Caragiulo et al. 2016). However, when collecting scat of a focal species like snow leopard in the field, it is likely it will be misidentified as it is that of another species. Therefore, the DNA extracted from scat is needed to be accurately identified whether it is that of snow leopard, or its co-predators. Here we study the distribution and population size of snow leopards along with that of other co-occurring carnivores (wolf, common leopard, red fox and golden jackal) based on a genetic identification of scat.

7.2 Study Areas

The study areas are in three important snow leopard areas in Nepal: (i) Lower Mustang (LM), (ii) Upper Manang (UM), both of which are in the Annapurna Conservation Area (ACA), and (iii) Sagarmatha National Park (SNP). Details of these areas are presented in Chap. 9.

7.3 Methods

7.3.1 Scat Sampling

From 2014 to 2016, we established transects covering a total linear distance of 139.3 km (102 transects, mean length—776 m, range 400–1200 m, SE = 34.5) in both summer and winter at the three sites studied. These transects were of the type used by the Snow Leopard Information Management System (SLIMS; Jackson and Hunter 1996). With the aid of 1:50,000 topographic maps, we established transects along land forms such as ridgelines, narrow valleys, trails and cliff-edges, where snow leopards are likely to walk and leave signs (Fox et al. 1991; Mallon 1991; Jackson 1996). Along these transects and by additional random collections during 2011–2013, we collected 268 putative snow leopard samples (261 samples of faeces, 6 of hairs and one of urine). From each scat found, a small portion was placed in a 15 ml plastic tube with silica desiccant and subsequently subjected to a DNA analysis (Janecka et al. 2008).

7.3.2 Extraction of DNA Used in the Identification of Snow Leopard

DNA from faeces and hair was extracted using a Qiagen QIAamp DNA Mini Stool Kit (Qiagen 2014). For identifying snow leopards, a ~ 148 bp segment of mitochondrial cytochrome b was PCR-amplified using the primers CYTB-SCT-PUN-R’ and CYTB-SCT-PUN-F’ (Farrel et al. 2000). The targeted region is unique for snow leopards (Fig. 7.1) (Janecka et al. 2008).

The 7 μl of PCR reaction mixture included 1.4 μl 5X PCR Buffer, 0.035 μl 5000 Units of Taq Polymerase, 0.21 μl of 10 μM forward and reverse primers, 0.14 μl of 10 mM dNTPs, and distilled water (3 μl) to which 2 μl DNA extract was added.

All PCRs were performed in duplicate for confirmation along with a negative and positive PCR controls. PCR conditions were as follows: Initial denaturation – 94 °C for 2 min followed by 95 °C for 30 s, annealing at 60 °C for 15 s followed by 68 °C for 1 min (35 Cycles) and a final extension at 68 °C for 10 min. The PCR products

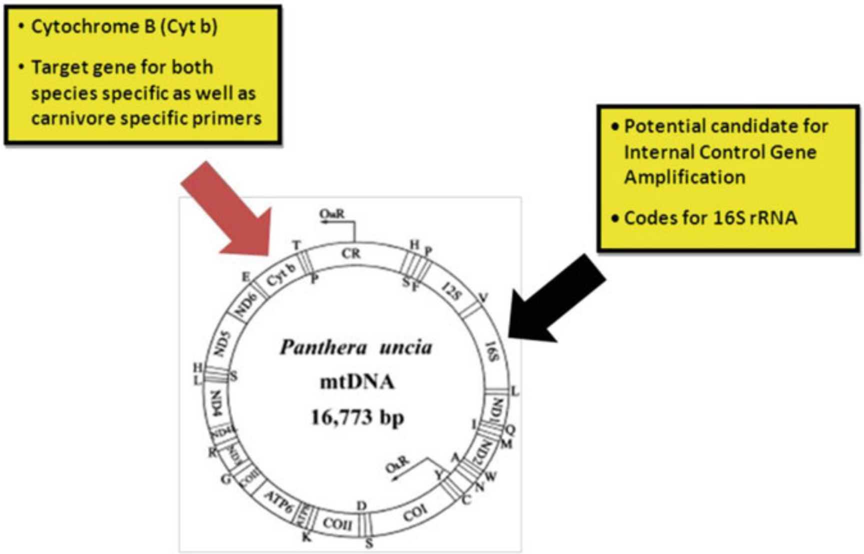


Fig. 7.1 Schematic diagram of the mitochondrial DNA of *Panthera uncia* depicting regions used for species and carnivore identification. Adapted from Wei et al. (2008)

were run on a 2% agarose gel, stained with Ethidium bromide and visualized under ultraviolet light (Janecka et al. 2008; Wei et al. 2008).

The PCR was performed in duplicate (2 of each sample). Any result that was singlet positive was repeated for a third time in order to confirm the identification. Duplicate positives were accepted as a positive identification and duplicate negatives were considered that the DNA was of another species.

7.3.3 ID PCR Used to Determine the Sex of a Snow Leopard

The sex of snow leopards was determined by testing samples of their scat for the presence of a Y chromosome using primers that amplify an intron of the AMELY gene (i.e., a gene found only on the Y chromosome). The size of this fragment (Y chromosome) is about 200 bp (Janecka et al. 2008).

A volume of 7 μl of PCR reaction mixture containing 3.5 μl of Qiagen 2X Master Mix Buffer, 0.7 μl of 5X Q solution, 0.05 μl of primers (AMELY-F and AMELY-R) 20 μM, 0.7 μl of distilled water and 2 μl of extracted undiluted DNA was prepared. The PCR reaction was carried out using the following thermocycling conditions: 95 °C for 15 min; followed by 45 cycles of 94 °C each for 15 s, 55 °C for 30 s and 72 °C for 1 min with a final extension at 72 °C for 10 min. PCRs were run in triplicates along with a positive and negative control. The PCR products were run on a 2% agarose gel stained with ethidium bromide and visualized under ultraviolet light. The PCRs were each triplicated (3 for each sample), three out of three male positives and two out of three male positives were considered positive. One of three male positives were repeated to re-confirm the sex. If the repeats were 1/3 for each triplicate, they were considered male if there were 6 positive replicates. Only 3 negatives were considered to indicate female. If only one out of six replicates indicated a Y chromosome, the samples were regarded as of unconfirmed sex.

7.3.4 Identification of Individuals Based on Microsatellite Loci

A set of 6 microsatellite loci located on 6 different chromosomes of snow leopard was targeted using the following six fluorescent dye tagged primers in two combinations. The six polymorphic microsatellite loci chosen were sufficient, using PID (Probability of Identity), for identifying individuals in a population with the same genotype (Janecka et al. 2008) (Table 7.1).

The 7 µl volume of PCR reaction mixture contained 3.5 µl of Qiagen 2X Master Mix buffer, 0.7 µl of 5X Q solution, 2 µl of extracted DNA and 0.88 µl of 20 µM primers in the first combination, and 0.78 µl of 20 µM primers and 0.02 µl of distilled water in the second combination. The multiple tubes method (Taberlet and Fumagalli 1996) was used for the multiple PCR reactions for each sample, in this case with three replicates. PCR products from both combinations were further diluted to 1:50 and processed using an ABI 31 Analyzer (Table 7.2). All samples were processed in triplicate.

COMBINATION 1	SEQUENCE
PUN124-F	NEDCCATTCCCTCCCTGTCTGTA
PUN124-R	TGTCCTCAAACCATAGACAGTTTC
PUN229-F	VICAGACAAACTGACAAGCTTAGAGG
PUN229-R	TCATGTCTTTACATTCATTTCTTTTT
PUN1157-F	FAMGAGAGTGCAGTCAGCCAGGT
PUN1157-R	TGAAATTCAGCTGCTTCAACTC

Table 7.1 The six microsatellite loci used for identifying snow leopards (Janecka et al. 2008, 2014; Rozhnov et al. 2011)

Locus name	Repeat motif	Size range (bp)	Chromosome	Label
PUN1157	(AC)17	101–109	B3	Blue
PUN229	(GT)23	104–112	A1	Green
PUN124	(AC)22	90–100	A2	Black
PUN935	NA	110–120	D1	Blue
PUN894	(GT)17	110–118	C2	Green
PUN132	(GT)19	117–123	D3	Black

Table 7.2 PCR profiles of the microsatellites used to identify individuals using a set of 6 primers in two different combinations, 1 and 2

Snow Leopard-Bikram Shrestha individual ID uSAT-ANALYSIS_combination 1							
1 Batch PCR (N = 13)							
SL-uSat PCR COM 1 Date: 15-May-16 JJ **Replica: 1,2,3**							
Multiplex Mix	1x	n	Final Conc	Unit	**Thermocycler: MJ Tetrad**		
	1x	48	conc		**Saved PCR Program: MSAT-WF_BS_SL**		
Master Mix (2x)	3.5	168	1x	x	SNOW LEOPARD		
Q solution (5x)	0.7	33.6	0.5	x	Number of cycles: 45		
PUN-124-F (20uM)	0.19	9.12	0.54	μM		Temp. (°C)	Time
PUN-124-R (20uM)	0.19	9.12	0.54	μM	Initial denature	95	15 min
PUN-229-F (20uM)	0.18	8.64	0.51	μM	Denaturation	94	30 s
PUN-229-R (20uM)	0.18	8.64	0.51	μM	Annealing	55	90 s
PUN-1157-F (20uM)	0.07	3.36	0.2	μM	Elongation	72	90 s
PUN-1157-R (20uM)	0.07	3.36	0.2	μM	Final elongation	72	10 min
dH20 from kit	0	0			Cool down	4	Hold
DNA	2						
Total volume	7.08	243.84					
Snow Leopard-Bikram Shrestha individual ID uSAT-ANALYSIS_combination 2							
1 Batch PCR (N = 13)							
SL-uSat PCR COM 1 Date: 15-May-16 JJ **Replica: 1,2,3**							
Multiplex Mix	1x	n	Final Conc	Unit	**Thermocycler: MJ Tetrad**		
	1x	48	conc		**Saved PCR Program: MSAT-WF_BS_SL**		
Master Mix (2x)	3.5	168	1x	x	SNOW LEOPARD		
Q solution (5x)	0.7	33.6	0.5	x	Number of cycles: 45		
PUN-132-F (20uM)	0.22	10.56	0.54	μM		Temp. (°C)	Time
PUN-132-R (20uM)	0.22	10.56	0.54	μM	Initial denature	95	15 min

(continued)

Table 7.2 (continued)

Snow Leopard-Bikram Shrestha individual ID uSAT-ANALYSIS_combination 2							
1 Batch PCR (N = 13)							
PUN-894-F (20uM)	0.1	4.8	0.51	µM	Denaturation	94	30 s
PUN-894-R (20uM)	0.1	4.8	0.51	µM	Annealing	55	90 s
PUN-935-F (20uM)	0.07	3.36	0.2	µM	Elongation	72	90 s
PUN-935-R (20uM)	0.07	3.36	0.2	µM	Final elongation	72	10 min
dH20 from kit	0.02	0.96			Cool down	4	Hold
DNA	2						
Total volume	7	240					

COMBINATION 2	SEQUENCE
PUN132-F	NEDCGAAATGCAGTAATGTTAGTTTTACA
PUN132-R	CACGGGTTCGTCTCTTTTG
PUN894-F	VICCATGCCAGACTGCATTTGTT
PUN894-R	CCCACACATGACAATCCTGTT
PUN935-F	FAMGCTGCTGTGACCTTCTGTGA
PUN935-R	CAGTGTTCCTGGTTTGCTCA

After processing the 6-microsatellite based PCR products using capillary electrophoresis and an ABI 31 Analyzer, the labelled fragments were separated on the basis of their size obtained from .fsa files. All the data in these .fsa files were analyzed and used to assign them to particular alleles. Allele calling was done using GeneMarker V1.85 (http://www.softgenetics.com) and then consensus genotypes were reconstructed (for details see Benesova 2018).

7.3.5 *Identification of Common Leopard*

Samples from scats that were negative for snow leopard were further tested using PCR to quickly identify whether they came from common leopard scats. For this, common leopard was identified by targeting the NADH region with the primer set NADH4 F/R as mentioned in Mondol et al. (2009), which amplifies a segment of 130 bp. The primer set included as follows:

NADH4 F - 5′ TRATAGCTGCYTGATGAC-3′
NADH4 R - 5′ GTTTGTGCCTATAAGGAC-3′ (Mondol et al. 2009)

The 7 μl PCR reaction mixture contained 3.5 μl of 2X Qiagen Master mix, 0.7 μl of 5X Q solution, 0.20 μl of 20 pmol/μl of each primer, 0.5 μl of distilled water to which 2 μl of extracted undiluted DNA was added. PCR thermo-cycling condition: 95 °C for 15 min followed by 50 cycles each of 94 °C for 30 s, 50 °C for 30 s and 72 °C for 30 s, and a final extension of 72 °C for 10 min. Five μl of the amplified PCR products, with incorporated positive controls, were visualized in 2% agarose gel by staining with 6.5 μl EtBr (Mondol et. al 2009).

7.3.6 Identification of the Sex of Common Leopards

DNA samples positive for common leopard were further screened to determine the sex by amplifying the Amelogenin area on sex chromosomes using specific PCR primers (AMEL-F and AMEL-R). The sex of the verified common leopard scat was determined by testing for the presence of the Y chromosome (196 bp) on which there is a 20 bp deletion not present on the X chromosome (214 bp). The primers used were:

AMEL-F 5′ CGAGGTAATTTTTCTGTTTACT-3′
AMEL-R 5′ GAAACTGAGTCAGAGAGGC-3′

The 7 μl PCR reaction mixture contained 3.5 μl of 2X Qiagen Master mix, 0.7 μl of 5X Q solution, 0.05 μl of 20 pmol/μl of each primer and 0.7 μl of distilled water to which 2 μl of extracted undiluted DNA. PCR thermo-cycling condition: 95 °C for 15 min followed by 45 cycles each at 94 °C for 15 s, 55 °C for 30 s and 72 °C for 1 min, with a final extension at 72 °C for 10 min. The PCR products with incorporated positive controls were subjected to electrophoresis and visualized on a 3% agarose gel.

7.3.7 Identification of Other Carnivores

Carnivore specific PCR was performed on samples that were not identified as either snow leopard or common leopard. For the carnivore specific PCR, a specific PCR primer set (CYTB-SCT-F and CYTB-SCT-R) was used, which targets a 150 bp region of cytochrome b (Farrell et al. 2000). The primer set used was:

CYTB-SCT-F: 5′ AAACTGCAGCCCCTCAGAATGATATTTGTCCTCA 3′
CYTB-SCT-R: 5′ TATTCTTTATCTGCCTATACATRCACG 3′

The PCR reaction mixture of total volume 25 μl contained 5 μl of 5X One Taq Standard Reaction Buffer, 0.50 μl of 10 mM dNTPs, 0.125 μl of 5000U One Taq DNA polymerase, 0.75 μl of each primer and 15.9 μl of distilled water to which 2.0 μl of extracted undiluted DNA. The PCR thermo-cycling conditions: 94 °C for 30 s followed by 45 cycles each at 94 °C for 30 s, 55 °C for 30 s and 72 °C for

1 min with final extension step at 68 °C for 10 min. The PCR products, along with an incorporated carnivore positive control were visualized in 2% agarose gel. The carnivore positive PCR amplicons were sequenced on an ABI 310 machine using the forward primer (CYTB-SCT-F); DNA sequences were BLAST searched in the NCBI database to identify the species of carnivore. Species identification of samples using BLAST results were based on cytochrome b DNA sequence data of 100 bp or more, with a maximum identity of 95% or higher and query coverage of more than 95%.

7.4 Results

7.4.1 PCR Identification of Snow Leopards

Out of the total of 268 samples of scat, hairs and urine obtained in three areas, 128 (48%) were identified as snow leopard (124 scat and 4 hair samples) based on species specific mitochondrial DNA (Fig. 7.2).

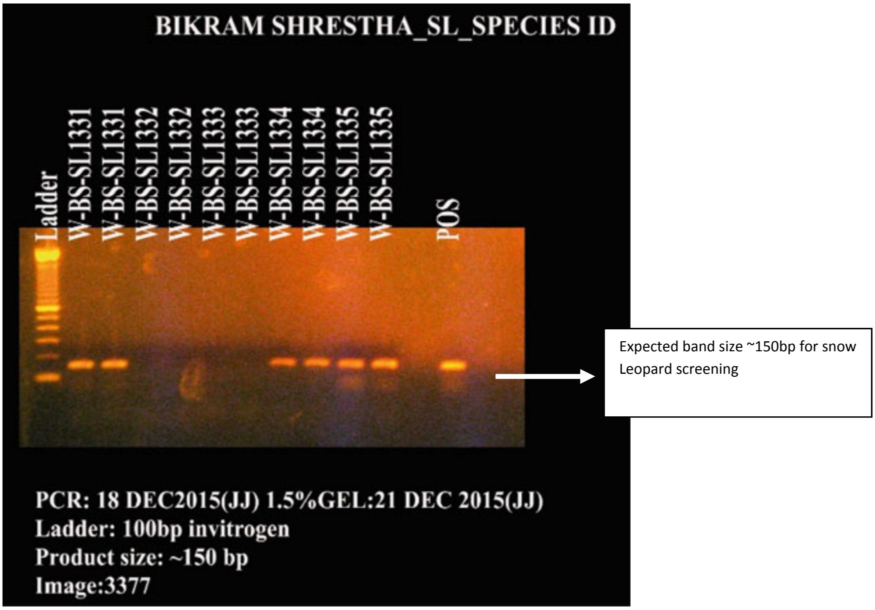


Fig. 7.2 Identification of snow leopards using gel electrophoresis and targeting the specific cytochrome b region (~150 bp) of *P. uncia*. Samples were duplicated and the positive control appeared in the expected region on the gel

7.4.2 PCR Identification of the Sex of Snow Leopards

Out of the samples positive for snow leopards that were PCR amplified and used for identifying the sex (Fig. 7.3), 40 were for males, 61 for females, and 10 did not identify the sex.

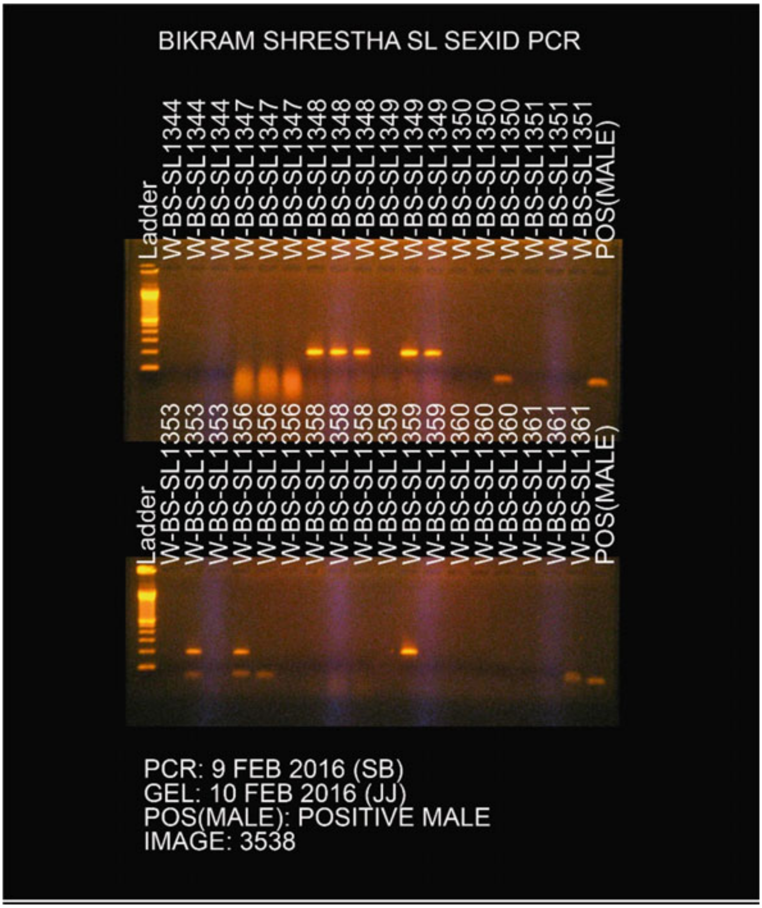


Fig. 7.3 Identifying the sex of the snow leopards by targeting the AMELY gene of ~ 200 bp specific for males, which was revealed by a band in the appropriate position when subjected to electrophoresis run on a 2% agarose gel. None of the samples from females were positive

7.4.3 Processing of Microsatellite Chromatograms

Microsatellite loci were not identified in twenty samples from snow leopards, therefore, these samples were not included in the following analyses. The number of samples in which microsatellites of snow leopards were identified was 108. After filtering of data quality, 63 microsatellite genotypes were obtained, corresponding to 22 individuals according to the identity analysis (Table 7.3). All loci were free of errors due to large allele drop out and stuttering, but two loci were suspect due

Table 7.3 The sex and numbers of individual snow leopards identified based on microsatellite DNA sequencing

Area/year	Samples	P	PM	PF	Individuals (male)	Individuals (female)	Total
Lower Mustang							
2011	17	13	1	9	1 (LM-SL1)	2 (LM-SL2, LM-SL3)	3
2013	3	2	1	0	1 (LM-SL1)		1
2014	23	12	5	1	4 (LM-SL4, LM-SL5, LM-SL6, LM-SL1)	2 (LM-SL3), LM-SL2)	6
2016	31	17	8	9	2 (LM-SL7, LM-SL8)	2 (LM-SL3, LM-SL2)	4
Total	74	44	15	19	6	2	8
Upper Manang							
2012	4	4	3	1	2 (UM-SL9, UM-SL10)	1 (UM-SL11)	3
2014	47	12	4	7	2 (UM-SL9, UM-SL10)	3 (UM-SL11), UM-SL12, UMSL13	5
2016	39	24	13	11	3 (UM-SL9, UM-SL14, UM-SL15, UM-SL16)	4 (UMSL13, UM-SL3, UM-SL11, UM-SL17)	7
Total	90	40	20	19	5	5	10
Sagarmatha National Park							
Spr, 2015	66	31	12	15	2 (SNP-SL18, SNP-SL19)	2 (SNP-SL20, SNP-SL21)	4
Win, 2015	38	13	3	8	2 (SNP-SL18, SNP-SL22)	2 (SNP-SL20, SNP-SL21)	4
TOTAL	104	44	15	23	3	2	5
Overall	268	128	50	61	14	8	22

P = Positive snow leopard, PM = Positive male snow leopard, PF = Positive female snow leopard, Spr = Spring; Win = Winter
Data on individuals 1–22 are based on the results of Benesova (2018)

to the presence of null alleles with estimated percentages of 20.27% and 14.45%, respectively. These two loci had a higher proportion of homozygotes than expected based on the allele frequency.

Of the 22 individuals, eight, ten and five were, respectively, recorded in LM, UM and SNP (one individual was recorded in both LM and UM). Of these, 14 (63%) were males and 8 (37%) females (Table 7.3). Of the 14 males identified, six were recorded in LM, five in UM and three in SNP. And of the eight females, two were recorded in LM, five in UM and two in SNP (one of the females was recorded in both LM and UM).

7.4.4 PCR Identification of Common Leopards and Their Sex

Seventy nine of 140 samples that were negative for snow leopard amplified positive for NADH-4 (Fig. 7.4). Of these, 39 were female, 23 male and 17 of unidentified sex.

7.4.5 Screening of the Samples for Evidence of Presence of Other Carnivores

Of 61 samples that were negative for snow leopard and common leopard, 47 amplified positive using CYTB-SCT-F/R primers, which indicates the presence of other carnivores in the band size ~ 150 bp (Fig. 7.5). These carnivore ID positives were sequenced and the species identified using BLAST. Of these, 16 were Himalayan wolf (*Canis lupus*), 6 golden jackal (*Canis aureus*), 23 red fox (*Vulpes vulpes*) (Table 7.4) and the remainder were not identified.

7.5 Discussion

Of the scats analyzed in this study 50% were produced by the target species (snow leopard) and 50% by four other carnivores, namely common leopard, Himalayan wolf, golden jackal and red fox, which is in accordance with the findings of previous research (e.g., Janecka et al. 2008, 2011; Anwar et al. 2011; Karmacharya et al. 2011; Shehzad et al. 2012; Jumabay-Uulu et al. 2013). It was thought that all the wolves in the Annapurna Conservation Area were killed by local herders four decades ago in retaliation for killing livestock. The genotyped scats and camera trap images (see in Chap. 5) showed that Himalayan wolves had recolonized the area. In addition to the snow leopard-human interaction in the area, the wolves are likely to have increased

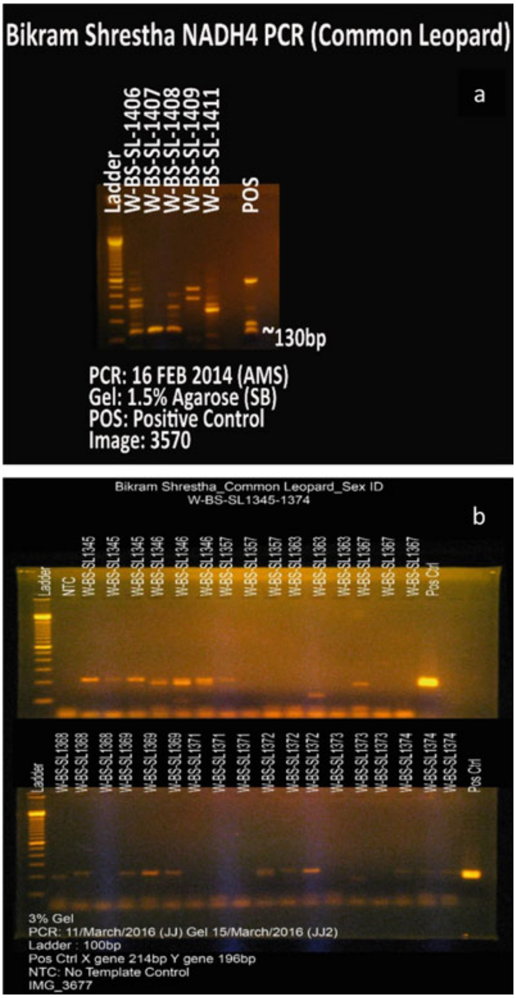
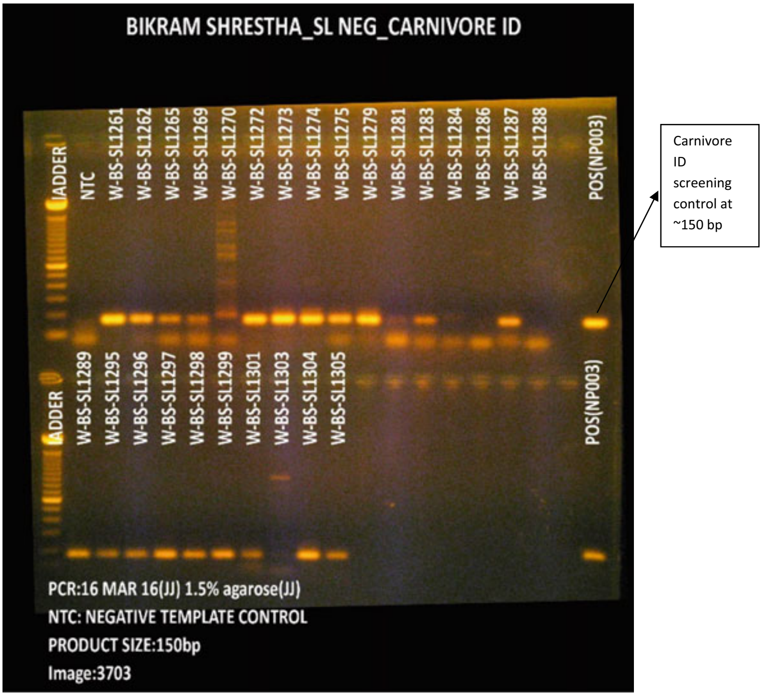


Fig. 7.4 **a** PCR identification of common leopards using NADH4 F/R primers. Amplified bands are expected at 130 bp. **b** The sex of the common leopards was identified using electrophoresis of amplified AMEL genes, of which the band size for males is ~ 196 bp and females ~ 214 bp

the conflict. Detailed studies of the interaction between snow leopards and wolves are needed as this information is likely to help mitigate their effects on humans.

In three of the areas studied, the abundance of snow leopards recorded using genetic identification was higher than that recorded using camera traps (19 individuals) (see Chap. 5). Similar results using these techniques are reported for snow leopard in Mongolia (Janecka et al. 2011). The difference is because the non-invasive genetic identification could not be used to determine age and exclude sub adults, the limited spatial distribution of sampling points as a consequence of collecting scat along linear transects and deposition of scats by several snow leopards at the same site.



Carnivore ID screening control at ~150 bp

Fig. 7.5 Screening of snow leopard and common leopard negatives for general Carnivores (~150 bp) using electrophoresis on a 2% agarose gel stained with Ethidium Bromide

Table 7.4 NCBI BLAST results of the targeted amplification of the cytochrome b region of mtDNA in snow leopard and common leopard negative samples

Samples	PCR DNA length (bp)	Identified gene and Species	Match %	Query %
6	100, 160, 165	*Canis aureus* haplotype CytbBlg01 cytochrome b (cytb) gene, *Canis aureus* isolate CAU_Kenya_2 mitochondrion	62–99	91–95
16	89, 90, 92, 103, 150, 160, 165	*Canis lupus lupaster* cytochrome b (CYTB) gene, *Canis lupus* isolate Alaska 28	60–100	90–98
23	60, 110, 130, 140, 150, 155, 160, 165	*Vulpes vulpes* haplotype U52 cytochrome b (cytb) gene, *Vulpes vulpes* mitochondrion	65–100	86–96

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Chapter 8
Snow Leopard-Human Conflict and Effectiveness of Mitigation Measures

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Abstract Understanding the dynamics of snow leopard-human conflicts and the perceptions of local people of the threats posed by snow leopards is important for gaining local support for mitigating the effects of the conflicts. This chapter presents an assessment of the knowledge and perception of local people of livestock losses due to snow leopards in the central and north-eastern Himalayas in Nepal. In nine settlements in three protected areas (Annapurna Conservation Area—ACA, Manaslu Conservation Area—MCA and Sagarmatha National Park—SNP) we recorded how the perception of local people of snow leopard depredation has changed over time, and its correlation with livestock losses. We carried out questionnaire-based interviews of 1015 households from 2004 to 2016, which included 26.45–100% of all households in the settlements. Herding of yak/nak (nak is a female yak), sheep/goats and cattle (cows, oxen and horses) were found to be the main sources of livelihood for all households in the villages. Herders reported losses of livestock mainly due to attacks by snow leopard and two other carnivores (wolf and lynx). Most of the (1.5–14.3%) losses were attributed to snow leopard, while the other predators accounted for meagre 0.16–5.3%. Predator-induced loss was substantial for the local families and reached $349 per household per year. However, livestock mortality due to other causes (disease or natural disasters) was higher than that attributed to predators. We also evaluated the effectiveness of existing mitigating programmes, designated community-based local mitigation measures, and assessed the subsequent reduction

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in the level of conflict. This revealed that the number of conflicts was lower than in 1990, and 50% of the respondents had changed their mind about snow leopard conservation. Surprisingly many respondents (15%) were against the conservation of snow leopards and even considered retaliatory killing of this predator as the best solution. Of the five snow leopard-human conflict mitigation measures, compensation from a community-based livestock insurance scheme and the improving of animal husbandry were the most popular in all the studied regions. Altogether, 15 human-induced threats to the future survival of snow leopards and its wild prey were identified in two protected areas. We conclude that there is still a major threat to the long-term survival of snow leopards and its natural prey in the studied areas. Mitigation measures identified during discussions with local people should be applied to create a win–win situation for both local people and the long-term survival of snow leopards.

8.1 Introduction

Snow leopard (*Panthera uncia*) inhabits alpine and sub-alpine meadows at altitudes of 2500–5500 m in the Himalayas in Nepal. It prefers a steep terrain, well broken by cliffs, ridges, gullies and rocky outcrops (Jackson and Ahlborn 1989; McCarthy and Chapron 2003).

In the Himalayas above 3000 m a.s.l., where the dominant vegetation is grass and alpine shrubs, the majority of people there is still dependent on animal husbandry for their livelihood (Miller 1995; Richard et al. 2000; Gurung and McVeigh 2002; McVeigh 2004), especially in areas away from trekking routes. Livestock is important in their day-to-day life and culture, and livestock herding is their main economic activity, as they have limited livelihood opportunities due to shortness of the summer season, which limits them to one crop per year (MOAC 2011). However, livestock and snow leopard share the same habitat. Because of this, snow leopards frequently encounter and kill livestock, and this can have a substantial effect on the local economy (Oli et al. 1994; Jackson et al. 1996; Bagchi and Mishra 2006; Shrestha 2006; Shrestha et al. 2012; Li et al. 2013; Suryawanshi et al. 2013; Ale et al. 2014; Alexander et al. 2015). Depredation of livestock is a major problem in the Himalayan region and is often reported in the local press (Fig. 8.1). The loss of livestock due to attacks by snow leopards has resulted in them being viewed as vermin that need to be eradicated (Din et al. 2017). Understanding the predation pressure on livestock and the existing ecological and social issues associated with human-snow leopard conflicts is important for developing effective means of managing and conserving large carnivores in habitats used for livestock grazing (Bagchi and Mishra 2006).

Oli et al. (1994) and Jackson et al. (1996) report the incidence of livestock losses due to attacks by snow leopards, and its effect on the human perception of this predator in Upper Manang in the Annapurna Conservation area (ACA) in 1990 and 1992. Shrestha et al. (2012) report the killing of livestock by snow leopards at Phortse in the Sagarmatha National Park (SNP) during 2005–2006. Similarly, Ale

National

Snow leopard kills 27 Himalayan goats

- RSS, Mustang

Jan 5, 2016-

At least 27 Himalayan goats died after a herd of snow leopards attacked the goats at Tetang village of Chhusang VDC-5 in upper Mustang.

Chief of LhoManthang Office of Annapurna Conservation Area Project (ACAP) Santosh Sherchan said that the snow leopards killed 27 Himalayan goats and injured two others by entering into the barn of farmer Ram Bahadur Gurung on Saturday night.

After the death of a large number of goats, farmer Gurung has suffered a huge loss.

As the campaign to conserve the snow leopard came into effect some four years ago, number of the beast has increased in the upper Mustang.

Sherchan said that the snow leopards enter into the villages for lack of preys in the jungle along with the rise in their number.

Earlier in September, the snow leopards had entered into the village and killed over 100 Himalayan goats of farmer resident Pemachheten Gurung at Marang village in Charang VDC.

ACAP Chief Sherchan said that the farmers would not have to bear losses from the snow leopard after the solar lights installation at animal sheds. “We are running awareness raising programmes targetting the locals,” he added. RSS

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Fig. 8.1 A local newspaper report of snow leopards killing 27 Himalayan goats. http://kathmandupost.ekantipur.com/news/2016-01-05/snow-leopard-kills-27-himalayan-goats.html

et al. (2014) report the killing of livestock in Lower Mustang, ACA, during 2010 and 2011. The incidence of killing, however, is highly site dependent, differs from site to site, between years, with changes in the pattern of livestock herding, and the density and behaviour of snow leopards (Jackson et al. 2010; Suryawanshi et al. 2013).

It is therefore urgent to study how the conflict between local people and snow leopards is changing over time and determine the major factor responsible for heightening this problem. Our study aims to compare the current level of predation and the conflict between snow leopards and people with that recorded two decades ago in Upper Manang and Sagarmatha National Park (Oli et al. 1994; Jackson et al. 1996). Moreover, we also assess the pattern in the killing of livestock in other snow leopard habitats.

Because of the human-wildlife conflict, there have been some attempts to tackle the problem in both ACA and SNP, however there are no assessments of whether they have been effective or whether the attitude of locals towards snow leopard has changed. In view of the above, this study also aims to evaluate the effectiveness of the attempts to intervene in the conflict and identify local community-based measures to mitigate the conflict and ensure the long-term survival of snow leopards in SNP and ACA.

8.2 Study Area

The study areas are located in the following five snow leopard habitats in Nepal, of which the first three are in the Annapurna Conservation Area (ACA):

(i) Lower Mustang (LM),
(ii) Upper Mustang (UMS),
(iii) Upper Manang (UM),
(iv) Tsum Valley (Chhekampar VDC), Manaslu Conservation Area (MCA),
(v) Sagarmatha National Park (SNP).

For details of these areas see Chap. 9.

8.3 Methodology

Questionnaire survey and threat assessment were used to study the level of existing snow leopard-human conflict in the study area.

8.3.1 Questionnaire and Survey

Questionnaires were used to obtain information on household size, livestock number and type, number killed by snow leopards and the estimated economic loss due to predation over the last 12 months.

These data were categorized and means and percentages calculated and illustrated graphically and in tables using MS Excel 2016.

For determining the attitude of local people to snow leopards, a multiple-choice questionnaire with answers constrained to either disagree, neutral, agree or strongly agree, or yes, no, or why was created. Below are the five most important measures aimed at mitigating the snow leopard-human conflict,

(i) improved husbandry (guarding of herds, corralling animals in predator-proof enclosures at night, use of dogs, electric fencing, keeping a close watch and warding of predators),

(ii) providing compensation through a community-initiated livestock insurance scheme,

(iii) wildlife-related measures (prey conservation, complete extermination of snow leopards, killing only those that attack livestock),

(iv) livestock-related measures (avoid grazing in areas in which there is a high risk of predation, reduce the number of livestock),

(v) incentive-based programs (saving and credit schemes, conservation advocacy, wildlife-based tourism, veterinary service for livestock, devices for deterring predators such as fox-lights and sound alarms; for each option a scale from 1 to 3 was used: 1—least important, 2—moderately important, 3—most important. The final value was the mean of these values.

Household survey was conducted in order to determine the number and type of livestock and the cause of their death in nine local areas from 2004 to 2016 (Table 8.1). In UMS, all of the 329 households in three settlements (Lo-Manthang, Chhoser and Charang) were surveyed, in LM, all of the 44 households in two settlements (Jhong and Lupra) and in UM, 50 out of 189 households in two settlements (Khangsar and ProperManang) were surveyed. In MCA, all 257 households in Chekampur VDC in Tsum valley were surveyed. In SNP, all 75 households in the settlements there were questioned. We compared our results with data obtained by previous researchers and published results in order to determine the extent to which the numbers have changed.

8.3.2 Threat Assessment

We identified the human-related factors that negatively affect snow leopard and its wild prey in order to determine the threat to conserving snow leopards in three regions. This was based on field observations and focus group discussions carried out from 2004 to 2015 in SNP and 2010–2016 in LM and UM (Table 8.2). The threats were ranked based on the area (proportion of the habitat(s) at a site that is threatened), intensity (severity of the threat) and urgency (immediacy of the threat), following Margoluis and Salafsky (2001). We identified 12 threats at each of three sites LM, UM and SNP. For a particular threat, a score was assigned ranging from the lowest (indicated by 1) to most severe (indicated by a number equal to the total number of threats in the region). Thus, for example in LM, there were 12 threats and scores ranging from 1–12 were assigned, with 1 indicating the "lowest" and 12 "most severe". Thus, the ranking of the threat (sum of scores for area, intensity and urgency) in LM was between 3 (= 3 × 1) and 36 (= 3 × 12). When calculating the average threat level, we considered scores of from 1 to 12 to indicate low threat, 13–24 medium threat and 25–36 severe threat. Likewise, in UM and SNP the scores for the different categories of threat are similar to that recorded for LM because 12 threats are recorded for each of these sites.

Percentage reduction in the level of threat was estimated based on a discussion of the degree to which a particular threat had been reduced by conservation activities

Table 8.1 Livestock status and mortality due to predation and other causes recorded in five different regions in Nepal (HH—household, SL—snow leopard, OP—other predators, OC—other causes)

			Number of livestock					Livestock mortality per year due to						Loss to predators per year
Village	Year	HH	Sheep/goats	Cattle	Yak/Nak	Horses mules	Total	SL	%	OP	%	OC	%	per HH
Upper Mustang														
Lo-Manthang	2012	87	2498	249	491	186	3424	80	2.3	55	1.6	53	1.5	1.6
Chhoser	2012	130	4610	389	4	183	5186	137	2.6	83	1.6	102	2.0	1.7
Tsarang	2012	112	2942	571	78	191	3782	55	1.5	33	0.9	116	3.1	0.8
Total		329	10,050	1209	573	560	12,392	272	2.2	171	1.4	271	2.2	1.3
Lower Mustang														
Lupra	2011	14	388	43	15	17	463	29	6.3	0	0	28	6.0	2.1
Lupra	2016	12	550	62	0	7	619	30	4.8	0	0	31	5.0	2.5
Jhong	2011	30	744	92	37	12	885	17	1.9	0	0	55	6.2	0.6
Jhong	2016	30	685	210	0	7	902	21	2.3	0	0	32	3.5	0.7
Upper Manang														
Khangsar	1990	29	388	145	169	33	735	21	2.9	0	0	NA	NA	0.7
Khangsar	1992	69	915	285	240	60	1500	126*	4.2	0	0	74*	4.9	1.4
Khangsar	2015	22	0	105	357	31	493	51	10.3	26	5.3	123	24.9	3.5
Proper Manang	1990a	52	1047	50	272	89	1458	23	1.6	0	0	NA	NA	0.4
Proper Manang	2015	28	111	49	294	42	496	71	14.3	23	4.6	164	33.1	3.4
Manaslu CA (MCA)														
Chekampar VDC	2012	257	26	1211	1004	331	2572	45	1.7	4	0.2	227	8.8	0.20
SNP														

(continued)

Table 8.1 (continued)

			Number of livestock					Livestock mortality per year due to						Loss to predators per year
Village	Year	HH	Sheep/goats	Cattle	Yak/Nak	Horses mules	Total	SL	%	OP	%	OC	%	per HH
Phortse	2004c	72	0	123	331	2	456	7	1.3	0	0	27	6	0.1
	2006d	73	0	142	334	1	477	16	3.4	0	0	29	6.1	0.22
	2007	73	0	152	364	1	517	25	4.8	0	0	26	5	0.3
	2015	75	0	159	470	3	632	16	2.5	0	0	28	4.4	0.2

Lower case letter attached to years: *a* Oli 1991 and Oli et al. 1994, *b* Jackson et al. 1996, *c* Shrestha 2004, *d* Shrestha et al. 2012, without a letter—this study, * livestock mortality over a period of 24 months

Table 8.2 Threat rankings of Margoluis and Salafsky (2001) recorded in Lower Mustang, Upper Manang and the Sagarmatha National Park, were calculated as outlined in the material and methods

Threat	Area	Intensity	Urgency	Total rank	Percentage reduction of threat	Raw score
Lower Mustang (LM)						
Retaliatory killing of snow leopards	5	12	12	**29**	50	14.5
Illegal hunting/poaching of snow leopard prey	6	3	6	*15*	70	10.5
Prey reduction due to competition with livestock	12	11	9	**32**	20	6.4
Prey reduction due to disease transmitted by livestock	10	8	8	**26**	50	13
Effects of road construction/maintenance on snow leopard habitats	8	9	10	**27**	0	0
Hotel/lodge expansion	7	7	5	*19*	50	9.5
Fuel wood collection by local communities	3	2	1	6	70	4.2
Collection of *Cordyceps* and *Allium* sp. (Jimbu)	11	10	11	**32**	0	0
Subsistence collection of terrestrial plants	9	6	7	***22***	0	0
Unregulated tourism (off-roading/camping/hiking in the wilderness)	4	5	4	*13*	50	6.5
Illegal fires	1	1	2	4	90	3.6
Killing of wildlife by free-ranging dogs	2	4	3	9	0	0
Total	78	78	78	234		68.2
TRA (assessment period 2010–2016)						29.1
Upper Manang (UM)						
Retaliatory killing of snow leopards	6	12	12	**30**	40	12
Illegal hunting/poaching of the prey of snow leopards	2	1	1	4	70	2.8
Prey reduction due to competition with livestock	12	10	10	**32**	20	6.4
Prey reduction due to disease transmitted by livestock	10	9	8	**27**	10	2.7

(continued)

Table 8.2 (continued)

Threat	Area	Intensity	Urgency	Total rank	Percentage reduction of threat	Raw score
Effects of road construction/maintenance on snow leopard habitats	1	3	2	6	80	4.8
Hotel/lodge expansion	7	8	7	*22*	70	15.4
Fuel wood collection by local communities	5	7	4	*16*	50	8
Litter/dung collection by local communities	4	2	3	9	30	2.7
Collection of *Cordyceps* and *Allium* sp. (Jimbu)	11	11	11	**33**	0	0
Subsistence collection of terrestrial plants	9	6	9	***24***	0	0
Unregulated tourism (off-roading/camping/hiking in the wilderness)	8	5	5	***18***	20	3.6
Killing of wildlife by free-ranging dogs	3	4	6	13	50	6.5
Total	78	78	78	234		64.9
TRA (assessment period 2010–2016)						27.7
Sagarmatha National Park (SNP)						
Retaliatory killing of snow leopards	10	12	12	**34**	50	17
Illegal hunting/poaching of the prey of snow leopards	8	3	6	***17***	70	11.9
Reduction in prey due to competition with livestock	12	11	10	**33**	20	6.6
Reduction in prey due to disease transmitted by livestock	9	4	2	***15***	20	3
Effects of hydro-electric projects on snow leopard habitats	2	2	3	7	50	3.5
Hotel/lodge expansion	3	7	7	*17*	50	8.5
Fuel wood collection by local communities	7	5	5	*17*	50	8.5
Litter/dung collection by local communities	6	10	9	**25**	0	0

(continued)

Table 8.2 (continued)

Threat	Area	Intensity	Urgency	Total rank	Percentage reduction of threat	Raw score
Subsistence collection of terrestrial plants	5	9	8	*22*	0	0
Stone mining by local communities	4	8	11	*23*	50	11.5
Unregulated tourism (off-roading/camping/hiking in the wilderness)	11	6	4	*21*	50	10.5
Killing of wildlife by free-ranging dogs	1	1	1	3	20	0.6
Total	78	78	78	234		81.6
TRA (assessment period 2004–2015)						34.9

Total rank is the sum of all three ranks presented in the columns left of the column “Total rank”. Percentage reduction in threat is the degree to which a particular threat was reduced by conservation activities at the end of the assessment period, see Table 8.3. Raw score is the total rank times the percentage reduction in threat expressed as a proportion (see methods). Regular font indicates a low level of threat, italic and bold italic font indicates a medium level, bold font a severe level of threat

at the end of the assessment period as explained in Table 8.3. What does 100% reduction in the level of a threat mean? For example, in the case of Lower Mustang, no snow leopards were killed by local people at the end of the assessment period. For reducing the adverse effect of livestock on the abundance of the natural prey of snow leopards it is important to implement a policy of sustainable grazing by livestock by regulating the use of pasture land.

The raw score is defined as the total rank times the percentage reduction in the threat. For example, convert 50% to 0.5 before multiplying it by 29 to get the total raw score of 14.5 for retaliatory killing of snow leopards by local people in the case of Lower Mustang. Then the total raw score is the sum of raw scores for each threat. While this raw score is not of any specific significance, it is critical for the calculation of the reduction in the level of a threat (Margoluis and Salafsky 2001, page 31).

Finally, the threat reduction assessment index (TRA) was calculated by dividing the total raw score by the total rankings of all the threats and multiplying it by 100: (TRA $= \sum$ total raw scores/$\sum$ total rankings $\times$ 100) (Margoluis and Salafsky 2001). Thus, the TRA in principle describes the efficiency of the measures used to reduce the level of threat in a region. It is an indirect measurement of the effect of conservation. TRA is a summary indicator of the degree to which a project has succeeded in reducing the threats to conservation at a particular site. If TRA is close to 1 (100% threat reduction), then the measures used to reduce the threat were very effective, but if TRA is close to 0 they were not effective.

Table 8.3 Explanation of the level of the threats recorded in Lower Mustang, Upper Manang and Sagarmatha National Park

S. No.	Explanation of threats
1	Threat: retaliatory killing of snow leopards by local people
	100% reduction: stop retaliatory killing of snow leopards
2	Threat: illegal hunting/poaching of snow leopard prey (musk deer/blue sheep/Himalayan tahr) by people for their own consumption and commercial purposes such as sale of musk deer's pod
	100% reduction: eliminate all illegal hunting of animals
3	Threat: reduction in prey due to competition with livestock
	100% reduction: control of livestock grazing by setting up and regulating the management of pastureland by implementing rotational grazing
4	Threat: reduction in prey due to disease transmitted by livestock
	100% reduction: eliminate all contacts between wild animals and livestock by establishing a restriction zone
5	Threat: effects of road construction/maintenance on snow leopard habitats—road access increases tourism, which disturbs and restricts the movements of wildlife due to noise and human activity
	100% reduction: document the effect of roads on snow leopards and their prey, identify the connectivity zones and recommend appropriate mitigation measures
6	Threat: hotel/lodge expansion—hotels affect habitat quality, produce solid waste, and the activity of snow leopards is adversely affected by lights and noise
	100% reduction: stop the building of hotels in snow leopard habitats
7	Threat: fuel wood collection by local communities
	100% reduction: collect fuel wood in less sensitive areas and on a sustainable basis
8	Threat: Collection of *Cordyceps* and *Allium* sp. (Jimbu) by large numbers of people for commercial purposes has an adverse effect on the habitat and disturbs both snow leopards and their prey
	100% reduction: document the adverse effect of collecting *Cordyceps* on snow leopards and plan to minimize this disturbance
9	Threat: subsistence collection of terrestrial plants—local people collect terrestrial plants (e.g., mushrooms) for their own subsistence, which affects the activity patterns of snow leopards and their prey
	100% reduction: document the adverse effect of collecting terrestrial plants on snow leopards and plan to minimize this disturbance, forbid the collecting of plants in core areas
10	Threat: unregulated tourism (off-roading/camping/hiking in the wilderness)—increasing trend in eco-tourism is having an adverse effect on the habitat and disturbs snow leopards and their prey
	100% reduction: manage tourism by restricting camping and hiking in core areas of snow leopard habitat
11	Lighting illegal fires

(continued)

Table 8.3 (continued)

S. No.	Explanation of threats
	100% reduction: only eliminate all illegal fires, but allow properly controlled fires for defined purposes
12	Threat: killing depredation of wildlife by free-ranging dogs
	100% reduction: remove/control all free-ranging dogs from/in snow leopard habitats
13	Threat: litter/dung collection by local communities from pastures land has an adverse effective impact on the habitat and affects snow leopard activity
	100% reduction: stop collecting of litter/dung from pastures by local communities from pastureland
14	Threat: Adverse impacts of hydro-electric project's infrastructure on snow leopard habitat
	100% reduction: Exclusion of hydro-electric projects from core areas
15	Threat: stone mining by local communities
	100% reduction: control stone mining in snow leopard habitats

8.4 Results

8.4.1 Livestock Mortality

Based on interviews with herders in nine settlements in three protected areas: ACA, MCA and SNP (Table 8.1), livestock losses due to snow leopards ranged from 1.5 to 14.3% of total stock per annum. The highest livestock mortality due to snow leopards was recorded in Proper Manang, followed by Khangsar, Lupra, Phortse, Chhoser and the lowest in Lo-Manthang, Jhong, Chhekampar VDC and Charang. There was an increase in the trend in percentage loss from 2.9 to 4.2% in 1990–1992 to 10.3% per annum in 2015 in Khangsar (UM), and from 1.6% in 1990 to 14.3% per annum in Proper Manang. In Phortse (SNP), the trend increased from 1.3% in 2004 to 4.8% in 2007, and then decreased to 2.5% in 2015. From 2011 to 2016, the trend decreased slightly in Lupra and increased slightly in Jhong.

The loss due to other predators, such as wolf, lynx, red fox or golden jackal, ranged from 0.16 to 5.3% per annum in the nine settlements. The livestock losses from all predators ranged from 0.2 to 3.5 per household per annum. On average, the monetary loss due to predators amounted to NRs. 34,880 (USD 349) per household per year in Upper Manang. The livestock mortality due to causes other than predators (disease, starvation, fighting, falling, avalanches etc.) was highest in UM (range: 24.9–33.1%), followed by UMS, LM, MCA and SNP (range: 1.5–8.8%).

The loss of livestock due to snow leopards, other predators and other causes were more or less equal in UMS. In LM and SNP, people did not think the other predators significantly affected their losses of livestock, while mortality due to other causes was reported to be greater than that due to snow leopards. In UM, the people similarly did not think the other predators significantly affected their losses of livestock over the period 1990–1992, but reported higher losses in 2015, mainly due to causes other than predation.

8.4.2 *Livestock Herding*

In UMS, goats/sheep are the major livestock with an average of 30.6 animals/household (HH) and a range of 26.3–35.5 animals in 2012. The next in importance was cattle (3.7 animals/HH; range: 2.9–5.1), yak/nak (1.7 animals/HH; range: 0.03–5.6) and horses/mules (1.7 animals/HH; range: 1.4–2.1) (Table 8.1).

In Lupra in LM, goats/sheep are the major livestock, which increased from 27.7/HH in 2011 to 45.8/HH in 2016. Cattle also increased from 3.1/HH in 2011 to 5.2/HH in 2016. Similarly, in Jhong in LM, goats/sheep are the major livestock but decreased slightly from 24.8/HH in 2011 to 22.8/HH in 2016. Cattle increased from 3.1/HH in 2011 to 7/HH in 2016.

In both Lupra and Jhong, yak/nak and horses/mules decreased from 1.1/HH in 2011 to 0/HH in 2016 and from 1.2/HH in 2011 to 0.6/HH in 2016, respectively.

In Khangsar in UM, yak/nak are the major livestock, which increased from 3.48/HH in 1992 to 16.2/HH in 2015. Goats/sheep were the major livestock in 1990–1992 but were not present in 2015. In Proper Manang in UM, yak/nak were the major livestock and increased from 5.2/HH in 1990 to 10.5/HH in 2015. Goats/sheep decreased from 20.1/HH in 1990 to 4/HH in 2015. In both Khangsar and Proper Manang, the numbers of cattle and horses/mules remained constant from 1990 to 2015.

In Chekampar VDC in MCA, cattle are the major livestock (4.7/HH) followed by yak/nak (3.9/HH), horses/mules (1.3/HH) and goats/sheep (0.1/HH).

In Phortse in SNP, yak/nak are the major livestock and increased slightly from 4.6/HH in 2004 to 6.3/HH in 2015. Similarly, cattle increased slightly from 1.7/HH in 2004 to 2.1/HH in 2015. Horses/mules were fewer in number and ranged from 0.01/HH in 2004 to 0.04/HH in 2015. Goats/sheep were not kept in SNP. People in Phortse did not own any horses in 2007 and 2015.

Herd sizes of households ranged from 5 to 250 goats/sheep in ACA (LM, UMS and UM), from 1 to 40 in SNP and from 1 to 10 in Jhong and Lubra (LM), and from 5 to 100 yak/nak in settlements in UM. In LM and UM, all the goats/sheep from one village were grouped into 2 or 3 herds ranging in size from 150 to 300 individuals. Similarly, in UM, two to four herders grouped their yak/nak into one herd ranging in size from 150 to 200 individuals, while in LM and SNP each herder only herded their own yak/nak.

Livestock herding pattern was similar in all areas in consisting of two to four seasonal rotations between different pasturelands. Some herds were kept at high altitudes in summer and low altitudes, usually close to the village, in winter. Some herds were moved between three or four pasturelands during the course of a year. Autumn and spring pasturelands were located between those used in summer and winter. In Namche (SNP), the people do not have a traditional rotational grazing system and let their animals roam freely all year round. In winter, most of the livestock were brought down to lower altitudes or kept in sheds next to their houses at night, where they were provided with hay or wheat straw. During the course of discussions with local herders, those that rear livestock reported that there was a scarcity of green grass over the last few years due to low rainfall and little snow. Due to this and climate change, cattle were not moved to low altitudes in winter. Therefore, some herders in Thini (LM) and Phortse (SNP) keep their yak/nak in high pastures even in winter.

All herds of goats/sheep were moved by one or two herders from place to place, keeping them in closed corrals at night. Some herders had a Tibetan dog to guard the herd. Herds of female yak (nak) with calves were left free to roam in pasturelands during the day and kept overnight in nearby fallow lands next to a Goth (a temporary shed where herders cook and stay overnight) or in poorly fenced corrals. At lower altitudes, livestock were kept in sheds often next to the villagers' houses at night. During the night, the calves were kept inside either in the corrals or depending on their availability in predator-proof corrals. Yak (adult male) were allowed to roam free in pasture lands throughout the year. During summer, horses were free to roam in pasture lands and used for transporting hay or tourists.

8.4.3 Local People's Knowledge and Perception of Snow Leopards

Almost all the respondents (70%) in all the areas studied believed that snow leopards do not attack humans but definitely attack livestock. More than 50% of them agreed that snow leopards are beautiful animals, but only 25–35% thought they would attract tourists. The majority of the respondents (85%) were aware that they are protected and that it is illegal to kill them. About 40–60% believed snow leopards are protected for religious reasons (Buddhist faith).

In terms of whether snow leopard should be conserved or not, many of the respondents were indifferent (38–55%), followed by those who agreed (20–36%), strongly agreed (10–16%) and disagreed (8–15%) (Fig. 8.2). Opinions of literate and illiterate people on whether snow leopards should be protected in UM differed significantly (Chi square = 28.8, df = 3, P = 0.00).

8.4.4 Ways of Mitigating Snow Leopard-Human Conflict Suggested by Local People

The people's perception of how to mitigate human-snow leopard conflicts were recorded in four of the regions studied. They were asked to choose one of the following five options:

(i) Improving husbandry (close guarding of herds, corralling animals in predator-proof enclosures at night, use of dogs, electric fencing, creating a disturbance and chasing leopards away).

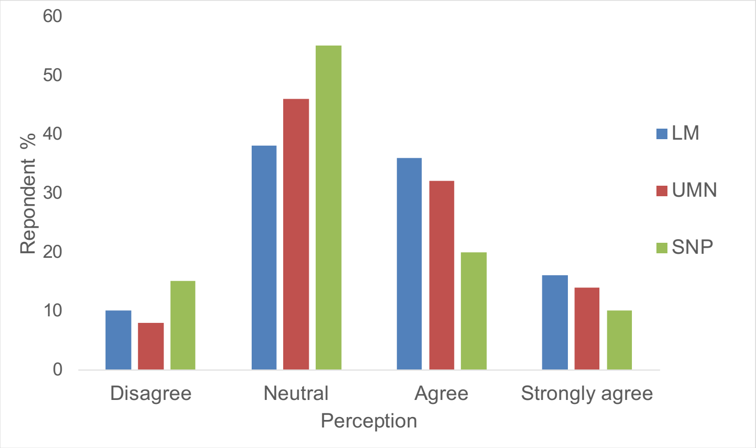

Fig. 8.2 Local people's opinion on whether snow leopards should be protected

(ii) Providing compensation through community-based livestock insurance schemes.
(iii) Wildlife-related measures (prey conservation, complete extermination of snow leopards, killing only those that attack livestock).
(iv) Livestock-related measures (avoid grazing in areas of high predation risk, reduce the number of livestock).
(v) Incentive programs (snow leopard saving and credit program, handicrafts or eco-tourism, veterinary service, use of lights that deter predators, such as fox-lights etc.).

All respondents agreed it is necessary to control the loss of livestock due to predation by snow leopards. Of the five mitigation measures, option (ii) was the most voted for in all regions except UMS, where most people voted for option (i). Wildlife-related measures (option (iii)) and incentive programs (option (v)) received more or less equal votes and ranked as the second-best choice of five options in the three regions (LM, UM and SNP) while these options stand as third-best choice in UMS. In three of the regions studied (LM, UM and SNP), improving husbandry (option (i)) was voted the third-best way of mitigating conflict. Livestock-related measures (option (iv)) were the most disliked option among five options in all four regions (Fig. 8.3).

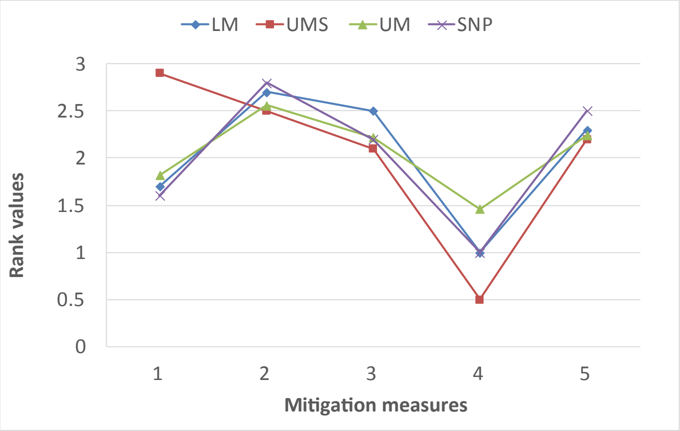

Fig. 8.3 People's perception of how to mitigate human-snow leopard conflicts recorded in four regions. The options were: (i) improving husbandry (ii) providing compensation through community-based livestock insurance schemes, (iii) wildlife-related measures, (iv) livestock-related measures, (v) incentive programs

8.4.5 Mitigation Measures Adopted

8.4.5.1 Livestock Insurance Scheme

In UM, 45 out of 50 respondents (90%) were aware and only 10% were unaware of the livestock insurance scheme (LIS) provided by the Conservation Area Management Committee (CAMC) in collaboration with Annapurna Conservation Area Project (ACAP). Compensation was provided only for the loss of livestock killed by snow leopards. Thus, of the respondents, only 23 had applied for compensation and only 17 of them had received compensation in 2014. However, in 2015, there were no claims for compensation. In UM, each Village Development Committee (VDC) received NRs 125,000 to provide compensation in the first year and additional NRs 50,000 in successive years. Local herders are required to insure their livestock in order to claim for compensation. The insurance premiums are NRs. 100, 50, 25, 10 and 10, respectively for horse/mule, yak/nak (1–3 years old), zhopa (hybrid between yak and cattle), goats/sheep and cows/oxen. If insured livestock are killed by snow leopards, the herder receives 20% of the cost of a goat/sheep, yak-cow calf (1–3 years old) and zhopa, and 15% of the cost of a horse/mule. This scheme was not effective, as the compensation was much lower than the loss and the process of claiming was too cumbersome, as it was necessary to provide evidence of a kill for verification, which is sometimes very difficult.

8.4.5.2 Partial Compensation Schemes

Similarly, most herders were not interested in the partial compensation scheme provided by Lower Mustang's conservation office. They complained about the procedure, the time it took to process their claim, and that the value of the compensation was meagre compared to that of the lost livestock. In 2015, only 9 local herders in LM were partially compensated by a payment of NRs 60,400 for 23 animals (16 goats, 3 sheep, 2 yaks/calves, 2 horses) killed by snow leopards. Only 10% of the total cost of the livestock killed was paid out in compensation in LM, where the usual compensation price for goat/sheep, yak-calf and horse are 2000, 8000 and 10,000 rupees, respectively. This compares unfavourably with the total annual budget allocated for partial compensation, which was only NRs 200,000 per year in LM. In LM, the partial compensation scheme is used only when LIS is not available.

In contrast, in SNP, no villagers were aware of the partial compensation scheme run by the Government of Nepal. Only one herder had applied for compensation for the loss of 4 yak calves in Gokyo valley in spring 2015. However, his request was still pending at the end of this study (December 2015).

In 2010, a public project called the "saving and credit village program" was established in four villages in SNP in collaboration with the Buffer Zone Management Committee (BZMC)—SNP, which aimed to support snow leopard conservation. Each village received NRS 200,000 as seed money. Each member of the group was asked to save NRS 100 per month. This money was used for standard loans etc. and 5% of the total interest on the money saved was allocated for funding partial compensation for losses of livestock due to snow leopards (the rest was distributed among the members).

After the first two years, however, the financing of the project from outside ceased. Since then, the project was solely under the control of the villages, which were inclined towards maximizing their gain (getting most of the interest) rather than providing compensation for domestic animals killed by snow leopards and in this way supporting their conservation. This became especially apparent after 2015, when the money deposited by the members of the group started to exceed the seed money. Thus, only NRs 500 was provided as compensation for each animal killed by snow leopards in 2015, and only one member in Phortse applied for compensation.

The main problem is probably that this program and its supervision is not involved in the institutional national park's framework and as a consequence income-generating schemes that contribute to the conservation of biodiversity are inadequate. Besides the saving and credit programmes that are public funded, the Wildlife Damage Relief Guidelines prepared by the Government of Nepal also provide partial compensation for damage caused by wild animals (GoN 2017). In the latter case, villagers should claim or apply for partial compensation to the Nepal Government through the national park office.

8.4.5.3 Predator-Proof Corrals

ACAP has supported local herders in constructing predator-proof corrals. In 2016, ACAP supported the construction of four corrals in selected pasturelands, two in LM, two in UMN, and ~ 25 in UMS. However, most of them were not repaired and are now non-functional. A well-developed predator-proof corral is a very effective way of reducing the number of livestock killed by snow leopards. As one snow leopard can kill up to100–150 goats/sheep per night, and as the herders keep moving their livestock to different locations, it makes sense to construct and maintain predator-proof corrals.

8.4.5.4 Distribution of Other Devices for Deterring Predators

ACAP has been distributing animal-deterring lights to selected herders in UMS, LM and UM, such as fox-lights and solar lamps (“tukis”), in order to deter snow leopards at night. It is reported, however, that the fox-light is not effective because snow leopards quickly become habituated to the light.

8.4.5.5 Anti-poaching Committee

ACAP has established an anti-poaching sub-committee in areas where there is a high incidence of poaching in order to collect information about suspicious poaching activities and the poachers.

8.4.5.6 Conservation Education Program

ACAP has produced a book on conservation written in Nepalese called “Prakriti ko sandes” (“Messages from Nature”) for school children in classes 6, 7 and 8, which is also widely used for teaching within the ACA region. In addition, on the occasion of wildlife week, ACAP conducts wildlife awareness programmes for school children, such as writing poems and essays, and drawing wildlife and nature. Occasional snow leopard environmental awareness camps and snow leopard street dramas are also staged.

In SNP, an informal school awareness programme was organized in which snow-leopards were painted by classes 1–8 in four schools (Shrestha 2007). In addition, a student campaign called “snow leopard scout” was held on the occasion of world environment day (5 June) at Thame School in 2012, which included painting and a short environmental camp for selected students in grades 6–8 (SLC/NTNC 2014).

8.4.6 Threats to Conservation

In total, 15 threats were identified in the three studied areas. The threat assessment (Table 8.2) indicates that the major threats for snow leopards in the studied areas are:

(i) retaliatory killing,
(ii) poaching of animals mainly by porters and labourers who come for a short-term employment,
(iii) loss of prey due to competition with livestock and disease,
(iv) disturbance due to the collecting of *Cordyceps* and other plant products,
(v) construction of infrastructure such as roads and hotels/lodges in snow leopard habitats,
(vi) killing of wildlife by free-ranging dogs.

Retaliatory killing, reduction in the abundance of prey due to competition with livestock and the collection of terrestrial plants were identified as severe threats in all three of the regions studied. Collecting *Cordyceps* and low prey abundance due to diseases transmitted by livestock were identified as severe threats in LM and UM. Road construction/maintenance was identified as severe threat in LM, hotels in UM and litter/dung collection and stone mining by local communities in SNP. The reduction in the threat assessment index was slightly higher in SNP than in the other two regions, in which this index remained approximately the same.

8.5 Discussion

8.5.1 Livestock Mortality

The percentage of livestock lost due to snow leopards varied greatly between sites and years. Especially in UM, livestock killed in 2015 was conspicuously greater than from 1990 to 1992 and was higher than at other sites. The variation in livestock mortality due to snow leopards may be due to a combination of factors, such as the abundance of snow leopards and their prey, differences in livestock herding and other reasons. For example, the high level of livestock loses recorded in UM in 2015 may be due to:

(i) increase in snow leopard population from 1990 to 2016 (see Chap. 5),
(ii) increase in the percentage of large livestock made up of calves, such as yak/nak,
(iii) stable blue sheep population during that period (see Chap. 5).

The percentage of livestock losses that can be attributed to snow leopards was in the range of 1.5–14.3%. This is higher than that reported by Alexander et al. (2015) in the Northern region of QNNR in Gansu Province, China (0.3%), but comparable with the 1.3–5.9% reported in Qinghai in China, Baltistan in Pakistan, Ladakh in India and Xinjiang in China (Schaller et al. 1987; Fox et al. 1991; Hussain 2000;

Namgail et al. 2007; Li et al. 2013). It would be interesting to know why the values reported by Alexander et al. (2015) are so small, as currently there is no indications of why.

Our questionnaire did not record any surplus killing (mass killing that ranges from 25–150 domestic goats/sheep when snow leopards enter a corral/pen). However, in September 2015, a kill of 104 mountain goats by snow leopards was reported in Charang in Upper Mustang (Fig. 8.4). Although these incidents account for only 14% of all the reported killings (n = 210), they account for nearly 50% of all the livestock killed in Hemis National Park, India (Jackson and Wangchuk 2001). Other studies also report mass killing by both snow leopards and wolves in the Pamir mountains (Hussain 2000; Mishra and Fitzherbert 2004; Watanabe et al. 2010). Thus, surplus killing, although not recorded in this study, cannot be neglected.

In the area studied, other predators such as wolf, red fox, golden jackal and lynx killed fewer livestock than snow leopards. This may be because Himalayan wolf, which was thought to have been exterminated by herdsmen three decades ago, has recently reappeared in ACA (Chetri et al. 2016; Shrestha 2016). These findings differ from those of other studies. For example, lynx or wolf-related mortality of livestock is reported to exceed three to four times that of snow leopards in QNNR and Xinjiang in China and Ladakh in India (Namgail et al. 2007; Li et al. 2013; Alexander et al. 2015).

Fig. 8.4 Surplus killing of mountain goats by snow leopards in Charang (Upper Mustang, Nepal) in 2015. *Photo by* Niraj Thakali

The economic value of livestock killed by predators was $29 per household per year in 1990 in UM (Oli et al. 1994), while in 2015 this study revealed it was higher by an order of magnitude ($349 per household per year). This can be attributed to both increases in the number killed and their value. It is a significant loss when compared with the per capita annual income, which was US $200 in 1990 and US $750 in 2015. Over the period of 1990–2007, annual economic losses associated with predation ranged from US $29 to US $300 per household, a significant sum compared with per capita annual incomes of US $250–400 (Oli et al. 1994; Jackson et al. 1996; Mishra 1997; Ikeda 2004; Namgail et al. 2007). After 2007, the annual economic loss was US $80–650 (Li et al. 2013; Din et al. 2017). Although the predator-induced loss was substantial, all these studies report that livestock mortality due to other causes such as diseases etc. was higher than that due to predators.

In Lupra in LM and Phortse in SNP, respondents were more negative in their attitude towards snow leopards and all kills were attributed to them, even though common leopards were present at 4000 m a.s.l. near to the forest line. However, there are many factors, which might have biased the results of the questionnaire:

(i) herders' perception of specific species as causative agents or exaggerated reporting by herders (Suryawanshi et al. 2013),
(ii) a kill may be attributed to a predator, even though it was only scavenging the carcass of an animal that had died for other reasons (Oli et al. 1994),
(iii) misidentification of predators when snow leopards are confused with other large carnivores like wolf, lynx and common leopard (Mishra 1997),
(iv) behaviour of specific carnivores in their interactions with humans may influence perceptions concerning the species (Lescureux and Linnell 2010); for example, the greater visibility and howling of wolves may heighten the perception of the risk they pose to livestock (Kellert et al. 1996),
(v) reports of predation by snow leopards might have been subject to a "social desirability" bias, as snow leopards are recognized as an iconic, protected species (Li et al. 2013); however, information on how the local people view predation will facilitate the development of a programme for mitigating human-wildlife conflicts and conserving snow leopards.

8.5.2 Livestock Herding

The present study showed that the abundance of large livestock has increased in UM and that of goats/sheep has increased in LM and UM. As indicated above, the variation in livestock mortality due to snow leopards may be due to both changes in the abundance of livestock and guarding practices in different regions and different years. Herding is just one factor influencing the number of attacks on livestock by predators. The most important are livestock abundance (Suryawanshi et al. 2013; Zarco-González et al. 2013), herd composition (Tortato et al. 2015), poor care of calves, improper carcass disposal (Pena-Mondragon et al. 2017), guarding, (Kolowski and Holekamp 2006; Hemson et al. 2009) and patterns of rotation (Kissling et al. 2009).

8.5.3 Local People's Perception of Snow Leopards and Suggested Mitigation Measures

In 1990 in UM, 52% of the respondents agreed that the elimination of snow leopards is the only viable option, while only 10% suggested compensation would be a satisfactory solution (Oli et al. 1994). This study revealed that the level of conflict has decreased slightly, but 15% of the respondents still had a negative attitude towards snow leopards (Fig. 8.2). Killing of snow leopards (especially those that attack livestock) was also ranked as the second or third of the five most appropriate mitigation measures (Fig. 8.3). Other studies report similar results: local people consider eradication of predators as a possible solution in the Spiti region in Indian Trans-Himalaya (Bagchi and Mishra 2006) and in Tajik in Afghan and Pakistan Pamir (Din et al. 2017). In contrast, Suryawanshi et al. (2014) report that most people have a positive attitude to snow leopards in the Spiti Valley in India, even if they suffer high levels of livestock loss due to predators. This may be due to their Buddhist faith and 15 years of conservation in this region. Our study also showed the effects of similar religious beliefs regarding snow leopards (Buddhist culture) in the studied areas. However, this tolerance of predators diminishes when the killing of livestock reaches a level when it becomes too high for the herders to survive in the absence of an alternative means of livelihood and income.

8.5.4 Threats to the Conservation of Snow Leopards

In the three studied areas, the lowest number of severe threats due to human-related activities were recorded in SNP. The threat reduction assessment index was higher in SNP than in the other studied areas, but could be improved by an intensification of the conservation programme. This indicates that there is further work to be done to improve the level of conservation of snow leopards and their prey in all three studied areas. In addition to these threats to conservation, the weak enforcement of the law is still a problem in UM. During the period of the survey, 2014–2016, the local people were still wearing fur hats made from fox and jackal pelts despite hunting being prohibited (Fig. 8.5).

We conclude that the conflict between snow leopards and people in the three studied areas is still major threat to the long-term survival of snow leopards. The mitigation measures that were recommended after consultation with the local people would go a long way to safeguarding the livelihoods of the local people and conserving snow leopards.

Fig. 8.5 Fur hat made from pelt of a predator in a house in Upper Manang in 2016

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Chapter 9
Description of the Study Areas

Bikram Shrestha and Pavel Kindlmann

Abstract Here we describe the five areas used for monitoring snow leopards and their prey, and the snow leopard-human conflict study. They are: Lower Mustang, Upper Mustang, Upper Manang, Tsum Valley (Chhekampar VDC) and Sagarmatha National Park. The first three are parts of the Annapurna Conservation Area (ACA), and Tsum Valley is a part of the Manaslu Conservation Area. Below we give a description of each of these areas and define the core areas for snow leopard within them.

9.1 Administrative Districts in Nepal

Nepal is divided into districts, which are further divided into "village development committees" (VDC). In Nepal these are seen as equivalent to a cadaster as each district consists of several VDCs, which are similar to municipalities, but with greater public-government interaction and administration.[1] VDCs were dissolved on March 10, 2017 and replaced by "rural municipalities". The main purpose of a rural municipality is similar to that of a village development committee. In addition, it collects various taxes like entertainment tax, business tax and residential tax at a local level.

Below we describe the areas used for monitoring snow leopards and their prey.

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[1] See https://en.wikipedia.org/wiki/Village_development_committee_(Nepal) for details.

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9.2 Annapurna Conservation Area (ACA)

The Annapurna Conservation Area (N 28°47′ to N 28.78° and E 83°58′ to E 83°58′, ca 7629 km^2) is located in west-central Nepal (Fig. 9.1), in a transition zone between the moist southern Himalayan slopes and high deserts in Tibet. The ACA includes the district of Mustang, some parts of Myagdi district and large parts of Kaski, Lamjung, and Manang districts. It consists of seven conservation units (Manang, Lower Mustang, Upper Mustang, Gandruk, Lwang, Sikles and Bhujung). This area borders the dry alpine deserts in Dolpo and Tibet in the north, the Dhaulagiri Himal in the West, the Marshyangdi Valley in the East and valleys and foothills surrounding Pokhara in the South. There are some of the world's highest peaks in ACA, over 8000 m a.s.l., and the deepest valley, that of the Kali Gandaki River (NTNC 2008a, b).

Lower Mustang (LM), Upper Mustang (UMS) and Upper Manang (UM) are conservation units within the Mustang and Manang districts (Fig. 9.2), respectively. They are all mostly covered by alpine grassland (4500–5000 m a.s.l.) and subalpine scrubland (4000–4500 m a.s.l.). *Juniperus squamata* dominates the scrub community on gentler slopes, while rocky areas and steeper slopes are dominated by *Caragana gerardiana*, *C. brevispina, Rosa sericea, Ephedra* sp. and *Lonicera* sp. Above 4800 m, the vegetation is meagre and dominated by *Rhododendron anthopogon*, *Potentilla biflora* and *Saxifraga* sp. Patches of *Pinus excelsa, Betula utilis* and *Juniperus indica* forests occur along riverbanks. *Salix* spp. and *Populus ciliate* also occur in UMS. Snow leopard (*Panther uncia*), common leopard (*Panthera pardus*), Eurasian lynx (*Lynx lynx isabellinus*), red fox (*Vulpes vulpes*), golden jackal (*Canis*

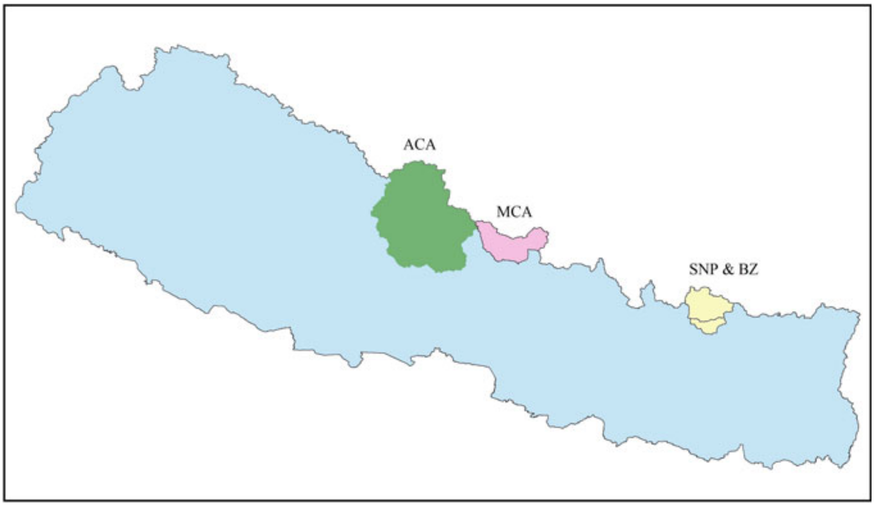

Fig. 9.1 Map of Nepal showing the three areas studied: ACA: Annapurna Conservation Area; MCA: Manaslu Conservation Area, and SNP and BZ: Sagarmatha National Park and buffer zone

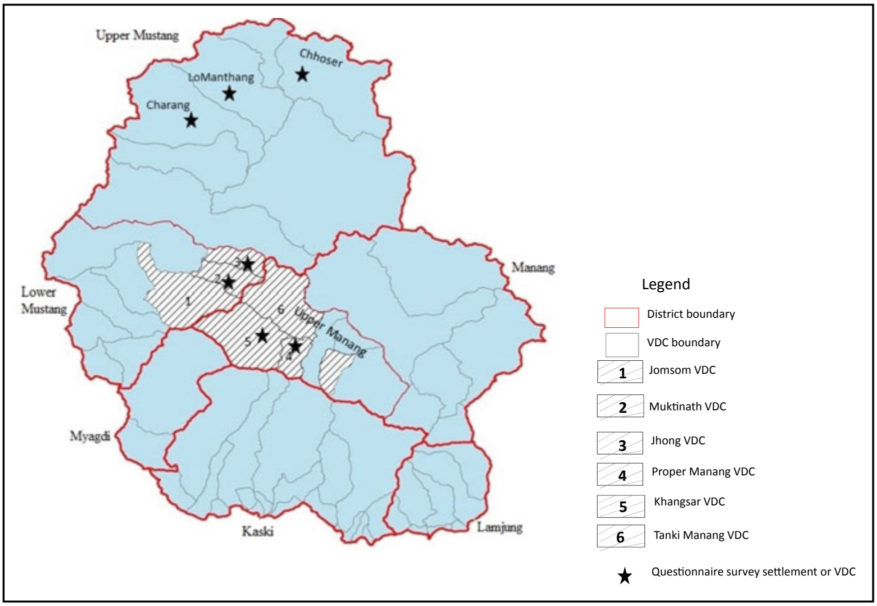

Fig. 9.2 Map of the Annapurna Conservation Area showing the VDCs (1–6) in which snow leopard and their prey were monitored, and the settlements included in the household survey

aureus), Himalayan wolf (*Canis lupus*) and blue sheep (*Pseudois naur*) are found in these areas. In addition, argali (*Ovis ammon hodgsonii*), Tibetan gazelle (*Procapra picticaudata*), kiang (*Equus kiang*) and Himalayan brown bear (*Ursus arctos*) also occur in UMS.

In these areas, unregulated collection of timber, fodder, fuel wood, leaf litter and medicinal and/or aromatic plants, combined with livestock grazing and roads have negatively affected the biodiversity of the forest and rangeland. Natural disasters, such as forest fires and avalanches have also negatively affected the wildlife. Heavy snowfall and avalanches in 2014 and 2015 killed ~ 200 yaks and ~ 50 blue sheep in these regions.

9.2.1 Lower Mustang (LM)

Lower Mustang is spread across former nine VDCs: Lete, Kunjo, Kowang, Tukuche, Marpha, Jomsom, Kagbeni, Muktinath and Jhong. LM covers the southern half of the Mustang district and the average rainfall is 193 mm per annum.

In 2011, local inhabitants (approx. 7759 people with 2200 households) of Lower Mustang owned 14,333 goats and sheep, and 5544 cattle, yak/nak, horses and zhopa, which is a hybrid between yak and cattle (CBS 2012; MoLD 2017). In 2016, local inhabitants owned 15,333 goats and sheep, 8544 cattle, yak/nak, horses and zhopa (DLSO-M 2016). The LM is an important tourist and trekking destination, which is

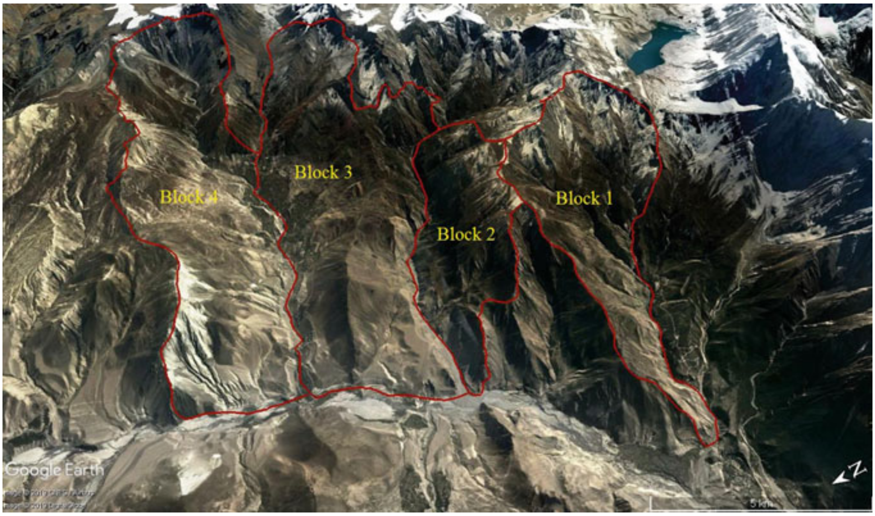

Fig. 9.3 Aerial photograph of the areas (blocks) in which snow leopards and their prey were monitored in Lower Mustang. Block 1—Thini, Block 2—Lubra, Block 3—Muktinath, Block 4—Jhong. *Source* Google Earth

visited by 18,000–30,000 tourists per year. Agriculture and livestock husbandry are the main occupations in LM.

The important areas for monitoring snow leopards and their prey in LM include four valleys: Thini (Jomsom VDC), Lupra and Muktinath (Muktinath VDC) and Jhong (Jhong VDC) (Figs. 9.2 and 9.3) covering ca 100 km^2. Lubra and Jhong settlements were selected for the snow leopard-human conflict study (Fig. 9.2).

9.2.2 Upper Mustang (UMS)

Upper Mustang is spread across seven former VDCs: Chuksang, Ghemi, Tsarang, Lomanthang, Chhoser, Chhunup and Surkhang. Upper Mustang covers the northern half of the Mustang District with an area of 2567 km^2 (NTNC 2008b). The area is in the arid trans-Himalayan zone of the ACA with altitudes ranging between 3000 and 6000 m a.s.l., and an average rainfall of 132 mm per annum.

There were 33 human settlements containing around 6100 people in 2001 (CBS 2001) and 3834 people and 1104 households in 2011 (CBS 2012). The area includes 1220 km^2 of rangeland, 0.48 km^2 of forest and 32 km^2 of agriculture land.

Up until 1991, outsiders were prohibited in this area except for a limited number of visitors: 1000 trekking permits were issued per year. Because of this ban the people in UMS do not depend on tourism but on a combination of livestock farming, agriculture and trading in winter. Agriculture and livestock husbandry are the major source of livelihood for the people in UMS. In Upper Mustang, local inhabitants (approx. 1104 households) owned 19,173 goats and sheep and 4327 cattle, yak/nak, horses and zhopa in 2011 (CBS 2012; GoN 2018), and in 2016 58,156 goats and sheep, 7327 cattle, yak/nak, horses and zhopa (DLSO-M 2016).

Three VDCs, Lomanthang Chhoser and Charang (Fig. 9.2) were selected for the study on the snow leopard-human conflict.

9.2.3 *Upper Manang (UM)*

Manang includes 13 VDCs: Dharapani, Chame, Bagarchap, Thoche, Pisang, Nar, Phu, Dhyaru, Humde, Bhakra, Proper Manang, Khangsar and Tanki Manang and about 25% of the ACA. Manang is divided into three broad ecological-cultural zones: Upper Manang (Nyeshang), Nar-Phoo and Lower Manang (Gyasumdo). Upper Manang includes former VDCs: Pisang, Ghyaru, Humde, Bhakra, Proper Manang, Khangsar and Tanki Manang.

The UM areas include 0.44 km^2 of uncultivated land, 10.78 km^2 of agriculture land, 1919.6 km^2 of hills or rocks, 154 km^2 of forest, 504.43 km^2 of pastureland, 3.81 km^2 of water and 48.82 km^2 of shrub (NTNC 2008a). In 2011 there were 6538 people and 1480 households there that owned 8153 goat and sheep, 5227 cattle, yak/nak, horses and zhopa (CBS 2012; MoLD 2017). Agriculture and livestock husbandry are the main occupations in UM.

The areas used for monitoring snow leopard and their prey in UM include the following valleys: Proper Manang (Proper Manang VDC), Yak Kharka (Tanki Manang VDC) and Khansar (Khangsar VDC), together covering ca. 105 km^2 (Figs. 9.2 and 9.4). Proper Manang and Khangsar settlements were selected for the snow leopard-human conflict study (Fig. 9.2).

9.3 Manaslu Conservation Area (MCA)

This Conservation Area (MCA) is in the central Himalayas in Nepal (Fig. 9.1) and covers an area of 1663 km^2. It includes seven former VDCs: Samagaon, Lho, Prok, Bihi, Chumchet, Chhekampar and Sirdibas of Gorkha District. The altitude there ranges from 1239 to 8163 m a.s.l. and the climate from subtropical to nival zones. A total of 2000 households and 9000 people reside in this area. 2000 species of plants, 33 mammals, 110 birds, 3 reptiles and 11 butterflies in 11 types of forest are reported occurring there (NTNC 2013). The upper valley is covered mostly by scrubland with juniper-rhododendron and alpine grasslands at high altitudes (>4000 m), and patches of forests (*Betula*, *Rhododendron*, *Pinus*, *Abies* or *Tsuga* pure or mixed). These areas include prime habitats for snow leopard, red fox, common leopard, Himalayan brown bear, Himalayan black bear (*Ursus thibetanus*), blue sheep, musk deer (*Moschus chrysogaster*), Himalayan serow (*Naemorhedus sumatraensis*), Himalayan tahr (*Hemitragus jemlahicus*) and ghoral (*Naemorhedus*

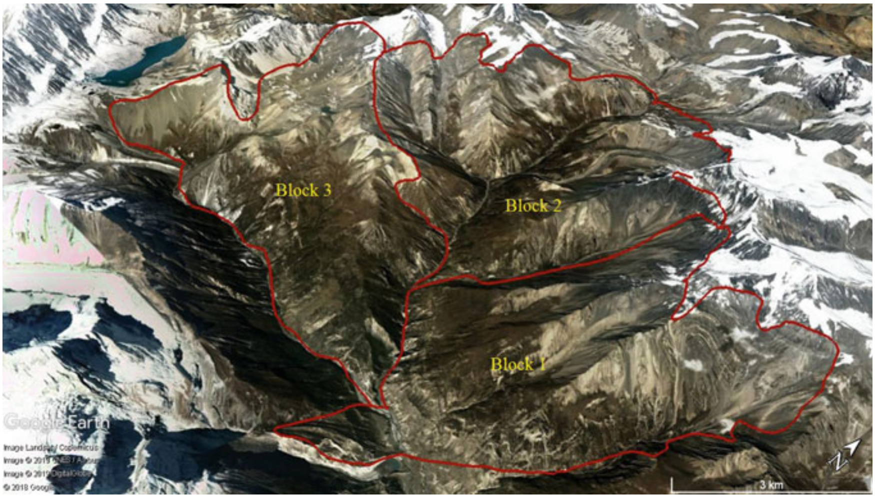

Fig. 9.4 Aerial photograph of areas (blocks) in which snow leopards and their prey were monitored in Upper Manang. Block 1—Proper Manang, Block 2—Yak Kharka, Block 3—Khangsar. *Source* Google Earth

goral). It was a restricted area up until 1991, but is now open for organized tourism. During the fiscal year 2017/18, 5745 tourists visited MCA (GoN 2018). This region is not yet connected by road with other parts of the country. However, collection of fodder, fuelwood, medicinal plants, litter, dung collection and grazing in such pristine habitats have negatively affected the local biodiversity.

9.3.1 Tsum Valley (Chhekampar VDC)

This valley is located in the north-east of Gorkha district and includes two former VDCs Chumchet (known as Lower Tsum) and Chhekampar (Upper Tsum) (Fig. 9.5). Scattered human settlements occur at altitudes between 1901 and 3100 m a.s.l. This valley has a south-west to north-east orientation in which the Shiyarkhola river flows north-east to south-west and is surrounded by beautiful mountains.

There are 33 small villages/settlements in this valley with 1810 inhabitants and 529 households that owned 1165 cattle, 1996 yak and nak, 601 sheep and goat in 2011 (CBS 2012; MoLD 2017). In 2008, tourists with a special permit from MCA were for the first time allowed to visit Tsum valley. The numbers of tourists, hotels, lodges and retail shops increase every year. The police check-post record at Chekam village reveals that a total of 221 tourists entered upper Tsum in the month 15 March to 15 April 2015 (Rai et al. 2016). Agriculture and livestock husbandry are the main occupations in the Tsum Valley.

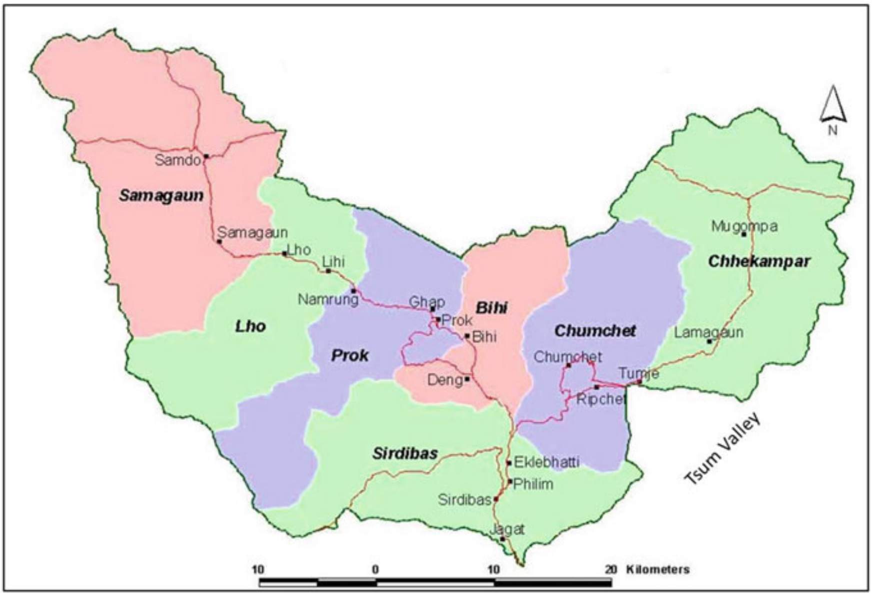

Fig. 9.5 Map of the Manaslu Conservation Area showing the location of the Tsum Valley (Chumchet and Chhekampar VDCs)

Chhekampur VDC was selected for the snow leopard-human conflict study (Fig. 9.5).

9.4 Sagarmatha National Park (SNP)

SNP (N 27°45′ to N 28°07′ and E 86°28′ to E87°07′, area 1148 km^2) and its buffer zone is in the Solo Khumbu district in north-eastern Nepal (Fig. 9.1). It includes the upper catchment areas of the Dudh Koshi and Bhote Koshi rivers and the Namche, Khumjung and Chaurikharka former Village Development Committees (VDCs). Below the snow line, at 3000 m a.s.l., there are alpine plants, shrubs and coniferous vegetation, such as pine (*Pinus* spp.), fir (*Abies spectabilis*), juniper (*Juniperus* spp.), birch (*Betula utilis*) and rhododendron (*Rhododendron* spp.). In SNP, we recorded snow leopard, common leopard, musk deer and Himalayan tahr in the four major valleys there: Gokyo and Phortse (Khumjung VDC), and Namche and Thame (Namche VDC) (Figs. 9.6 and 9.7), which cover ca. 100 km^2. These four areas were inhabited by 1031 households and 3452 inhabitants, which owned 184 cattle, and 3191 yak and nak in 2011 (CBS 2012; MoLD 2017), and 5332 domestic animals, including yak, cattle and horses in 2015. The Phorse settlement was selected for the snow leopard-human conflict study (Fig. 9.6). Every year, 30,000 to 37,000 tourists and trekkers visit SNP (SNP 2016). This region is not yet connected with the

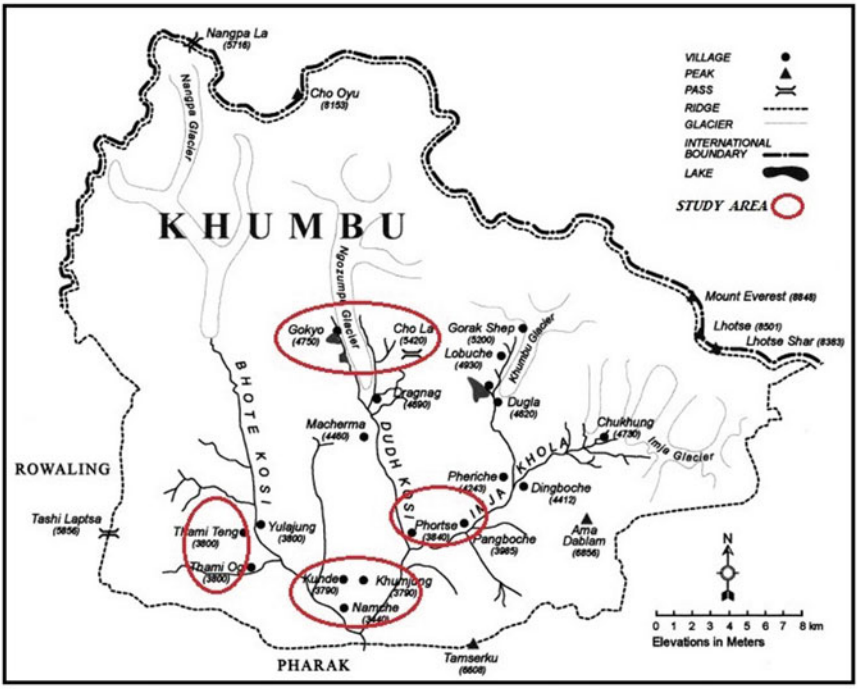

Fig. 9.6 Map of the Sagarmatha National Park showing the locations of the areas in which snow leopards and their prey were monitored

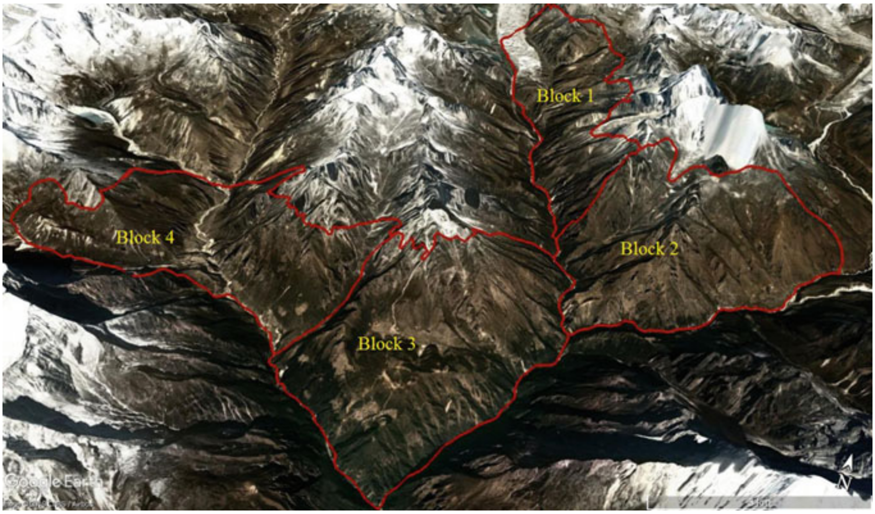

Fig. 9.7 Aerial photograph of the areas (blocks) in which snow leopards and their prey were monitored in Sagarmatha National Park. Block 1—Gokyo, Block 2—Phortse, Block 3—Namche, Block 4—Thame. *Source* Google Earth

rest of the country by road, but there are helipads at Namche, Khumjun and Phortse. Other negative effects on wildlife and their habitats include collection of fodder, fuel wood, leaf litter, mushrooms and medicinal and aromatic plants, as well as livestock grazing, stone-mining and livestock dung collection from shrub and grassland areas.

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